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

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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 ≥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 kg/m$^2$ (95% CI: 0.82 to 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 kg/m$^2$ (95% CI: 0.77 to 1.00), Persistently Active: 0.85 kg/m$^2$ (95% CI: 0.81 to 0.89), Active to Inactive: 0.90 kg/m$^2$ (95% CI: 0.79 to 1.00), Inactive to Active 0.85 kg/m$^2$ (95% CI: 0.75 to 0.95), p=0.84). Conversely, increasing BMI was associated with Persistently Inactive (odds ratio (OR): 1.17, 95% CI: 1.08 to 1.27, p<0.001) and changing from Active to Inactive (OR: 1.16, 95% CI: 1.07 to 1.25, p<0.001) compared with being Persistently Active.

**Conclusion:** 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*.

**Keywords**; [1]occupational physical activity, [2]obesity, [3]overweight, [4]adiposity, [5]longitudinal, [6]prospective, [7]energy expenditure, [8]energy balance

# INTRODUCTION

The prevalence of overweight and obesity is continuously growing worldwide where 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 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 Figure 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%) 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).

**Insert Figure 1 about here.**

## Participants

Participant selection for our analyses is illustrated in Figure 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 (Figure 2).

**Insert Figure 2 about here.**

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 (Figure 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.

**Insert Figure 3 about here.**

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 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 ≥2 at T1 and T2; n=7314); 3) *Active to Inactive* (rank ≥2 at T1 and rank 1 at T2; n=1167); and 4) *Inactive to Active* (rank 1 at T1 and rank ≥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 ≥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 meters (m). BMI was calculated as $kg/m^2$ and categorized into normal weight (<25 $kg/m^2$), overweight (25-29 $kg/m^2$) and obese (≥30 $kg/m^2$) 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 selected 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 ≥4 years (≥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.

## Availability of data and materials

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.

## 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 6 groups; 1) *Persistently Inactive*, 2) *Persistently Active*, 3) *Active but decreasing* (rank 4 or 3 → 3 or 2), 4) *Active and Increasing* (rank 2 or 3 → 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 ($p=0.96$).

**Insert Table 1 about here**

## 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).

**Insert Table 2 about here**

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 ≤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 BMI ($kg/m^2$)-increase, 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 to 1.08, p=0.97) compared with those being Persistently Active at T2 and T3 (Table 3).

**Insert Table 3 about here**

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 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 $1^{st}$ to a $2^{nd}$ examination and BMI changes from the $1^{st}$ to a $3^{rd}$ 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 $1^{st}$ to a $2^{nd}$ examination, followed by BMI change from the $2^{nd}$ to a $3^{rd}$ 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 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 (kcals)) 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. Additionally, 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 kcals) 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 kcals) per day from the 1970s 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 minutes 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 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, as BMI change regressed on physical activity change, our models 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.

# DECLARATIONS

## 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).

## Availability of data and materials

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.

## Competing interests

The authors declare that they have no competing interests.

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## Authors´ 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.

