BMJ Open

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-036991
Article Type:	Original research
Date Submitted by the Author:	23-Jan-2020
Complete List of Authors:	Aars, Nils; UiT – The Arctic University of Norway, Department of Community Medicine; Nordlandssykehuset HF Beldo, Sigurd; UiT Arctic University of Norway, School of Sport Sciences Jacobsen, Bjarne; UiT – The Arctic University of Norway, Department of Community Medicine; UiT – The Arctic University of Norway, Centre for Sami Health Research Horsch, Alexander; UiT – The Arctic University of Norway, Department of Computer Science Morseth, Bente; UiT Arctic University of Norway, School of Sport Sciences; UiT – The Arctic University of Norway, Department of Community Medicine Emaus, Nina; Uit The Arctic University of Norway, Department of Health and Care Siences Furberg, Anne-Sofie; UiT The Arctic University of Norway, Department of Comunity Medicine; Universitetssykehuset Nord-Norge, Department of Microbiology and Infection Control Grimsgaard, Sameline; UiT The Arctic University of Norway, Department of Community Medicine
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, SPORTS MEDICINE

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Nils Abel Aars[1, 2*]

Sigurd Beldo[3]

Bjarne K Jacobsen[1, 4]

Alexander Horsch[5]

Bente Morseth[3, 1]

Nina Emaus[6]

Anne-Sofie Furberg[1, 7]

Sameline Grimsgaard[1]

Affiliations

1. Department of Community Medicine, UiT the Arctic University of Norway, Tromsø, Norway

2. Nordland Hospital, Bodø, Norway.

3. School of Sport Sciences, UiT the Arctic University of Norway, Alta, Norway

4. Centre for Sami Health Research, Department of Community Medicine, UiT the Arctic University of Norway, Tromsø, Norway

5. Department of Computer Science, UiT the Arctic University of Norway, Tromsø, Norway

6. Department of Health and Care Sciences, UiT the Arctic University of Norway, Tromsø, Norway

7. Department of Microbiology and Infection Control, University Hospital of North Norway, Tromsø, Norway

* Corresponding author. Correspondence to nils.a.aars@uit.no

Nils Abel Aars

Department of Community Medicine

UiT the Arctic University of Norway

9037 Tromsø, Norway.

1

2

Abstract

Objectives: Physical activity may play an important role in deterring the world-wide obesity epidemic. This study explored the effect of objectively measured physical activity on changes in body composition over two years of follow up in an adolescent population in Northern Norway.

Design: A longitudinal study of adolescents (60.5% girls, mean age 16 at baseline) participating in the Fit Futures studies 1 (2010-11) and 2 (2012-13).

Setting: Upper secondary high schools in neighboring municipalities of Tromsø and Balsfjord, northern Norway.

Participants: Students participating in both studies and under the age of 18 at baseline, and with valid measurement of both exposure and outcomes. Physical activity was measured using a hip-worn accelerometer, and provided measurements of minutes per day spent in sedentary-, light and moderate-to-vigorous physical activity.

Primary- and secondary outcomes: Change in objectively measured body mass index and waist circumference, and change in dual-energy x-ray absorptiometry measured fat mass index, lean mass index and appendicular lean mass index between baseline and follow-up. Differences in measures of physical activity at baseline between sexes was also compared.

Results: Boys had significantly higher physical activity volume (p=0.01) and spent more minutes in moderate physical activity (MVPA) than girls (6.4 minutes, p <0.01). In multivariate regression analyses there was no significant association between either measure of physical activity and changes in body composition in boys. In girls there was a significant association between sedentary- and light activity and changes in lean mass index (p < 0.01) and appendicular lean mass index (p = 0.05).

Conclusions: In this cohort of Norwegian adolescents, sedentary and light physical activity were associated with changes in indices of lean mass in girls, but not boys. Minutes spent in moderate-to-vigorous physical activity was not associated with changes in either measure of body composition in neither boys nor girls.

Strengths and limitations of this study

- This study used objective measures of physical activity.

- The study included objectively measured weight, height and waist circumference, and dual-energy x-ray absorptiometry (DXA) measures of fat- and lean mass.
- We were not able to fully adjust for nutrition and not for pubertal development.
- The 431 participants with complete data from both baseline and follow-up represents 41% of those attending Fit Futures 1, indicating a degree of selection.

Background

The potential of physical activity to prevent or treat a number of diseases has been highlighted by the World Health Organization,[1] with inactivity accounting for 9% of worldwide premature mortality.[2] Public health guidelines state that adolescents should engage in Moderate-to-Vigorous Physical Activity (MVPA) ≥ 60 minutes per day,[3] but in 2011, only 50% of Norwegian 15 year olds met these recommendations.[4] During adolescence there is a decline in both total physical activity and MVPA,[5, 6] and many quit or reduce participation in organized sports.[7] As of 2013, the prevalence of overweight and obesity (Body Mass Index (BMI) ≥ 25 kg/m^2) in Norwegians aged <20 years appear to be stabilizing at around 20% in boys and 16% in girls - comparable to the Nordic countries.[8] This is lower than in the United States (around 29% in boys and girls) [8], but the health effects for those concerned may still be substantial over the long term.[9]

While physical activity has many positive health effects, its relationship with adiposity is less clear and it has proven difficult to determine causality, direction and magnitude of this relationship.[10] Cross-sectional research typically shows a strong negative

association between physical activity and weight status,[11] but temporality cannot be ascertained using such study designs.[12] Longitudinal studies may ascertain if lower physical activity precedes excess weight gain, but a review found no evidence for a relationship between objectively measured physical activity and body fat gain in adolescents.[12] The lack of congruent results may in part be explained by the diverse and inadequate measures of both exposure and outcome used in research of the association between physical activity and body composition.[10, 11]

Although many methods to measure physical activity are available, the most common and most feasible is self-report which commonly overestimates the total amount of physical activity.[13] Body composition is most commonly assessed using BMI, but BMI does not distinguish between fat- and muscle mass.[14] This has the potential to cause misclassification of overweight status and may attenuate a true association between physical activity and fat or muscle mass. Thus, in the current study, we sought to overcome these limitations by applying objective measures of both physical activity and specific measures of body composition. Our aim was to investigate the association between objectively measured physical activity and changes in five different measures of body composition (body mass index, waist circumference, fat

mass index, lean mass index and appendicular lean mass index) over two years of follow-up in a cohort of Norwegian adolescents.

Methods and materials

We used data from the first and second Fit Futures cohort studies, performed in 2010-2011 and 2012-2013, respectively. The first study invited all students (n=1,117) in their first year of upper secondary high school in the neighboring municipalities of Tromsø and Balsfjord in northern Norway, and had a participation of 93%. The study was repeated two years later, when the students were in their last year of upper secondary high school or had started as apprentices if they studied vocational subjects. The second study included 868 participants, giving an attendance of 77%. Altogether 735 adolescents attended both surveys. We excluded those aged ≥ 18 years of age at baseline (n = 38). Some participants (n = 240) did not have valid measurements of physical activity at baseline, and were therefore not included in the study. We also excluded those with missing data on outcomes or variables included in the model (n = 26). Thus, 431 participants were included in the present study (60.3% girls).

Students were granted leave of absence from school to attend an examination at the Clinical Research Unit at the University Hospital of Northern Norway in both surveys. The participants signed a letter of informed consent and attended a clinical examination where they also answered a questionnaire. Those under the age of 16 brought a letter of consent signed by their parent or guardian.

All measurements were performed by trained personnel. Height was measured to the nearest centimeter and weight to the nearest 100 gram, wearing light clothing and using an automatic electronic scale/stadiometer (Jenix DS 102 stadiometer, Dong Sahn Jenix, Seoul, Korea). Body mass index was calculated as body weight in kilograms/height in meters^2. Waist circumference was measured to the nearest 0.1 centimeter at the height of the umbilicus. Fat and soft tissue lean mass in grams was estimated by whole-body dual energy X-ray absorptiometry (DXA) (GE Lunar Prodigy, Lunar Corporation, Madison, WI, USA). Fat mass comprises all fat, while soft tissue lean mass comprises all bodily tissue except fat and skeletal mass. These variables were used to calculate fat mass index (FMI, fat mass in kilograms/height in meters^2) and lean mass index (LMI, lean mass in kilograms/height in meters^2). In addition we calculated appendicular lean mass index (aLMI), which is the sum of soft tissue lean mass in kilograms in all four extremities divided by height in meters^2. Although most commonly used in studies of sarcopenia in elderly,[15] this variable is arguably more specific to skeletal muscle mass than total lean mass index. The ability of DXA to detect changes in appendicular lean mass in young adolescents is good, and has been validated against Magnetic Resonance Imaging (MRI).[16]

Physical activity was objectively measured using the ActiGraph GT3X accelerometer (ActiGraph, LLC, Pensacola, USA). Participants were instructed to wear the device on their right hip for seven consecutive days, and to remove it only when showering, swimming or sleeping. The ActiLife software was used to initialize the accelerometer and download data, which was imported into the Quality Control & Analysis Tool (QCAT) for data processing. This software was developed by the research group of professor Horsch in Matlab (The MathWorks, Inc., Massachusetts, USA) for processing of accelerometer data. The accelerometer was set in raw data mode, with a sampling frequency of 30 Hertz and with normal filtering epochs of 10 seconds.

Data collection was initiated at 14:00 hours the first day, and concluded at 23:58 on the 8th day of measurement. We excluded data from the first day of measurement to reduce reactivity bias. The criteria for a valid measurement of physical activity was wear time of ≥ four consecutive days, with ≥ ten hours wear time per day. This has been demonstrated as representative of activity over a full week.[17] The triaxial algorithm developed by Hecht et al. was used to calculate wear time.[18] Minutes per day in sedentary (0 – 99 CPM), light (100 – 1951 CPM), moderate (1952 – 5723 CPM) and vigorous (≥ 5724 CPM) physical activity was determined using the cut-offs developed by Freedson.[19] The device collected data in both uniaxial- and triaxial mode, but in the present study only the uniaxial data had been processed and therefore available. Studies have shown that uniaxial data recorded from the GT3X correlate well with uniaxial data recorded from previous ActiGraph models.[20]

Baseline characteristics were presented as means with standard deviation (SD) or prevalence in percentages with number of subjects (n). Sex-specific difference in body composition between baseline and follow-up was tested using a paired samples t-test. The difference in physical activity between sexes was tested using a two-sample t-test, while sex differences in categories of minutes spent in MVPA was tested using a chi-square test. Difference in linear trend across categories of minutes spent in MVPA was tested using STATA's non-parametric test for trend, developed by Cuzick.[21] Linear regression was used to determine the effect of baseline physical activity on change in body composition, i.e., the change in BMI, waist circumference, FMI, LMI and aLMI from the first to the second Fit Futures Study.

We used three different predictors of change in body composition, performing three sets of analyses, with first; minutes per day spent in sedentary activity (Table 2) second; minutes per day spent in light activity (Table 3) and third; minutes per day spent in MVPA (Table 4). We divided the continuous variables sedentary- and light activity by 30 and the continuous variable MVPA by 15 before inclusion in the models, thus presenting the beta coefficient for change in outcome per 30 minutes of sedentary- or light activity, or per 15 minutes of MVPA, with 95% confidence intervals and a p-value. In model 1 we adjusted for the baseline measurement of the outcome. In the adjusted models (models 2) we also included time between measurements (mean: 730 days) and baseline values of device wear time, age in half years and questionnaire data on screen time on weekdays (how many hours per weekday the students spent in front of a computer or television - answers ranged from none to more than ten hours per weekday) and regularity of eating breakfast as an indicator of healthy meal patterns (answers ranging from rarely/never to every day). In the analyses of sedentary- and light activity we also adjusted for minutes spent in MVPA (models 3). In a subset of analyses (Appendix tables 1 and 2) we repeated the analyses performed in Table 2 and 3, adjusting also for self-reported pubertal status measured by either pubertal development scale (boys) or age at menarche (girls). These analyses included the 143 boys and 256 girls with valid data on pubertal status. In all the analyses, a p-value of < 0.05 was considered statistically significant.

All analyses were performed sex-specific as decided a-priori, using STATA version 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP.).

Patient and public involvement

No patients were involved in this study.

Results

Table 1 displays the participants' body composition measurements at baseline and follow-up, as well as physical activity measurements at baseline. Boys had a statistically significant increase in all measures of body composition. Girls had a statistically significant increase in body weight, BMI, fat mass in kg and FMI, but not in LMI and appendicular lean mass. Boys were statistically significantly more physically active than girls in some aspects, with higher mean counts per minute (p=0.01) and more minutes in MVPA (p<0.01). Time spent in sedentary- or light intensities did not differ significantly between sexes. Twenty-seven percent of boys and 17% of girls complied with the recommendations of 60 minutes per day Moderate-to-Vigorous Physical Activity (MVPA).

Table 1. Characteristics of the longitudinal cohort of the Tromsø Study; Fit Futures 2010-11 and 2012-13 ◊.

	Boys (n = 171)		Girls (n = 260)	
	FF1	FF2	FF1	FF2
Age (years)	16.0 (0.4)	18.2 (0.4)	16.1 (0.4)	18.1 (0.4)
Height (cm)	177.1 (6.6)	179.0 (6.5)*	165.4 (6.6)	166.1 (6.6)*
Body weight (kg)	69.0 (12.3)	74.3 (13.0)*	60.8 (10.8)	63.4 (11.6)*
Body mass index (BMI kg/m2)	22.0 (3.5)	23.2 (3.7)*	22.2 (3.7)	23.0 (4.0)*
Waist circumference (cm)	81.0 (10.3)	83.9 (10.9)*	76.7 (9.8)	78.0 (10.8)*
Total Body Fat Mass (kg)	13.3 (9.4)	15.6 (10.4)*	19.9 (8.3)	21.7 (9.1)*
Fat Mass Index (FMI kg/m2)	4.2 (3.0)	4.9 (3.2)*	7.3 (3.0)	7.9 (3.3)*
Total Body Lean Mass (kg)	54.0 (6.5)	56.4 (6.9)*	38.9 (4.5)	39.3 (4.7)*
Lean Mass Index (LMI kg/m2)	17.2 (1.6)	17.6 (1.8)*	14.2 (1.3)	14.2 (1.4)
Appendicular Lean Mass (kg)	25.3 (3.4)	26.2 (3.6)*	17.4 (2.3)	17.4 (2.3)
Appendicular Lean Mass Index (aLMI kg/m2)	8.1 (0.9)	8.2 (0.9)*	6.4 (0.7)	6.3 (0.7)*

Accelerometer variables				
Wear time per valid day	14.2 (1.2)		14.1 (1.1)	
Counts per minute	362.9 (137.5)		334.0 (111.9)[∞]	
Minutes per day in different intensities				
Sedentary (cpm 0 – 99)	573.3 (77.3)		565.3 (63.2)	
Light (cpm 100 – 1951)	230.5 (58.8)		236.2 (48.4)	
Moderate (cpm 1952 – 5723)	45.8 (20.6)		40.2 (17.7)[∞]	
Vigorous (cpm ≥ 5724)	3.7 (5.8)		2.9 (4.1)[∞]	
MVPA[#] (cpm ≥ 1952)	49.5 (23.4)		43.1 (19.6)[∞]	
Proportion of minutes in MVPA/day				
0 – 29 minutes	20.5 (35)		26.5 (69)	
30 – 59 minutes	52.6 (90)		56.2 (146)	
≥ 60 minutes	26.9 (46)		17.3 (45)[§]	

◊: Values are means with standard deviation (SD) or prevalence in percentages (n). BMI: body weight in kg/height in meters^2, FMI: fat mass in kg/height in meters^2, LMI: lean mass in kg/height in meters^2, aLMI: appendicular lean mass in kg/height in meters^2. Data on physical activity in FF2 was not available.

*: Significantly different from baseline measurement ($p < 0.05$)

∞: Significantly different from boys (mean).

#: MVPA: moderate to vigorous physical activity, using cut-offs suggested by Freedson.[19]

§: significantly different linear trend from boys ($p<0.05$)

Table 2 displays the association between minutes spent in sedentary activity at baseline and changes in body composition between baseline and follow-up. There was no association between sedentary activity and changes in BMI, waist circumference and FMI in neither boys nor girls. In girls, but not in boys, there was a significant association between minutes spent in sedentary activity at baseline and changes in both LMI ($p < 0.01$) and aLMI ($p = 0.02$). Adjustment for covariates and MVPA slightly attenuated the association with aLMI ($p = 0.05$).

Table 2. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition[#].

