



# The bidirectional associations between leisure time physical activity change and body mass index gain. The Tromsø Study 1974–2016

Edvard H. Sagelv<sup>1</sup> · Ulf Ekelund<sup>2,3</sup> · Laila A. Hopstock<sup>4</sup> · Marius Steiro Fimland<sup>5,6</sup> · Ola Løvsletten<sup>4</sup> · Tom Wilsgaard<sup>4</sup> · Bente Morseth<sup>1</sup>

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## Abstract

**Objectives** To examine whether leisure time physical activity changes predict subsequent body mass index (BMI) changes, and conversely, whether BMI changes predict subsequent leisure time physical activity changes.

**Methods** This prospective cohort study included adults attending  $\geq 3$  consecutive Tromsø Study surveys (time: T1, T2, T3) during 1974–2016 ( $n = 10779$ ). If participants attended  $>3$  surveys, we used the three most recent surveys. We computed physical activity change (assessed by the Saltin-Grimby Physical Activity Level Scale) from T1 to T2, categorized as Persistently Inactive ( $n = 992$ ), Persistently Active ( $n = 7314$ ), Active to Inactive ( $n = 1167$ ) and Inactive to Active ( $n = 1306$ ). We computed BMI change from T2 to T3, which regressed on preceding physical activity changes using analyses of covariance. The reverse association (BMI change from T1 to T2 and physical activity change from T2 to T3;  $n = 4385$ ) was assessed using multinomial regression.

**Results** Average BMI increase was  $0.86 \text{ kg/m}^2$  (95% CI: 0.82–0.90) from T2 to T3. With adjustment for sex, birth year, education, smoking and BMI at T2, there was no association between physical activity change from T1 to T2 and BMI change from T2 to T3 (Persistently Inactive:  $0.89 \text{ kg/m}^2$  (95% CI: 0.77–1.00), Persistently Active:  $0.85 \text{ kg/m}^2$  (95% CI: 0.81–0.89), Active to Inactive:  $0.90 \text{ kg/m}^2$  (95% CI: 0.79–1.00), Inactive to Active  $0.85 \text{ kg/m}^2$  (95% CI: 0.75–0.95),  $p = 0.84$ ). Conversely, increasing BMI was associated with Persistently Inactive (odds ratio (OR): 1.17, 95% CI: 1.08–1.27,  $p < 0.001$ ) and changing from Active to Inactive (OR: 1.16, 95% CI: 1.07–1.25,  $p < 0.001$ ) compared with being Persistently Active.

**Conclusions** We found no association between leisure time physical activity changes and subsequent BMI changes, whereas BMI change predicted subsequent physical activity change. These findings indicate that BMI change predicts subsequent physical activity change at population level and not vice versa.

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1038/s41366-021-00853-y>.

✉ Edvard H. Sagelv  
edvard.h.sagelv@uit.no

<sup>1</sup> School of Sport Sciences, Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway

<sup>2</sup> Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway

<sup>3</sup> Department of Chronic Diseases and Ageing, Norwegian Institute of Public Health, Oslo, Norway

## Introduction

The prevalence of overweight and obesity is continuously growing worldwide, and now over 50% of the population is classified as either overweight or obese in western high-income countries [1]. As overweight and obesity is associated with a substantial increased risk of non-communicable

<sup>4</sup> Department of Community Medicine, Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway

<sup>5</sup> Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology, Trondheim, Norway

<sup>6</sup> Unicare Helsefort Rehabilitation Centre, Rissa, Norway

diseases and premature death [2], it is one of the greatest threats to public health in western high-income countries [1, 2].

Weight gain prevention at populational level is challenging. Obviously, excessive adiposity and weight gain are effects of an imbalanced energy intake and expenditure [3]. Thus, increasing physical activity levels could potentially serve as an effective public health strategy to prevent population weight gain [3, 4]. However, studies examining whether population levels of physical activity can prevent weight gain show conflicting results [4, 5], which may be attributed to methodological issues [5]. For example, although current weight is a strong predictor of future weight gain [5], some studies failed to adjust for baseline weight or body mass index (BMI) [6–14]. Moreover, most studies did not take the temporal reciprocal relationship between changing physical activity and weight into account [5], as they assessed the association between baseline physical activity level and future weight or BMI change [9, 10, 15–22]. Other studies examined the associations between change scores in both physical activity and weight or BMI [6, 8, 11–14, 23–37], which basically are cross-sectional analyses of change scores [5]. Finally, the association between physical activity and weight change may be reverse as weight change may lead to physical activity change [5, 6, 22, 25, 26, 35, 37–39], or this may be bidirectional [5].

Furthermore, the association between physical activity change and BMI change may be modified by other behavioural or societal factors, including sex [10], age [17, 18, 28–30], smoking [23, 29], education [24], physical activity domain (e.g., occupation or leisure time) [29], and baseline BMI [28, 29]. However, these observations are not

consistent [12, 15, 26, 33], which warrant further investigation.

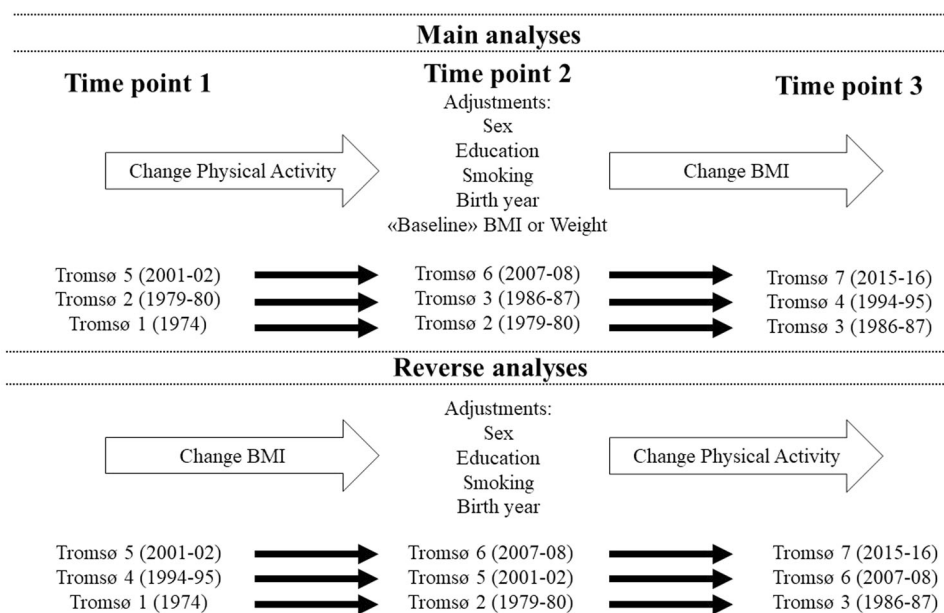
Declines in both leisure time and occupational physical activity may contribute to population BMI gains [4]. We have previously reported on the association between occupational physical activity and BMI change in a population-based cohort (The Tromsø Study) from Norway followed through repeated examinations every ~6 years. Our results suggested that occupational physical activity declines did not contribute to population BMI gains [40]. As large proportions of the population are inactive during work hours [41, 42], leisure time physical activity may have greater potential to prevent weight gain. Thus, the aims of this study were to assess: (1) Whether changes in leisure time physical activity from examination 1 (time (T) 1) to the next (T2) predicted subsequent changes in BMI from T2 to the next examination (T3), and (2) Whether BMI changes from T1 to T2 predicted subsequent leisure time physical activity changes from T2 to T3, with ~6 years follow up between each examination.