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# FIGURE LEGENDS

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

**Figure 2:** Flow chart of participant selection.

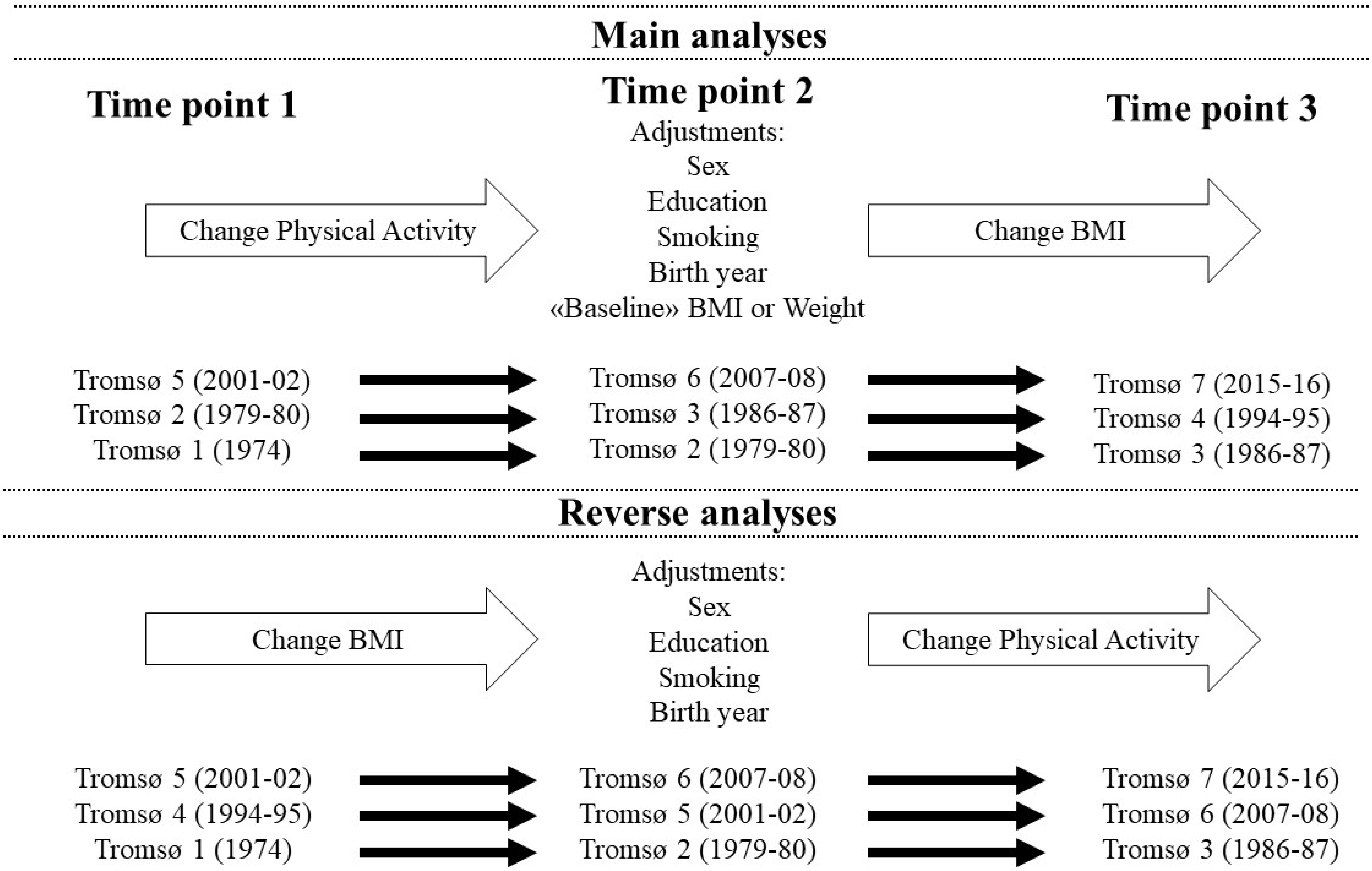
**Figure 3:** Flow chart of participant selection for the reversed analyses.