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	-0.02	-0.13, 0.09	0.76	-0.05	-0.15, 0.05	0.33
Model 2	-0.02	-0.17, 0.12	0.75	-0.11	-0.24, 0.03	0.12
Model 3	0.01	-0.17, 0.20	0.88	-0.11	-0.27, 0.05	0.16
∆ waist circumference						
Model 1	0.17	-0.21, 0.56	0.37	-0.01	-0.41, 0.40	0.96
Model 2	0.27	-0.24, 0.78	0.30	-0.33	-0.87, 0.20	0.22
Model 3	0.42	-0.23, 1.07	0.20	-0.44	-1.06, 0.18	0.17
∆ FMI						
Model 1	0.00	-0.10, 0.10	0.99	-0.01	-0.11, 0.08	0.83
Model 2	-0.02	-0.16, 0.11	0.74	-0.06	-0.18, 0.07	0.36
Model 3	0.00	-0.17, 0.17	0.98	-0.05	-0.20, 0.09	0.48
∆ LMI						
Model 1	0.00	-0.05, 0.05	0.88	-0.06	-0.09, -0.02	<0.01
Model 2	0.01	-0.06, 0.07	0.77	-0.07	-0.12, -0.02	<0.01
Model 3	0.02	-0.06, 0.10	0.63	-0.08	-0.13, -0.03	<0.01

∆ aLMI						
Model 1	0.00	-0.03, 0.03	0.84	-0.02	-0.04, -0.00	0.02
Model 2	0.00	-0.03, 0.04	0.81	-0.03	-0.05, -0.01	0.02
Model 3	0.01	-0.04, 0.05	0.71	-0.03	-0.06, 0.00	0.05

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 3 displays the association between minutes spent in light activity at baseline and changes in body composition between baseline and follow-up. There was no association between the exposure and either outcome in boys. In girls there was some evidence to suggest an association with change in waist circumference (p =0.05), but the association was attenuated after adjustments (p = 0.17). Minutes spent in light physical activity was also associated with changes in LMI (p < 0.01 (Models 2 and 3)) and aLMI (p = 0.04 (Model 2) and 0.05 (Model 3)).

Table 3. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition$^{\#}$.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	0.04	-0.11, 0.18	0.60	0.05	-0.09, 0.19	0.47
Model 2	0.01	-0.17, 0.18	0.93	0.12	-0.04, 0.27	0.13
Model 3	-0.01	-0.20, 0.17	0.88	0.11	-0.05, 0.27	0.16
∆ waist circumference						
Model 1	-0.11	-0.62, 0.40	0.68	0.54	0.01, 1.07	0.05
Model 2	-0.38	-1.00, 0.23	0.22	0.43	-0.19, 1.05	0.17
Model 3	-0.42	-1.07, 0.23	0.20	0.44	-0.19, 1.06	0.17
∆ FMI						
Model 1	0.03	-0.10, 0.16	0.67	0.02	-0.10, 0.15	0.71
Model 2	0.01	-0.15, 0.18	0.87	0.06	-0.09, 0.20	0.43
Model 3	-0.00	-0.17, 0.17	0.98	0.05	-0.09, 0.20	0.49
∆ LMI						
Model 1	-0.01	-0.07, 0.06	0.84	0.04	-0.01, 0.09	0.08
Model 2	-0.02	-0.09, 0.06	0.67	0.08	0.03, 0.13	<0.01
Model 3	-0.02	-0.10, 0.06	0.63	0.08	0.03, 0.13	<0.01
∆ aLMI						

Model 1	0.00	-0.03, 0.04	0.87	0.02	-0.01, 0.04	0.16
Model 2	-0.01	-0.05, 0.04	0.73	0.03	0.00, 0.06	0.04
Model 3	-0.01	-0.05, 0.04	0.70	0.03	-0.00, 0.06	0.05

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 4 displays the association between minutes in MVPA at baseline and changes in body composition between baseline and follow-up. There was no association between time spent in MVPA and changes in either measure of body composition for either sex.

Table 4. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition#.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	0.11	-0.07, 0.30	0.22	-0.00	-0.17, 0.16	0.97
Model 2	0.08	-0.13, 0.29	0.47	0.07	-0.11, 0.25	0.47

∆ waist circumference						
Model 1	0.25	-0.39, 0.89	0.44	-0.03	-0.68, 0.63	0.94
Model 2	-0.02	-0.75, 0.71	0.95	0.02	-0.70, 0.74	0.96
∆ FMI						
Model 1	0.02	-0.15, 0.19	0.83	-0.01	-0.17, 0.14	0.86
Model 2	0.06	-0.14, 0.25	0.57	0.05	-0.12, 0.22	0.54
∆ LMI						
Model 1	0.07	-0.02, 0.15	0.11	0.03	-0.03, 0.09	0.33
Model 2	0.01	-0.08, 0.10	0.86	0.02	-0.04, 0.09	0.44
∆ aLMI						
Model 1	0.03	-0.02, 0.08	0.19	0.02	-0.01, 0.05	0.13
Model 2	0.00	-0.05, 0.05	0.92	0.02	-0.01, 0.05	0.18

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

In Appendix Table 1-3, the analyses which gave the results displayed in Tables 2-4 were repeated with adjustment for pubertal development in those with complete data.

Overall, adjustment for pubertal development had no substantial impact on an association between sedentary, light and moderate-to-vigorous physical activity and changes in body composition for either sex in complete case analyses. However, the association between minutes spent in sedentary activity- and light activity and changes in appendicular lean mass index was no longer significant for girls in Model 3. The point estimates did not differ from those from analyses without adjustments for pubertal development, however.

Discussion

In this longitudinal population-based study of Norwegian adolescents there were no associations between objectively measured physical activity and change in BMI, waist circumference and FMI for either sex at two years of follow up. Both boys and girls had statistically significant increases in the measures of body composition (except lean mass index and appendicular lean mass in girls). Objectively measured physical activity did not predict changes in boys. In girls there was a weak association between minutes spent in sedentary- and light physical activity and changes in indices of lean mass.

Although the magnitude of change differed, both sexes experienced increases in measures of body composition. In boys, FMI increased by 0.7 units, (+ 16.7%), whereas LMI increased by 0.4 units (+ 2.3 %) from baseline. Similar relative changes were observed in girls, (FMI +8.2 %) and (LMI + 0.7%), indicating that FMI increases more than LMI during late adolescence. We observed statistically significant differences in minutes spent in moderate ($p < 0.01$) and vigorous ($p = 0.04$) intensity between boys and girls, but time spent in other intensity levels did not differ. Discrepancies in physical activity by sex is consistent with previous research.[22, 23] Differences in changes in body composition by sex are biologically determined during adolescence, with sex hormones resulting in fat mass accrual in girls and lean mass accrual in boys.[24, 25] The observation that sedentary- and light activity predicted changes in indices of lean mass in girls, but not boys, may be explained by these expected biological differences. Physical activity may have somewhat greater potential to influence lean mass accrual in girls than in boys during this period, as fat-free mass is relatively stable in girls in late adolescence whereas it increases up to 18 years of age in boys.[26]

In the present study sedentary- and light activity had opposing effects on lean mass in girls. In a study using iso-temporal substitution models, positive prospective effects on fat mass was found when substituting 30 minutes of sedentary activity with MVPA, but not when substituted with light activity.[27] We did not use such modelling techniques, but it is reasonable that sedentary- and light physical activity have opposing effects on lean mass.[28] Sedentary- and light activity was correlated (r = -0.39), but minutes spent in different intensity levels are not directly a function of each other as wear time in the participants varies between individuals. Based on wear time inclusion criteria, the theoretical time span for wear time lies between 10 and 24 hours. Thus, minutes spent in sedentary activity may not be deduced from the sum of minutes spent in other intensities and vice versa, but it is plausible that higher wear time results in more sedentary time. This was evident in an exploratory analyses on the same cohort (not included in the present study), where higher wear time was significantly associated with more sedentary activity and less light activity ($p < 0.01$). Adjusting for wear time (Models 2) did not change the associations substantially for sedentary activity (Table 2), but had some effect on the associations with light physical activity (Table 3). Because of the inverse relationship between minutes spent sedentary and in light activity, it is not possible to determine whether it is sedentary time or light activity-time that is associated with change in LMI. The practical consequences are nevertheless that being active increases lean mass in girls.

When interpreting results, we must acknowledge the limitations of DXA in the estimation of lean mass, which can be affected by both biological factors and measurement error.[29] Because the relative increase in lean mass was small, only slight differences in for instance individual hydration status at the two time-points may influence estimates and thus the association.

There was no associations between objectively measured physical activity and change in BMI, waist circumference and FMI for either sex. It may be that the negative effects of less physical activity have not yet had time to manifest themselves in a population still undergoing physiological changes as a result of natural growth, especially considering the relatively short follow-up. Our results are in line with a systematic review suggesting that objectively measured PA is not an important predictor of change in adiposity in children, adolescents and adults.[12] In contrast, another systematic review found a protective effect of physical activity on adiposity in adolescents.[10] There were however several methodological weaknesses in the included studies of this review, particularly regarding the validity of the measurement of both physical activity and body composition. In contrast, our study employed robust measures of both these exposures- and outcomes, a combination which is lacking in much past research on the association between the two.[10-12]

In adolescents, physical activity is influenced by friends, family and other social support,[30] and is less stable than in adults.[31-33] Follow-up data on objectively measured physical activity was not available in the present study. Observations from the same cohort showed that change in self-reported physical activity between baseline and follow-up was a stronger predictor of change in body composition than self-reported baseline physical activity[34]. Other studies have suggested that change in activity during follow-up might obscure an association with body composition.[35, 36] In a subset of analyses, one of four in both the highest and lowest categories of MVPA at baseline reported decreased (high MVPA at baseline) and increased (low MVPA at baseline) self-reported physical activity at follow up, thus indicating that physical activity in adolescents is fluctuant. These two observations, assuming that measurement of both MVPA and self-reported hours per week of physical activity are representative of actual physical activity behavior at the time, work in opposing directions with regard to the effect of physical activity on changes in adiposity. This phenomenon is known as regression dilution bias and may flatten the regression slope and cause an underestimate of the actual association.[37] With an annual decline in total physical activity of 7% in adolescents, researchers must consider the possibility that measured physical activity has a “best before-date”. It remains questionable whether baseline measurements of a fluctuant behavior such as physical activity is representative of actual habits during the period of follow-up. It may be that the measurement represents current, but not future (or even prior) habits.[12, 38] This has implications for longitudinal studies of the relationship between physical activity and body composition.[36]

Strengths and limitations

The primary strength of this study are objective measures of both exposure and outcome, and the use of tissue-specific measures of body composition. Some limitations have to be considered. As the Fit Futures study did not include a validated food frequency questionnaire or similar instrument for nutritional assessment, we were not able to fully adjust for the potential confounding effects of nutrition and changes in food habits of adolescents on changes in body composition. Accelerometer-measured physical activity has limitations. A hip worn accelerometer such as the ActiGraph GT3X is not able to correctly measure cycling and swimming.[39] Furthermore, accelerometers are dependent on user-compliance, and non-wear time therefore affects the amount of activity which is actually measured. Subjective judgement determines data management and analyses, e.g. the decision to exclude participants with wear time < 10 hours and < 4 consecutive days, is a trade-off between quality of data and the number of participants with valid data. We lacked complete data on physical activity and adjustment variables in 212 participants, but changes in BMI, waist circumference, FMI, LMI (except in girls, p = 0.04) and aLMI were not significantly different between those with- and without complete exposure data. Lastly, although longitudinal observational studies are superior to cross-sectional studies to examine causation, they are also susceptible to directional bias, since participants may avoid physical activity because they are overweight, and not be overweight because they are inactive.[40, 41]

Conclusion

Objectively measured physical activity was not significantly associated with change in objectively measured BMI, waist circumference or FMI after two years in this cohort of Norwegian adolescents. There was evidence to suggest that sedentary- and light activity affected indices of lean mass in girls, but not boys.

Acknowledgements

The authors thank the participants in the study, as well as the staff at the Clinical Research Unit at the University Hospital of North Norway for data collection and clinical measurements. We also thank the Fit Futures Steering Committee in both studies.

Footnotes

Contributors

NAA wrote the draft of the manuscript, which was revised and edited by all authors several times during the process. SB produced the accelerometer variables in close collaboration with AH, who wrote the software which converted raw accelerometer data to variables. BKJ contributed to the statistical analyses, and BM specifically contributed to the discussion of physical activity. NE and ASF were among the principal investigators in FF1 and FF2 and contributed significantly to the acquisition of data. SG formulated the research question and conceived the study. All authors have substantially contributed to the study, and have read and approved the final manuscript.

Funding

This particular manuscript has not received any specific funding, while the Fit Futures surveys were funded by, *inter alia*, the Northern Norway Regional Health Authority and UiT – The Arctic University of Norway, Tromsø, the National Public Health Institute, Oslo, and the Troms County Council.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Ethics approval

This study was approved by The Regional Committee of Medical and Health Research Ethics (2014/1666/REK nord).

Data availability statement

The data that support the findings of this study are available from UiT – The Arctic University of Norway. Restrictions apply to the availability of these data, which were used under license for the current study, and are thus not publicly available.

References

1. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. Geneva 2018.

2. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219-29.

3. World Health Organization. Global Recommendations on Physical Activity for Health. WHO Guidelines. Geneva 2010.

4. Kolle E SJ, Hansen BH, Anderssen SA. [Fysisk aktivitet blant 6-, 9- og 15-åringer i Norge. Resultater fra en kartlegging i 2011]. The Norwegian Directorate of Health, Oslo, Norway. 2012.

5. Dumith SC, Gigante DP, Domingues MR, et al. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol.* 2011;40:685-98.

6. Collings PJ, Wijndaele K, Corder K, et al. 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*. 2015;12:61.

7. Crane J, Temple V. A systematic review of dropout from organized sport among children and youth. *Eur Phys Educ Rev.* 2015;21:114-31.

8. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384:766-81.

9. NCD Risck Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*. 2017. doi:10.1016/S0140-6736(17)32129-3.

10. Reichert FF, Baptista Menezes AM, Wells JC, et al. Physical activity as a predictor of adolescent body fatness: a systematic review. *Sports Med*. 2009;39:279-94.

11. Jimenez-Pavon D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *Int J Pediatr Obes*. 2010;5:3-18.

12. Wilks DC, Besson H, Lindroos AK, et al. Objectively measured physical activity and obesity prevention in children, adolescents and adults: a systematic review of prospective studies. *Obes Rev*. 2011;12:e119-29.

13. Dyrstad SM, Hansen BH, Holme IM, et al. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014;46:99-106.

14. Aars NA, Jacobsen BK, Furberg AS, et al. Self-reported physical activity during leisure time was favourably associated with body composition in Norwegian adolescents. *Acta Paediatr*. 2018. doi:10.1111/apa.14660.

15. Goulding A, Taylor RW, Grant AM, et al. Relationships of appendicular LMI and total body LMI to bone mass and physical activity levels in a birth cohort of New Zealand five-year olds. *Bone*. 2009;45:455-9.

16. Bridge P, Pocock NA, Nguyen T, et al. Validation of longitudinal DXA changes in body composition from pre- to mid-adolescence using MRI as reference. *J Clin Densitom*. 2011;14:340-7.

17. Trost SG, Pate RR, Freedson PS, et al. Using objective physical activity measures with youth: how many days of monitoring are needed? *Med Sci Sports Exerc*. 2000;32:426-31.

18. Hecht A, Ma S, Porszasz J, et al. Methodology for using long-term accelerometry monitoring to describe daily activity patterns in COPD. *COPD*. 2009;6:121-9.

19. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*. 1998;30:777-81.

20. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14:411-6.

21. Cuzick J. A Wilcoxon-type test for trend. *Stat Med*. 1985;4:87-90.

22. Kolle E, Steene-Johannessen J, Andersen LB, et al. Objectively assessed physical activity and aerobic fitness in a population-based sample of Norwegian 9- and 15-year-olds. *Scand J Med Sci Sports*. 2010;20:e41-7.

23. Van Hecke L, Loyen A, Verloigne M, et al. Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *Int J Behav Nutr Phys Act*. 2016;13:70.

24. Baxter-Jones AD, Eisenmann JC, Mirwald RL, et al. The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. *J Appl Physiol (1985)*. 2008;105:734-41.

25. Wohlfahrt-Veje C, Tinggaard J, Winther K, et al. Body fat throughout childhood in 2647 healthy Danish children: agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry. *Eur J Clin Nutr*. 2014;68:664-70.

26. Siervogel RM, Demerath EW, Schubert C, et al. Puberty and body composition. *Horm Res*. 2003;60:36-45.

27. Sardinha LB, Marques A, Minderico C, et al. Cross-sectional and prospective impact of reallocating sedentary time to physical activity on children's body composition. *Pediatr Obes*. 2017;12:373-9.

28. Kenney WL, Wilmore JH, Costill DL. Physiology of sport and exercise. Seventh edition. Champaign, IL: Human Kinetics; 2020.

29. Lohman TG, Milliken LA. ACSM's body composition assessment. Champaign, IL: Human Kinetics; 2020.

30. Mendonca G, Cheng LA, Melo EN, et al. Physical activity and social support in adolescents: a systematic review. *Health Educ Res*. 2014;29:822-39.