## Materials and methods

### Design

The study design is illustrated in Fig. 1. We studied participants from the Tromsø Study, a population-based cohort study in Tromsø Municipality, Norway. There are seven repeated Tromsø Study surveys (attendance of invited participants = %): 1974 (Tromsø 1; 83%), 1979–80 (Tromsø 2; 85%), 1986–87 (Tromsø 3; 81%), 1994–95 (Tromsø 4; 77%), 2001 (Tromsø 5; 79%), 2007–08 (Tromsø 6; 66%)

**Fig. 1** The study design for assessing the association between physical activity changes and future BMI changes, and conversely for assessing BMI changes and physical activity changes. BMI body mass index.



and 2015–16 (Tromsø 7: 65%). Invited participants were selected from total birth cohorts and random samples of inhabitants in Tromsø municipality [41, 43]. Only men were invited to Tromsø 1 (1974), while in Tromsø 2–7 (1979–2016) both men and women were invited (details described elsewhere [41, 43]). In this study, we included participants attending at least three consecutive surveys (hereafter called T1, T2, T3). To assess the association between change in physical activity from T1 to T2 and change in BMI from T2 to T3, the inclusion criteria were information on: (1) physical activity at T1 and T2, and height and weight at T2 and T3; (2) information on educational level and smoking habits at T2; and (3) not pregnant at T2 and/or T3. We also reversed the analyses to assess whether BMI change from T1 to T2 predicted physical activity change from T2 to T3. Here, inclusion criteria were: (1) height and weight at T1 to T2, physical activity at T2 to T3; (2) educational level and smoking habits at T2; and (3) not pregnant at T1 and/or T2. If the participants attended more than three consecutive surveys, we used their data from the three most recent surveys in the analyses of the overall cohort, while their data could be included in multiple period-specific samples (Tromsø 1–3: 1974–1987, Tromsø 2–4: 1979–1995, Tromsø 5–7: 2001–2016).

## Participants

Participant selection for our analyses is illustrated in Fig. 2. The overall cohort comprised 10779 participants, which

derive from the participants' three most recent Tromsø Study attendances. We also created period-specific samples where each participant may be included in multiple period-specific samples: Tromsø 1–3 (1974–1987,  $n = 3598$ ), Tromsø 2–4 (1979–1995,  $n = 9691$ ) and Tromsø 5–7 (2001–2016,  $n = 2206$ ). Therefore, the period-specific samples do not add up to the overall cohort, which only includes participants with their three most recent consecutive surveys (Fig. 2).

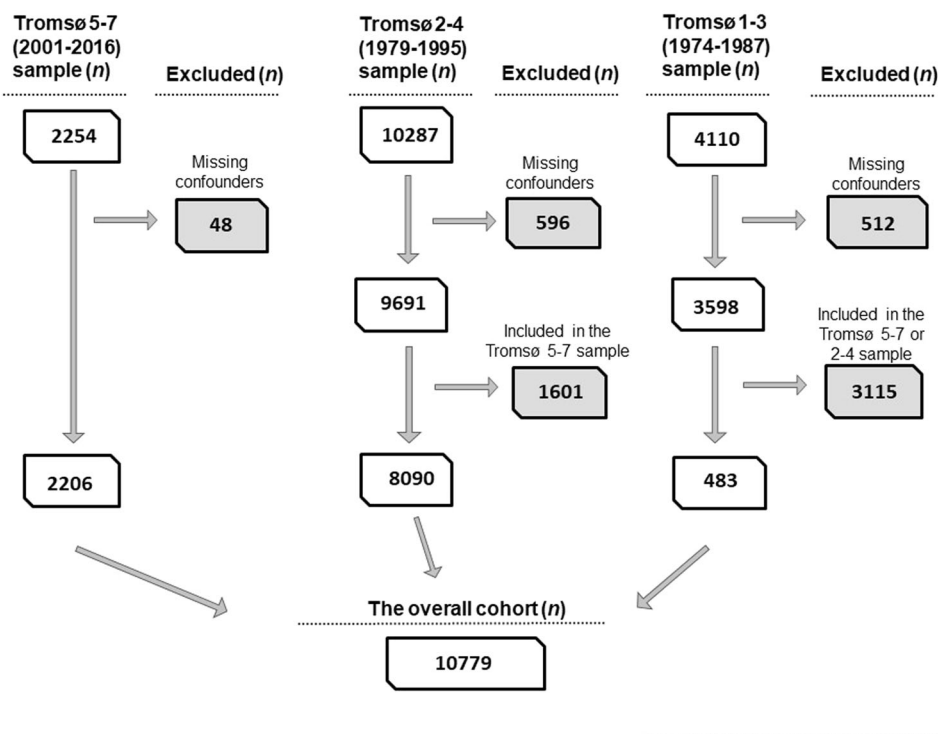
The reversed analyses (BMI change from T1 to T2 followed by physical activity change from T2 to T3) were assessed in an overall cohort comprising 4385 participants (Fig. 3). The leisure time physical activity questionnaire was not included in Tromsø 4 and only those <70 years answered the questionnaire in Tromsø 5; this explains the lower sample size in the reversed analyses compared with the main analyses.

All participants from Tromsø 4–7 provided written informed consent and the present study was approved by the Regional Ethics Committee for Medical Research (ref. 2016/758410).

