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Title: Bi-directional prospective associations between sedentary time, physical activity and adiposity in 10-year old Norwegian children

Running title: Adiposity and activity – which direction?

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Background: There is an adverse cross-sectional association between sedentary time, physical activity (PA) and adiposity, but weak and inconsistent estimates raise question to the direction of associations. The present study aims to examine whether the prospective association between sedentary time, different PA intensities and indicators of adiposity are bi-directional.

Methods: The Active Smarter Kids Study obtained data from 869 ten-year-old Norwegian children with valid measurements for sedentary time, PA, and adiposity at baseline (Autumn 2014) and follow-up (Spring 2015). Time spent sedentary and PA was measured by accelerometry, adiposity was assessed by three different measures: body mass index (BMI), waist circumference (WC) and sum of four skinfolds (S4SF). Analyses are performed by linear mixed models adjusted for sex, pubertal stage, birth weight, parental weight, parental education, and baseline value of the outcome.

Results: Neither overall PA nor time spent sedentary predicted lower BMI or WC at follow-up, but time spent in moderate-and-vigorous PA (MVPA) and vigorous PA (VPA) predicted lower S4SF at follow-up among boys (MVPA β -0.066 [95% CI -0.105, -0.027] p = 0.001). Baseline BMI and WC predicted less overall PA, MVPA and VPA in boys. All adiposity measures predicted more time spent sedentary at follow-up in boys.

Conclusions: The results suggest that overall PA and sedentary time do not predict future adiposity. Baseline adiposity may rather predict more sedentary time and less higher intensity activity.

Introduction

Overweight and obesity among children is an unfavorable condition that adversely affects almost every organ system (Daniels, 2009) and increases the risk of early onset cardiovascular disease and type 2 diabetes (Maffeis & Tato, 2001). Reasons for overweight and obesity in children include a complex mix of social, cultural, genetic, and behavioral factors (Ebbeling, Pawlak, & Ludwig, 2002). At a fundamental level, however, weight gain occurs when energy intake exceeds energy expenditure over time (Lee, Djousse, Sesso, Wang, & Buring, 2010). Physical activity (PA) increases energy expenditure and is acknowledged as an important modifiable factor for preventing weight gain (Han, Lawlor, & Kimm, 2010). Cross-sectional studies report that increasing time spent in moderate-to-vigorous PA (MVPA) not only reduces risk of obesity (Katzmarzyk et al., 2015; Mitchell et al., 2017), but also is inversely associated with cardiometabolic risk factors (Renninger et al., 2020). On the other hand, time spent in sedentary behaviors is strongly associated with weight gain (Ekelund et al., 2006; Mitchell, Pate, Beets, & Nader, 2013), suggesting that sedentary time is a risk factor for children's health (Saunders, Chaput, & Tremblay, 2014).

However, the cross-sectional associations between sedentary time, PA, and adiposity are not straightforward due to lack of temporality between exposure and outcome. A recent systematic review of prospective studies using objective PA measurement methods found no association between baseline sedentary time and adiposity, and inconsistent association between MVPA and adiposity at follow-up (Skrede, Steene-Johannessen, Anderssen, Resaland, & Ekelund, 2019). Correspondingly, a few prospective studies have observed that high body fat or body mass index (BMI) predicts a decrease in children's PA levels (Hjorth et al., 2014; Kwon, Janz, Burns, & Levy, 2011; Metcalf et al., 2011; Tanaka et al., 2018) and abdominal adiposity predicts more time spent in sedentary behaviors (Ekelund et al., 2012). Thus, it is hypothesized that adiposity could be a determinant for PA, and physical inactivity

67 the result of adiposity rather than its cause (Ekelund, Brage, Besson, Sharp, & Wareham,
68 2008; Ekelund et al., 2017). Therefore, the aim of this study was to examine whether
69 sedentary time or higher intensity PA predict indicators of adiposity or vice versa using a
70 prospective study design in a sample of healthy 10-year-old Norwegian children.

