## Physical Activity

# Leisure-time physical inactivity and association with body mass index: a Finnish Twin Study with a 35-year follow-up

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## Abstract

**Background:** We investigated the stability and change of leisure-time physical inactivity in adult men and women during a 35-year follow-up. We also analysed the impact of long-term physical inactivity on the development of body mass index (BMI).
**Methods**: In this population-based cohort study, 5254 Finnish twin individuals (59% women) participated in four surveys in 1975, 1981, 1990 and 2011. Mean age at baseline was 23.9 years. Individual long-term leisure-time physical activity (LTPA) was categorized into seven classes varying from 'persistently inactive' to 'persistently active'. We used the multivariate multilevel mixed-effects linear regression model and paired-sample t-test in the analyses. Co-twin control design was used for examining within-pair associations.
**Results**: Of men 11%, and of women 8%, were persistently inactive. Among both sexes, the mean BMI slope trajectories were steeper among the persistently inactive and those who became inactive than among those who were persistently active. Overall, the inactive participants gained 1.4 kg/m$^2$ [95% confidence interval (CI) 1.2 to 1.7] more in weight than did the active participants from 1975 to 2011. Among twin pairs discordant for LTPA, the corresponding difference was 1.4 kg/m$^2$ (95% CI 0.83 to 2.0) in dizygotic pairs and 0.68 kg/m$^2$ (95% CI 0.05 to1.3) in monozygotic pairs.
**Conclusions:** Over a 35-year time span from young adulthood, persistently inactive participants and those who had become inactive had greater weight increases than those who were persistently active. This association was also found in twin-pair analyses, although attenuated in monozygotic pairs. This may support the importance of LTPA in weight management, although further causal inference is required.

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**Key messages**

- The study had an exceptionally long follow-up of 35 years, with four surveys from early adulthood to retirement age.
- Most people changed their leisure-time physical activity (LTPA) behaviour, whereas only every 10th person was persistently inactive and less than a fifth were persistently active.
- Body mass index increased among all participants, but more so among those who were persistently physically inactive or those who became inactive in their leisure time. This was found in the analyses of individuals and twin pairs discordant for LTPA.
- Leisure-time physical activity is important in weight management.

## Introduction

Physical inactivity and high body mass index (BMI) are among the 10 leading risk factors for non-communicable diseases[1] with consequent health care costs,[2,3] as well as for an increased risk of premature death.[1,4–6] The prevalence of physical inactivity among adults varies from 17%[7] to 31%[4] in populations, and 35% of adults are reported to be overweight (BMI $\geq$ 25 kg/m$^2$).[4]

The long-term trends of leisure-time physical activity (LTPA) are mainly based on repeated assessments of population-based samples.[8–16] The lack of a global definition of physical inactivity[6,7,17,18] complicates comparisons between studies. In Finland, leisure-time physical inactivity has shown a decreasing long-term trend from the 1970s,[10,11,16] as it has in the USA,[9] Canada,[19] Sweden[20] and Denmark.[12] In contrast, in Norway, inactivity has increased[13] or remained stable.[8]

LTPA is a major component of behaviourally regulated energy expenditure and is thus regarded as fundamental to weight control.[9,21] Strong evidence exists of the importance of LTPA in the management of obesity and in the prevention of weight re-gain among those who have successfully lost weight.[22] Strong evidence also exists of an association between long-term physical inactivity and increased weight gain, when compared with the weight of those who are persistently active,[14,15] even after controlling for familial factors.[23–25] However, the increase of food intake due to short-term increased energy expenditure,[26] i.e. whether LTPA regulates long-term weight maintenance,[27,28] needs confirmation from long-term studies. The extent to which LTPA maintains or improves homeostatic weight control, or whether increased food intake is the primary driver of long-term weight gain, is not known. Subsequently, increased weight can also decrease LTPA.[20,29,30] Evidence also exists that overeating does not affect LTPA, whereas under-eating decreases habitual or voluntary LTPA.[26] Despite some reports of an association between LTPA and BMI or weight with large samples and multiple time points,[19,20,30,31] the development and associations of long-term physical inactivity and BMI over the life course with information of familial factors has been rarely reported.

Since both BMI[32,33] and LTPA[34,35] are known to have a strong genetic component, genetics may play a role also in the associations between them. Twin data provide the possibility to adjust for familial factors (genetics and shared environment) to determine whether an association is likely to reflect a causal relationship.[36–38] For example, by comparing weight development among twin pairs discordant for LTPA, we can observe the association between BMI and LTPA, adjusted for familial factors. A lack of association between BMI and LTPA within discordant twin pairs compared with all individuals indicates confounding by familial factors. Associations that remain after adjusting for familial factors may therefore reflect associations that can be close to causal effects.[37,38]

The aim of this study was to investigate the stability and change of leisure-time physical inactivity in adult men and women during a 35-year follow-up, and to analyse the impact of long-term inactivity on the development of BMI. A further aim was to study whether familial factors influence the association between BMI and physical inactivity.