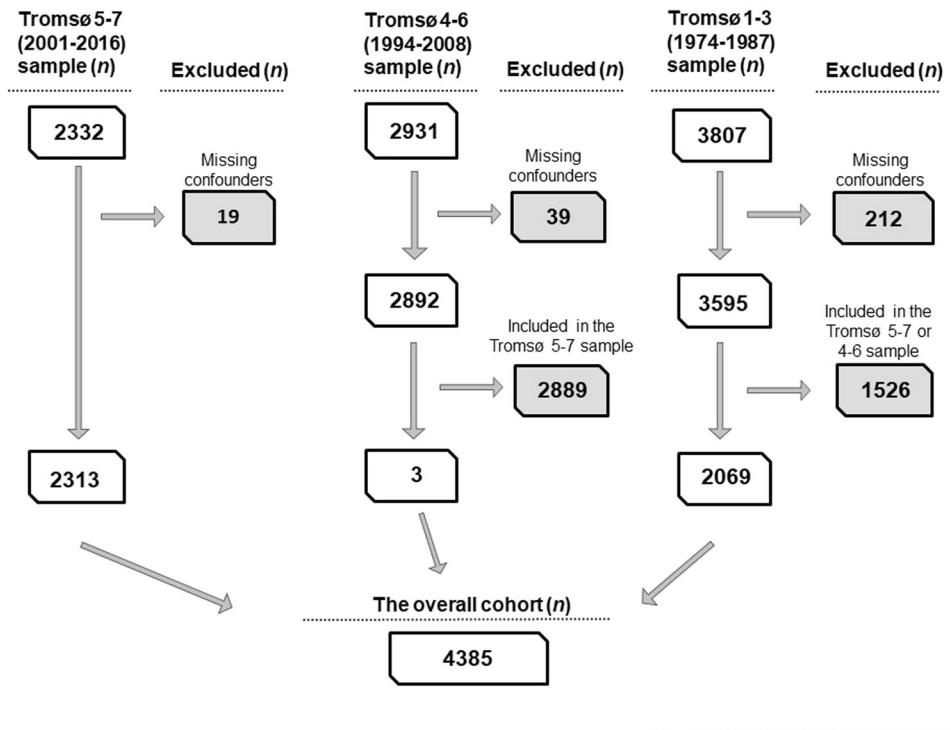
## Self-reported physical activity

Physical activity was measured with the Saltin-Grimby Physical Activity Level Scale (SGPALS) questionnaire [44, 45], which asks participants to rank their physical activity by four hierarchical levels for leisure- and occupational time physical activity, separately, during the last

Fig. 2 Flow chart of participant selection.



**Fig. 3** Flow chart of participant selection for the reversed analyses.



12 months [44]. The SGPALS in the Tromsø Study is slightly modified compared to the original by Saltin and Grimby [44] (Supplementary Table 1). The SGPALS is found to provide acceptable reliability [45] and validation studies have demonstrated acceptable ability to rank physical activity level when evaluated against accelerometry and cardiorespiratory fitness as the criterions [45].

Physical activity change was computed as (1) *Persistently Inactive* (reporting rank 1 at T1 and T2;  $n = 992$ ); (2) *Persistently Active* (rank  $\geq 2$  at T1 and T2;  $n = 7314$ ); (3) *Active to Inactive* (rank  $\geq 2$  at T1 and rank 1 at T2;  $n = 1167$ ); and (4) *Inactive to Active* (rank 1 at T1 and rank  $\geq 2$  at T2;  $n = 1306$ ).

The leisure time SGPALS was used in all Tromsø Study surveys except Tromsø 4 (1994–95), and in Tromsø 5 (2001) not by those  $\geq 70$  years. The occupational time SGPALS was used in all surveys by participants of all ages.

### Body mass index and weight

Weight and height were measured in light clothing and are expressed as kilograms (kg) and metres (m). BMI was calculated as  $\text{kg/m}^2$  and categorized into normal weight ( $< 25 \text{ kg/m}^2$ ), overweight ( $25\text{--}29 \text{ kg/m}^2$ ) and obese ( $\geq 30 \text{ kg/m}^2$ ) for stratified analyses. Change in BMI from T2 to T3 was calculated with height being fixed at T2 and change in BMI from T1 to T2 fixed at T1, to avoid a possible effect of height loss between the measurements.

### Confounders and effect modifiers

We included sex, birth year, smoking, education and BMI measured at T2 as confounders, and we also assessed potential effect modification of the confounders in addition to occupational physical activity change from T1 to T2. Data on smoking, education and occupational physical activity were retrieved from questionnaires. We categorized smoking into (1) Current smoker, (2) Previous smoker, and (3) Never smoker. The participants reported years of education in Tromsø 2 (1979–80), Tromsø 3 (1986–87) and Tromsø 5 (2001), which we categorized into (1) Primary school ( $< 10$  years), (2) High school (10–12 years), (3) University  $< 4$  years (13–15 years), and (4) University  $\geq 4$  years ( $\geq 16$  years). In Tromsø 4 (1994–95) and Tromsø 6 (2007–08), the participants reported education with five response options, which included the four abovementioned groups and a fifth named “Technical school 2 years senior high” (vocational training), which we categorized as (2) High school.

### Statistical analyses

Paired  $t$  tests were used to assess whether participants changed BMI from T2 to T3. Analyses of covariance (ANCOVA) were used to assess the association between physical activity change from T1 to T2 and BMI change from T2 to T3, adjusted for sex, birth year, smoking, education and BMI at T2. The ANCOVA was applied on the

overall cohort and the period-specific samples, in total and stratified by sex, birth year, smoking, education and occupational physical activity change from T1 to T2. We interpreted the Q-Q plots of BMI change from T2 to T3 to not deviate from normal distribution. Although the Levene's test of equality variance violated the assumption of homogeneity of variance across physical activity change groups ( $p < 0.001$ ), we considered our large sample size in all physical activity change groups to make the ANCOVA robust for this heterogeneity. Interaction effects were tested between physical activity change and potential effect modifiers (sex, birth year, smoking, education and BMI at T2, and occupational time physical activity change from T1 to T2) in the overall cohort. We performed sensitivity analyses with leisure time physical activity change categorized into six groups; (1) *Persistently Inactive*, (2) *Persistently Active*, (3) *Active but decreasing* (rank 4 or 3  $\rightarrow$  3 or 2), (4) *Active and Increasing* (rank 2 or 3  $\rightarrow$  3 or 4), (5) *Active to Inactive* and (6) *Inactive to Active*. Alpha was set to 0.05 and data are shown as mean and 95% confidence intervals (CI) from  $t$  tests and ANCOVAs.