31. Telama R, Yang X. Decline of physical activity from youth to young adulthood in Finland. *Med Sci Sports Exerc*. 2000;32:1617-22.

32. Varma VR, Dey D, Leroux A, et al. Re-evaluating the effect of age on physical activity over the lifespan. *Prev Med*. 2017;101:102-8.

33. Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 2000;32:1601-9.

34. Aars NA, Jacobsen BK, Morseth B, et al. Longitudinal changes in body composition and waist circumference by self-reported levels of physical activity in leisure among adolescents: the Tromsø study, Fit Futures. *BMC Sports Sci Med Rehabil*. 2019;11:37.

35. O'Loughlin J, Gray-Donald K, Paradis G, et al. One- and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic, low-income, inner-city neighborhoods. *Am J Epidemiol*. 2000;152:739-46.

36. Collings PJ, Wijndaele K, Corder K, et al. Objectively measured physical activity and longitudinal changes in adolescent body fatness: an observational cohort study. *Pediatr Obes*. 2016;11:107-14.

37. Hutcheon JA, Chiolero A, Hanley JA. Random measurement error and regression dilution bias. *BMJ*. 2010;340:c2289.

38. Kettaneh A, Oppert JM, Heude B, et al. Changes in physical activity explain paradoxical relationship between baseline physical activity and adiposity changes in adolescent girls: the FLVS II study. *Int J Obes (Lond)*. 2005;29:586-93.

39. Herman Hansen B, Bortnes I, Hildebrand M, et al. Validity of the ActiGraph GT1M during walking and cycling. *J Sports Sci*. 2014;32:510-6.

40. van Sluijs EM, Sharp SJ, Ambrosini GL, et al. The independent prospective associations of activity intensity and dietary energy density with adiposity in young adolescents. *Br J Nutr*. 2016;115:921-9.

41. Hjorth MF, Chaput JP, Ritz C, et al. 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 Obes (Lond)*. 2014;38:959-65.

Appendix

Appendix Table 1. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition, adjusted for puberty$^{\#}$.

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	-0.02	-0.14, 0.09	0.70	-0.05	-0.15, 0.05	0.32
Model 2	-0.02	-0.17, 0.13	0.82	-0.10	-0.24, 0.03	0.14
Model 3	0.02	-0.18, 0.22	0.85	-0.10	-0.26, 0.06	0.20
∆ waist circumference						
Model 1	0.12	-0.27, 0.51	0.55	-0.01	-0.42, 0.40	0.96
Model 2	0.24	-0.28, 0.76	0.37	-0.38	-0.92, 0.16	0.16
Model 3	0.38	-0.30, 1.05	0.27	-0.52	-1.15, 0.11	0.10
∆ FMI						
Model 1	-0.01	-0.12, 0.09	0.84	-0.01	-0.11, 0.08	0.80
Model 2	-0.02	-0.16, 0.13	0.83	-0.06	-0.18, 0.07	0.36
Model 3	0.01	-0.18, 0.19	0.96	-0.05	-0.20, 0.10	0.49
∆ LMI						
Model 1	0.00	-0.05, 0.06	0.90	-0.06	-0.09, -0.02	< 0.01
Model 2	0.00	-0.07, 0.08	0.90	-0.07	-0.11, -0.02	< 0.01
Model 3	0.02	-0.07, 0.10	0.73	-0.07	-0.13, -0.02	< 0.01
∆ aLMI						
Model 1	-0.00	-0.03, 0.03	0.91	-0.02	-0.04, -0.00	0.02

Model 2	0.00	-0.04, 0.04	0.97	-0.03	-0.05, -0.00	0.03
Model 3	0.01	-0.04, 0.06	0.65	-0.03	-0.05, 0.00	0.08

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Appendix Table 2. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition, adjusted for puberty$^{\#}$.

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	0.05	-0.10, 0.20	0.53	0.04	-0.10, 0.18	0.56
Model 2	0.00	-0.18, 0.19	0.98	0.11	-0.05, 0.27	0.17
Model 3	-0.02	-0.22, 0.18	0.85	0.10	-0.06, 0.26	0.20
∆ waist circumference						
Model 1	-0.01	-0.53, 0.51	0.97	0.53	-0.01, 1.06	0.05
Model 2	-0.34	-0.97, 0.29	0.29	0.51	-0.11, 1.13	0.11
Model 3	-0.38	-1.05, 0.30	0.27	0.52	-0.11, 1.15	0.11
∆ FMI						
Model 1	0.05	-0.09, 0.18	0.51	0.02	-0.11, 0.14	0.80
Model 2	0.01	-0.16, 0.18	0.93	0.06	-0.09, 0.20	0.43
Model 3	-0.01	-0.19, 0.18	0.96	0.05	-0.10, 0.20	0.49
∆ LMI						
Model 1	-0.01	-0.08, 0.06	0.84	0.04	-0.01, 0.09	0.09
Model 2	-0.01	-0.10, 0.07	0.80	0.08	0.02, 0.13	< 0.01

Model 3	-0.02	-0.10, 0.07	0.73	0.07	0.02, 0.13	< 0.01
∆ aLMI						
Model 1	0.00	-0.04, 0.04	0.93	0.02	-0.01, 0.04	0.19
Model 2	-0.01	-0.05, 0.04	0.78	0.03	-0.00, 0.06	0.06
Model 3	-0.01	-0.06, 0.04	0.65	0.03	-0.00, 0.05	0.08

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Appendix Table 3. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition, adjusted for puberty[#].

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	0.11	-0.08, 0.31	0.24	-0.01	-0.17, 0.16	0.95
Model 2	0.06	-0.15, 0.28	0.55	0.07	-0.12, 0.25	0.48
∆ waist circumference						
Model 1	0.28	-0.38, 0.95	0.40	-0.03	-0.69, 0.63	0.94
Model 2	-0.03	-0.77, 0.72	0.95	-0.00	-0.72, 0.72	0.99
∆ FMI						
Model 1	0.02	-0.16, 0.20	0.80	-0.01	-0.17, 0.14	0.86
Model 2	0.04	-0.16, 0.24	0.68	0.05	-0.12, 0.22	0.55
∆ LMI						
Model 1	0.08	-0.02, 0.17	0.11	0.03	-0.03, 0.09	0.35
Model 2	0.01	-0.09, 0.11	0.81	0.02	-0.04, 0.09	0.49
∆ aLMI						
Model 1	0.05	-0.01, 0.10	0.09	0.02	-0.01, 0.05	0.14
Model 2	0.02	-0.04, 0.07	0.60	0.02	-0.01, 0.05	0.20

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

STROBE statement for submitted manuscript entitled “*The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.”*

	Item No	Recommendation
Title and abstract	1	(*a*) P. 1,lines. 1-2.
		(*b*) P. 3, lines 1-23
Introduction		
Background/rationale	2	P. 5, lines 1-25 and P. 6, lines 1-3.
Objectives	3	P. 6, lines 3-8.
Methods		
Study design	4	P. 6, lines 11-12.
Setting	5	P. 6, lines 12-17 and P. 6, lines 22-23.
Participants	6	(*a*) P. 6, lines 18-21.
Variables	7	P. 8, lines 7-10, lines 15-25. P. 9, lines 1-14.
Data sources/ measurement	8*	P. 6, lines 22-24. P. 7, lines 3-25. P. 8, lines 1-11.
Bias	9	P. 9, lines 10-14.
Study size	10	P. 6, lines 17-21.
Quantitative variables	11	P. 9, lines 1-3.
Statistical methods	12	(*a*) P. 8, lines 14-25 and P. 9, lines 1-16.
		(*b*) P. 9, lines 10-15.
		(*c*) P. 6, lines 17-21.
		(*e*) P. 17, lines 22-25
Results		
Participants	13*	(a) P. 6, lines 12-21.
		(b) See (a).
Descriptive data	14*	(a) See Table 1.
		(b) See 13a
		(c) See Table 1.
Outcome data	15*	See Table 1.
Main results	16	(*a*) See Tables and P. 9, lines 4-15.
		(*b*) See Table 1.
Other analyses	17	P. 9, lines 11-15, and P. 16, lines 19-22. P. 17, lines 22-25.
Discussion		
Key results	18	P. 14, lines 4-10.
Limitations	19	P. 15, lines 20-24. P. 17, lines 2-8 and 11-25. P. 18, lines 1-3.
Interpretation	20	P. 14, lines 11 – 24. P. 15, 1-24. P. 16, lines 1-25. P. 17, lines 1-8.
Generalisability	21	
Other information		
Funding	22	P. 19, lines 15-19.

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-036991.R1
Article Type:	Original research
Date Submitted by the Author:	29-Apr-2020
Complete List of Authors:	Aars, Nils; UiT – The Arctic University of Norway, Department of Community Medicine; Nordlandssykehuset HF Beldo, Sigurd; UiT Arctic University of Norway, School of Sport Sciences Jacobsen, Bjarne; UiT – The Arctic University of Norway, Department of Community Medicine; UiT – The Arctic University of Norway, Centre for Sami Health Research Horsch, Alexander; UiT – The Arctic University of Norway, Department of Computer Science Morseth, Bente; UiT Arctic University of Norway, School of Sport Sciences; UiT – The Arctic University of Norway, Department of Community Medicine Emaus, Nina; Uit The Arctic University of Norway, Department of Health and Care Siences Furberg, Anne-Sofie; UiT The Arctic University of Norway, Department of Comunity Medicine; Universitetssykehuset Nord-Norge, Department of Microbiology and Infection Control Grimsgaard, Sameline; UiT The Arctic University of Norway, Department of Community Medicine
Primary Subject Heading:	Public health
Secondary Subject Heading:	Sports and exercise medicine, Epidemiology
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, SPORTS MEDICINE

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Nils Abel Aars[1, 2*]

Sigurd Beldo[3]

Bjarne K Jacobsen[1, 4]

Alexander Horsch[5]

Bente Morseth[3, 1]

Nina Emaus[6]

Anne-Sofie Furberg[1, 7]

Sameline Grimsgaard[1]

Affiliations

1. Department of Community Medicine, UiT the Arctic University of Norway, Tromsø, Norway

2. Nordland Hospital, Bodø, Norway.

3. School of Sport Sciences, UiT the Arctic University of Norway, Alta, Norway

4. Centre for Sami Health Research, Department of Community Medicine, UiT the Arctic University of Norway, Tromsø, Norway

5. Department of Computer Science, UiT the Arctic University of Norway, Tromsø, Norway

6. Department of Health and Care Sciences, UiT the Arctic University of Norway, Tromsø, Norway

7. Department of Microbiology and Infection Control, University Hospital of North Norway, Tromsø, Norway

* Corresponding author. Correspondence to nils.a.aars@uit.no

Nils Abel Aars

Department of Community Medicine

UiT the Arctic University of Norway

9037 Tromsø, Norway.

Abstract

Objectives: Physical activity may play an important role in deterring the world-wide obesity epidemic. This study aimed to determine if objectively measured physical activity in first year of upper secondary high school predicted changes in body composition over two years of follow up in a cohort of Norwegian adolescents (n =431).

Design: A longitudinal study of adolescents (60.3% girls, mean age 16 (SD 0.4) at baseline) participating in the Fit Futures studies 1 (2010-11) and 2 (2012-13).

Setting: All eight upper secondary high schools in neighbouring municipalities of Tromsø and Balsfjord, Northern Norway.

Participants: Students participating in both studies and under the age of 18 at baseline, and with valid measurement of physical activity at baseline and body composition at both time points.

Primary- and secondary outcomes: Change in objectively measured body mass index and waist circumference, and change in dual-energy x-ray absorptiometry measured fat mass index, lean mass index and appendicular lean mass index between baseline and follow-up. Differences in physical activity at baseline between sexes was also compared.

Results: At baseline, boys had significantly higher physical activity volume (p=0.01) and spent on average 6.4 (95% CI: 2.1, 10.6) more minutes in moderate-to-vigorous physical activity (MVPA) than girls (p <0.01). In multivariate regression analyses there was no significant association between either measure of baseline physical activity and changes in body composition parameters in boys. In girls there was a significant association between sedentary- and light activity and changes in lean mass index (p < 0.01) and appendicular lean mass index (p = 0.05).

Conclusions: In this cohort of Norwegian adolescents, sedentary and light physical activity were associated with changes in indices of lean mass in girls, but not boys. Minutes spent in moderate-to-vigorous physical activity was not associated with changes in either measure of body composition in either sex.

Strengths and limitations of this study

- This study used objective measures of physical activity.

- The study included objectively measured weight, height and waist circumference, and dual-energy x-ray absorptiometry (DXA) measures of fat- and lean mass.
- We were not able to fully adjust for nutrition and not for pubertal development.
- The 431 participants with complete data from both baseline and follow-up represents 41% of those attending Fit Futures 1, indicating a degree of selection.

Background

The potential of physical activity to prevent or treat a number of diseases has been highlighted by the World Health Organization,[1] with inactivity accounting for 9% of worldwide premature mortality.[2] Public health guidelines state that adolescents should engage in Moderate-to-Vigorous Physical Activity (MVPA) ≥ 60 minutes per day,[3] but in 2011, only 50% of Norwegian 15 year olds met these recommendations.[4] During adolescence there is a decline in both total physical activity and MVPA,[5, 6] and many quit or reduce participation in organized sports.[7] As of 2013, the prevalence of overweight and obesity (Body Mass Index (BMI) ≥ 25 kg/m^2) in Norwegians aged <20 years appear to be stabilizing at around 20% in boys and 16% in girls - comparable to the Nordic countries.[8] This is lower than in the United States (around 29% in boys and girls) [8], but the health effects for those concerned may still be substantial over the long term.[9]

While physical activity has many positive health effects, its relationship with adiposity is less clear and it has proven difficult to determine causality, direction and magnitude of this relationship.[10] Cross-sectional research typically shows a strong inverse

association between physical activity and weight status,[11] but temporality cannot be ascertained using such study designs.[12] Longitudinal studies may ascertain if lower physical activity precedes excess weight gain, but a review found no evidence for a relationship between objectively measured physical activity and body fat gain in adolescents.[12] The lack of congruent results may in part be explained by the diverse and inadequate measures of both exposure and outcome used in research of the association between physical activity and body composition.[10, 11]

Although many methods to measure physical activity are available, the most common and most feasible is self-report which commonly overestimates the total amount of physical activity.[13] Body composition is most commonly assessed using BMI, but BMI does not distinguish between fat- and muscle mass.[14] This has the potential to cause misclassification of overweight status and may attenuate a true association between physical activity and fat or muscle mass. Thus, in the current study, we sought to overcome these limitations by applying objective measures of both physical activity and specific measures of body composition. Our aim was to investigate the association between objectively measured physical activity and changes in five different measures of body composition (body mass index, waist circumference, fat

mass index, lean mass index and appendicular lean mass index) over two years of follow-up in a cohort of Norwegian adolescents.

Methods and materials

We used data from the first and second Fit Futures cohort studies, performed in 2010-2011 and 2012-2013, respectively. The first study invited all students (n=1,117) in their first year of upper secondary high school in the neighbouring municipalities of Tromsø and Balsfjord in Northern Norway, and had a participation of 93%. The study was repeated two years later, when the students were in their last year of upper secondary high school or had started as apprentices if they studied vocational subjects. The second study included 868 participants, giving an attendance of 77%. All eight upper secondary high schools in the two municipalities participated in both studies. Altogether 735 adolescents attended both surveys. For the present study we excluded those aged ≥ 18 years of age at baseline (n = 38). Some participants (n = 240) did not have valid measurements of physical activity at baseline, and were therefore not included in the study. We also excluded those with missing data on change in body composition parameters or variables included in the model (n = 26). Thus, 431 participants were included in the present study (60.3% girls).

Students were granted leave of absence from school to attend an examination at the Clinical Research Unit at the University Hospital of Northern Norway in both surveys. The participants attended a clinical examination where they also completed a questionnaire, which included questions on lifestyle, screen time, dietary habits etc. The participants signed a letter of informed consent, and those under the age of 16 brought a letter of consent signed by their parent or guardian.