## Methods

### Sample

Our data were based on the Finnish Older Twin Cohort with four surveys in 1975, 1981, 1990 and 2011[39–41] (Figure 1; Appendix Table 1, available as Supplementary data at *IJE* online). Only same-sex twins born between 1945 and 1957, with complete LTPA data in all four surveys, ($n = 5254$) were included (Figure 1, left line). The
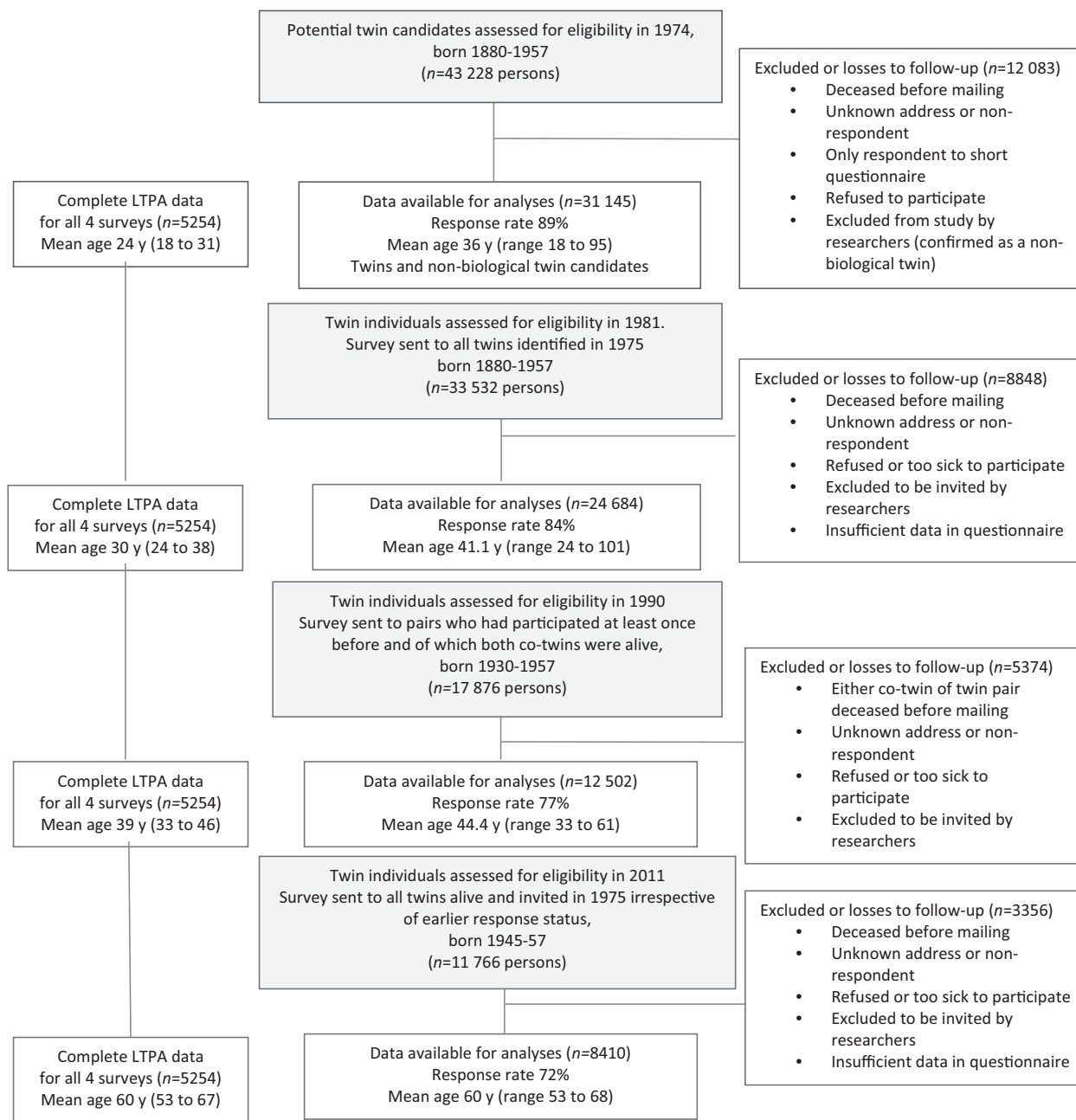
**Figure 1**. Flow chart of surveys and final sample with complete data of leisure-time physical activity (LTPA) in 1975, 1981, 1990 and 2011.

protocol was designed and performed according to the principles of the Helsinki Declaration and was approved by the Ethical Committee, Helsinki University Department of Public Health. Participants gave their informed consent.