We performed multinomial logistic regressions to estimate odds ratios (OR) with 95% confidence intervals (CI) for changing leisure time physical activity from T2 to T3 per unit BMI change from T1 to T2, adjusted for sex, birth year, smoking and education at T2. The analyses were performed in the overall sample ( $n = 4385$ ) and stratified by sex, birth year, smoking, education and occupational physical activity change (T1 to T2). We assessed interaction effects between BMI change and potential effect modifiers (sex, birth year, smoking, education and BMI at T2, and occupational physical activity change from T1 to T2). *Persistently Active* was set as reference category. We used the Statistical Package for Social Sciences (SPSS, Version 26, IBM, Armonk, NY, United States) for all statistical analyses.

## Results

The descriptive characteristics at T2 for the overall cohort and period-specific samples (Tromsø 1–3, 1974–1987; Tromsø 2–4, 1979–1995; Tromsø 5–7, 2001–2016) are presented in Table 1. The participants increased their BMI from T2 to T3 (all  $p < 0.001$ ), except for the Tromsø 5–7 sample ( $p = 0.96$ ).

### Change in BMI by preceding change in leisure time physical activity

Changes in BMI by preceding leisure time physical activity change are presented in Table 2, and BMI at T2 and T3 by leisure time physical activity change are presented in

Supplementary Table 2. In the overall cohort, we observed no differences in BMI change between categories of leisure time physical activity change ( $p = 0.84$ ), and in general no associations in strata by sex, birth year, smoking, education and occupational physical activity change (Table 2).

In the period-specific sample Tromsø 5–7 (2001–2016), we observed differences in BMI change between the leisure time physical activity change groups, where those changing from Active to Inactive increased their BMI more than those changing from Inactive to Active ( $p = 0.01$ ). In stratified analyses, higher BMI change was observed in those changing from Active to Inactive in men ( $p = 0.02$ ) but not in women ( $p = 0.22$ ), and among those born  $\leq 1949$  ( $p = 0.05$ ). In those who never smoked, Persistently Inactive participants decreased their BMI more than those changing from Active to Inactive ( $p = 0.03$ ). Finally, there were differences among the leisure time physical activity change groups among those having  $< 4$  years university education; those changing from Active to Inactive increased their BMI more than all other leisure time physical activity change groups ( $p = 0.003$ ) (Supplementary Table 3). There were no differences in BMI increase by leisure time physical activity change in the Tromsø 1–3 (1974–1987) and Tromsø 2–4 (1979–1995) samples (Supplementary Table 4–5).

In the overall cohort, we observed no interaction for the association between leisure time physical activity change and BMI change by sex ( $p = 0.62$ ), birth year ( $p = 0.23$ ), smoking ( $p = 0.08$ ) or BMI ( $p = 0.44$ ) at T2, or occupational physical activity change from T1 to T2 ( $p = 0.10$ ). However, we observed that education modified the association between leisure time physical activity change and BMI change ( $p = 0.002$ ).

In the sensitivity analyses (in the overall cohort), with six physical activity change groups, the results were similar (Supplementary Table 6).

### Change in leisure time physical activity with preceding BMI change

Participants who increased their BMI from T1 to T2 were more likely to be Persistently Inactive (OR: 1.17, 95% CI: 1.08 to 1.27 per 1 unit increase in BMI ( $\text{kg}/\text{m}^2$ ),  $p < 0.001$ ) and to change from Active to Inactive (OR: 1.16, 95% CI: 1.07 to 1.25,  $p < 0.001$ ) from T2 to T3 compared with those being Persistently Active at T2 and T3. Increasing BMI was not associated with changing from Inactive to Active (OR: 1.01, 95% CI: 0.94–1.08,  $p = 0.97$ ) compared with those being Persistently Active at T2 and T3 (Table 3)

Sex, birth year, BMI, smoking and education at T2, and occupational physical activity change from T1 to T2, all modified the associations between BMI change and subsequent leisure time physical activity change (Table 3). Stratified analyses showed slight differences in ORs