# TABLE LEGENDS

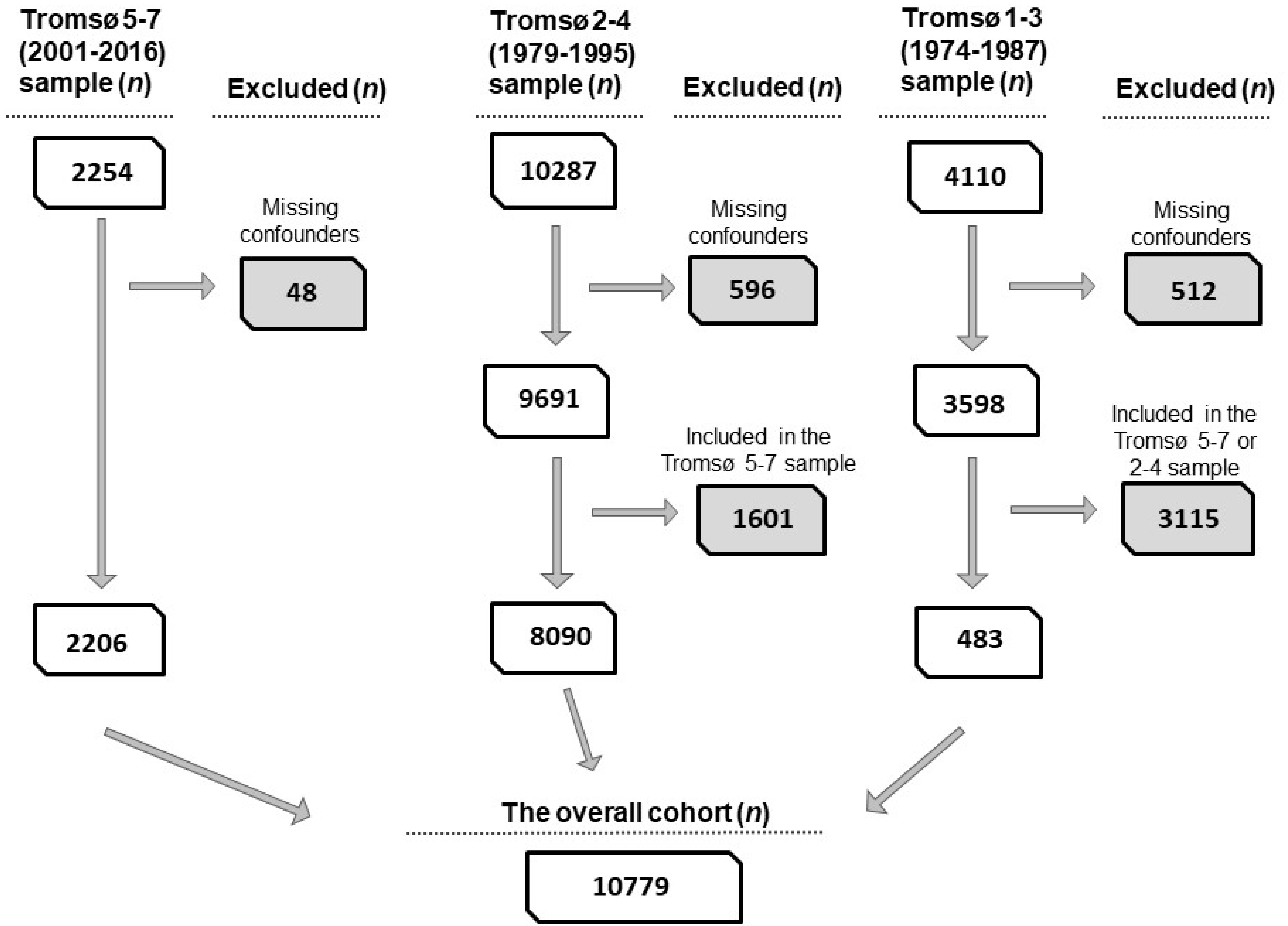
**Table 1.** Descriptive characteristics of the overall cohort and period-specific samples. The Tromsø Study 1974-2016.

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

**Table 3.** Odds Ratio of leisure time physical activity change with body mass index change (per kg/$m^2$ increase). The Tromsø Study 1974-2016.



Main analyses
Time point 1
Time point 2
Time point 3
Adjustments:
Sex
Education
Smoking
Birth year
«Baseline» BMI or Weight
Change Physical Activity
Change BMI
Tromsø 5 (2001-02)
Tromsø 2 (1979-80)
Tromsø 1 (1974)
Tromsø 6 (2007-08)
Tromsø 3 (1986-87)
Tromsø 2 (1979-80)
Tromsø 7 (2015-16)
Tromsø 4 (1994-95)
Tromsø 3 (1986-87)
Reverse analyses
Adjustments:
Sex
Education
Smoking
Birth year
Change BMI
Change Physical Activity
Tromsø 5 (2001-02)
Tromsø 4 (1994-95)
Tromsø 1 (1974)
Tromsø 6 (2007-08)
Tromsø 5 (2001-02)
Tromsø 2 (1979-80)
Tromsø 7 (2015-16)
Tromsø 6 (2007-08)
Tromsø 3 (1986-87)


Tromsø 5-7 (2001-2016) sample (n)
Excluded (n)
Tromsø 2-4 (1979-1995) sample (n)
Excluded (n)
Tromsø 1-3 (1974-1987) sample (n)
Excluded (n)
2254
Missing confounders
48
2206
10287
Missing confounders
596
9691
Included in the Tromsø 5-7 sample
1601
8090
4110
Missing confounders
512
3598
Included in the Tromsø 5-7 or 2-4 sample
3115
483
The overall cohort (n)
10779