All measurements were performed by trained personnel. Height was measured to the nearest centimeter and weight to the nearest 100 gram, wearing light clothing and using an automatic electronic scale/stadiometer (Jenix DS 102 stadiometer, Dong Sahn Jenix, Seoul, Korea). Body mass index was calculated as body weight in kilograms/height in meters^2. Waist circumference was measured to the nearest 0.1 centimeter at the height of the umbilicus. Fat and soft tissue lean mass in grams was estimated by whole-body dual energy X-ray absorptiometry (DXA) (GE Lunar Prodigy, Lunar Corporation, Madison, WI, USA). Fat mass comprises all fat, while soft tissue lean mass comprises all bodily tissue except fat and skeletal mass. These variables were used to calculate fat mass index (FMI, fat mass in kilograms/height in meters^2) and lean mass index (LMI, lean mass in kilograms/height in meters^2). In addition we calculated appendicular lean mass index (aLMI), which is the sum of soft tissue lean mass in kilograms in all four extremities divided by height in meters^2. Although most commonly used in studies of sarcopenia in elderly,[15] this variable is arguably more specific to skeletal muscle mass than total lean mass index. The ability of DXA to detect changes in appendicular lean mass in young adolescents is good, and has been validated against Magnetic Resonance Imaging (MRI).[16]

Physical activity was objectively measured using the ActiGraph GT3X accelerometer (ActiGraph, LLC, Pensacola, USA). Participants were instructed to wear the device on their right hip for seven consecutive days, and to remove it only when showering, swimming or sleeping. The ActiLife software was used to initialize the accelerometer and download data, which was imported into the Quality Control & Analysis Tool (QCAT) for data processing. This software was developed by the research group of professor Horsch in Matlab (The MathWorks, Inc., Massachusetts, USA) for processing of accelerometer data. The accelerometer was set in raw data mode, with a sampling frequency of 30 Hertz and with normal filtering epochs of 10 seconds. Data collection was initiated at 14:00 hours the first day, and concluded at 23:58 on the 8th day of measurement. We excluded data from the first day of measurement to reduce reactivity bias. The criteria for a valid measurement of physical activity was wear time of ≥ four consecutive days, with ≥ ten hours wear time per day. This has been demonstrated as representative of activity over a full week.[17] The triaxial algorithm developed by Hecht et al. was used to calculate wear time.[18] Minutes per day in sedentary (0 – 99 CPM), light (100 – 1951 CPM), moderate (1952 – 5723 CPM) and vigorous (≥ 5724 CPM) physical activity was determined using the cut-offs developed by Freedson.[19] The choice of these cut-offs enables direct comparisons as the cohort ages, and although these cut-offs are not commonly used for adolescents, we consider the bodily proportions of an adolescent to resemble that of an adult in terms of measured acceleration. The device collected data in both uniaxial- and triaxial mode, but in the present study only the uniaxial data had been processed and therefore available. Studies have shown that uniaxial data recorded from the GT3X correlate well with uniaxial data recorded from previous ActiGraph models.[20] Data on objectively measured physical activity was only available from Fit Futures 1.

Baseline characteristics were presented as means with standard deviation (SD) or prevalence in percentages with number of subjects (n) (Table 1). Sex-specific difference in body composition between baseline and follow-up was tested using a paired samples t-test. The difference in physical activity between sexes was tested using a two-sample t-test, while sex differences in categories of minutes spent in MVPA was tested using a chi-square test. Difference in linear trend across categories of minutes spent in MVPA was tested using STATA's non-parametric test for trend, developed by Cuzick.[21] Linear regression was used to determine the effect of baseline physical activity on change in body composition, i.e., the change in BMI, waist circumference, FMI, LMI and aLMI from the first to the second Fit Futures Study.

We used three different predictors of change in body composition, performing three sets of analyses, with first; minutes per day spent in sedentary activity (Table 2) second; minutes per day spent in light activity (Table 3) and third; minutes per day spent in MVPA (Table 4). We divided the continuous variables sedentary- and light activity by 30 and the continuous variable MVPA by 15 before inclusion in the models, thus presenting the beta coefficient for change in body composition parameter per 30 minutes of sedentary- or light activity, or per 15 minutes of MVPA, with 95% confidence intervals and a p-value. In model 1 we adjusted for the baseline measurement of the body composition parameter. In the adjusted models (models 2) we also included time between measurements (mean (SD): 730 (74) days) and baseline values of device wear time, age in half years and questionnaire data on screen time on weekdays (how many hours per weekday the students spent in front of a computer or television - answers ranged from none to more than ten hours per weekday) and regularity of eating breakfast as an indicator of healthy meal patterns (answers ranging from rarely/never to every day). In the analyses of sedentary- and light activity we also adjusted for minutes spent in MVPA (models 3). In a subset of analyses (Appendix tables 1 and 2) we repeated the analyses performed in Table 2 and 3, adjusting also for self-reported pubertal status measured by either pubertal development scale (boys) or age at menarche (girls). These analyses included the

143 boys and 256 girls with valid data on pubertal status. In all the analyses, a p-value of < 0.05 was considered statistically significant.

All analyses were performed sex-specific as decided a-priori, using STATA version 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP.).

Patient and public involvement

Participating schools were consulted and included in the design phase of the study.

Results

Table 1 displays the participants' body composition measurements at baseline and follow-up, as well as physical activity measurements at baseline. Boys had a statistically significant increase in all measures of body composition. Girls had a statistically significant increase in body weight, BMI, fat mass in kg and FMI, but not in LMI and appendicular lean mass. Boys were statistically significantly more physically active than girls in some aspects, with higher mean counts per minute ($p=0.01$) and more minutes in MVPA ($p<0.01$). Time spent in sedentary- or light intensities did not differ significantly between sexes. Twenty-seven percent of boys and 17% of girls complied with the recommendations of 60 minutes per day Moderate-to-Vigorous Physical Activity (MVPA).

Table 1. Characteristics of the longitudinal cohort of the Tromsø Study; Fit Futures 2010-11 and 2012-13 ◊.

	Boys (n = 171)		Girls (n = 260)	
	FF1	FF2	FF1	FF2
Age (years)	16.0 (0.4)	18.2 (0.4)	16.1 (0.4)	18.1 (0.4)
Height (cm)	177.1 (6.6)	179.0 (6.5)*	165.4 (6.6)	166.1 (6.6)*
Body weight (kg)	69.0 (12.3)	74.3 (13.0)*	60.8 (10.8)	63.4 (11.6)*
Body mass index (BMI kg/m2)	22.0 (3.5)	23.2 (3.7)*	22.2 (3.7)	23.0 (4.0)*
Waist circumference (cm)	81.0 (10.3)	83.9 (10.9)*	76.7 (9.8)	78.0 (10.8)*
Total Body Fat Mass (kg)	13.3 (9.4)	15.6 (10.4)*	19.9 (8.3)	21.7 (9.1)*
Fat Mass Index (FMI kg/m2)	4.2 (3.0)	4.9 (3.2)*	7.3 (3.0)	7.9 (3.3)*
Total Body Lean Mass (kg)	54.0 (6.5)	56.4 (6.9)*	38.9 (4.5)	39.3 (4.7)*

Lean Mass Index (LMI kg/m2)	17.2 (1.6)	17.6 (1.8)*	14.2 (1.3)	14.2 (1.4)
Appendicular Lean Mass (kg)	25.3 (3.4)	26.2 (3.6)*	17.4 (2.3)	17.4 (2.3)
Appendicular Lean Mass Index (aLMI kg/m2)	8.1 (0.9)	8.2 (0.9)*	6.4 (0.7)	6.3 (0.7)*
Accelerometer variables				
Wear time per valid day	14.2 (1.2)		14.1 (1.1)	
Counts per minute	362.9 (137.5)		334.0 (111.9)$^\infty$	
Minutes per day in different intensities				
Sedentary (cpm 0 – 99)	573.3 (77.3)		565.3 (63.2)	
Light (cpm 100 – 1951)	230.5 (58.8)		236.2 (48.4)	
Moderate (cpm 1952 – 5723)	45.8 (20.6)		40.2 (17.7) $^\infty$	
Vigorous (cpm ≥ 5724)	3.7 (5.8)		2.9 (4.1) $^\infty$	
MVPA$^\#$ (cpm ≥ 1952)	49.5 (23.4)		43.1 (19.6) $^\infty$	
Meeting MVPA guidelines per day				
0 – 29 minutes	35 (20.5)		69 (26.5)	
30 – 59 minutes	90 (52.6)		146 (56.2)	
≥ 60 minutes	46 (26.9)		45 (17.3) §	

◊: Values are means with standard deviation (SD) or n (prevalence in percentages). BMI: body weight in kg/height in meters^2, FMI: fat mass in kg/height in meters^2, LMI: lean mass in kg/height in meters^2, aLMI: appendicular lean mass in kg/height in meters^2. Data on physical activity in FF2 was not available.

*: Significantly different from baseline measurement ($p < 0.05$)

∞: Significantly different from boys (mean).

#: MVPA: moderate to vigorous physical activity, using cut-offs suggested by Freedson.[19]

§: significantly different linear trend from boys ($p<0.05$)

Table 2 displays the association between minutes spent in sedentary activity at baseline and changes in body composition between baseline and follow-up. There was no association between sedentary activity and changes in BMI, waist circumference and FMI in neither boys nor girls. In girls, but not in boys, there was a significant association between minutes spent in sedentary activity at baseline and changes in both LMI (p < 0.01) and aLMI (p = 0.02). Adjustment for covariates and MVPA slightly attenuated the association with aLMI (p = 0.05).

Table 2. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition#.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	-0.02	-0.13, 0.09	0.76	-0.05	-0.15, 0.05	0.33
Model 2	-0.02	-0.17, 0.12	0.75	-0.11	-0.24, 0.03	0.12
Model 3	0.01	-0.17, 0.20	0.88	-0.11	-0.27, 0.05	0.16
Δ waist circumference						
Model 1	0.17	-0.21, 0.56	0.37	-0.01	-0.41, 0.40	0.96
Model 2	0.27	-0.24, 0.78	0.30	-0.33	-0.87, 0.20	0.22
Model 3	0.42	-0.23, 1.07	0.20	-0.44	-1.06, 0.18	0.17
Δ FMI						
Model 1	0.00	-0.10, 0.10	0.99	-0.01	-0.11, 0.08	0.83
Model 2	-0.02	-0.16, 0.11	0.74	-0.06	-0.18, 0.07	0.36
Model 3	0.00	-0.17, 0.17	0.98	-0.05	-0.20, 0.09	0.48
Δ LMI						
Model 1	0.00	-0.05, 0.05	0.88	-0.06	-0.09, -0.02	<0.01

Model 2	0.01	-0.06, 0.07	0.77	-0.07	-0.12, -0.02	<0.01
Model 3	0.02	-0.06, 0.10	0.63	-0.08	-0.13, -0.03	<0.01
∆ aLMI						
Model 1	0.00	-0.03, 0.03	0.84	-0.02	-0.04, -0.00	0.02
Model 2	0.00	-0.03, 0.04	0.81	-0.03	-0.05, -0.01	0.02
Model 3	0.01	-0.04, 0.05	0.71	-0.03	-0.06, 0.00	0.05

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 3 displays the association between minutes spent in light activity at baseline and changes in body composition between baseline and follow-up. There was no association between the exposure and either body composition parameter in boys. In girls there was some evidence to suggest an association with change in waist circumference (p =0.05), but the association was attenuated after adjustments (p = 0.17). Minutes spent in light physical activity was also associated with changes in LMI (p < 0.01 (Models 2 and 3)) and aLMI (p = 0.04 (Model 2) and 0.05 (Model 3)).

Table 3. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition#.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	0.04	-0.11, 0.18	0.60	0.05	-0.09, 0.19	0.47
Model 2	0.01	-0.17, 0.18	0.93	0.12	-0.04, 0.27	0.13
Model 3	-0.01	-0.20, 0.17	0.88	0.11	-0.05, 0.27	0.16
∆ waist circumference						
Model 1	-0.11	-0.62, 0.40	0.68	0.54	0.01, 1.07	0.05
Model 2	-0.38	-1.00, 0.23	0.22	0.43	-0.19, 1.05	0.17
Model 3	-0.42	-1.07, 0.23	0.20	0.44	-0.19, 1.06	0.17
∆ FMI						
Model 1	0.03	-0.10, 0.16	0.67	0.02	-0.10, 0.15	0.71
Model 2	0.01	-0.15, 0.18	0.87	0.06	-0.09, 0.20	0.43
Model 3	-0.00	-0.17, 0.17	0.98	0.05	-0.09, 0.20	0.49
∆ LMI						
Model 1	-0.01	-0.07, 0.06	0.84	0.04	-0.01, 0.09	0.08
Model 2	-0.02	-0.09, 0.06	0.67	0.08	0.03, 0.13	<0.01

Model 3	-0.02	-0.10, 0.06	0.63	0.08	0.03, 0.13	<0.01
∆ aLMI						
Model 1	0.00	-0.03, 0.04	0.87	0.02	-0.01, 0.04	0.16
Model 2	-0.01	-0.05, 0.04	0.73	0.03	0.00, 0.06	0.04
Model 3	-0.01	-0.05, 0.04	0.70	0.03	-0.00, 0.06	0.05

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 4 displays the association between minutes in MVPA at baseline and changes in body composition between baseline and follow-up. There was no association between time spent in MVPA and changes in either measure of body composition for either sex.

Table 4. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition$^{\#}$.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value

∆ BMI						
Model 1	0.11	-0.07, 0.30	0.22	-0.00	-0.17, 0.16	0.97
Model 2	0.08	-0.13, 0.29	0.47	0.07	-0.11, 0.25	0.47
∆ waist circumference						
Model 1	0.25	-0.39, 0.89	0.44	-0.03	-0.68, 0.63	0.94
Model 2	-0.02	-0.75, 0.71	0.95	0.02	-0.70, 0.74	0.96
∆ FMI						
Model 1	0.02	-0.15, 0.19	0.83	-0.01	-0.17, 0.14	0.86
Model 2	0.06	-0.14, 0.25	0.57	0.05	-0.12, 0.22	0.54
∆ LMI						
Model 1	0.07	-0.02, 0.15	0.11	0.03	-0.03, 0.09	0.33
Model 2	0.01	-0.08, 0.10	0.86	0.02	-0.04, 0.09	0.44
∆ aLMI						
Model 1	0.03	-0.02, 0.08	0.19	0.02	-0.01, 0.05	0.13
Model 2	0.00	-0.05, 0.05	0.92	0.02	-0.01, 0.05	0.18

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

In Appendix Tables 1-3, we present sub-analyses restricted to those with complete data on pubertal development, confirming the results displayed in Tables 2-4 also after adjustments for pubertal development. Overall, adjustment for pubertal development had no substantial impact on an association between sedentary, light and moderate-to-vigorous physical activity and changes in body composition for either sex in complete case analyses. However, the association between minutes spent in sedentary activity- and light activity and changes in appendicular lean mass index was no longer significant for girls in Model 3. The point estimates did not differ from those from analyses without adjustments for pubertal development, however.

Discussion

In this longitudinal population-based study of Norwegian adolescents there were in both boys and girls no associations between objectively measured physical activity at baseline and two-year changes in BMI, waist circumference and FMI. Both boys and girls had statistically significant increases in the measures of body composition (except lean mass index and appendicular lean mass in girls). Objectively measured physical activity did not predict changes in boys. In girls there was a weak association between minutes spent in sedentary- and light physical activity and changes in indices of lean mass.

Although the magnitude of change differed, both sexes experienced increases in measures of body composition. In boys, FMI increased by 0.7 units, (+ 16.7%), whereas LMI increased by 0.4 units (+ 2.3 %) from baseline. Similar relative changes were observed in girls, (FMI +8.2 %) and (LMI + 0.7%), indicating that FMI increases relatively more than LMI during late adolescence. We observed statistically significant differences in minutes spent in moderate ($p < 0.01$) and vigorous ($p = 0.04$) intensity between boys and girls, but time spent in other intensity levels did not differ. Differences in physical activity by sex is consistent with previous research.[22, 23] Differences in changes in body composition by sex are biologically determined during adolescence, with sex hormones resulting in fat mass accrual in girls and lean mass accrual in boys.[24, 25] The observation that sedentary- and light activity predicted changes in indices of lean mass in girls, but not boys, may be explained by these expected biological differences. Physical activity may have somewhat greater potential to influence lean mass accrual in girls than in boys during this period, as fat-free mass is relatively stable in girls in late adolescence whereas it increases up to 18 years of age in boys.[26]

In the present study sedentary- and light activity had opposing effects on lean mass in girls. In a study using iso-temporal substitution models, positive prospective effects on fat mass was found when substituting 30 minutes of sedentary activity with MVPA, but not when substituted with light activity.[27] We did not use such modelling techniques, but it is reasonable that sedentary- and light physical activity have opposing effects on lean mass.[28] Sedentary- and light activity was correlated (r = -0.39), but minutes spent in different intensity levels are not directly a function of each other as wear time in the participants varies between individuals. Based on wear time inclusion criteria, the theoretical time span for wear time lies between 10 and 24 hours. Thus, minutes spent in sedentary activity may not be deduced from the sum of minutes spent in other intensities and vice versa, but it is plausible that higher wear time results in more sedentary time. This was evident in an exploratory analyses on the same cohort (not included in the present study), where higher wear time was significantly associated with more sedentary activity and less light activity (p < 0.01). Adjusting for wear time (Models 2) did not change the associations substantially for sedentary activity (Table 2), but had some effect on the associations with light physical activity (Table 3). Because of the inverse relationship between minutes spent sedentary and in light activity, it is not possible to determine whether it is sedentary time or light activity-time that is associated with change in LMI. The practical consequences are nevertheless that being active increases lean mass in girls.