**Table 1** Descriptive characteristics of the overall cohort and period-specific samples.

Cohort		Overall cohort <sup>a</sup>		Period-specific samples <sup>b</sup>	
		Tromsø 1–7 (1974–2016)	Tromsø 1–3 (1974–1986)	Tromsø 2–4 (1979–1995)	Tromsø 5–7 (2001–2016)
Total <i>n</i> (%)		10779 (100%)	3598 (100%)	9691 (100%)	2206 (100%)
BMI (kg/m <sup>2</sup> )					
Time point 2	Mean	24.81	24.65	24.25	26.93
	95% CI	24.74 to 24.88	24.56 to 24.74	24.18 to 24.32	26.75 to 27.11
Time point 3	Mean	25.67	25.15	25.38	26.93
	95% CI	25.60 to 25.74	25.05 to 25.25	25.31 to 25.45	26.75 to 27.11
Change time point 2–3	Mean	0.86	0.49	1.13	−0.002
	95% CI	0.82 to 0.90	0.44 to 0.53	1.10 to 1.17	−0.09 to 0.08
Baseline		Time point 2	Tromsø 2 (1979–80)	Tromsø 3 (1986–87)	Tromsø 6 (2007–08)
Sex					
Women	<i>n</i> (%)	5195 (48.2%)	N/A	4834 (49.9%)	1273 (57.7%)
Men	<i>n</i> (%)	5584 (51.8%)	3598 (100%)	4857 (50.1%)	933 (42.3%)
Age (yr)	Mean	46.19	39.78	42.59	62.04
	95% CI	45.96 to 46.42	39.51 to 40.05	42.42 to 42.76	61.65 to 62.43
10-year age groups					
≤39 years	<i>n</i> (%)	3837 (35.6%)	1824 (50.7%)	3836 (39.9%)	36 (1.6%)
40–49 years	<i>n</i> (%)	2917 (27.1%)	1199 (33.3%)	3512 (36.2%)	289 (13.1%)
50–59 years	<i>n</i> (%)	2238 (20.8%)	575 (16.0%)	2110 (21.8%)	327 (14.8%)
60–69 years	<i>n</i> (%)	1326 (12.3%)	N/A	233 (2.4%)	1093 (49.5%)
≥70 years	<i>n</i> (%)	461 (4.3%)	N/A	N/A	461 (20.9%)
BMI groups					
Normal weight	<i>n</i> (%)	6276 (58.2%)	2138 (59.4%)	6255 (64.5%)	759 (34.4%)
Overweight	<i>n</i> (%)	3594 (33.3%)	1313 (36.5%)	2920 (30.1%)	1011 (45.8%)
Obese	<i>n</i> (%)	909 (8.4%)	147 (4.1%)	516 (5.3%)	436 (19.8%)
Smoking					
Current smoker	<i>n</i> (%)	4316 (40.0%)	1720 (47.8%)	4226 (43.6%)	360 (16.3%)
Previous smoker	<i>n</i> (%)	1715 (15.9%)	505 (14.0%)	754 (7.8%)	1019 (46.2%)
Never smoker	<i>n</i> (%)	4748 (44.1%)	1373 (38.2%)	4711 (48.6%)	828 (37.5%)
Education					
Primary school	<i>n</i> (%)	4555 (42.3%)	1860 (51.7%)	4331 (44.7%)	719 (32.6%)
High school	<i>n</i> (%)	3368 (31.2%)	1009 (28.0%)	2938 (30.3%)	772 (35.0%)
University <4 years	<i>n</i> (%)	1576 (14.6%)	426 (11.8%)	1381 (14.3%)	364 (16.5%)
University ≥4 years	<i>n</i> (%)	1280 (11.9%)	303 (8.4%)	1041 (10.7%)	351 (15.9%)
Reverse analyses					
Total	<i>n</i> (%)	4385 (100%)	N/A	N/A	N/A
BMI (kg/m <sup>2</sup> )	Mean	25.64	N/A	N/A	N/A
	95% CI	25.53 to 25.75			
Sex					
Women	<i>n</i> (%)	1307 (29.8%)	N/A	N/A	N/A
Men	<i>n</i> (%)	3078 (70.2%)	N/A	N/A	N/A
Age (yr)	Mean	50.63	N/A	N/A	N/A
	95% CI	50.16 to 51.10			
10-year age groups					
≤39 years	<i>n</i> (%)	1489 (34%)	N/A	N/A	N/A
40–49 years	<i>n</i> (%)	647 (14.8%)	N/A	N/A	N/A
50–59 years	<i>n</i> (%)	601 (13.7%)	N/A	N/A	N/A

**Table 1** (continued)

Cohort		Overall cohort <sup>a</sup> Tromsø 1–7 (1974–2016)	Period-specific samples <sup>b</sup>		
			Tromsø 1–3 (1974–1986)	Tromsø 2–4 (1979–1995)	Tromsø 5–7 (2001–2016)
60–69 years	<i>n</i> (%)	1063 (24.2%)	N/A	N/A	N/A
≥70 years	<i>n</i> (%)	585 (13.3%)	N/A	N/A	N/A
<b>BMI groups</b>					
Normal weight	<i>n</i> (%)	2131 (48.6%)	N/A	N/A	N/A
Overweight	<i>n</i> (%)	1746 (39.8%)	N/A	N/A	N/A
Obese	<i>n</i> (%)	508 (11.6%)	N/A	N/A	N/A
<b>Smoking</b>					
Current smoker	<i>n</i> (%)	1396 (31.8%)	N/A	N/A	N/A
Previous smoker	<i>n</i> (%)	1372 (31.3%)	N/A	N/A	N/A
Never smoker	<i>n</i> (%)	1617 (36.9%)	N/A	N/A	N/A
<b>Education</b>					
Primary school	<i>n</i> (%)	1731 (39.5%)	N/A	N/A	N/A
High school	<i>n</i> (%)	1432 (32.7%)	N/A	N/A	N/A
University <4 years	<i>n</i> (%)	672 (15.3%)	N/A	N/A	N/A
University ≥4 years	<i>n</i> (%)	550 (12.5%)	N/A	N/A	N/A

The Tromsø Study 1974–2016.

Data are shown as unadjusted mean and 95% CI or as frequency and percentage.

CI confidence interval.

<sup>a</sup>The overall cohort includes participants attending ≥3 surveys and the analyses are based on their three most recent surveys.

<sup>b</sup>Period specific samples include all participants meeting our inclusion criteria for that period, and each participant may contribute in more than one period; therefore, these samples do not add up to the overall cohort (Tromsø 1–7).

We only assessed the reverse association in an overall cohort, which explains the N/As in the period-specific samples for the reverse association.

between strata. For example, men were more likely to be Persistently Inactive than Persistently Active per BMI-unit increase, while this was not observed in women. Those in higher birth year strata (1940–49, ≥1950) were more likely to be Persistently Inactive or changing from Active to Inactive with increasing BMI, which was not observed in those born ≤1939 (Table 3).

## Discussion

In this prospective cohort study, we found no association between leisure time physical activity changes and subsequent BMI changes, whereas BMI increases predicted subsequent low and decreasing physical activity levels.

Most previous studies assessing the prospective association between leisure time physical activity and BMI either used baseline physical activity as the predictor [9, 10, 15–23, 30], which do not take temporal changes between physical activity and BMI into account [5], or assessed associations between change scores for both physical activity and BMI [6, 8, 11–14, 23–37], which basically are cross-sectional analyses that cannot provide an

indication of the direction of the association [5]. One study examined the association between physical activity changes from a 1st to a 2nd examination and BMI changes from the 1st to a 3rd examination and found an association between physical activity decline and BMI gain [46]. Although assessing associations over three examinations are likely less influenced by confounding compared with two examinations, computing both exposure and outcome change from baseline still opens for reverse causation (i.e., weight gain potentially preceding physical activity decline). In the present study, we examined physical activity change from a 1st to a 2nd examination, followed by BMI change from the 2nd to a 3rd examination, which may be more suitable to assess the direction of the association, which provides an indication of causality [5].