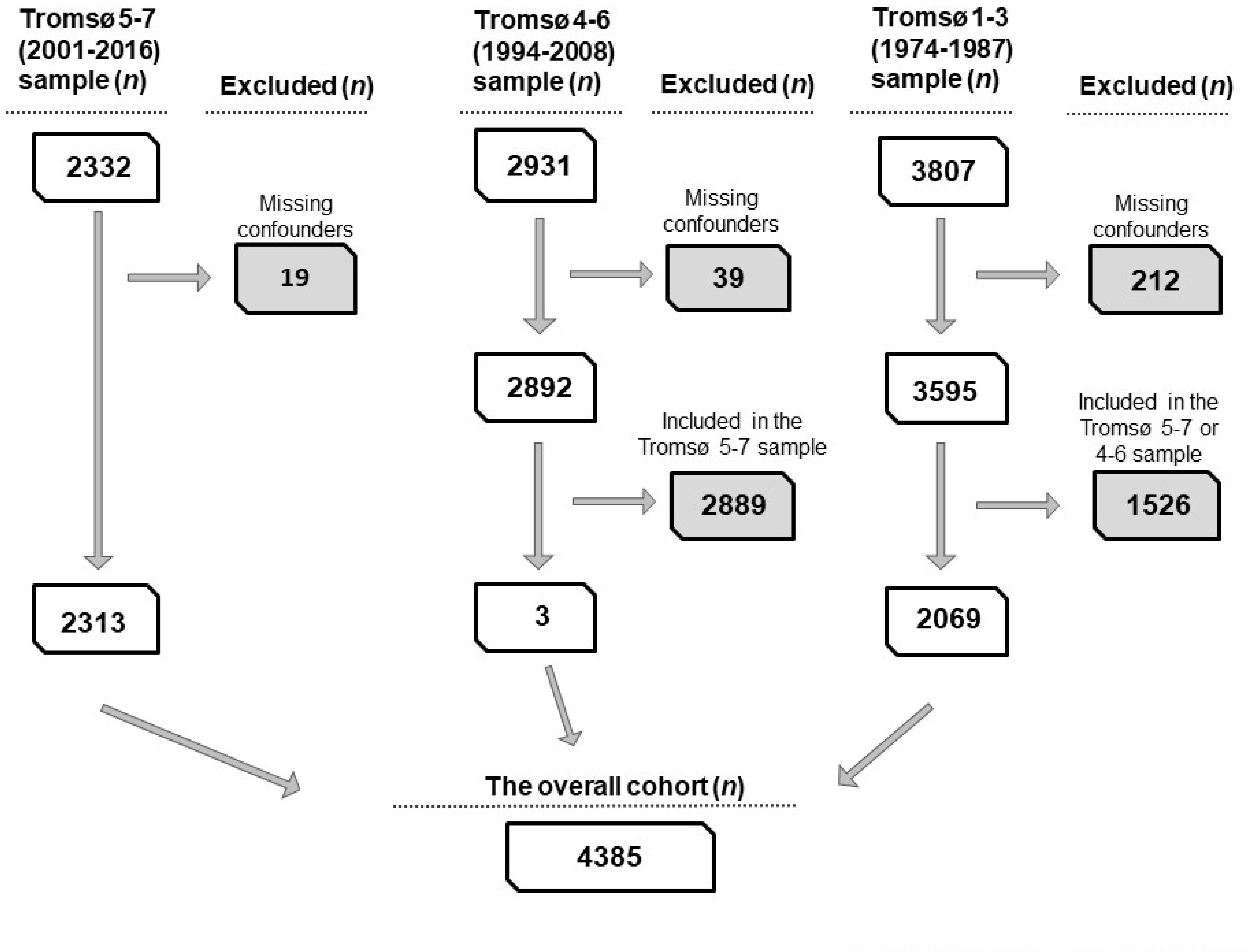

Tromsø 5-7 (2001-2016) sample (n)
Excluded (n)
Tromsø 4-6 (1994-2008) sample (n)
Excluded (n)
Tromsø 1-3 (1974-1987) sample (n)
Excluded (n)
2332
Missing confounders
19
2313
2931
Missing confounders
39
2892
Included in the Tromsø 5-7 sample
2889
3
3807
Missing confounders
212
3595
Included in the Tromsø 5-7 or 4-6 sample
1526
2069
The overall cohort (n)
4385