## Questionnaires

All surveys included questions about LTPA[5,42,43]; frequency (per month), duration (per one session), intensity and daily time spent commuting by physically active means (walking, jogging and cycling) to and from work (min/day). Intensity was elicited by asking 'Is your leisure-time

physical exercise on average as intensive as ... ' with four response alternatives: walking, walking and jogging, jogging or running. The total metabolic equivalent (MET) index of LTPA per day was calculated by multiplying general intensity and the average duration and frequency of activities at each time point.[5,44,45] For the daily MET calculations, we used 4 MET/h for walking, 6 for a combination of walking and jogging, 10 for jogging and 13 for running.[5,44,45] For commuting, a mean value of 4 MET/h was used. Those not at work were assigned 0 min of commuting. All surveys included a specific question about average LTPA/year. Individuals who reported practically

no LTPA at all in this question were categorized as having an LTPA of 0 METs.

In the 1990 survey, LTPA and commuting were combined,[43] but intensity was elicited as in the other surveys. The total MET h per week of LTPA were calculated by multiplying the time used (class midpoints for five response time categories) by the estimated MET value of each of the possible physical activity grades and then adding the four values together.[43]

In this study, inactivity was defined as a mean daily energy cost of LTPA $\leq 1.5$ of MET h (no more than 10.5 MET h/week), and those with MET $> 1.5$ h were considered active, based on the energy expenditure cut-off of the definition of sedentary behaviour.[17] The categorization of inactivity applied a cut-off point of 10 MET h per week (600 MET min) for inactive persons, as has also been done earlier.[6,7] The questionnaire-based MET index has shown modest agreements with the interview data of a subsample of the Finnish Twin Cohort,[25] which is consistent with known modest associations of self-reported and interviewed physical activity with measures of physical activity using accelerometers or measures of physical fitness.[46]

Each individual was assigned to one of seven LTPA categories that evaluated inactive (I) vs active (A) behaviour in LTPA at each survey to construct a pattern of LTPA during the 35-year follow-up: persistently inactive (IIII), change from active to inactive (AIII, AAII or AAAI), mainly inactive (IIAI or IAII), mixed (IAIA, IAAI, AIAI or AIIA), mainly active (AAIA or AIAA), change from inactive to active (IAAA, IIAA or IIIA), or persistently active (AAAA).

Body mass index (BMI) was computed from self-reported weight and height (kg/m$^2$) at each time point. The high validity of self-reported weight in the 1990 survey has been reported earlier.[47]

Educational level was elicited at both baseline and in 1981 by completed education and was converted into years of education[48,49]. Marital status was reclassified into three categories: single, married or cohabiting and divorced or widowed. Work status and occupational physical loading[49] were combined and categorized into not at work, sedentary work and other kind of work. Cigarette smoking was elicited in detail with a series of questions and categorized as previously,[50] including answers from all the surveys: never-smoker, former smoker and current smoker.

### Statistical methods

Descriptive statistics were stratified by LTPA categories. We used analysis of variance (ANOVA) with Bonferroni *post hoc* tests[51] by sex for analysing mean BMI values over the seven LTPA categories at baseline. Multilevel mixed-effects linear regression[51] was used for analysing the effect of LTPA behaviour patterns on the mean BMI slope trajectory differences over time. The persistently active group was used as a reference group. In the final multivariate mixed-effect analyses, BMI, age and education years in 1981 were used as continuous covariates; and long-term LTPA, year of survey, marital status in 1975, work status including occupational physical loading in 1975 and smoking in 1975 were used as categorical variables. All analyses were clustered by twin-pair identity in order to adjust the standard errors for a lack of statistical independence within pairs. In the mixed analyses, a second cluster was applied for the repeated measurements.

Twin pairs generally share the same childhood environment and experiences. Whereas dizygotic (DZ) pairs are genetically full siblings and monozygotic (MZ) pairs share 100% of the gene sequence, discordant twin pairs are informative as regards the contribution of familial confounding between BMI and long-term physical inactivity. Hence a co-twin control setting was applied.[38,52] These discordant pair analyses should be interpreted by comparing them with the results of all individuals. If familial confounding plays a role in the association of BMI with physical inactivity, we should see an association among all individuals but not in discordant twin pairs.