When interpreting results, we must acknowledge the limitations of DXA in the estimation of lean mass, which can be affected by both biological factors and measurement error.[29] Because the relative increase in lean mass was small, only slight differences in for instance individual hydration status at the two time-points may influence estimates and thus the association.

There was no associations between objectively measured physical activity and change in BMI, waist circumference and FMI for either sex. It may be that the negative effects of less physical activity have not yet had time to manifest themselves in a population still undergoing physiological changes as a result of natural growth, especially considering the relatively short 2-year follow-up. Our results are in line with a systematic review suggesting that objectively measured PA is not an important predictor of change in adiposity in children, adolescents and adults.[12] In contrast, another systematic review found a protective effect of physical activity on adiposity in adolescents.[10] There were however several methodological weaknesses in the included studies of this review, particularly regarding the validity of the measurement of both physical activity and body composition. In contrast, our study employed robust measures of both these exposures- and outcomes, a combination which is lacking in much past research on the association between the two.[10-12]

In adolescents, physical activity is influenced by friends, family and other social support,[30] and is less stable than in adults.[31-33] Follow-up data on objectively measured physical activity was not available in the present study, but some evidence suggests that the decline in physical activity is steeper prior to the onset of adolescence.[34] Reductions in level of physical activity during the transition from adolescence to young adulthood nevertheless often occur.[35] Prior observations from the same cohort showed that change in self-reported physical activity between baseline and follow-up was a stronger predictor of change in body composition than self-reported baseline physical activity.[36] Other studies have suggested that change in activity during follow-up might obscure an association with body composition.[37, 38] In a sub-analyses, one of four in both the highest and lowest categories of MVPA at baseline reported decreased (high MVPA at baseline) and increased (low MVPA at baseline) self-reported physical activity at follow up, thus indicating that physical activity in adolescents is fluctuant. These two observations, assuming that measurement of both MVPA and self-reported hours per week of physical activity are representative of actual physical activity behaviour at the time, work in opposing directions with regard to the effect of physical activity on changes in adiposity. This phenomenon is known as regression dilution bias and may flatten the regression slope and cause an underestimate of the actual association.[39] With an annual decline in total physical activity of 7% in adolescents, researchers must consider the possibility that measured physical activity has a “best before-date”. It remains questionable whether baseline measurements of a fluctuant behaviour such as physical activity is representative of actual habits during the period of follow-up. It may be that the measurement represents current, but not future (or even prior) habits.[12, 40] This has implications for longitudinal studies of the relationship between physical activity and body composition.[38]

Strengths and limitations

The primary strength of this study are objective measures of both physical activity and body composition parameters, and the inclusion of tissue-specific measures of body composition. Some limitations have to be considered. As the Fit Futures study did not include a validated food frequency questionnaire or similar instrument for nutritional assessment, we were not able to fully adjust for the potential confounding effects of nutrition and changes in food habits of adolescents on changes in body composition. Accelerometer-measured physical activity has limitations. A hip worn accelerometer such as the ActiGraph GT3X is not able to correctly measure cycling and swimming.[41] Furthermore, accelerometers are dependent on user-compliance, and non-wear time therefore affects the amount of activity which is actually measured. Subjective judgement determines data management and analyses, e.g. the decision to exclude participants with wear time < 10 hours and < 4 consecutive days, is a trade-off between quality of data and the number of participants with valid data. We lacked complete data on physical activity and adjustment variables in 212 participants, but changes in BMI, waist circumference, FMI, LMI (except in girls, p = 0.04) and aLMI were not significantly different between those with- and without complete exposure data. Furthermore, of those with valid data concerning both physical activity and body composition parameters at baseline, close to 25% did not attend the follow up. Although longitudinal observational studies are superior to cross-sectional studies to examine causation, they are also susceptible to directional bias, since participants may avoid physical activity because they are overweight, and not be overweight because they are inactive.[42-44] Finally, as the participants were 16 years old, much may already have happened both to the level of physical activity and the different measures of body composition prior to participation. In light of this, 2 years of follow-up may be a short time frame to determine the potential effects of physical activity on changes in the different body composition parameters.

Conclusion

Objectively measured physical activity was not significantly associated with change in objectively measured BMI, waist circumference or FMI after two years in this cohort of Norwegian adolescents. There was evidence to suggest that sedentary- and light activity affected indices of lean mass in girls, but not boys.

Acknowledgements

The authors thank the participants in the study, as well as the staff at the Clinical Research Unit at the University Hospital of North Norway for data collection and clinical measurements. We also thank the Fit Futures Steering Committee in both studies.

Footnotes

Contributors

NAA wrote the draft of the manuscript, which was revised and edited by all authors several times during the process. SB produced the accelerometer variables in close collaboration with AH, who wrote the software which converted raw accelerometer data to variables. BKJ contributed to the statistical analyses, and BM specifically contributed to the discussion of physical activity. NE and ASF were among the principal investigators in FF1 and FF2 and contributed significantly to the acquisition of data. SG formulated the research question and conceived the study. All authors have substantially contributed to the study, and have read and approved the final manuscript.

Funding

This particular manuscript has not received any specific funding.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Ethics approval

This study was approved by The Regional Committee of Medical and Health Research Ethics (2014/1666/REK nord).

Data availability statement

The data that support the findings of this study are available from UiT – The Arctic University of Norway. Restrictions apply to the availability of these data, which were used under license for the current study, and are thus not publicly available.

References

1. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. Geneva 2018.

2. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219-29.

3. World Health Organization. Global Recommendations on Physical Activity for Health. WHO Guidelines. Geneva 2010.

4. Kolle E SJ, Hansen BH, Anderssen SA. [Fysisk aktivitet blant 6-, 9- og 15-åringer i Norge. Resultater fra en kartlegging i 2011]. The Norwegian Directorate of Health, Oslo, Norway. 2012.

5. Dumith SC, Gigante DP, Domingues MR, et al. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol.* 2011;40:685-98.

6. Collings PJ, Wijndaele K, Corder K, et al. 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*. 2015;12:61.

7. Crane J, Temple V. A systematic review of dropout from organized sport among children and youth. *Eur Phys Educ Rev.* 2015;21:114-31.

8. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384:766-81.

9. NCD Risck Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*. 2017. doi:10.1016/S0140-6736(17)32129-3.

10. Reichert FF, Baptista Menezes AM, Wells JC, et al. Physical activity as a predictor of adolescent body fatness: a systematic review. *Sports Med*. 2009;39:279-94.

11. Jimenez-Pavon D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *Int J Pediatr Obes*. 2010;5:3-18.

12. Wilks DC, Besson H, Lindroos AK, et al. Objectively measured physical activity and obesity prevention in children, adolescents and adults: a systematic review of prospective studies. *Obes Rev*. 2011;12:e119-29.

13. Dyrstad SM, Hansen BH, Holme IM, et al. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014;46:99-106.

14. Aars NA, Jacobsen BK, Furberg AS, et al. Self-reported physical activity during leisure time was favourably associated with body composition in Norwegian adolescents. *Acta Paediatr*. 2018. doi:10.1111/apa.14660.

15. Goulding A, Taylor RW, Grant AM, et al. Relationships of appendicular LMI and total body LMI to bone mass and physical activity levels in a birth cohort of New Zealand five-year olds. *Bone*. 2009;45:455-9.

16. Bridge P, Pocock NA, Nguyen T, et al. Validation of longitudinal DXA changes in body composition from pre- to mid-adolescence using MRI as reference. *J Clin Densitom*. 2011;14:340-7.

17. Trost SG, Pate RR, Freedson PS, et al. Using objective physical activity measures with youth: how many days of monitoring are needed? *Med Sci Sports Exerc*. 2000;32:426-31.

18. Hecht A, Ma S, Porszasz J, et al. Methodology for using long-term accelerometry monitoring to describe daily activity patterns in COPD. *COPD*. 2009;6:121-9.

19. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*. 1998;30:777-81.

20. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14:411-6.

21. Cuzick J. A Wilcoxon-type test for trend. *Stat Med*. 1985;4:87-90.

22. Kolle E, Steene-Johannessen J, Andersen LB, et al. Objectively assessed physical activity and aerobic fitness in a population-based sample of Norwegian 9- and 15-year-olds. *Scand J Med Sci Sports*. 2010;20:e41-7.

23. Van Hecke L, Loyen A, Verloigne M, et al. Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *Int J Behav Nutr Phys Act*. 2016;13:70.

24. Baxter-Jones AD, Eisenmann JC, Mirwald RL, et al. The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. *J Appl Physiol (1985)*. 2008;105:734-41.

25. Wohlfahrt-Veje C, Tinggaard J, Winther K, et al. Body fat throughout childhood in 2647 healthy Danish children: agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry. *Eur J Clin Nutr*. 2014;68:664-70.

26. Siervogel RM, Demerath EW, Schubert C, et al. Puberty and body composition. *Horm Res*. 2003;60:36-45.

27. Sardinha LB, Marques A, Minderico C, et al. Cross-sectional and prospective impact of reallocating sedentary time to physical activity on children's body composition. *Pediatr Obes*. 2017;12:373-9.

28. Kenney WL, Wilmore JH, Costill DL. Physiology of sport and exercise. Seventh edition. Champaign, IL: Human Kinetics; 2020.

29. Lohman TG, Milliken LA. ACSM's body composition assessment. Champaign, IL: Human Kinetics; 2020.

30. Mendonca G, Cheng LA, Melo EN, et al. Physical activity and social support in adolescents: a systematic review. *Health Educ Res*. 2014;29:822-39.

31. Telama R, Yang X. Decline of physical activity from youth to young adulthood in Finland. *Med Sci Sports Exerc*. 2000;32:1617-22.

32. Varma VR, Dey D, Leroux A, et al. Re-evaluating the effect of age on physical activity over the lifespan. *Prev Med*. 2017;101:102-8.

33. Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 2000;32:1601-9.

34. Farooq MA, Parkinson KN, Adamson AJ, et al. Timing of the decline in physical activity in childhood and adolescence: Gateshead Millennium Cohort Study. *Br J Sports Med*. 2018;52:1002-6..

35. Corder K, Winpenny E, Love R, et al. Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. *Br J Sports Med*. 2019;53:496-503.

36. Aars NA, Jacobsen BK, Morseth B, et al. Longitudinal changes in body composition and waist circumference by self-reported levels of physical activity in leisure among adolescents: the Tromsø study, Fit Futures. *BMC Sports Sci Med Rehabil*. 2019;11:37.

37. O'Loughlin J, Gray-Donald K, Paradis G, et al. One- and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic, low-income, inner-city neighborhoods. *Am J Epidemiol*. 2000;152:739-46.

38. Collings PJ, Wijndaele K, Corder K, et al. Objectively measured physical activity and longitudinal changes in adolescent body fatness: an observational cohort study. *Pediatr Obes*. 2016;11:107-14.

39. Hutcheon JA, Chiolero A, Hanley JA. Random measurement error and regression dilution bias. *BMJ*. 2010;340:c2289.

40. Kettaneh A, Oppert JM, Heude B, et al. Changes in physical activity explain paradoxical relationship between baseline physical activity and adiposity changes in adolescent girls: the FLVS II study. *Int J Obes (Lond)*. 2005;29:586-93.

41. Herman Hansen B, Bortnes I, Hildebrand M, et al. Validity of the ActiGraph GT1M during walking and cycling. *J Sports Sci*. 2014;32:510-6.

42. van Sluijs EM, Sharp SJ, Ambrosini GL, et al. The independent prospective associations of activity intensity and dietary energy density with adiposity in young adolescents. *Br J Nutr*. 2016;115:921-9.

43. Hjorth MF, Chaput JP, Ritz C, et al. 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 Obes (Lond)*. 2014;38:959-65.

44. Jago R, Salway RE, Ness AR, et al. Associations between physical activity and asthma, eczema and obesity in children aged 12-16: an observational cohort study. *BMJ Open*. 2019;9:e024858. doi:10.1136/bmjopen-2018-024858.

Supplementary file

Appendix Table 1. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition, adjusted for puberty#.

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	-0.02	-0.14, 0.09	0.70	-0.05	-0.15, 0.05	0.32
Model 2	-0.02	-0.17, 0.13	0.82	-0.10	-0.24, 0.03	0.14
Model 3	0.02	-0.18, 0.22	0.85	-0.10	-0.26, 0.06	0.20
Δ waist circumference						
Model 1	0.12	-0.27, 0.51	0.55	-0.01	-0.42, 0.40	0.96
Model 2	0.24	-0.28, 0.76	0.37	-0.38	-0.92, 0.16	0.16
Model 3	0.38	-0.30, 1.05	0.27	-0.52	-1.15, 0.11	0.10
Δ FMI						
Model 1	-0.01	-0.12, 0.09	0.84	-0.01	-0.11, 0.08	0.80
Model 2	-0.02	-0.16, 0.13	0.83	-0.06	-0.18, 0.07	0.36
Model 3	0.01	-0.18, 0.19	0.96	-0.05	-0.20, 0.10	0.49
Δ LMI						
Model 1	0.00	-0.05, 0.06	0.90	-0.06	-0.09, -0.02	< 0.01
Model 2	0.00	-0.07, 0.08	0.90	-0.07	-0.11, -0.02	< 0.01
Model 3	0.02	-0.07, 0.10	0.73	-0.07	-0.13, -0.02	< 0.01
Δ aLMI						
Model 1	-0.00	-0.03, 0.03	0.91	-0.02	-0.04, -0.00	0.02
Model 2	0.00	-0.04, 0.04	0.97	-0.03	-0.05, -0.00	0.03
Model 3	0.01	-0.04, 0.06	0.65	-0.03	-0.05, 0.00	0.08

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Appendix Table 2. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition, adjusted for puberty[#].

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	0.05	-0.10, 0.20	0.53	0.04	-0.10, 0.18	0.56
Model 2	0.00	-0.18, 0.19	0.98	0.11	-0.05, 0.27	0.17
Model 3	-0.02	-0.22, 0.18	0.85	0.10	-0.06, 0.26	0.20
Δ waist circumference						
Model 1	-0.01	-0.53, 0.51	0.97	0.53	-0.01, 1.06	0.05
Model 2	-0.34	-0.97, 0.29	0.29	0.51	-0.11, 1.13	0.11
Model 3	-0.38	-1.05, 0.30	0.27	0.52	-0.11, 1.15	0.11
Δ FMI						
Model 1	0.05	-0.09, 0.18	0.51	0.02	-0.11, 0.14	0.80
Model 2	0.01	-0.16, 0.18	0.93	0.06	-0.09, 0.20	0.43
Model 3	-0.01	-0.19, 0.18	0.96	0.05	-0.10, 0.20	0.49
Δ LMI						
Model 1	-0.01	-0.08, 0.06	0.84	0.04	-0.01, 0.09	0.09
Model 2	-0.01	-0.10, 0.07	0.80	0.08	0.02, 0.13	< 0.01
Model 3	-0.02	-0.10, 0.07	0.73	0.07	0.02, 0.13	< 0.01
Δ aLMI						
Model 1	0.00	-0.04, 0.04	0.93	0.02	-0.01, 0.04	0.19
Model 2	-0.01	-0.05, 0.04	0.78	0.03	-0.00, 0.06	0.06
Model 3	-0.01	-0.06, 0.04	0.65	0.03	-0.00, 0.05	0.08

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Appendix Table 3. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition, adjusted for puberty[#].

	Boys (n = 143)			Girls (n = 256)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	0.11	-0.08, 0.31	0.24	-0.01	-0.17, 0.16	0.95
Model 2	0.06	-0.15, 0.28	0.55	0.07	-0.12, 0.25	0.48
Δ waist circumference						
Model 1	0.28	-0.38, 0.95	0.40	-0.03	-0.69, 0.63	0.94
Model 2	-0.03	-0.77, 0.72	0.95	-0.00	-0.72, 0.72	0.99
Δ FMI						
Model 1	0.02	-0.16, 0.20	0.80	-0.01	-0.17, 0.14	0.86
Model 2	0.04	-0.16, 0.24	0.68	0.05	-0.12, 0.22	0.55
Δ LMI						
Model 1	0.08	-0.02, 0.17	0.11	0.03	-0.03, 0.09	0.35
Model 2	0.01	-0.09, 0.11	0.81	0.02	-0.04, 0.09	0.49
Δ aLMI						
Model 1	0.05	-0.01, 0.10	0.09	0.02	-0.01, 0.05	0.14
Model 2	0.02	-0.04, 0.07	0.60	0.02	-0.01, 0.05	0.20

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

STROBE statement for submitted manuscript entitled "*The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.*"

	Item No	Recommendation
Title and abstract	1	(*a*) P. 1,lines. 1-2.
		(*b*) P. 3, lines 1-23.
Introduction		
Background/rationale	2	P. 5, lines 1-25 and P. 6, lines 1-3.
Objectives	3	P. 6, lines 3-8.
Methods		
Study design	4	P. 6, lines 11-16.
Setting	5	P. 6, lines 11-23.
Participants	6	(*a*) P. 6, lines 18-23.
Variables	7	P. 8, lines 8-25. P. 9, lines 1-22.
Data sources/ measurement	8*	P. 6, lines 17-23. P. 7, lines 1-25. P. 8, lines 1-14.
Bias	9	P. 9, lines 12-23.
Study size	10	P. 6, lines 11-23.
Quantitative variables	11	P. 9, lines 8-12.
Statistical methods	12	(*a*) P. 8, lines 22-25 and P. 9, lines 1-24.
		(*b*) P. 9, lines 20-24.
		(*c*) P. 6, lines 19-22.
		(*e*) P. 18, lines 21-25 and P. 19, line 1.
Results		
Participants	13*	(a) P. 6, lines 11-23.
		(b) See (a).
Descriptive data	14*	(a) See Table 1.
		(b) See 13a
		(c) See Table 1.
Outcome data	15*	See Table 1.
Main results	16	(*a*) See Tables and P. 9, lines 6-20.
		(*b*) See Table 1.
Other analyses	17	P. 9, lines 20-23, and P. 17, lines 18-24. P. 18, lines 21-25 and P. 19, line 1.
Discussion		
Key results	18	P. 15, lines 2-8.
Limitations	19	P. 16, lines 17-21. P. 17, lines 18-25. P. 18, lines 1-7.
Interpretation	20	P. 15, lines 9 – 25. P. 16, 1-25. P. 17, lines 1-25. P. 18, lines 1-7.
Generalisability	21	P. 19, lines 4-6.
Other information		
Funding	22	P. 20, lines 16.