**Table 1.** Descriptive characteristics of the overall cohort and period-specific samples. The Tromsø Study 1974-2016.

| Cohort | | Overall cohort* Tromsø 1-7 (1974-2016) | Period-specific samples** Tromsø 1-3 (1974-1986) | Tromsø 2-4 (1979-1995) | Tromsø 5-7 (2001-2016) |
|---|---|---|---|---|---|
| **Total N (%)** | | 10779 (100%) | 3598 (100%) | 9691 (100%) | 2206 (100%) |
| **BMI (kg/m²)** | | | | | |
| 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 | n (%) | 5195 (48.2%) | N/A | 4834 (49.9%) | 1273 (57.7%) |
| Men | n (%) | 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 | n (%) | 3837 (35.6%) | 1824 (50.7%) | 3836 (39.9%) | 36 (1.6%) |
| 40-49 years | n (%) | 2917 (27.1%) | 1199 (33.3%) | 3512 (36.2%) | 289 (13.1%) |
| 50-59 years | n (%) | 2238 (20.8%) | 575 (16.0%) | 2110 (21.8%) | 327 (14.8%) |
| 60-69 years | n (%) | 1326 (12.3%) | N/A | 233 (2.4%) | 1093 (49.5%) |
| ≥70 years | n (%) | 461 (4.3%) | N/A | N/A | 461 (20.9%) |
| **BMI groups** | | | | | |
| Normal weight | n (%) | 6276 (58.2%) | 2138 (59.4%) | 6255 (64.5%) | 759 (34.4% |
| Overweight | n (%) | 3594 (33.3% | 1313 (36.5%) | 2920 (30.1%) | 1011 (45.8%) |
| Obese | n (%) | 909 (8.4%) | 147 (4.1%) | 516 (5.3%) | 436 (19.8%) |
| **Smoking** | | | | | |
| Current smoker | n (%) | 4316 (40.0%) | 1720 (47.8%) | 4226 (43.6%) | 360 (16.3%) |
| Previous smoker | n (%) | 1715 (15.9%) | 505 (14.0%) | 754 (7.8%) | 1019 (46.2%) |
| Never smoker | n (%) | 4748 (44.1%) | 1373 (38.2%) | 4711 (48.6%) | 828 (37.5%) |
| **Education** | | | | | |
| Primary school | n (%) | 4555 (42.3%) | 1860 (51.7%) | 4331 (44.7%) | 719 (32.6%) |
| High school | n (%) | 3368 (31.2%) | 1009 (28.0%) | 2938 (30.3%) | 772 (35.0%) |
| University <4 years | n (%) | 1576 (14.6%) | 426 (11.8%) | 1381 (14.3%) | 364 (16.5%) |
| University ≥4 years | n (%) | 1280 (11.9%) | 303 (8.4%) | 1041 (10.7%) | 351 (15.9%) |
| | | | | | |
| **Reverse analyses** | | | | | |
| **Total** | N (%) | 4385 (100%) | N/A | N/A | N/A |
| **BMI (kg/m²)** | Mean | 25.64 | N/A | N/A | N/A |
| | 95%CI | 25.53 to 25.75 | | | |
| **Sex** | | | | | |
| Women | n (%) | 1307 (29.8%) | N/A | N/A | N/A |
| Men | n (%) | 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 | n (%) | 1489 (34%) | N/A | N/A | N/A |
| 40-49 years | n (%) | 647 (14.8%) | N/A | N/A | N/A |
| 50-59 years | n (%) | 601 (13.7%) | N/A | N/A | N/A |
| 60-69 years | n (%) | 1063 (24.2%) | N/A | N/A | N/A |
| ≥70 years | n (%) | 585 (13.3%) | N/A | N/A | N/A |
| **BMI groups** | | | | | |
| Normal weight | n (%) | 2131 (48.6%) | N/A | N/A | N/A |
| Overweight | n (%) | 1746 (39.8%) | N/A | N/A | N/A |
| Obese | n (%) | 508 (11.6%) | N/A | N/A | N/A |
| **Smoking** | | | | | |
| Current smoker | n (%) | 1396 (31.8%) | N/A | N/A | N/A |
| Previous smoker | n (%) | 1372 (31.3%) | N/A | N/A | N/A |
| Never smoker | n (%) | 1617 (36.9% | N/A | N/A | N/A |
| **Education** | | | | | |
| Primary school | n (%) | 1731 (39.5%) | N/A | N/A | N/A |
| High school | n (%) | 1432 (32.7%) | N/A | N/A | N/A |
| University <4 years | n (%) | 672 (15.3%) | N/A | N/A | N/A |
| University ≥4 years | n (%) | 550 (12.5%) | N/A | N/A | N/A |

Data are shown as unadjusted mean and 95%CI or as frequency and percentage. *The overall cohort includes participants attending ≥3 surveys and the analyses are based on their three most recent surveys.**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). CI=confidence interval.