In discordant analyses, the long-term LTPA was dichotomized into broadly inactive (i.e. persistently inactive, mainly inactive and change from active to inactive) and broadly active (persistently active, mainly active, and change from inactive to active). Those with mixed LTPA behaviour ($n = 962$) or missing BMI in 1975 or in 2011 ($n = 114$) were excluded from these analyses. We identified 356 twin pairs discordant for long-term LTPA, including 17 pairs of uncertain zygosity. Discordant pairs (MZ$n = 110$, DZ$n = 229$) were analysed separately using a two-sided paired-sample t-test, and all individuals with linear regression model.[51]

To estimate possible selection bias, mortality by 2011 and participation rate in 2011 were analysed in relation to those with physical activity measures in 1975. We used an age- and sex-adjusted Cox proportional hazard[53] model. Stata SE version 13.1 (StataCorp, College Station, TX, USA) was used for the analyses.

### Results

The mean age of 5254 subjects was 23.9 years (range 18 to 31) at baseline (1975), and 60.3 years (range 53 to 67) in 2011 (Figure 1). Table 1 describes the characteristics in each survey by sex and activity level.

The proportion of inactive individuals at each time point (LTPA $\leq 1.5$ MET h/day) decreased over time from

**Table 1.** Characteristics of men ($n = 2143$) and women ($n = 3111$) at baseline and at each follow-up time point by leisure-time physical activity (LTPA)

| | LTPA category per year | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | 1975 | | 1981 | | 1990 | | 2011 | |
| | Inactive | Active | Inactive | Active | Inactive | Active | Inactive | Active |
| **Men, *n* (%)** | 1102 (51) | 1041 (49) | 987 (46) | 1156 (54) | 832 (39) | 1311 (61) | 924 (43) | 1219 (57) |
| Age (years), mean (SD) | 23.9 (3.7) | 24.3 (3.7) | 30.5 (3.8) | 30.2 (3.7) | 39.6 (3.8) | 39.3 (3.7) | 60.7 (3.8) | 60.4 (3.7) |
| Weight (kg), mean (SD) | 70.6 (9.8) | 70.3 (8.9) | 74.4 (10.5) | 73.1 (9.3) | 78.6 (11.4) | 76.9 (10.8) | 85.9 (14.7) | 81.1 (11.9) |
| Height (m), mean (SD) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) | 1.77 (0.06) |
| BMI (kg/m$^2$), mean (SD) | 22.6 (2.8) | 22.5 (2.4) | 23.7 (2.9) | 23.4 (2.6) | 25.1 (3.3) | 24.6 (3.0) | 27.5 (4.3) | 26.0 (3.4) |
| Education (years), mean (SD) | 8.1 (2.6) | 8.6 (2.9) | 8.0 (3.2) | 8.7 (3.7) | | | | |
| Marital status (%) | | | | | | | | |
|    Single | 61 | 59 | 30 | 30 | 16 | 14 | 13 | 10 |
|    Married or cohabiting | 38 | 40 | 68 | 67 | 81 | 81 | 76 | 80 |
|    Divorced or widowed | 1 | 1 | 2 | 3 | 3 | 5 | 11 | 10 |
| Working status and physical loading (%) | | | | | | | | |
|    Sedentary work | 15 | 20 | 30 | 31 | 35 | 36 | 14 | 25 |
|    More active work | 55 | 59 | 59 | 63 | 58 | 58 | 29 | 32 |
|    Not at work | 30 | 21 | 11 | 6 | 7 | 6 | 57 | 43 |
| Smoking status | | | | | | | | |
|    Never-smoker | 35 | 45 | 35 | 41 | 36 | 40 | 33 | 45 |
|    Former smoker | 17 | 20 | 21 | 26 | 25 | 29 | 37 | 36 |
|    Current smoker | 48 | 35 | 44 | 33 | 38 | 31 | 30 | 20 |
| **Women, *n* (%)** | 1843 (59) | 1268 (41) | 1505 (48) | 1606 (52) | 976 (31) | 2135 (69) | 991 (32) | 2120 (68) |
| Age (years), mean (SD) | 23.5 (3.8) | 23.9 (3.7) | 30.0 (3.7) | 30.0 (3.8) | 39.1 (3.9) | 38.9 (3.7) | 60.6 (3.8) | 59.9 (3.7) |
| Weight (kg), mean (SD) | 55.9 (7.8) | 55.7 (7.5) | 58.6 (9.3) | 57.3 (7.7) | 63.1 (11.8) | 61.2 (9.3) | 73.1 (14.5) | 66.7 (11.0) |
| Height (m), mean (SD) | 1.63 (0.05) | 1.64 (0.05) | 1.63 (0.05) | 1.64 (0.06) | 1.63 (0.05) | 1.64 (0.06) | 1.63 (0.06) | 1.63 (0.06) |
| BMI (kg/m$^2$), mean (SD) | 20.9 (2.6) | 20.8 (2.4) | 22.0 (3.2) | 21.4 (2.6) | 23.7 (4.3) | 22.8 (3.2) | 27.5 (5.3) | 25.0 (3.9) |
| Education (years), mean (SD) | 8.4 (2.6) | 8.5 (2.7) | 8.6 (3.0) | 9.0 (3.2) | | | | |
| Marital status (%) | | | | | | | | |
|    Single | 51 | 56 | 20 | 29 | 11 | 15 | 11 | 11 |
|    Married or cohabiting | 47 | 42 | 76 | 67 | 81 | 76 | 69 | 68 |
|    Divorced or widowed | 2 | 2 | 4 | 4 | 8 | 9 | 20 | 21 |
| Working status and physical loading (%) | | | | | | | | |
|    Sedentary work | 23 | 34 | 27 | 41 | 39 | 37 | 16 | 25 |
|    More active work | 29 | 42 | 36 | 44 | 48 | 49 | 24 | 34 |
|    Not at work | 48 | 25 | 37 | 15 | 14 | 14 | 60 | 41 |
| Smoking status | | | | | | | | |
|    Never-smoker | 53 | 58 | 52 | 56 | 51 | 55 | 52 | 57 |
|    Former smoker | 14 | 13 | 22 | 19 | 21 | 21 | 23 | 24 |
|    Current smoker | 34 | 29 | 26 | 24 | 28 | 24 | 25 | 19 |