Materials and methods

The study comprises data from the Active Smarter Kids study (ASK), a seven-month cluster-randomized controlled school trial conducted during the school year of 2014–2015 in Western Norway (Resaland et al., 2016). As PA levels did not differ from baseline to follow-up between intervention and control schools (Resaland et al., 2016), data were pooled and analyzed as a prospective observational cohort in the present study. The methods and procedures relevant for the present study are presented in the following, and a detailed description of the ASK study and sample size calculation have been previously published (Resaland et al., 2015). All measurements were assessed at school sites from April–Oct 2014 and from April–June 2015. Children who provided valid measurements for all exposures and outcomes (PA and adiposity) at both time points were included. Figure 1 shows the flow of schools and children throughout the study. Our procedures and methods conformed to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions. The Western Norway Regional Committee for Medical Research Ethics committee in Norway approved the study protocol (Resaland et al., 2015). We obtained written informed consent from each child's parents or legal guardians and from the responsible school authorities prior to all testing.

Physical activity and sedentary time were measured using GT3X/GT3X+ accelerometers (ActiGraph, LLC, Pensacola, Florida, USA). All children were fitted with accelerometers at the school sites and instructed to wear the accelerometers on their right hips for seven consecutive days, except during water-based activities and while sleeping. Valid monitor wear-time was defined as achieving ≥ 480 minutes day accumulated between 06:00 a.m. and 00:00 p.m. Continuous bouts of ≥ 20 minutes of zero counts were defined as non-wear time (Esliger, Copeland, Barnes, & Tremblay, 2005). Children recording valid monitor wear time for ≥ four of seven days were included in the analyses. Sedentary time (< 100 counts per

minute [cpm]), MVPA (≥ 2,296 cpm), and vigorous PA (VPA; ≥ 4,012 cpm) were defined according to previously established and validated cut points (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). All accelerometer data were analyzed in 10-second epochs using the Kinesoft analytical software (KineSoft version 3.3.80, Loughborough, UK).

Body weight was measured to the nearest 0.1 kg using an electronic scale (SECA 899, SECA GmbH, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a portable altimeter (SECA 217, SECA GmbH, Hamburg, Germany). Body mass index (kg/m^2) was calculated and children were categorized as being of normal weight, overweight, or obese according to age-adjusted thresholds (Cole, Bellizzi, Flegal, & Dietz, 2000). Waist circumference was measured with an ergonomic circumference measuring tape (SECA 201, SECA GmbH, Hamburg, Germany). Two measurements were taken between the lowest rib and the iliac crest with the abdomen relaxed at the end of a gentle expiration. If the two results differed by > 1 cm, new measurements were taken until the two results were ≤ 1 cm apart. The mean of the two nearest measurements was recorded and used in analyses.

Body fat was assessed by the sum of four skinfolds (S4SF), which is a reliable and valid method for use in population-based studies in children (Silva et al., 2013). We collected skinfold thickness from four sites (biceps, triceps, subscapular, and suprailiac) on the non-dominant side of the body using a Harpenden skinfold caliper (Bull; British Indicators Ltd., West Sussex, England). We collected two measurements at each site in sequence. If the difference between measures was > 2 mm, a third measurement was conducted. The mean of the two nearest measurements was recorded and the S4SF in mm was used in analyses. Trained test personnel performed all anthropometric measurements, but as skinfold measurements are prone to high measurement error, we recruited seven persons specifically trained to perform skinfold measurements.

Children self-assessed pubertal stage according to the Tanner method using a scale of color images (stage 1–5) in a private room (Carel & Leger, 2008). Stage 2 marks the onset of pubertal development. Parents self-reported their education levels, body weights, and their respective children's birth weights. Parental education level was used as an indicator of socio-economic status (SES) and was categorized into three groups: low (< two years of high school), middle (< four years of college/university), or high (≥ four years of college/university).

Statistical analysis

Descriptive characteristics are presented as mean and standard deviation (SD), median and interquartile range, or frequencies (%). All adiposity and PA variables except sedentary time were log-transformed (ln) to improve the normality of the distributions. All adiposity and PA variables were standardized to z scores for ease of interpretation; thus, all regression coefficients are presented in SD units with confidence intervals (CI). First, we modelled the prospective association between baseline MVPA, VPA, and sedentary time (exposure) and the three different adiposity measures (outcome) in separate linear mixed models. The models were adjusted for sex, accelerometer wear time, pubertal stage, parental SES and weight, children's birth weight, group allocation, and baseline value of the outcome. Second, we modelled the prospective association between baseline adiposity (BMI, waist circumference [WC], and skinfolds; exposure) and MVPA, VPA, and sedentary time (outcome), adjusted for the same covariates as in the previous model and the baseline value of the outcome. We also tested for interactions by sex (baseline exposure × sex) and group allocation (group allocation x baseline PA). If a significant interaction ($P < 0.05$) was observed, the analyses were additionally stratified. Lastly, BMI was split into the categories of normal weight versus overweight/obese according to Cole et al. (2000), and MVPA was split into two groups based on whether the current recommendations for PA for children – a mean of ≥ 60 min