BMJ Open

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-036991.R2
Article Type:	Original research
Date Submitted by the Author:	13-Aug-2020
Complete List of Authors:	Aars, Nils; UiT The Arctic University of Norway, Department of Community Medicine; Nordlandssykehuset HF Beldo, Sigurd; UiT Arctic University of Norway, School of Sport Sciences Jacobsen, Bjarne; UiT The Arctic University of Norway, Department of Community Medicine; UiT The Arctic University of Norway, Centre for Sami Health Research Horsch, Alexander; UiT The Arctic University of Norway, Department of Computer Science Morseth, Bente; UiT Arctic University of Norway, School of Sport Sciences; UiT The Arctic University of Norway, Department of Community Medicine Emaus, Nina; UiT The Arctic University of Norway, Department of Health and Care Siences Furberg, Anne-Sofie; UiT The Arctic University of Norway, Department of Comunity Medicine; Universitetssykehuset Nord-Norge, Department of Microbiology and Infection Control Grimsgaard, Sameline; UiT The Arctic University of Norway, Department of Community Medicine
Primary Subject Heading:	Public health
Secondary Subject Heading:	Sports and exercise medicine, Epidemiology
Keywords:	EPIDEMIOLOGY, PUBLIC HEALTH, SPORTS MEDICINE

SCHOLARONE™
Manuscripts

The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.

Nils Abel Aars[1, 2*]

Sigurd Beldo[3]

Bjarne K Jacobsen[1, 4]

Alexander Horsch[5]

Bente Morseth[3, 1]

Nina Emaus[6]

Anne-Sofie Furberg[1, 7]

Sameline Grimsgaard[1]

Affiliations

1. Department of Community Medicine, UiT The Arctic University of Norway, Tromsø, Norway

2. Nordland Hospital, Bodø, Norway.

3. School of Sport Sciences, UiT The Arctic University of Norway, Alta, Norway

4. Centre for Sami Health Research, Department of Community Medicine, UiT The Arctic University of Norway, Tromsø, Norway

5. Department of Computer Science, UiT The Arctic University of Norway, Tromsø, Norway

6. Department of Health and Care Sciences, UiT The Arctic University of Norway, Tromsø, Norway

7. Department of Microbiology and Infection Control, University Hospital of North Norway, Tromsø, Norway

* Corresponding author. Correspondence to nils.a.aars@uit.no

Nils Abel Aars

Department of Community Medicine

UiT The Arctic University of Norway

9037 Tromsø, Norway.

Word count: 3992

Abstract

Objectives: Physical activity may be important in deterring the obesity epidemic. This study aimed to determine if objectively measured physical activity in first year of upper secondary high school predicted changes in body composition over two years of follow-up in a cohort of Norwegian adolescents (n =431).

Design: A longitudinal study of adolescents (mean age 16 (SD 0.4) at baseline, 60.3% girls) participating in the Fit Futures studies 1 (2010-11) and 2 (2012-13).

Setting: All eight upper secondary high schools in two municipalities in Northern Norway.

Participants: Students participating in both studies and under the age of 18 at baseline, and with valid measurement of physical activity at baseline and body composition in both surveys.

Primary- and secondary outcomes: Change in objectively measured body mass index and waist circumference, and change in dual-energy x-ray absorptiometry measured fat mass index (FMI), lean mass index (LMI) and appendicular lean mass index (aLMI) between baseline and follow-up.

Results: At baseline, boys had significantly higher physical activity volume (p=0.01) and spent on average 6.4 (95% CI: 2.1, 10.6) more minutes in moderate-to-vigorous physical activity (MVPA) than girls (p <0.01). In girls, multivariate regression analyses showed that more sedentary time was negatively associated with changes in LMI (p < 0.01) and aLMI (p < 0.05), whereas more light activity had opposite effects on these measures (p < 0.01 and p < 0.05, respectively). No significant associations between measures of baseline physical activity and changes in body composition parameters was observed in boys.

Conclusions: In this cohort of Norwegian adolescents, sedentary and light physical activity was associated with changes in LMI and aLMI in girls, but not boys. Minutes spent in MVPA in first year of upper secondary high school was not associated with changes in measures of body composition in neither sex after two years.

Strengths and limitations of this study

- This study used objective measures of physical activity.

- The study included objectively measured weight, height and waist circumference, and dual-energy x-ray absorptiometry (DXA) measures of fat- and lean mass.
- We were not able to fully adjust for nutrition and not for pubertal development.
- The 431 participants with complete data from both baseline and follow-up represents 41% of those attending Fit Futures 1, indicating a degree of selection.

Background

The potential of physical activity to prevent or treat a number of diseases has been highlighted by the World Health Organization,[1] with inactivity accounting for 9% of worldwide premature mortality.[2] Public health guidelines state that adolescents should engage in Moderate-to-Vigorous Physical Activity (MVPA) ≥ 60 minutes per day,[3] but in 2011, only 50% of Norwegian 15 year olds met these recommendations.[4] During adolescence there is a decline in both total physical activity and MVPA,[5, 6] and many quit or reduce participation in organized sports.[7] As of 2013, the prevalence of overweight and obesity (Body Mass Index (BMI) ≥ 25 kg/m^2) in Norwegians aged <20 years appear to be stabilizing at around 20% in boys and 16% in girls - comparable to the Nordic countries.[8] This is lower than in the United States (around 29% in boys and girls), [8] but the health effects for those concerned may still be substantial over the long term.[9]

While physical activity has many positive health effects, its relationship with adiposity is less clear and it has proven difficult to determine causality, direction and magnitude of this relationship.[10] Cross-sectional research typically shows a strong inverse

association between physical activity and weight status,[11] but temporality cannot be ascertained using such study designs.[12] Longitudinal studies may ascertain if lower physical activity precedes excess weight gain, but a review found no evidence for a relationship between objectively measured physical activity and body fat gain in adolescents.[12] The lack of congruent results may in part be explained by the diverse and inadequate measures of both exposure and outcome used in research of the association between physical activity and body composition.[10, 11]

Although many methods to measure physical activity are available, the most common and most feasible is self-report which commonly overestimates the total amount of physical activity.[13] Body composition is most commonly assessed using BMI, but BMI does not distinguish between fat- and muscle mass.[14] This has the potential to cause misclassification of overweight status and may attenuate a true association between physical activity and fat or muscle mass. Thus, in the current study, we sought to overcome these limitations by applying objective measures of both physical activity and specific measures of body composition. Our aim was to investigate the association between objectively measured physical activity and changes in five different measures of body composition (body mass index, waist circumference, fat

mass index, lean mass index and appendicular lean mass index) over two years of follow-up in a cohort of Norwegian adolescents.

Methods and materials

We used data from the first and second Fit Futures cohort studies, performed in 2010-2011 and 2012-2013, respectively. In the first study we invited all students (n=1,117) in their first year of upper secondary high school in the neighbouring municipalities of Tromsø and Balsfjord in Northern Norway, and 93% participated. The study was repeated two years later, when the students were in their last year of upper secondary high school or had started as apprentices if they studied vocational subjects. The second study included 868 participants, giving an attendance of 77%. All eight upper secondary high schools in the two municipalities participated in both studies. Altogether 735 adolescents attended both surveys. For the present study we excluded those aged ≥ 18 years of age at baseline (n = 38). Some participants (n = 240) did not have valid measurements of physical activity at baseline, and were therefore not included in the study. We also excluded those with missing data on change in body composition parameters or variables included in the model (n = 26). Thus, 431 participants were included in the present study (60.3% girls). Appendix Table 1 includes descriptive characteristics of the boys and girls with a valid baseline measurement of physical activity and variables included in the analyses, but who were missing follow-up data on body composition parameters (n = 133).

Students were granted leave of absence from school to attend an examination at the Clinical Research Unit at the University Hospital of Northern Norway in both surveys. The participants attended a clinical examination where they also completed a questionnaire, which included questions on lifestyle, screen time, dietary habits etc. The participants signed a letter of informed consent, and those under the age of 16 brought a letter of consent signed by their parent or guardian.

All measurements were performed by trained personnel. Height was measured to the nearest centimeter and weight to the nearest 100 gram, wearing light clothing and using an automatic electronic scale/stadiometer (Jenix DS 102 stadiometer, Dong Sahn Jenix, Seoul, Korea). Body mass index was calculated as body weight in kilograms/height in meters^2. Waist circumference was measured to the nearest 0.1

centimeter at the height of the umbilicus. Fat and soft tissue lean mass in grams was estimated by whole-body dual energy X-ray absorptiometry (DXA) (GE Lunar Prodigy, Lunar Corporation, Madison, WI, USA). Fat mass comprises all fat, while soft tissue lean mass comprises all bodily tissue except fat and skeletal mass. These variables were used to calculate fat mass index (FMI, fat mass in kilograms/height in meters^2) and lean mass index (LMI, lean mass in kilograms/height in meters^2). In addition we calculated appendicular lean mass index (aLMI), which is the sum of soft tissue lean mass in kilograms in all four extremities divided by height in meters^2. Although most commonly used in studies of sarcopenia in elderly,[15] this body composition parameter is arguably more specific to skeletal muscle mass than total lean mass index. The ability of DXA to detect changes in appendicular lean mass in young adolescents is good, and has been validated against Magnetic Resonance Imaging (MRI).[16]

Physical activity was objectively measured using the ActiGraph GT3X accelerometer (ActiGraph, LLC, Pensacola, USA). Participants were instructed to wear the device on their right hip for seven consecutive days, and to remove it only when showering, swimming or sleeping. The ActiLife software was used to initialize the accelerometer and download data, which was imported into the Quality Control & Analysis Tool (QCAT) for data processing. This software was developed by the research group of professor Horsch in Matlab (The MathWorks, Inc., Massachusetts, USA) for processing of accelerometer data. The accelerometer was set in raw data mode, with a sampling frequency of 30 Hertz and with normal filtering epochs of 10 seconds. Data collection was initiated at 14:00 hours the first day, and concluded at 23:58 on the 8th day of measurement. We excluded data from the first day of measurement to reduce reactivity bias. The criteria for a valid measurement of physical activity was wear time of ≥ four consecutive days, with ≥ ten hours wear time per day. This has been demonstrated as representative of activity over a full week.[17] The triaxial algorithm developed by Hecht et al. was used to calculate wear time.[18] Minutes per day in sedentary (0 – 99 CPM), light (100 – 1951 CPM), moderate (1952 – 5723 CPM) and vigorous (≥ 5724 CPM) physical activity was determined using the cut-offs developed by Freedson.[19] The choice of these cut-offs enables direct comparisons as the cohort ages, and although these cut-offs are not commonly used for adolescents, we consider the bodily proportions of an adolescent to resemble that of an adult in terms of measured acceleration. The device collected data in both uniaxial- and triaxial mode, but in the present study only the uniaxial data had been processed and therefore available. Studies have shown that uniaxial data recorded from the GT3X correlate well with uniaxial data recorded from previous ActiGraph models.[20] Data on objectively measured physical activity was only available from Fit Futures 1.

Baseline characteristics were presented as means with standard deviation (SD) or prevalence in percentages with number of subjects (n) (Table 1). Sex-specific difference in body composition between baseline and follow-up was tested using a paired samples t-test. The difference in physical activity between sexes was tested using a two-sample t-test, while sex differences in categories of minutes spent in MVPA was tested using a chi-square test. Difference in linear trend across categories of minutes spent in MVPA was tested using STATA’s non-parametric test for trend, developed by Cuzick.[21] Linear regression was used to determine the effect of baseline physical activity on change in body composition, i.e., the change in BMI, waist circumference, FMI, LMI and aLMI from the first to the second Fit Futures Study.

We used three different predictors of change in body composition, performing three sets of analyses, with first; minutes per day spent in sedentary activity (Table 2) second; minutes per day spent in light activity (Table 3) and third; minutes per day spent in MVPA (Table 4). We divided the continuous variables sedentary- and light activity by 30 and the continuous variable MVPA by 15 before inclusion in the models, thus presenting the beta coefficient for change in body composition parameter per 30 minutes of sedentary- or light activity, or per 15 minutes of MVPA, with 95% confidence intervals and a p-value. In model 1 we adjusted for the baseline measurement of the body composition parameter. In the adjusted models (models 2) we also included time between measurements (mean (SD): 730 (74) days) and baseline values of device wear time, age in half years and questionnaire data on screen time on weekdays (how many hours per weekday the students spent in front of a computer or television - answers ranged from none to more than ten hours per weekday) and regularity of eating breakfast as an indicator of healthy meal patterns (answers ranging from rarely/never to every day). In the analyses of sedentary- and light activity we also adjusted for minutes spent in MVPA (models 3). In a subset of analyses (Appendix Tables 2 - 4) we repeated the analyses performed in Table 2 - 4, adjusting also for self-reported pubertal status measured by either pubertal development scale (boys) or age at menarche (girls). These analyses included the 143 boys and 256 girls with valid data on pubertal status. In all the analyses, a p-value of < 0.05 was considered statistically significant.

All analyses were performed sex-specific as decided a-priori, using STATA version 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP.).

Patient and public involvement

Participating schools were consulted and included in the design phase of the study.

Results

Table 1 displays the participants' body composition measurements at baseline and follow-up, as well as physical activity measurements at baseline. Boys had a statistically significant increase in all measures of body composition. Girls had a statistically significant increase in body weight, BMI, fat mass in kg and FMI, but not in LMI and appendicular lean mass. Boys were statistically significantly more physically active than girls in some aspects, with higher mean counts per minute (p=0.01) and more minutes in MVPA (p<0.01). Time spent in sedentary- or light intensities did not differ significantly between sexes. Twenty-seven percent of boys and 17% of girls complied with the recommendations of 60 minutes per day Moderate-to-Vigorous Physical Activity (MVPA).

Table 1. Characteristics of the longitudinal cohort of the Tromsø Study; Fit Futures 2010-11 and 2012-13 $^{\diamond}$.

	Boys (n = 171)		Girls (n = 260)	
	FF1	FF2	FF1	FF2
Age (years)	16.0 (0.4)	18.2 (0.4)	16.1 (0.4)	18.1 (0.4)
Height (cm)	177.1 (6.6)	179.0 (6.5)*	165.4 (6.6)	166.1 (6.6)*
Body weight (kg)	69.0 (12.3)	74.3 (13.0)*	60.8 (10.8)	63.4 (11.6)*
Body mass index (BMI kg/m2)	22.0 (3.5)	23.2 (3.7)*	22.2 (3.7)	23.0 (4.0)*
Waist circumference (cm)	81.0 (10.3)	83.9 (10.9)*	76.7 (9.8)	78.0 (10.8)*
Total Body Fat Mass (kg)	13.3 (9.4)	15.6 (10.4)*	19.9 (8.3)	21.7 (9.1)*
Fat Mass Index (FMI kg/m2)	4.2 (3.0)	4.9 (3.2)*	7.3 (3.0)	7.9 (3.3)*
Total Body Lean Mass (kg)	54.0 (6.5)	56.4 (6.9)*	38.9 (4.5)	39.3 (4.7)*
Lean Mass Index (LMI kg/m2)	17.2 (1.6)	17.6 (1.8)*	14.2 (1.3)	14.2 (1.4)
Appendicular Lean Mass (kg)	25.3 (3.4)	26.2 (3.6)*	17.4 (2.3)	17.4 (2.3)

Appendicular Lean Mass Index (aLMI kg/m2)	8.1 (0.9)	8.2 (0.9)*	6.4 (0.7)	6.3 (0.7)*
Accelerometer variables				
Wear time per valid day	14.2 (1.2)		14.1 (1.1)	
Counts per minute	362.9 (137.5)		334.0 (111.9)∞	
Minutes per day in different intensities				
Sedentary (cpm 0 – 99)	573.3 (77.3)		565.3 (63.2)	
Light (cpm 100 – 1951)	230.5 (58.8)		236.2 (48.4)	
Moderate (cpm 1952 – 5723)	45.8 (20.6)		40.2 (17.7) ∞	
Vigorous (cpm ≥ 5724)	3.7 (5.8)		2.9 (4.1) ∞	
MVPA# (cpm ≥ 1952)	49.5 (23.4)		43.1 (19.6) ∞	
Meeting MVPA guidelines per day				
0 – 29 minutes	35 (20.5)		69 (26.5)	
30 – 59 minutes	90 (52.6)		146 (56.2)	
≥ 60 minutes	46 (26.9)		45 (17.3) §	

◊: Values are means with standard deviation (SD) or n (prevalence in percentages). BMI: body weight in kg/height in meters^2, FMI: fat mass in kg/height in meters^2, LMI: lean mass in kg/height in meters^2, aLMI: appendicular lean mass in kg/height in meters^2. Data on physical activity in FF2 was not available.