Inactive: leisure-time physical activity energy expenditure $\leq 1.5$ MET h per day.

Active: leisure-time physical activity energy expenditure $> 1.5$ MET h per day.

51% to 43% among men and from 59% to 32% among women (Table 1). Only 25% to 30% of individuals were either persistently inactive (11% men, 8% women) or persistently active (19% men, 17% women) whereas most changed categories over time (Table 2).

Over the 35 years, men's mean BMI increased from 22.5 kg/m$^2$ to 26.7 kg/m$^2$, and women's from 20.9 kg/m$^2$ to 25.8 kg/m$^2$. At baseline, the mean BMI of those who were persistently inactive was higher than the mean BMI of persistently active individuals of both sexes (Table 3,

Figure 2). For both sexes, BMI increased in all LTPA categories during the follow-up, with the steepest slope trajectories' increase being among the persistently inactive participants and those who had become inactive. This was also seen after adjustment for covariates in the mixed model analyses for the long-term mean BMI slopes between LTPA categories (Table 3).

The results of longitudinal dichotomized LTPA analysis in relation to baseline BMI, final BMI and change in BMI for all individuals and within pairs showed that the mean

**Table 2.** Distribution of leisure-time physical activity (LTPA) behaviour categories, and mean body mass index (BMI) with 95% confidence intervals (95% CI), and mean weight change with standard deviations (SD) by LTPA category for all participants ($n = 5254$) and/ or for men and women during the 35-year follow-up

| LTPA category | Distribution | | | Mean BMI change from 1975 to 2011 | | Mean weight change from 1975 to 2011 | |
|---|---|---|---|---|---|---|---|
| | ALL % ($n$) | MEN % ($n$) | WOMEN % ($n$) | MEN BMI Mean (95% CI) | WOMEN BMI Mean (95% CI) | MEN kg Mean (SD) | WOMEN kg Mean (SD) |
| Persistently inactive | 9 (470) | 11 (232) | 8 (238) | 4.2 (3.8, 4.7) | 6.1 (5.6, 6.7) | 13.0 (12.0) | 15.8 (10.6) |
| Become inactive | 10 (515) | 13 (283) | 8 (232) | 5.2 (4.7, 5.6) | 6.6 (6.0, 7.2) | 15.8 (11.8) | 17.2 (12.0) |
| Mainly inactive | 7 (352) | 8 (161) | 6 (191) | 4.8 (4.2, 5.3) | 6.3 (5.7, 6.9) | 14.8 (11.2) | 16.2 (11.2) |
| Mixed | 18 (962) | 19 (406) | 18 (556) | 4.2 (3.9, 4.5) | 5.4 (5.0, 5.7) | 13.1 (10.2) | 14.2 (10.9) |
| Mainly active | 9 (480) | 9 (182) | 10 (298) | 4.2 (3.7, 4.8) | 4.7 (4.3, 5.2) | 13.1 (11.4) | 12.4 (9.5) |
| Become active | 29 (1518) | 22 (464) | 34 (1054) | 3.5 (3.3, 3.8) | 4.4 (4.2, 4.6) | 10.8 (9.1) | 11.5 (9.0) |
| Persistently active | 18 (957) | 19 (415) | 17 (542) | 3.6 (3.3, 3.8) | 4.1 (3.8, 4.4) | 11.0 (9.8) | 10.7 (9.0) |

Inactive: leisure-time physical activity energy expenditure $\leq 1.5$ MET h per day.