MVPA/day – were achieved or not. Thereafter, we examined if BMI (normal weight vs. overweight/obese) and MVPA (≥ 60 min MVPA/day) categories at baseline differed regarding PA and adiposity outcomes respectively at follow-up. In all models, sedentary time and PA variables were analyzed one by one to avoid multi-collinearity, and schools were included as random intercepts to account for clustering within data.

Analyses were performed using the SPSS software, version 26 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA). A p-value of < 0.05 indicated statistical significance.

Results

Participants' characteristics at baseline are presented in Table 1. Of the 1,129 participants who agreed to participate, only n = 8 children dropped out/withdrew during the study, and n = 869 children provided measurements for PA and adiposity at baseline and follow-up. Excluded children (total n = 253) did not differ in any of the adiposity measures at baseline ($p \geq 0.280$), but they had lower overall PA (cpm) at baseline ($p = 0.030$). At baseline, 77.4% were normal weight, while 18.6% were categorized as overweight and 3.9% were obese. Mean accelerometer wear time was 6.3 days (±0.9) at baseline and 6.4 days (±0.9) at follow-up.

Time spent sedentary, overall PA, or VPA did not predict lower adiposity at follow-up ($p \geq 0.080$) (Table 2), but there was an interaction for sex and MVPA ($p = 0.017$) for S4SF. Moderate-to-vigorous PA predicted lower S4SF at follow-up among boys (MVPA β -0.066 [95% CI -0.105, -0.027] $p = 0.001$), but not among girls ($p = 0.889$).

All adiposity measures predicted a decrease in overall PA, MVPA, and VPA and a higher amount of sedentary time at follow-up ($p < 0.043$) (Table 3). We observed significant interactions by sex between all baseline adiposity measures and PA outcomes ($p < 0.048$), but not for sedentary time ($p \geq 0.477$). Baseline BMI and WC predicted a decrease in overall PA,

MVPA, and VPA in boys ($p < 0.001$) but not in girls ($p \geq 0.112$). When S4SF was modelled as the exposure, time spent in VPA was lower at follow-up in both girls (β -0.098 [95% CI -0.194, -0.002] $p = 0.045$) and boys (β -0.276 [95% CI -0.372, -0.180] $p < 0.001$).

Lastly, we examined the associations according to weight status categories and whether MVPA recommendations were met or not (Table 4). There was no difference in adiposity at follow up between children categorized as sufficiently active or insufficiently active at baseline ($p > 0.235$). Children who were overweight or obese according to cut points had lower overall PA (β -0.235 [95% CI -0.405, -0.065] $p = 0.007$), MVPA (β -0.199 [95% CI -0.347, -0.052] $p = 0.008$), and VPA at follow-up (β -0.266 [95% CI -0.423, -0.110] $p = 0.001$) than normal-weight children. There was no difference between groups (normal-weight and overweight/obese) in relation to sedentary time at follow-up.

Discussion

To our knowledge, this is the first study based on a larger sample and a longer follow-up time than previous studies. The aim of this study was to examine the bi-directional prospective associations between sedentary time, PA, and adiposity in children. At seven months follow-up, both time spent sedentary and higher intensity PA predicted a lower BMI or WC. Baseline MVPA predicted lower S4SF only in boys. All adiposity measures at baseline (BMI, WC, and S4SF) predicted a decrease in overall PA, MVPA, and VPA in boys. All adiposity measures at baseline predicted more time spent sedentary at follow-up in both girls and boys.

Our findings corroborate with the few studies examining bi-directional associations between PA, sedentary time, and adiposity. In a study of 10-year-old Danish children, a higher fat mass index at baseline was associated with less PA and more sedentary time at a six-month follow-up (Hjorth et al., 2014). A meta-analysis from the International Children's Accelerometer Database found that neither children's MVPA nor sedentary time were associated with WC at follow-up, but baseline WC did predict more sedentary time two years later (Ekelund et al., 2012). A study using the Mendelian Randomization approach to infer putative causal relations between modifiable risk factors and disease suggested that adiposity is a causal risk factor for lower overall PA and MVPA and increased sedentary time, but it was not able to elucidate whether low PA may lead to increases in adiposity (Richmond et al., 2014). Recently, data from the Gateshead Millennium Study examined a bi-directional hypothesis and found that high body fat at age seven predicted less MVPA and VPA two years later (Tanaka et al., 2018). It should be noted that the prospective associations were based on modelling change versus change, which may be considered a "masked" cross-sectional study. Nonetheless, these studies imply that PA and sedentary time do not predict adiposity and instead support the hypothesis that the association could be in the opposite direction.