**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** | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Persistently Inactive** | **Persistently Active** | **Active to Inactive** | **Inactive to Active** | $\mathbf{P_{equality}}$ |
| *Total (n)* | *10779* | *992* | *7314* | *1167* | *1306* | |
| BMI T2 (kg/m$^2$)* | 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$^2$) | 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 (n)* | *5195* | *490* | *3481* | *594* | *630* | |
| BMI change (kg/m$^2$) | 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 (n)* | *5584* | *502* | *3833* | *573* | *676* | |
| BMI change (kg/m$^2$) | 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 (n)* | *687* | *56* | *456* | *84* | *91* | |
| BMI change (kg/m$^2$) | 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 (n)* | *2868* | *234* | *2017* | *274* | *343* | |
| BMI change (kg/m$^2$) | 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 (n)* | *4115* | *409* | *2804* | *412* | *490* | |
| BMI change (kg/m$^2$) | 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 (n)* | *2821* | *269* | *1825* | *364* | *363* | |
| BMI change (kg/m$^2$) | 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 (n)* | *288* | *24* | *212* | *33* | *19* | |
| BMI change (kg/m$^2$) | 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 (n)* | *6276* | *524* | *4311* | *704* | *737* | |
| BMI change (kg/m$^2$) | 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 (n)* | *3594* | *352* | *2440* | *376* | *426* | |
| BMI change (kg/m$^2$) | 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 (n)* | *909* | *116* | *563* | *87* | *143* | |
| BMI change (kg/m$^2$) | 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 (n)* | *4316* | *521* | *2570* | *541* | *684* | |
| BMI change (kg/m$^2$) | 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 (n)* | *1715* | *135* | *1224* | *190* | *166* | |
| BMI change (kg/m$^2$) | 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 (n)* | *4748* | *336* | *3520* | *436* | *356* | |
| BMI change (kg/m$^2$) | 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 (n)* | *4555* | *465* | *2921* | *534* | *635* | |
| BMI change (kg/m$^2$) | 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 (n)* | *3368* | *317* | *2300* | *368* | *383* | |

| | | | | | | |
|---|---|---|---|---|---|---|
| BMI change (kg/m$^2$) | 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 | |
| *University <4 years (n)* | *1576* | *106* | *1173* | *135* | *162* | |
| BMI change (kg/m$^2$) | 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 (n)* | *1280* | *104* | *920* | *130* | *126* | |
| BMI change (kg/m$^2$) | 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$^2$) | 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$^2$) | 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$^2$) | 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$^2$) | 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.*Data are shown as unadjusted mean BMI at T2 with 95% CI. CI=confidence interval, BMI=body mass index, $P_{equality}$=main difference between groups, T1=time point 1, T2=time point 2, T3=time point 3.

**Table 3.** Odds Ratio of leisure time physical activity change with body mass index change (per kg/m$^2$ increase). The Tromsø Study 1974-2016.

| **Tromsø 1-7 (1974-2016)** | | **Persistently Inactive** | **Active to Inactive** | **Inactive to Active** | **Persistently Active** |
|---|---|---|---|---|---|
| Total (N) | *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** | | | | | |
| $P_{interaction}$ | | <0.001 | 0.003 | 0.59 | |
| Women (n) | *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 (n) | *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** | | | | | |
| $P_{interaction}$ | | <0.001 | <0.001 | 0.17 | |
| ≤1939 (n) | *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 (n) | *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 (n) | *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** | | | | | |
| $P_{interaction}$ | | <0.001 | <0.001 | 0.29 | |
| *Normal weight (n)* | *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 (n)* | *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 (n)* | | | | | |
| | *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** | | | | | |
| $P_{interaction}$ | | <0.001 | <0.001 | 0.61 | |
| Current smoker (n) | *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 (n) | *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 (n) | *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** | | | | | |
| $P_{interaction}$ | | 0.008 | <0.001 | 0.47 | |
| Primary school (n) | *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 | |
| High school (n) | *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 (n) | *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 (n) | *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** | | | | | |
| $P_{interaction}$ | | *0.01* | *<0.001* | *0.81* | |
| Persistently Inactive (n) | *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 (n) | *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 (n) | *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 (n) | *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 | |

Data are are adjusted for sex, birth year, smoking and education at T2, and shown as adjusted OR with 95% CI. $P_{interaction}$=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.