Active: leisure-time physical activity energy expenditure $> 1.5$ MET h per day).

change in BMI for all subjects was $1.4 \, \text{kg/m}^2$ higher among inactive individuals than among those who were active (Table 4). Within discordant twin pairs, the change in BMI was $1.4 \, \text{kg/m}^2$ (95% CI 0.83 to 2.0) in DZ pairs and $0.68 \, \text{kg/m}^2$ (95% CI 0.05 to 1.3) in MZ pairs. A similar result was seen for final BMI in 2011, whereas in 1975 the within-pair difference in MZ was non-existent.

As regards drop-out analysis, of those who replied to the LTPA questions in 1975 ($n = 12\,340$), 10% had died by 2011, but there was no increase in mortality among inactive compared with active individuals in 1975 [age- and sex-adjusted hazard ratio (HR) 1.07; 95% CI 0.95 to 1.19). Of those alive and resident in Finland in 2011 ($n = 10\,557$), 26% did not reply in 2011, with similar proportions among inactive (27%) and active (26%) individuals at baseline.

## Discussion

This longitudinal study with a 35-year follow-up investigated the association between the stability of and change in physical inactivity and the change in BMI, accounting for familial confounding. This study is among the first to have access to comprehensive LTPA data on the same individuals over three decades. Our results indicate that every 10th adult was persistently inactive throughout adulthood, but many became active (22% men; 34% women) and almost every fifth remained active. The relatively rare long-term results add to the knowledge regarding the stability and change of LTPA that has mainly been based on cross-sectional[54] or series of cross-sectional studies,[9–13,16] shorter follow-ups,[14,19,20,24,30,31] smaller samples[23] or two to three time points.[8,15,20,24,30] The development of LTPA

over time was somewhat different for men than women. Women became inactive slightly less often, and became active more often than men. The overall and sex-specific development of LTPA may be related to family-, sex- and work-related factors as well as to the social desirability of reporting LTPA.[55]

Our study also adds to the knowledge of the relationship between long-term inactivity and BMI. BMI increased in both sexes, but particularly among the persistently inactive and those who became inactive. This may reflect the known inter-relationship between sufficient LTPA and energy expenditure, used for weight control.[21] Although this is one of the first studies to show the existence of this association from young adulthood until retirement age, the finding is in line with earlier results that show an association between long-term physical activity and weight.[19,31,56] We regard all this as supporting the effect of long-term physical inactivity on weight gain.[14,15,23–25,56]

In this study, BMI increased in all LTPA categories, which is consistent with the tendency to accumulate fat deposits during human mid-life,[57–59] at least in industrialized societies with Caucasian populations. Therefore, some increase in BMI from young adulthood to the end of middle-age in all individuals seems to be part of 'typical ageing'. Though we had no information on exact body adiposity, BMI showed strong agreement with body fat mass at the population level.[60] It is notable, however, that baseline BMI was already slightly higher among those who were persistently inactive than among those who were persistently active. In this study, body composition or muscle mass is the likely confounder for the BMI difference in lean young adults at baseline, whereas an increase in fat mass in

**Table 3.** Distribution of mean BMI and 95% confidence intervals (95% CI) by survey, and coefficients (95% CI's) with p-values of the difference between mean BMI slope trajectories of leisure-time physical activity (LTPA) categories of men ($n = 2143$) and women ($n = 3111$) during the 35-year follow-up