The present study observed interaction in associations by sex. One possible explanation is that boys with excess weight are less active than their peers (Page et al., 2005). Moreover, PA is progressively lower across the weight spectrum in boys but consistently lower across all weight categories in girls, indicating a continuous negative association between PA and weight in boys (Purslow, Hill, Saxton, Corder, & Wardle, 2008). Indeed, the amount of MVPA declines and sedentary time increases between age six and 11, but the decline in MVPA is lager over time for those who are overweight and obese compared to 'healthier' children (Jago et al., 2020). In addition, boys were generally more active at baseline than girls in the present sample (data not shown), which is well-known from other studies (Cooper et al., 2015). Thus, a possible effect of the regression-to-the-mean phenomenon could be present, meaning that those with high levels of PA at baseline potentially experience a larger decrease in PA levels compared with those starting with lower PA levels (Collings et al., 2015), and so the decrease in PA is likely to be greater in boys than in girls (Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). With time, these differences between boys and girls might be attenuated, as recently published data from the Norwegian PA Surveillance System show that the proportion of boys at age nine who meet PA recommendations decreased between 2005 and 2018, but not the proportion of girls (Steene-Johannessen et al., 2019).

It is a common belief that the longitudinal reduction observed in PA levels, with its subsequent increases in sedentary time, is responsible for weight gain. Our present findings do not support this assumption. We found no differences in either BMI, WC, or S4SF at follow-up when children who achieved the PA recommendations were compared to those that did not achieve the PA recommendations at baseline. This does not mean that PA is an ineffective strategy in tackling childhood overweight and obesity (Hallal et al., 2012). Current recommendations for the minimum dose of PA are not specifically tailored to prevent weight gain, but rather aimed at several health outcomes beyond adiposity, including

cardiorespiratory fitness, cardiometabolic risk factors, and bone and mental health (Janssen & Leblanc, 2010; Renninger et al., 2020). Prevention is the best approach to counter the short and long-term health problems of excess weight, and increased MVPA is suggested as a main component in obesity prevention (Mitchell et al., 2017). However, the most effective intervention is unknown (Han et al., 2010). Actions to solely increase PA level do not solve the complex issue of overweight and obesity in children. Reasons for excess weight is a complex figure including i.e. parental weight, pubertal status, SES, and sleep duration, but unequivocally a result of long-term energy imbalances mainly resulting from dietary factors (Lean, Astrup, & Roberts, 2018; Swinburn, Sacks, & Ravussin, 2009), with PA as an important moderator of weight gain and maintenance (Swinburn et al., 2009).

Accelerometers are considered a criterion method for measuring PA, but are limited by misclassification and underestimation of PA intensity (Brond & Arvidsson, 2016). Repeated measurements of PA in the same individuals have substantial intra-individual variability with an intraclass correlation of about 0.5, suggesting that PA levels are highly variable over time (Aadland et al., 2017). Physical activity and sedentary time are measured less precisely than BMI, WC, and skinfolds, and therefore, it is not surprising that baseline BMI and WC predict PA at follow-up whereas, because of measurement error, the reverse may not be detectable (Ekelund et al., 2008). Examining the direction of associations between exposure and outcome measures with different degrees of measurement error is therefore problematic. When a more imprecise variable is modelled as the outcome (i.e., PA), the magnitude of effect is estimated accurately, but with wider CIs. In contrast, when a more imprecise variable is modelled as the exposure, it tends to attenuate the regression coefficient (Hutcheon, Chiolero, & Hanley, 2010). Increasing sample size, however, does not solve the issue and may only result in a more precisely erroneous estimate of the effect size (Hutcheon et al., 2010).