Compared with the number of studies that examined whether physical activity is associated with BMI gain, fewer studies assessed a potential reverse association (i.e., BMI change predict physical activity change) [5]. In those that did, high baseline BMI [6, 37] and BMI gain [22, 25, 35, 37, 39] were associated with physical activity declines. In one study, baseline BMI, but not BMI changes, was associated with physical activity declines [26]. In a

**Table 2** Change in BMI from T2 to T3 by leisure physical activity change from T1 to T2. The Tromsø Study 1974–2016.

Tromsø 1–7 (1974–2016)	Change leisure physical activity T1 to T2					P <sub>equality</sub>
	Total	Persistently Inactive	Persistently Active	Active to Inactive	Inactive to Active	
<i>Total (n)</i>	10779	992	7314	1167	1306	
BMI T2 (kg/m <sup>2</sup> ) <sup>a</sup>	Mean	25.25	24.73	24.64	25.05	
	95% CI	24.99 to 25.51	24.65 to 24.81	24.43 to 24.85	24.83 to 25.27	
	BMI change T2 to T3					
BMI change (kg/m <sup>2</sup> )	Mean	0.89	0.85	0.90	0.85	0.84
	95% CI	0.77 to 1.00	0.81 to 0.89	0.79 to 1.00	0.75 to 0.95	
Sex						
Women ( <i>n</i> )	5195	490	3481	594	630	
BMI change (kg/m <sup>2</sup> )	Mean	1.23	1.08	1.13	1.08	0.48
	95% CI	1.05 to 1.41	1.01 to 1.15	0.96 to 1.29	0.92 to 1.24	
Men ( <i>n</i> )	5584	502	3833	573	676	
BMI change (kg/m <sup>2</sup> )	Mean	0.56	0.64	0.68	0.64	0.67
	95% CI	0.42 to 0.70	0.59 to 0.69	0.55 to 0.82	0.51 to 0.76	
Birth year						
≤1929 ( <i>n</i> )	687	56	456	84	91	
BMI change (kg/m <sup>2</sup> )	Mean	0.01	0.17	0.05	0.07	0.82
	95% CI	−0.42 to 0.43	0.02 to 0.32	−0.30 to 0.40	−0.26 to 0.41	
1930–1939 ( <i>n</i> )	2868	234	2017	274	343	
BMI change (kg/m <sup>2</sup> )	Mean	0.42	0.47	0.45	0.53	0.92
	95% CI	0.18 to 0.66	0.39 to 0.55	0.22 to 0.67	0.33 to 0.73	
1940–1949 ( <i>n</i> )	4115	409	2804	412	490	
BMI change (kg/m <sup>2</sup> )	Mean	1.01	0.93	0.95	0.94	0.89
	95% CI	0.82 to 1.19	0.86 to 1.00	0.77 to 1.14	0.77 to 1.10	
1950–1959 ( <i>n</i> )	2821	269	1825	364	363	
BMI change (kg/m <sup>2</sup> )	Mean	1.29	1.33	1.40	1.25	0.72
	95% CI	1.08 to 1.50	1.25 to 1.41	1.22 to 1.58	1.07 to 1.43	
≥1960 ( <i>n</i> )	288	24	212	33	19	
BMI change (kg/m <sup>2</sup> )	Mean	1.47	0.60	1.44	0.06	0.09
	95% CI	0.47 to 2.47	0.27 to 0.94	0.59 to 2.30	−1.07 to 1.19	
BMI groups						
Normal weight ( <i>n</i> )	6276	524	4311	704	737	
BMI change (kg/m <sup>2</sup> )	Mean	1.04	1.01	1.02	1.04	0.96
	95% CI	0.90 to 1.18	0.96 to 1.06	0.90 to 1.14	0.93 to 1.16	
Overweight ( <i>n</i> )	3594	352	2440	376	426	
BMI change (kg/m <sup>2</sup> )	Mean	0.86	0.81	0.92	0.83	0.77
	95% CI	0.66 to 1.07	0.73 to 0.89	0.72 to 1.16	0.65 to 1.02	
Obese ( <i>n</i> )	909	116	563	87	143	
BMI change (kg/m <sup>2</sup> )	Mean	0.06	0.05	0.06	−0.15	0.89
	95% CI	−0.45 to 0.56	−0.19 to 0.28	−0.53 to 0.65	−0.61 to 0.32	
Smoking						
Current smoker ( <i>n</i> )	4316	521	2570	541	684	
BMI change (kg/m <sup>2</sup> )	Mean	0.92	1.07	0.99	0.93	0.16
	95% CI	0.75 to 1.08	1.00 to 1.15	0.83 to 1.15	0.79 to 1.07	
Previous smoker ( <i>n</i> )	1715	135	1224	190	166	
BMI change (kg/m <sup>2</sup> )	Mean	0.34	0.29	0.46	0.30	0.71
	95% CI	0.02 to 0.66	0.19 to 0.40	0.19 to 0.73	0.01 to 0.59	
Never smoker ( <i>n</i> )	4748	336	3520	436	356	
BMI change (kg/m <sup>2</sup> )	Mean	1.07	0.88	0.98	0.96	0.15
	95% CI	0.89 to 1.26	0.82 to 0.93	0.81 to 1.15	0.80 to 1.13	
Education						
Primary school ( <i>n</i> )	4555	465	2921	534	635	
BMI change (kg/m <sup>2</sup> )	Mean	0.82	0.83	0.73	0.69	0.32
	95% CI	0.65 to 1.00	0.76 to 0.90	0.56 to 0.89	0.54 to 0.84	
High school ( <i>n</i> )	3368	317	2300	368	383	
BMI change (kg/m <sup>2</sup> )	Mean	0.93	0.91	0.87	0.96	0.92
	95% CI	0.72 to 1.13	0.83 to 0.98	0.68 to 1.06	0.78 to 1.15	



**Table 2** (continued)

Tromsø 1–7 (1974–2016)	Change leisure physical activity T1 to T2					P <sub>equality</sub>
	Total	Persistently Inactive	Persistently Active	Active to Inactive	Inactive to Active	
University < 4 years ( <i>n</i> )	1576	106	1173	135	162	
BMI change (kg/m <sup>2</sup> )	Mean	0.90	0.87	1.53	0.95	0.001
	95% CI	0.55 to 1.25	0.76 to 0.97	1.22 to 1.84	0.66 to 1.23	
University > 4 years ( <i>n</i> )	1280	104	920	130	126	
BMI change (kg/m <sup>2</sup> )	Mean	0.99	0.80	0.95	1.16	0.08
	95% CI	0.69 to 1.30	0.69 to 0.90	0.67 to 1.22	0.88 to 1.43	
Occupational Physical Activity Change T1 to T2						
Persistently Inactive	2637	340	1650	303	344	
BMI change (kg/m <sup>2</sup> )	Mean	0.81	0.85	0.93	0.92	0.79
	95% CI	0.61 to 1.00	0.76 to 0.94	0.72 to 1.14	0.72 to 1.11	
Persistently Active	5014	372	3514	539	589	
BMI change (kg/m <sup>2</sup> )	Mean	1.04	1.07	1.05	1.01	0.92
	95% CI	0.86 to 1.23	1.01 to 1.13	0.89 to 1.20	0.86 to 1.16	
Active to Inactive	673	62	439	96	76	
BMI change (kg/m <sup>2</sup> )	Mean	1.43	0.89	0.88	0.95	0.13
	95% CI	1.01 to 1.86	0.73 to 1.04	0.54 to 1.22	0.57 to 1.33	
Inactive to Active	1277	1144	799	129	205	
BMI change (kg/m <sup>2</sup> )	Mean	1.03	0.99	0.96	0.90	0.91
	95% CI	0.73 to 1.33	0.86 to 1.11	0.64 to 1.28	0.65 to 1.15	

Data are adjusted for sex, birth year, smoking, education and BMI at T2, and shown as adjusted mean BMI change with 95% CI.