| LTPA category during 35 years of follow-up | Mean BMI (95% CI) by survey | | | | Difference between mean BMI slope trajectories during the 35-year follow-up | | | |
| | | | | | Age-adjusted model* | | Multivariate model** | |
| | 1975 | 1981 | 1990 | 2011 | Coefficient (95% CI) | p-Value for slope | Coefficient (95% CI) | p-Value for slope |
|---|---|---|---|---|---|---|---|---|
| **MEN** | | | | | | | | |
| Persistently inactive | 23.3 (22.9, 23.7) | 24.2 (23.8, 24.5) | 25.5 (25.1, 26.0) | 27.5 (26.9, 28.1) | 1.01 (0.61, 1.41) | 6.8 e$^{-07}$ | 0.86 (0.46, 1.27) | 2.6 e$^{-05}$ |
| Become inactive | 22.6 (22.3, 22.9) | 23.8 (23.5, 24.2) | 25.3 (24.9, 25.7) | 27.8 (27.3, 28.3) | 0.87 (0.51, 1.24) | 2.9 e$^{-06}$ | 0.77 (0.40, 1.14) | 3.9 e$^{-05}$ |
| Mainly inactive | 22.5 (22.0, 22.9) | 23.8 (23.4, 24.3) | 25.1 (24.6, 25.6) | 27.2 (26.6, 27.8) | 0.93 (0.49, 1.37) | 3.7 e$^{-05}$ | 0.77 (0.32, 1.21) | 7.1 e$^{-04}$ |
| Mixed | 22.7 (22.5, 23.0) | 23.7 (23.5, 24.0) | 25.0 (24.7, 25.3) | 26.9 (26.6, 27.3) | 0.71 (0.38, 1.04) | 2.4 e$^{-05}$ | 0.61 (0.28, 0.94) | 3.1 e$^{-04}$ |
| Mainly active | 22.7 (22.3, 23.1) | 23.7 (23.3, 24.1) | 25.0 (24.6, 25.5) | 26.9 (26.3, 27.5) | 0.76 (0.33, 1.18) | 4.7 e$^{-04}$ | 0.61 (0.19, 1.04) | 4.7 e$^{-03}$ |
| Become active | 22.2 (22.0, 22.4) | 23.1 (22.8, 23.3) | 24.2 (24.0, 24.5) | 25.8 (25.5, 26.1) | 0.05 (−0.28, 0.37) | 0.77 | −0.05 (−0.38, 0.28) | 0.77 |
| Persistently active | 22.2 (22.0, 22.4) | 23.1 (22.9, 23.3) | 24.2 (23.9, 24.4) | 25.8 (25.5, 26.1) | reference | reference | reference | reference |
| **WOMEN** | | | | | | | | |
| Persistently inactive | 21.5 (21.1, 22.0) | 22.8 (22.3, 23.3) | 24.8 (24.1, 25.5) | 27.6 (26.9, 28.3) | 1.77 (1.35, 2.19) | 9.8 e$^{-17}$ | 1.66 (1.24, 2.08) | 9.1 e$^{-15}$ |
| Become inactive | 21.3 (20.9, 21.7) | 22.5 (22.0, 23.0) | 24.4 (23.8, 25.0) | 27.9 (27.1, 28.6) | 1.49 (1.07, 1.90) | 2.5 e$^{-12}$ | 1.53 (1.12, 1.95) | 4.8 e$^{-13}$ |
| Mainly inactive | 20.9 (20.5, 21.3) | 21.9 (21.5, 22.4) | 23.3 (22.8, 23.8) | 27.1 (26.4, 27.8) | 1.05 (0.60, 1.50) | 4.4 e$^{-06}$ | 0.94 (0.49, 1.39) | 4.4 e$^{-05}$ |
| Mixed | 20.9 (20.7, 21.1) | 21.7 (21.4, 21.9) | 23.2 (22.9, 23.5) | 26.2 (25.8, 26.6) | 0.64 (0.31, 0.96) | 1.1 e$^{-04}$ | 0.64 (0.32, 0.96) | 9.6 e$^{-05}$ |
| Mainly active | 20.8 (20.5, 21.1) | 21.5 (21.2, 21.8) | 23.0 (22.7, 23.4) | 25.5 (25.0, 26.0) | 0.41 (0.03, 0.80) | 0.03 | 0.38 (−0.01, 0.76) | 0.05 |
| Become active | 20.8 (20.6, 20.9) | 21.5 (21.3, 21.7) | 22.8 (22.6, 23.0) | 25.2 (24.9, 25.4) | 0.34 (0.06, 0.63) | 0.02 | 0.28 (−0.01, 0.57) | 0.05 |
| Persistently active | 20.7 (20.5, 20.8) | 21.2 (21.0, 21.4) | 22.4 (22.2, 22.7) | 24.7 (24.4, 25.1) | reference | reference | reference | reference |

Inactive: leisure-time physical activity energy expenditure $\leq 1.5$ MET h per day.

Active (leisure-time physical activity energy expenditure $> 1.5$ MET h per day.

* Age-adjusted linear mixed model for the mean BMI slope trajectories between LTPA patterns. BMI slope trajectories are compared with persistently active (reference group). Analyses are adjusted for age and year of survey.