The main strengths of the current study are the use of objective measurements of PA, the use of clinically relevant adiposity measures, and the use of prospective analyses with baseline adjustments of the outcome. The short time frame between baseline and follow-up, however, could raise questions as to whether the present observations are meaningful and have lasting effects in either direction. Moreover, the temporal association between PA and adiposity *before* our baseline measurements is also unknown. The traditional association between baseline sedentary time, PA, and adiposity at follow-up could therefore be evident in studies with longer durations (Hallal et al., 2012). Seven months is a fair amount of time in a child's life, but the "short-term" observations could be stronger in magnitude if the study had a longer follow-up. Repeated measurements of PA and more precise measures of adiposity (i.e., DEXA) over a longer period would allow additional modelling of the complex longitudinal relationships between sedentary time, PA, and adiposity. Experimental and observational studies using the Mendelian Randomization approach are needed to examine the causal associations between sedentary time, PA, and adiposity in children. However, physical activity interventions are unfortunately difficult to conduct given the long time it takes to develop excess weight or achieve weight loss in children, combined with issues of cost and compliance. Lastly, we cannot exclude the possibility that our observations are explained by residual confounding, and the study was carried out in a rural county with most children being Caucasian. Thus, the generalization of our results to other populations is at best limited. It should be noted that we did not adjust for multiple testing, which may inflate type 1 error. However, correction for multiple comparisons is debated, as it may increase the risk of type 2 error (Perneger, 1998).

Our results suggest that overall PA and sedentary time do not predict future adiposity in this sample of 10-year-old children. Baseline adiposity rather predicts more sedentary time and

less high-intensity PA. Our findings were more pronounced among boys. Adiposity level may therefore be a determinant of lower levels of physical activity.

References

Aadland, E., Andersen, L. B., Skrede, T., Ekelund, U., Anderssen, S. A., & Resaland, G. K. (2017). Reproducibility of objectively measured physical activity and sedentary time over two seasons in children; Comparing a day-by-day and a week-by-week approach. *PLoS One, 12*(12), e0189304. doi:10.1371/journal.pone.0189304

Brond, J. C., & Arvidsson, D. (2016). Sampling frequency affects the processing of Actigraph raw acceleration data to activity counts. *J Appl Physiol (1985), 120*(3), 362-369. doi:10.1152/japplphysiol.00628.2015

Carel, J. C., & Leger, J. (2008). Clinical practice. Precocious puberty. *N Engl J Med, 358*(22), 2366-2377. doi:10.1056/NEJMcp0800459

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ, 320*(7244), 1240-1243.

Collings, P. J., Wijndaele, K., Corder, K., Westgate, K., Ridgway, C. L., Sharp, S. J., . . . Brage, S. (2015). Magnitude and determinants of change in objectively-measured physical activity, sedentary time and sleep duration from ages 15 to 17.5y in UK adolescents: the ROOTS study. *Int J Behav Nutr Phys Act, 12*, 61. doi:10.1186/s12966-015-0222-4

Cooper, A. R., Goodman, A., Page, A. S., Sherar, L. B., Esliger, D. W., van Sluijs, E. M., . . . Ekelund, U. (2015). Objectively measured physical activity and sedentary time in youth: the International Children's Accelerometry Database (ICAD). *Int J Behav Nutr Phys Act, 12*, 113. doi:10.1186/s12966-015-0274-5

Daniels, S. R. (2009). Complications of obesity in children and adolescents. *Int J Obes (Lond), 33 Suppl 1*, S60-65. doi:10.1038/ijo.2009.20

Ebbeling, C. B., Pawlak, D. B., & Ludwig, D. S. (2002). Childhood obesity: public-health crisis, common sense cure. *Lancet, 360*(9331), 473-482. doi:10.1016/S0140-6736(02)09678-2

Ekelund, U., Brage, S., Besson, H., Sharp, S., & Wareham, N. J. (2008). Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? *Am J Clin Nutr, 88*(3), 612-617.

Ekelund, U., Brage, S., Froberg, K., Harro, M., Anderssen, S. A., Sardinha, L. B., . . . Andersen, L. B. (2006). TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. *PLoS Med, 3*(12), e488. doi:10.1371/journal.pmed.0030488

Ekelund, U., Kolle, E., Steene-Johannessen, J., Dalene, K. E., Nilsen, A. K. O., Anderssen, S. A., & Hansen, B. H. (2017). Objectively measured sedentary time and physical activity and associations with body weight gain: does body weight determine a decline in moderate and vigorous intensity physical activity? *Int J Obes (Lond)*. doi:10.1038/ijo.2017.186

Ekelund, U., Luan, J., Sherar, L. B., Esliger, D. W., Griew, P., Cooper, A., & International Children's Accelerometry Database, C. (2012). Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA, 307*(7), 704-712. doi:10.1001/jama.2012.156

Esliger, D. W., Copeland, J. L., Barnes, J. D., & Tremblay, M. S. (2005). Standardizing and Optimizing the Use of Accelerometer Data for Free-Living Physical Activity Monitoring. *Journal of Physical Activity and Health, 3*.

Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *J Sports Sci, 26*(14), 1557-1565. doi:10.1080/02640410802334196

Hallal, P. C., Reichert, F. F., Ekelund, U., Dumith, S. C., Menezes, A. M., Victora, C. G., & Wells, J. (2012). Bidirectional cross-sectional and prospective associations between physical activity and body composition in adolescence: birth cohort study. *J Sports Sci, 30*(2), 183-190. doi:10.1080/02640414.2011.631570

Han, J. C., Lawlor, D. A., & Kimm, S. Y. (2010). Childhood obesity. *Lancet, 375*(9727), 1737-1748. doi:10.1016/S0140-6736(10)60171-7

Hjorth, M. F., Chaput, J. P., Ritz, C., Dalskov, S. M., Andersen, R., Astrup, A., . . . Sjodin, A. (2014). Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. *Int J Obesity, 38*(7), 959-965. doi:10.1038/ijo.2013.229

Hutcheon, J. A., Chiolero, A., & Hanley, J. A. (2010). Random measurement error and regression dilution bias. *BMJ, 340*, c2289. doi:10.1136/bmj.c2289

Jago, R., Salway, R., Emm-Collison, L., Sebire, S. J., Thompson, J. L., & Lawlor, D. A. (2020). Association of BMI category with change in children's physical activity between ages 6 and 11 years: a longitudinal study. *Int J Obes (Lond), 44*(1), 104-113. doi:10.1038/s41366-019-0459-0

Janssen, I., & Leblanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act, 7*, 40. doi:10.1186/1479-5868-7-40

Katzmarzyk, P. T., Barreira, T. V., Broyles, S. T., Champagne, C. M., Chaput, J. P., Fogelholm, M., . . . Church, T. S. (2015). Physical Activity, Sedentary Time, and Obesity in an International Sample of Children. *Med Sci Sports Exerc, 47*(10), 2062-2069. doi:10.1249/MSS.0000000000000649

Kwon, S., Janz, K. F., Burns, T. L., & Levy, S. M. (2011). Effects of adiposity on physical activity in childhood: Iowa Bone Development Study. *Med Sci Sports Exerc, 43*(3), 443-448. doi:10.1249/MSS.0b013e3181ef3b0a

Lean, M. E. J., Astrup, A., & Roberts, S. B. (2018). Making progress on the global crisis of obesity and weight management. *BMJ, 361*, k2538. doi:10.1136/bmj.k2538

Lee, I. M., Djousse, L., Sesso, H. D., Wang, L., & Buring, J. E. (2010). Physical activity and weight gain prevention. *JAMA, 303*(12), 1173-1179. doi:10.1001/jama.2010.312

Maffeis, C., & Tato, L. (2001). Long-term effects of childhood obesity on morbidity and mortality. *Horm Res, 55 Suppl 1*, 42-45. doi:10.1159/000063462

Metcalf, B. S., Hosking, J., Jeffery, A. N., Voss, L. D., Henley, W., & Wilkin, T. J. (2011). Fatness leads to inactivity, but inactivity does not lead to fatness: A longitudinal study in children (EarlyBird 45). *Arch Dis Child, 96*(10), 942-947.

Mitchell, J. A., Dowda, M., Pate, R. R., Kordas, K., Froberg, K., Sardinha, L. B., . . . Page, A. (2017). Physical Activity and Pediatric Obesity: A Quantile Regression Analysis. *Med Sci Sports Exerc, 49*(3), 466-473. doi:10.1249/MSS.0000000000001129

Mitchell, J. A., Pate, R. R., Beets, M. W., & Nader, P. R. (2013). Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years. *Int J Obesity, 37*(1), 54-60. doi:10.1038/ijo.2012.41

Nader, P. R., Bradley, R. H., Houts, R. M., McRitchie, S. L., & O'Brien, M. (2008). Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA, 300*(3), 295-305. doi:10.1001/jama.300.3.295

Page, A., Cooper, A. R., Stamatakis, E., Foster, L. J., Crowne, E. C., Sabin, M., & Shield, J. P. (2005). Physical activity patterns in nonobese and obese children assessed using minute-by-minute accelerometry. *Int J Obes (Lond), 29*(9), 1070-1076. doi:10.1038/sj.ijo.0802993

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *BMJ, 316*(7139), 1236-1238.