CI confidence interval, BMI body mass index, *Pequality* main difference between groups, T1 time point 1, T2 time point 2, T3 time point 3.

<sup>a</sup>Data are shown as unadjusted mean BMI at T2 with 95% CI.

Mendelian randomization study, high body weight appeared causally associated with lower physical activity levels [38]. Thus, except for one previous study [26], our study corroborates previous studies, suggesting that BMI gain leads to lower physical activity level.

Lower physical activity levels following weight gain are likely due to movement limitations. In a case-control study of normal weight and obese adolescents, physical activity measured by accelerometry was substantially lower in obese individuals compared with their normal weight peers despite similar physical activity energy expenditures [47]. Similarly, this was also demonstrated in an experimental study of overfeeding with 4 MJ (1000 kilocalories (kcal)) per day over eight weeks, where free-living walking distances decreased due to lower walking velocity (i.e., movement limitation) in both normal weight and obese individuals following overfeeding, likely due to the increased weight [48].

Furthermore, our study contradicts a previous study, which reported that female but not male university alumni with high baseline BMI decreased their physical activity level over time [6], while we observed that both women and men were likely to decrease their physical activity with increasing BMI. This may be explained by demography (e.g., socioeconomic status, age) or by differences in analytical approach. In addition, we observed that sex, birth year, baseline (T2) BMI, smoking, education and occupational physical activity change all modified the association

between BMI change and subsequent physical activity change. This indicates that the effect of BMI change on physical activity change is dependent on multiple behavioural and societal factors, which warrants additional research.

A pertinent question may be whether population levels of physical activity are sufficiently high to prevent weight gain. One previous study estimated that a physical activity energy expenditure increase of ~0.4 megajoule (MJ) (i.e., 100 kcal) per day would be sufficient to prevent weight gain at population level [49], which could be feasible for the general population. However, highly active women who performed 60 minutes per day of moderate intensity activity (considerably higher physical activity energy expenditure than 0.4 MJ per day) seemed to still gain weight, but at a lower rate than their less active peers, indicating that such physical activity levels at best mitigates weight gain [28]. Moreover, in another study, women and men being physically active at baseline had a lower baseline weight, but similar weight gain rate as those being inactive [26]. Energy intake has increased with ~2 MJ (i.e., 500 kcal) per day from the 1970 to 2000s in the United States, [50], which is similar to Western European countries from the 1960s to 2011 in a recent global study [51]. About 110–150 min of walking per day is needed to compensate for the increased energy intake of 2 MJ [50]. This is seven times more than the current minimal recommendations for physical activity of 150 minutes per week [52]. In Western high-income

**Table 3** Odds ratio of leisure time physical activity change with body mass index change (per kg/m<sup>2</sup> increase).

Tromsø 1–7 (1974–2016)		Persistently inactive	Active to inactive	Inactive to active	Persistently active
Total ( <i>n</i> )	4385	378	397	512	3098
	OR	1.14	1.16	1.02	Ref.
	95% CI	1.07 to 1.22	1.09 to 1.24	0.96 to 1.09	
Sex					
	<i>P</i> <sub>interaction</sub>	<0.001	0.003	0.59	
Women ( <i>n</i> )	1307	107	102	118	980
	OR	1.09	1.21	1.05	Ref.
	95% CI	0.98 to 1.22	1.09 to 1.34	0.95 to 1.16	
Men ( <i>n</i> )	3078	271	295	394	2118
	OR	1.19	1.14	1.02	Ref.
	95% CI	1.09 to 1.30	1.04 to 1.23	0.95 to 1.10	
Birth year					
	<i>P</i> <sub>interaction</sub>	<0.001	<0.001	0.17	
≤1939 ( <i>n</i> )	1473	135	132	203	1003
	OR	1.11	1.01	0.94	Ref.
	95% CI	0.99 to 1.24	0.90 to 1.14	0.85 to 1.04	
1940–49 ( <i>n</i> )	1906	162	171	205	1368
	OR	1.13	1.21	1.06	Ref.
	95% CI	1.02 to 1.25	1.10 to 1.34	0.96 to 1.16	
≥1950 ( <i>n</i> )	1006	81	94	104	727
	OR	1.23	1.28	1.10	Ref.
	95% CI	1.06 to 1.43	1.12 to 1.45	0.96 to 1.26	
BMI groups					
	<i>P</i> <sub>interaction</sub>	<0.001	<0.001	0.29	
Normal weight ( <i>n</i> )	2131	153	176	227	1575
	OR	0.94	1.07	0.96	Ref.
	95% CI	0.83 to 1.06	0.95 to 1.20	0.86 to 1.07	
Overweight ( <i>n</i> )	1746	149	163	208	1226
	OR	1.15	1.12	1.01	Ref.
	95% CI	1.04 to 1.28	1.01 to 1.24	0.92 to 1.11	
Obese ( <i>n</i> )	508	76	58	77	297
	OR	1.17	1.21	1.00	Ref.
	95% CI	1.03 to 1.31	1.07 to 1.38	0.88 to 1.13	
Smoking					
	<i>P</i> <sub>interaction</sub>	<0.001	<0.001	0.61	
Current smoker ( <i>n</i> )	1396	180	168	218	830
	OR	1.14	1.14	1.00	Ref.
	95% CI	1.02 to 1.28	1.02 to 1.28	0.90 to 1.11	
Previous smoker ( <i>n</i> )	1372	93	102	152	1025
	OR	1.18	1.23	1.0	Ref.
	95% CI	1.06 to 1.32	1.11 to 1.37	0.95 to 1.15	
Never smoker ( <i>n</i> )	1617	105	127	142	1243
	OR	1.13	1.14	1.02	Ref.
	95% CI	0.99 to 1.30	1.00 to 1.29	0.90 to 1.15	
Education					
	<i>P</i> <sub>interaction</sub>	0.008	<0.001	0.47	
Primary school ( <i>n</i> )	1731	188	171	124	1129
	OR	1.17	1.11	1.04	Ref.
	95% CI	1.07 to 1.28	1.00 to 1.22	0.95 to 1.13	