*: Significantly different from baseline measurement ($p < 0.05$)

∞: Significantly different from boys (mean).

#: MVPA: moderate to vigorous physical activity, using cut-offs suggested by Freedson.[19]

§: significantly different linear trend from boys ($p<0.05$)

Table 2 displays the association between minutes spent in sedentary activity at baseline and changes in body composition between baseline and follow-up. There was no association between sedentary activity and changes in BMI, waist circumference and FMI in neither boys nor girls. In girls, but not in boys, more minutes spent in sedentary activity at baseline was associated with lower LMI ($p < 0.01$) and aLMI ($p = 0.02$). Adjustment for covariates and MVPA slightly attenuated the association with aLMI ($p = 0.05$).

Table 2. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition#.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	-0.02	-0.13, 0.09	0.76	-0.05	-0.15, 0.05	0.33
Model 2	-0.02	-0.17, 0.12	0.75	-0.11	-0.24, 0.03	0.12
Model 3	0.01	-0.17, 0.20	0.88	-0.11	-0.27, 0.05	0.16
∆ waist circumference						
Model 1	0.17	-0.21, 0.56	0.37	-0.01	-0.41, 0.40	0.96
Model 2	0.27	-0.24, 0.78	0.30	-0.33	-0.87, 0.20	0.22
Model 3	0.42	-0.23, 1.07	0.20	-0.44	-1.06, 0.18	0.17
∆ FMI						
Model 1	0.00	-0.10, 0.10	0.99	-0.01	-0.11, 0.08	0.83
Model 2	-0.02	-0.16, 0.11	0.74	-0.06	-0.18, 0.07	0.36
Model 3	0.00	-0.17, 0.17	0.98	-0.05	-0.20, 0.09	0.48
∆ LMI						
Model 1	0.00	-0.05, 0.05	0.88	-0.06	-0.09, -0.02	<0.01
Model 2	0.01	-0.06, 0.07	0.77	-0.07	-0.12, -0.02	<0.01

Model 3	0.02	-0.06, 0.10	0.63	-0.08	-0.13, -0.03	<0.01
∆ aLMI						
Model 1	0.00	-0.03, 0.03	0.84	-0.02	-0.04, -0.00	0.02
Model 2	0.00	-0.03, 0.04	0.81	-0.03	-0.05, -0.01	0.02
Model 3	0.01	-0.04, 0.05	0.71	-0.03	-0.06, 0.00	0.05

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 3 displays the association between minutes spent in light activity at baseline and changes in body composition between baseline and follow-up. There was no association between the exposure and either body composition parameter in boys. In girls there was some evidence to suggest an association with change in waist circumference (p =0.05), but the association was attenuated after adjustments (p = 0.17). More minutes spent in light physical activity was associated with higher LMI (p < 0.01 (Models 2 and 3)) and aLMI (p = 0.04 (Model 2) and 0.05 (Model 3)).

Table 3. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition#.

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value
∆ BMI						
Model 1	0.04	-0.11, 0.18	0.60	0.05	-0.09, 0.19	0.47
Model 2	0.01	-0.17, 0.18	0.93	0.12	-0.04, 0.27	0.13
Model 3	-0.01	-0.20, 0.17	0.88	0.11	-0.05, 0.27	0.16
∆ waist circumference						
Model 1	-0.11	-0.62, 0.40	0.68	0.54	0.01, 1.07	0.05
Model 2	-0.38	-1.00, 0.23	0.22	0.43	-0.19, 1.05	0.17
Model 3	-0.42	-1.07, 0.23	0.20	0.44	-0.19, 1.06	0.17
∆ FMI						
Model 1	0.03	-0.10, 0.16	0.67	0.02	-0.10, 0.15	0.71
Model 2	0.01	-0.15, 0.18	0.87	0.06	-0.09, 0.20	0.43
Model 3	-0.00	-0.17, 0.17	0.98	0.05	-0.09, 0.20	0.49
∆ LMI						
Model 1	-0.01	-0.07, 0.06	0.84	0.04	-0.01, 0.09	0.08
Model 2	-0.02	-0.09, 0.06	0.67	0.08	0.03, 0.13	<0.01

Model 3	-0.02	-0.10, 0.06	0.63	0.08	0.03, 0.13	<0.01
∆ aLMI						
Model 1	0.00	-0.03, 0.04	0.87	0.02	-0.01, 0.04	0.16
Model 2	-0.01	-0.05, 0.04	0.73	0.03	0.00, 0.06	0.04
Model 3	-0.01	-0.05, 0.04	0.70	0.03	-0.00, 0.06	0.05

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Table 4 displays the association between minutes in MVPA at baseline and changes in body composition between baseline and follow-up. There was no association between time spent in MVPA and changes in either measure of body composition for either sex.

Table 4. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition[#].

	Boys (n = 171)			Girls (n = 260)		
	Beta	95% CI	p value	Beta	95% CI	p value

∆ BMI						
Model 1	0.11	-0.07, 0.30	0.22	-0.00	-0.17, 0.16	0.97
Model 2	0.08	-0.13, 0.29	0.47	0.07	-0.11, 0.25	0.47
∆ waist circumference						
Model 1	0.25	-0.39, 0.89	0.44	-0.03	-0.68, 0.63	0.94
Model 2	-0.02	-0.75, 0.71	0.95	0.02	-0.70, 0.74	0.96
∆ FMI						
Model 1	0.02	-0.15, 0.19	0.83	-0.01	-0.17, 0.14	0.86
Model 2	0.06	-0.14, 0.25	0.57	0.05	-0.12, 0.22	0.54
∆ LMI						
Model 1	0.07	-0.02, 0.15	0.11	0.03	-0.03, 0.09	0.33
Model 2	0.01	-0.08, 0.10	0.86	0.02	-0.04, 0.09	0.44
∆ aLMI						
Model 1	0.03	-0.02, 0.08	0.19	0.02	-0.01, 0.05	0.13
Model 2	0.00	-0.05, 0.05	0.92	0.02	-0.01, 0.05	0.18

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the body composition parameter. In model 2 also adjusted for time between measurements and baseline values of screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

Appendix Table 1 shows the descriptive characteristics of the participants with valid baseline measurements of physical activity and adjustment variables, but who were lost to follow-up. Both boys and girls lost to follow-up had significantly higher mean BMI, waist circumference, fat mass and FMI at baseline, as well as significantly less minutes per day spent in light- and moderate-to-vigorous (girls only) physical activity. In Appendix Tables 2-4, we present sub-analyses restricted to those with complete data on pubertal development, confirming the results displayed in Tables 2-4 also after adjustments for pubertal development. Overall, adjustment for pubertal development had no substantial impact on an association between sedentary, light and moderate-to-vigorous physical activity and changes in body composition for either sex in complete case analyses. However, the association between minutes spent in sedentary activity- and light activity and changes in appendicular lean mass index was no longer significant for girls in Model 3. The point estimates did not differ from those from analyses without adjustments for pubertal development, however.

Discussion

In this longitudinal population-based study of Norwegian adolescents there were in both boys and girls no associations between objectively measured physical activity at baseline and two-year changes in BMI, waist circumference and FMI. Both boys and girls had statistically significant increases in the measures of body composition (except lean mass index and appendicular lean mass in girls). Objectively measured physical activity did not predict changes in boys. In girls there was a significant association between minutes spent in sedentary- and light physical activity and changes in indices of lean mass.

Although the magnitude of change differed, both sexes experienced increases in measures of body composition. In boys, FMI increased by 0.7 units (+ 16.7%), whereas LMI increased by 0.4 units (+ 2.3 %) from baseline. Similar relative changes were observed in girls, (FMI +8.2 %) and (LMI + 0.7%), indicating that FMI increases relatively more than LMI during late adolescence. We observed statistically significant differences in minutes spent in moderate ($p < 0.01$) and vigorous ($p = 0.04$) intensity between boys and girls, but time spent in other intensity levels did not differ.

Differences in physical activity by sex is consistent with previous research.[22, 23] Differences in changes in body composition by sex are biologically determined during adolescence, with sex hormones resulting in fat mass accrual in girls and lean mass accrual in boys.[24, 25] The observation that sedentary- and light activity predicted changes in indices of lean mass in girls, but not boys, may be explained by these expected biological differences. Physical activity may have somewhat greater potential to influence lean mass accrual in girls than in boys during this period, as fat-free mass is relatively stable in girls in late adolescence whereas it increases up to 18 years of age in boys.[26]

In the present study sedentary- and light activity had opposing effects on lean mass in girls. In a study using iso-temporal substitution models, positive prospective effects on fat mass was found when substituting 30 minutes of sedentary activity with MVPA, but not when substituted with light activity.[27] It is reasonable that sedentary- and light physical activity have opposing effects on lean mass.[28] In the present study sedentary- and light activity was inversely correlated (r = - 0.39), but minutes spent in different intensity levels are not directly a function of each other as wear time in the participants varies between individuals. Based on wear time inclusion criteria, the theoretical time span for wear time lies between 10 and 24 hours. Thus, minutes spent in sedentary activity may not be deduced from the sum of minutes spent in other intensities and vice versa, but it is plausible that higher wear time results in more sedentary time. This was evident in an exploratory analyses on the same cohort (not included in the present study), where higher wear time was significantly associated with more sedentary activity and less light activity ($p < 0.01$). Adjusting for wear time (Models 2) did not change the associations substantially for sedentary activity (Table 2), but had some effect on the associations with light physical activity (Table 3). Because of the inverse relationship between minutes spent sedentary and in light activity, it is not possible to determine whether it is sedentary time or light activity-time that is associated with change in LMI. The practical consequences are nevertheless that being active increases lean mass in girls.

When interpreting results, we must acknowledge the limitations of DXA in the estimation of lean mass, which can be affected by both biological factors and measurement error.[29] Because the relative increase in lean mass was small, only slight differences in for instance individual hydration status at the two time-points may influence estimates and thus the association.

There was no associations between objectively measured physical activity and change in BMI, waist circumference and FMI for either sex. It may be that the negative effects of less physical activity have not yet had time to manifest themselves in a population still undergoing physiological changes as a result of natural growth, especially considering the relatively short 2-year follow-up. Our results are in line with a systematic review suggesting that objectively measured PA is not an important predictor of change in adiposity in children, adolescents and adults.[12] In contrast, another systematic review found a protective effect of physical activity on adiposity in adolescents.[10] There were however several methodological weaknesses in the studies included in this review, particularly regarding the validity of the measurement of both physical activity and body composition. In contrast, our study employed robust measures of both these exposures- and outcomes, a combination which is lacking in much past research on the association between the two.[10-12]

In adolescents, physical activity is influenced by friends, family and other social support,[30] and is less stable than in adults.[31-33] Follow-up data on objectively measured physical activity was not available in the present study, but some evidence suggests that the decline in physical activity is steeper prior to the onset of adolescence.[34] Reductions in level of physical activity during the transition from adolescence to young adulthood nevertheless often occur.[35] Prior observations from the same cohort showed that change in self-reported physical activity between baseline and follow-up was a stronger predictor of change in body composition than self-reported baseline physical activity.[36] Other studies have suggested that change in activity during follow-up might obscure an association with body composition.[37, 38] In a sub-analyses, one of four in both the highest and lowest categories of MVPA at baseline reported decreased (high MVPA at baseline) and increased (low MVPA at baseline) self-reported physical activity at follow up, thus indicating that physical activity in adolescents is fluctuant. These two observations, assuming that measurement of both MVPA and self-reported hours per week of physical activity are representative of actual physical activity behaviour at the time, work in opposing directions with regard to the effect of physical activity on changes in adiposity. This phenomenon is known as regression dilution bias and may flatten the regression slope and cause an underestimate of the actual association.[39] With an annual decline in total physical activity of 7% in adolescents, researchers must consider the possibility that measured physical activity has a “best before-date”. It remains questionable whether baseline measurements of a fluctuant behaviour such as physical activity is representative of actual habits during the period of follow-up. It may be that the measurement represents current, but not future (or even prior) habits.[12, 40] This has implications for longitudinal studies of the relationship between physical activity and body composition.[38]

Strengths and limitations

The primary strength of this study are objective measures of both physical activity and body composition parameters, and the inclusion of tissue-specific measures of body composition. Some limitations have to be considered. As the Fit Futures study did not include a validated food frequency questionnaire or similar instrument for nutritional assessment, we were not able to fully adjust for the potential confounding effects of nutrition and changes in food habits of adolescents on changes in body composition. Accelerometer-measured physical activity has limitations. A hip worn accelerometer such as the ActiGraph GT3X is not able to correctly measure cycling and swimming.[41] Furthermore, accelerometers are dependent on user-compliance, and non-wear time therefore affects the amount of activity which is actually measured. Subjective judgement determines data management and analyses, e.g. the decision to exclude participants with wear time < 10 hours and < 4 consecutive days, is a trade-off between quality of data and the number of participants with valid data. We lacked complete data on physical activity and adjustment variables in 212 participants, but changes in BMI, waist circumference, FMI, LMI (except in girls, p = 0.04) and aLMI were not significantly different between those with- and without complete exposure data. Furthermore, of those with valid data concerning both physical activity and body composition parameters at baseline, close to 25% did not attend the follow up (Appendix Table 1). This group differed significantly from those included in the main analyses with respect to both physical activity and body composition parameters. The prospective associations between physical activity and changes in body composition parameters in this group (n = 133) may be different from those observed in the group of participants included in the main analyses (n = 431), and the associations in all the 564 participants with valid baseline data may therefore be different from what we find in the main analyses. This is however not possible to determine given the lack of follow-up data.

Although longitudinal observational studies are superior to cross-sectional studies to examine causation, they are also susceptible to directional bias, since participants may avoid physical activity because they are overweight, and not be overweight because they are inactive.[42-44] Finally, as the participants were 16 years old, much may already have happened both to the level of physical activity and the different measures of body composition prior to participation. In light of this, 2 years of follow-up may be a short time frame to determine the potential effects of physical activity on changes in the different body composition parameters.

Conclusion

Objectively measured physical activity was not significantly associated with change in objectively measured BMI, waist circumference or FMI after two years in this cohort of Norwegian adolescents. There was evidence to suggest that sedentary- and light activity affected indices of lean mass in girls, but not boys.

Acknowledgements

The authors thank the participants in the study, as well as the staff at the Clinical Research Unit at the University Hospital of North Norway for data collection and clinical measurements. We also thank the Fit Futures Steering Committee in both studies.

Footnotes

Contributors

NAA wrote the draft of the manuscript, which was revised and edited by all authors several times during the process. SB produced the accelerometer variables in close collaboration with AH, who wrote the software which converted raw accelerometer data to variables. BKJ contributed to the statistical analyses, and BM specifically contributed to the discussion of physical activity. NE and ASF were among the principal investigators in FF1 and FF2 and contributed significantly to the acquisition of data. SG formulated the research question and conceived the study. All authors have substantially contributed to the study, and have read and approved the final manuscript.

Funding

This particular manuscript has not received any specific funding.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Ethics approval

This study was approved by The Regional Committee of Medical and Health Research Ethics (2014/1666/REK nord).

Data availability statement

The data that support the findings of this study are available from UiT – The Arctic University of Norway. Restrictions apply to the availability of these data, which were used under license for the current study, and are thus not publicly available.

References

1. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. Geneva 2018.

2. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219-29.

3. World Health Organization. Global Recommendations on Physical Activity for Health. WHO Guidelines. Geneva 2010.

4. Kolle E SJ, Hansen BH, Anderssen SA. [Fysisk aktivitet blant 6-, 9- og 15-åringer i Norge. Resultater fra en kartlegging i 2011]. The Norwegian Directorate of Health, Oslo, Norway. 2012.