Purslow, L. R., Hill, C., Saxton, J., Corder, K., & Wardle, J. (2008). Differences in physical activity and sedentary time in relation to weight in 8-9 year old children. *Int J Behav Nutr Phys Act, 5*, 67. doi:10.1186/1479-5868-5-67

Renninger, M., Hansen, B. H., Steene-Johannessen, J., Kriemler, S., Froberg, K., Northstone, K., . . . Accelerometry, I. C. s. (2020). Associations between accelerometry measured physical activity and sedentary time and the metabolic syndrome: A meta-analysis of more than 6000 children and adolescents. *Pediatric Obesity, 15*(1). doi:ARTN e1257810.1111/ijpo.12578

Resaland, G. K., Aadland, E., Moe, V. F., Aadland, K. N., Skrede, T., Stavnsbo, M., . . . Anderssen, S. A. (2016). Effects of physical activity on schoolchildren's academic performance: The Active Smarter Kids (ASK) cluster-randomized controlled trial. *Prev Med, 91*, 322-328. doi:10.1016/j.ypmed.2016.09.005

Resaland, G. K., Moe, V. F., Aadland, E., Steene-Johannessen, J., Glosvik, O., Andersen, J. R., . . . group, A. S. K. s. (2015). Active Smarter Kids (ASK): Rationale and design of a cluster-randomized controlled trial investigating the effects of daily physical activity on children's academic performance and risk factors for non-communicable diseases. *BMC Public Health, 15*, 709. doi:10.1186/s12889-015-2049-y

Richmond, R. C., Davey Smith, G., Ness, A. R., den Hoed, M., McMahon, G., & Timpson, N. J. (2014). Assessing causality in the association between child adiposity and physical activity levels: a Mendelian randomization analysis. *PLoS Med, 11*(3), e1001618. doi:10.1371/journal.pmed.1001618

Saunders, T. J., Chaput, J. P., & Tremblay, M. S. (2014). Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. *Can J Diabetes, 38*(1), 53-61. doi:10.1016/j.jcjd.2013.08.266

Silva, D. R., Ribeiro, A. S., Pavao, F. H., Ronque, E. R., Avelar, A., Silva, A. M., & Cyrino, E. S. (2013). Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: a systematic review. *Rev Assoc Med Bras (1992), 59*(5), 475-486. doi:10.1016/j.ramb.2013.03.006

Skrede, T., Steene-Johannessen, J., Anderssen, S. A., Resaland, G. K., & Ekelund, U. (2019). The prospective association between objectively measured sedentary time, moderate-to-vigorous physical activity and cardiometabolic risk factors in youth: a systematic review and meta-analysis. *Obes Rev, 20*(1), 55-74. doi:10.1111/obr.12758

Steene-Johannessen, J., Anderssen, S. A., Bratteteig, M., M., D. E., Andersen, I. D., Andersen, O. K., . . . Dalene, K. E. (2019). *Nasjonalt overvåkingssystem for fysisk aktivitetog fysisk form. Kartlegging av fysisk aktivitet, sedat tid og fysisk form blant barn og unge 2018 (ungKan3)*. Retrieved from Oslo:

Swinburn, B., Sacks, G., & Ravussin, E. (2009). Increased food energy supply is more than sufficient to explain the US epidemic of obesity. *Am J Clin Nutr, 90*(6), 1453-1456. doi:10.3945/ajcn.2009.28595

Tanaka, C., Janssen, X., Pearce, M., Parkinson, K., Basterfield, L., Adamson, A., & Reilly, J. J. (2018). Bidirectional Associations Between Adiposity, Sedentary Behavior, and Physical Activity: A Longitudinal Study in Children. *J Phys Act Health*, 1-9. doi:10.1123/jpah.2018-0011

Trost, S. G., Loprinzi, P. D., Moore, R., & Pfeiffer, K. A. (2011). Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc, 43*(7), 1360-1368. doi:10.1249/MSS.0b013e318206476e