**Table 3** (continued)

Tromsø 1–7 (1974–2016)		Persistently inactive	Active to inactive	Inactive to active	Persistently active
High school ( <i>n</i> )	1432	113	117	164	1038
	OR	1.15	1.12	0.96	Ref.
	95% CI	1.01 to 1.30	0.99 to 1.26	0.86 to 1.06	
University <4 years ( <i>n</i> )	672	44	60	65	503
	OR	1.13	1.20	1.17	Ref.
	95% CI	0.89 to 1.43	0.98 to 1.46	0.96 to 1.42	
University ≥4 years ( <i>n</i> )	550	33	49	40	428
	OR	0.95	1.38	1.04	Ref.
	95% CI	0.76 to 1.18	1.17 to 1.64	0.85 to 1.28	
Occupational Physical Activity Change from T1 to T2					
<i>P</i> <sub>interaction</sub>		0.01	<0.001	0.81	
Persistently Inactive ( <i>n</i> )	1125	129	119	124	753
	OR	1.24	1.12	0.96	Ref.
	95% CI	1.09 to 1.42	0.98 to 1.28	0.85 to 1.08	
Persistently Active ( <i>n</i> )	1536	106	142	178	1110
	OR	1.17	1.17	1.06	Ref.
	95% CI	1.04 to 1.32	1.05 to 1.30	0.96 to 1.18	
Active to Inactive ( <i>n</i> )	248	19	37	36	156
	OR	0.96	1.23	0.88	Ref.
	95% CI	0.66 to 1.41	0.93 to 1.63	0.66 to 1.16	
Inactive to Active ( <i>n</i> )	341	33	25	53	230
	OR	1.07	1.33	0.94	Ref.
	95% CI	0.83 to 1.38	1.01 to 1.75	0.76 to 1.16	

The Tromsø Study 1974–2016.

Data are adjusted for sex, birth year, smoking and education at T2, and shown as adjusted ORs with 95% CI.  $P_{\text{interaction}}$  = interaction effect for the stratified variable and BMI change on physical activity change.

BMI body mass index, CI confidence interval, OR odds ratio, T2 time point 2.

countries, one out of three fail to meet these recommendations [53]. Consequently, the current physical activity levels in the general population is unlikely preventing population weight gain [5].

Our study with a comprehensive analytical approach showed no association between leisure time physical activity change and subsequent BMI change. However, we observed that BMI gains were associated with subsequent lower leisure time physical activity, which is consistent with previous studies [6, 22, 25, 26, 35, 37, 38]. These observations are important, as public health initiatives aimed at weight gain prevention must acknowledge the major societal drivers for obesity in order to be successful [54, 55]. As physical activity has numerous health effects independent of weight change [56], it should not be neglected, but simply acknowledged in its limited potential for weight gain prevention [5]. Although still ineffective [57], well-designed whole system approaches targeting multiple factors associated with population weight gain may be needed to shift the current curve of the obesity epidemic [55, 57, 58].

## Strengths and limitations

As BMI has gradually increased over decades [1], the long observation period in this study (~6 years between each examination) allowed us to examine whether physical activity change have affected the gradual long-term BMI gain [5]. Further, our analytical approach allowed us to interpret the direction of the association with more certainty [5]. Furthermore, the merged overall cohort increased our sample size, which allowed us to assess effect modification in the association between physical activity and BMI. Finally, the Tromsø Study cohorts have high attendance of invited participants, which indicate high generalizability to high-income countries' populations [43].

There are also limitations that should be addressed. Self-reported physical activity change was categorized into crude groups; this may have introduced misclassification. Consequently, potential physical activity energy expenditure changes that could influence our results may have been missed. However, self-reported physical activity categorized into crude groups appears appropriate at population

levels [59] and moreover, the SGPALS indicate predictive validity by being associated with multiple health outcomes [45]. Moreover, our sensitivity analysis of six groups physical activity change showed similar results as our main analyses. Further, self-reported physical activity is likely influenced by recall and social desirability bias, which indicate that over-reporting of physical activity levels is inevitable [59]. This is illustrated in our study by low variability in leisure time physical activity change, with most of the included participants (68%) being classified as Persistently Active. These biases are likely to under- or overestimate the effect magnitude between physical activity and health outcomes [5] and might have influenced our results. Future long-term studies using physical activity instruments with higher accuracy (e.g., device measured physical activity) are warranted to further examine whether population levels of physical activity influence weight change. Furthermore, disease onset may drive physical activity and weight change, which thus could be included as a potential confounder in our models. However, it is more likely that disease onset is a *mediator* (i.e. physical activity decline leads to disease, which leads to BMI change) or *ancestor* (i.e., disease onset leads to physical activity decline, which leads to BMI change) in the association between physical activity and BMI. Consequently, as our study's aims were to assess the total effect of physical activity change on BMI change and vice versa, adjusting for disease would not assess the total effect [60]. Finally, our results may be influenced by residual confounding due to unavailable energy intake data.

## Conclusion

In this prospective cohort study, there was no association between leisure time physical activity changes and subsequent BMI changes, whereas BMI increase was associated with subsequent consistently low and decreasing physical activity levels. These findings indicate that weight gain may lead to lower leisure time physical activity, while population levels of leisure time physical activity appears insufficient to prevent overweight and obesity.

## Data availability

The data that support the findings of this study are available from the Tromsø Study but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. The data are however available from the Tromsø Study upon application to the Data and Publication Committee for the Tromsø Study: tromsous@uit.no.

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**Author contributions** EHS, BM, UE, LAH designed the study, EHS carried out data analysis, OL and TW provided statistical expertise, all authors interpreted the study results, EHS drafted the manuscript, and all authors contributed with manuscript revisions and approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

**Ethics approval and consent to participate** All participants from Tromsø 4–7 provided written informed consent and the present study was approved by the Regional Ethics Committee for Medical Research (ref. 2016/758410).

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