5. Dumith SC, Gigante DP, Domingues MR, et al. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol.* 2011;40:685-98.

6. Collings PJ, Wijndaele K, Corder K, et al. 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*. 2015;12:61.

7. Crane J, Temple V. A systematic review of dropout from organized sport among children and youth. *Eur Phys Educ Rev.* 2015;21:114-31.

8. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384:766-81.

9. NCD Risck Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*. 2017. doi:10.1016/S0140-6736(17)32129-3.

10. Reichert FF, Baptista Menezes AM, Wells JC, et al. Physical activity as a predictor of adolescent body fatness: a systematic review. *Sports Med*. 2009;39:279-94.

11. Jimenez-Pavon D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *Int J Pediatr Obes*. 2010;5:3-18.

12. Wilks DC, Besson H, Lindroos AK, et al. Objectively measured physical activity and obesity prevention in children, adolescents and adults: a systematic review of prospective studies. *Obes Rev*. 2011;12:e119-29.

13. Dyrstad SM, Hansen BH, Holme IM, et al. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014;46:99-106.

14. Aars NA, Jacobsen BK, Furberg AS, et al. Self-reported physical activity during leisure time was favourably associated with body composition in Norwegian adolescents. *Acta Paediatr*. 2018. doi:10.1111/apa.14660.

15. Goulding A, Taylor RW, Grant AM, et al. Relationships of appendicular LMI and total body LMI to bone mass and physical activity levels in a birth cohort of New Zealand five-year olds. *Bone*. 2009;45:455-9.

16. Bridge P, Pocock NA, Nguyen T, et al. Validation of longitudinal DXA changes in body composition from pre- to mid-adolescence using MRI as reference. *J Clin Densitom*. 2011;14:340-7.

17. Trost SG, Pate RR, Freedson PS, et al. Using objective physical activity measures with youth: how many days of monitoring are needed? *Med Sci Sports Exerc*. 2000;32:426-31.

18. Hecht A, Ma S, Porszasz J, et al. Methodology for using long-term accelerometry monitoring to describe daily activity patterns in COPD. *COPD*. 2009;6:121-9.

19. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*. 1998;30:777-81.

20. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14:411-6.

21. Cuzick J. A Wilcoxon-type test for trend. *Stat Med*. 1985;4:87-90.

22. Kolle E, Steene-Johannessen J, Andersen LB, et al. Objectively assessed physical activity and aerobic fitness in a population-based sample of Norwegian 9- and 15-year-olds. *Scand J Med Sci Sports*. 2010;20:e41-7.

23. Van Hecke L, Loyen A, Verloigne M, et al. Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *Int J Behav Nutr Phys Act*. 2016;13:70.

24. Baxter-Jones AD, Eisenmann JC, Mirwald RL, et al. The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. *J Appl Physiol (1985)*. 2008;105:734-41.

25. Wohlfahrt-Veje C, Tinggaard J, Winther K, et al. Body fat throughout childhood in 2647 healthy Danish children: agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry. *Eur J Clin Nutr*. 2014;68:664-70.

26. Siervogel RM, Demerath EW, Schubert C, et al. Puberty and body composition. *Horm Res*. 2003;60:36-45.

27. Sardinha LB, Marques A, Minderico C, et al. Cross-sectional and prospective impact of reallocating sedentary time to physical activity on children's body composition. *Pediatr Obes*. 2017;12:373-9.

28. Kenney WL, Wilmore JH, Costill DL. Physiology of sport and exercise. Seventh edition. Champaign, IL: Human Kinetics; 2020.

29. Lohman TG, Milliken LA. ACSM's body composition assessment. Champaign, IL: Human Kinetics; 2020.

30. Mendonca G, Cheng LA, Melo EN, et al. Physical activity and social support in adolescents: a systematic review. *Health Educ Res*. 2014;29:822-39.

31. Telama R, Yang X. Decline of physical activity from youth to young adulthood in Finland. *Med Sci Sports Exerc*. 2000;32:1617-22.

32. Varma VR, Dey D, Leroux A, et al. Re-evaluating the effect of age on physical activity over the lifespan. *Prev Med*. 2017;101:102-8.

33. Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 2000;32:1601-9.

34. Farooq MA, Parkinson KN, Adamson AJ, et al. Timing of the decline in physical activity in childhood and adolescence: Gateshead Millennium Cohort Study. *Br J Sports Med*. 2018;52:1002-6..

35. Corder K, Winpenny E, Love R, et al. Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. *Br J Sports Med*. 2019;53:496-503.

36. Aars NA, Jacobsen BK, Morseth B, et al. Longitudinal changes in body composition and waist circumference by self-reported levels of physical activity in leisure among adolescents: the Tromsø study, Fit Futures. *BMC Sports Sci Med Rehabil*. 2019;11:37.

37. O'Loughlin J, Gray-Donald K, Paradis G, et al. One- and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic, low-income, inner-city neighborhoods. *Am J Epidemiol*. 2000;152:739-46.

38. Collings PJ, Wijndaele K, Corder K, et al. Objectively measured physical activity and longitudinal changes in adolescent body fatness: an observational cohort study. *Pediatr Obes*. 2016;11:107-14.

39. Hutcheon JA, Chiolero A, Hanley JA. Random measurement error and regression dilution bias. *BMJ*. 2010;340:c2289.

40. Kettaneh A, Oppert JM, Heude B, et al. Changes in physical activity explain paradoxical relationship between baseline physical activity and adiposity changes in adolescent girls: the FLVS II study. *Int J Obes (Lond)*. 2005;29:586-93.

41. Herman Hansen B, Bortnes I, Hildebrand M, et al. Validity of the ActiGraph GT1M during walking and cycling. *J Sports Sci*. 2014;32:510-6.

42. van Sluijs EM, Sharp SJ, Ambrosini GL, et al. The independent prospective associations of activity intensity and dietary energy density with adiposity in young adolescents. *Br J Nutr*. 2016;115:921-9.

43. Hjorth MF, Chaput JP, Ritz C, et al. 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 Obes (Lond)*. 2014;38:959-65.

44. Jago R, Salway RE, Ness AR, et al. Associations between physical activity and asthma, eczema and obesity in children aged 12-16: an observational cohort study. *BMJ Open*. 2019;9:e024858. doi:10.1136/bmjopen-2018-024858.

Supplementary file

Appendix Table 1. Descriptive characteristics of participants lost to follow-up (n = 133), with p-value for difference from sample in Table 1[*].

	Boys (n = 79)	P for difference	Girls (n = 54)	P for difference
Age (years)	16.1 (0.4)	0.26	16.1 (0.4)	0.42
Height (cm)	176.7 (13.8)	0.31	164.5 (5.9)	0.18
Body weight (kg)	73.3 (18.0)	0.01	63.5 (1.9)	0.06
Body mass index (BMI kg/m2)	23.4 (5.2)	0.01	23.4 (4.4)	0.02
Waist circumference (cm)	85.1 (13.9)	<0.01	80.0 (12.4)	0.02
Total Body Fat Mass (kg)	17.6 (12.8)	<0.01	22.8 (10.3)	0.01
Fat Mass Index (FMI kg/m2)	5.6 (4.0)	<0.01	8.4 (3.5)	0.01
Total Body Lean Mass (kg)	53.9 (7.8)	0.46	38.6 (4.6)	0.33
Lean Mass Index (LMI kg/m2)	17.2 (1.9)	0.43	14.2 (1.4)	0.42
Appendicular Lean Mass (kg)	25.3 (4.1)	0.49	17.4 (2.5)	0.48
Appendicular Lean Mass Index (aLMI kg/m2)	8.1 (1.0)	0.41	6.4 (0.76)	0.29
Accelerometer variables				
Wear time per valid day	14.3 (1.2)	0.26	13.7 (1.0)	<0.01
Counts per minute	338.4 (112.1)	0.08	300.5 (121.5)	0.03
Minutes per day in different intensities				
Sedentary (cpm 0 – 99)	570.1 (82.6)	0.38	562.6 (68.9)	0.39
Light (cpm 100 – 1951)	244.3 (64.7)	0.05	223.4 (46.3)	0.04
Moderate (cpm 1952 – 5723)	42.9 (19.6)	0.15	33.0 (17.6)	<0.01
Vigorous (cpm ≥ 5724)	2.3 (2.9)	0.03	2.7 (5.1)	0.40
MVPA[#] (cpm ≥ 1952)	45.2 (21.0)	0.08	35.6 (20.0)	0.01
Meeting MVPA guidelines per day				
0 – 29 minutes	21 (26.6)		24 (44.4)	
30 – 59 minutes	41 (51.9)		23 (42.6)	
≥ 60 minutes	17 (21.5)		7 (13.0)*	

*: Statistically significantly different linear trend from sample included in manuscript (Table 1).

Appendix Table 2. Association between minutes per day spent in sedentary activity (CPM 0 – 99) at baseline and changes in body composition, adjusted for puberty[#].

	Boys (n = 143)			Girls (n = 258)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	-0.02	-0.14, 0.09	0.70	-0.05	-0.15, 0.05	0.32
Model 2	-0.01	-0.17, 0.14	0.85	-0.11	-0.24, 0.03	0.12
Model 3	0.03	-0.17, 0.23	0.76	-0.11	-0.27, 0.05	0.19
Δ waist circumference						
Model 1	0.12	-0.27, 0.51	0.55	-0.01	-0.42, 0.39	0.95
Model 2	0.24	-0.28, 0.77	0.36	-0.38	-0.91, 0.15	0.16
Model 3	0.37	-0.32, 1.06	0.29	-0.52	-1.14, 0.10	0.10
Δ FMI						
Model 1	-0.01	-0.12, 0.09	0.84	-0.01	-0.11, 0.08	0.81
Model 2	-0.01	-0.15, 0.13	0.85	-0.06	-0.18, 0.07	0.35
Model 3	0.01	-0.17, 0.20	0.90	-0.05	-0.20, 0.10	0.49
Δ LMI						
Model 1	0.00	-0.05, 0.06	0.90	-0.06	-0.09, -0.02	< 0.01
Model 2	0.01	-0.07, 0.08	0.89	-0.07	-0.12, -0.02	< 0.01
Model 3	0.02	-0.08, 0.11	0.74	-0.08	-0.13, -0.02	< 0.01
Δ aLMI						
Model 1	-0.00	-0.03, 0.03	0.91	-0.02	-0.04, -0.00	0.02
Model 2	0.00	-0.04, 0.04	0.92	-0.03	-0.05, -0.00	0.02
Model 3	0.01	-0.04, 0.07	0.59	-0.03	-0.06, 0.00	0.06

#: The table displays the association between minutes spent in sedentary activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in sedentary activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM $\geq$ 1952).

Appendix Table 3. Association between minutes per day spent in light activity (CPM 100 – 1951) at baseline and changes in body composition, adjusted for puberty[#].						
	Boys (n = 143)			Girls (n = 258)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	0.05	-0.10, 0.20	0.53	0.04	-0.09, 0.18	0.54
Model 2	-0.00	-0.19, 0.18	0.97	0.11	-0.04, 0.27	0.15
Model 3	-0.03	-0.23, 0.17	0.76	0.11	-0.05, 0.27	0.19
Δ waist circumference						
Model 1	-0.01	-0.53, 0.51	0.97	0.53	-0.00, 1.07	0.05
Model 2	-0.34	-0.98, 0.30	0.30	0.50	-0.11, 1.11	0.11
Model 3	-0.37	-1.06, 0.32	0.29	0.51	-0.11, 1.13	0.10
Δ FMI						
Model 1	0.05	-0.09, 0.18	0.51	0.02	-0.11, 0.14	0.78
Model 2	0.00	-0.17, 0.18	0.97	0.06	-0.09, 0.20	0.43
Model 3	-0.01	-0.20, 0.17	0.90	0.05	-0.10, 0.20	0.49
Δ LMI						
Model 1	-0.01	-0.08, 0.06	0.84	0.04	-0.01, 0.09	0.08
Model 2	-0.01	-0.10, 0.07	0.80	0.08	0.02, 0.13	< 0.01
Model 3	-0.02	-0.11, 0.07	0.74	0.08	0.02, 0.13	< 0.01
Δ aLMI						
Model 1	0.00	-0.04, 0.04	0.93	0.02	-0.01, 0.04	0.17
Model 2	-0.01	-0.06, 0.04	0.73	0.03	0.00, 0.06	0.04
Model 3	-0.01	-0.07, 0.04	0.59	0.03	-0.00, 0.06	0.06

#: The table displays the association between minutes spent in light activity and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 30 minutes increase in light activity. All models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time. In Model 3 adjusted also for minutes spent in Moderate-to-vigorous physical activity (CPM ≥ 1952).

Appendix Table 4. Association between minutes per day spent in MVPA (CPM ≥ 1952) at baseline and changes in body composition, adjusted for puberty[#].

	Boys (n = 143)			Girls (n = 258)		
	Beta	95% CI	p value	Beta	95% CI	p value
Δ BMI						
Model 1	0.11	-0.08, 0.31	0.24	-0.00	-0.17, 0.16	0.97
Model 2	0.07	-0.15, 0.29	0.51	0.07	-0.11, 0.25	0.43
Δ waist circumference						
Model 1	0.28	-0.38, 0.95	0.40	-0.02	-0.68, 0.64	0.95
Model 2	-0.06	-0.82, 0.70	0.88	0.02	-0.69, 0.72	0.97
Δ FMI						
Model 1	0.02	-0.16, 0.20	0.80	-0.01	-0.17, 0.14	0.88
Model 2	0.05	-0.16, 0.25	0.66	0.06	-0.11, 0.22	0.52
Δ LMI						
Model 1	0.08	-0.02, 0.17	0.11	0.03	-0.03, 0.09	0.34
Model 2	0.01	-0.09, 0.11	0.84	0.03	-0.04, 0.09	0.42
Δ aLMI						
Model 1	0.05	-0.01, 0.10	0.09	0.02	-0.01, 0.05	0.13
Model 2	0.02	-0.04, 0.07	0.60	0.02	-0.01, 0.06	0.15

#: The table displays the association between minutes spent in moderate-to-vigorous physical activity (MVPA) and difference in BMI (kg/m^2), waist circumference, FMI (fat mass in kg/m^2), LMI (lean mass in kg/m^2) and aLMI (appendicular lean mass in kg/m^2) between Fit Futures 1 (2010-2011) and Fit Futures 2 (2012-2013). The models give the beta coefficient for 15 minutes increase in MVPA. Both models were adjusted for baseline values of the outcome. In model 2 also adjusted for time between measurements and baseline values of pubertal development (pds (boys) and age at menarche (girls)), screen time on weekdays, study specialisation, age in half-years, regularity of eating breakfast and device wear time.

STROBE statement for submitted manuscript entitled "*The association between objectively measured physical activity and longitudinal changes in body composition in adolescents; The Tromsø Study Fit Futures Cohort.*"

	Item No	**Recommendation**
Title and abstract	1	(*a*) P. 1,lines. 1-2.
		(*b*) P. 3, lines 1-23.
Introduction		
Background/rationale	2	P. 5, lines 1-25 and P. 6, lines 1-3.
Objectives	3	P. 6, lines 3-8.
Methods		
Study design	4	P. 6, lines 11-16.
Setting	5	P. 6, lines 11-23.
Participants	6	(*a*) P. 6, lines 18-23.
Variables	7	P. 8, lines 11-24. P. 9, lines 1-25.
Data sources/ measurement	8*	P. 6, lines 17-23. P. 7, lines 3-24. P. 8, lines 1-17.
Bias	9	P. 9, lines 17-25 and P. 10, lines 1-3.
Study size	10	P. 6, lines 11-23.
Quantitative variables	11	P. 9, lines 12-17.
Statistical methods	12	(*a*) P. 9, lines 1-24 and P. 10, lines 1-6.
		(*b*) P. 9, line 1 and P. 10, lines 1-3.
		(*c*) P. 6, lines 19-24 and P. 7, lines 1-2.
		d) P. 6, lines 23-24 and P. 7, lines 1-2.
		(*e*) P. 19, lines 1-12.
Results		
Participants	13*	(a) P. 6, lines 11-23.
		(b) See (a).
Descriptive data	14*	(a) See Table 1.
		(b) See 13a
		(c) See Table 1.
Outcome data	15*	See Table 1.
Main results	16	(*a*) See Tables and P. 9, lines 11-25.
		(*b*) See Table 1.
Other analyses	17	P. 10, lines 1-3, and P. 14, lines 9-17. P. 15, lines 1-4. P. 17, lines 22-25. P. 19, lines 1-12.
Discussion		
Key results	18	P. 15, lines 6-12.
Limitations	19	P. 16, lines 21-25. P. 17, lines 22-25. P. 18 lines 1-11 and lines 16-25. P. 19, lines 1- 19.
Interpretation	20	P. 15, lines 13-24. P. 16, 1-25. P. 17, lines 1-25. P. 18, lines 1-11.
Generalisability	21	P. 19, lines 1-12 and lines 16-18.
Other information		

Funding	22	P. 21, lines 16.