** Multivariate linear mixed model for the mean BMI slope trajectories between LTPA patterns. BMI slope trajectories are compared with persistently active (reference group). Analyses are adjusted for age, year of survey, education years in 1981, marital status in 1975, working status and physical loading in 1975, and smoking in 1975.
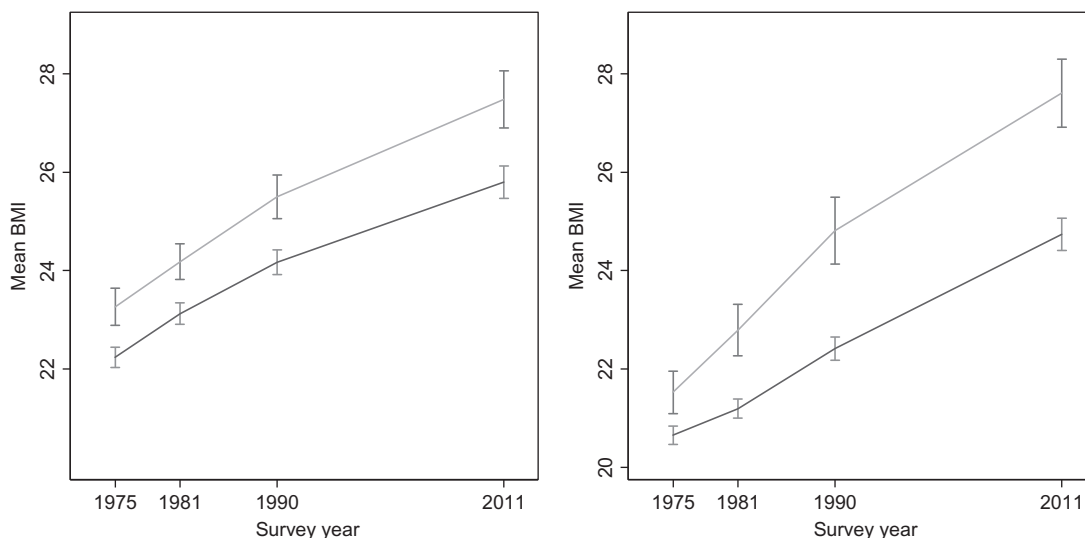
**Figure 2**. Development of mean BMI from 1975 to 2011 among men (left panel) and women (right panel) for persistently inactive (upper line) and persistently active individuals (lower line) in the Finnish Twin Cohort data ($n = 5254$). Data points show mean BMI and 95% confidence intervals during survey years.

response to physical inactivity probably accounts for the association later in adulthood. Nevertheless, a change in physical inactivity also affected BMI values, indicating that longitudinal changes in LTPA seem to drive weight development. Our findings are in line with previous results indicating that over 150 min/week of at least moderate-intensity activity ($> 10$ MET h/week) is needed for weight control.[15,19,61,62] Earlier analyses of Finnish twins, which also controlled for familial factors, have shown LTPA to be strongly associated with reduced body fat percentage.[23–25] However, we cannot rule out the contribution of increased body weight,[20,29,30] the effect of an increased amount of leisure-time (e.g. decreased amount of working hours, changes in family-related factors and retirement) and social desirability of reporting LTPA[55] to a decrease in LTPA.

The results of LTPA-discordant pairs are intriguing. In the analyses of both all individuals and DZ twin pairs, BMI differed between inactive and active co-twins at baseline, at the end of follow-up and in long-term change. For the MZ twin pairs, the within-pair difference in BMI was non-existent at baseline, but about half that of the DZ difference at the end of follow-up and in long-term change. Our findings regarding BMI development in LTPA-discordant pairs supports the idea that increasing regular physical activity should be encouraged through multiple policies in public decision making.

This large long-term twin cohort study has several strengths. The comprehensive surveys were repeated four times, hence enabling us to study stability and change in LTPA over a 35-year follow-up. Adult twins are highly representative of the population,[39] and the co-twin design

provides the possibility to control for familial confounding, which is a unique feature that adds to existing epidemiological knowledge. Furthermore, we also accounted for several covariates with a known influence on LTPA and BMI, although we had no data on energy intake. Unfortunately, objective measures of LTPA for epidemiological studies were not available until recently. In addition, the questions did not cover domestic (everyday) activities. Furthermore, it is possible that self-reported LTPA may lead to under- or over-estimation of LTPA level, especially among those with a higher BMI.[63,64] In this study, the LTPA was measured four times, using the same LTPA questions among the same individuals. Therefore, the majority of the bias due to under- or over-estimation of LTPA should be stable among the individuals in all four assessments. If higher BMI measures and increased public awareness of the importance of LTPA increased the over-estimation of LTPA, especially in 2011, the observed association of long-term physical inactivity with higher BMI may be diluted. However, the comprehensive survey data enabled us to calculate MET values for total energy expenditure over LTPA and commuting. Finally, one source of bias may be related to dropout. We analysed the participation rate in 2011 according to BMI categories in 1975. Among men, we found no difference in participation rates in any BMI categories ($p = 0.18$). Among women, the participation rate was 78% for those categorized as underweight (BMI $< 18.5$ kg/m$^2$), 78% for those with normal weight (BMI 18.5 to $< 25$ kg/m$^2$), 70% for overweight individuals (BMI 25 to $< 30$ kg/m$^2$) and 71% for obese individuals (BMI $\geq 30$ kg/m$^2$) ($p < 0.007$ for the difference between the BMI categories). It is also significant that in the Finnish twin cohort in

**Table 4.** Role of long-term leisure-time physical activity (LTPA) in mean body mass index (BMI) and change in mean BMI between 1975 and 2011 among all individuals and LTPA discordant twin pairs

| BMI | Long-term LTPA group | All individuals, n = 4198* | | Long-term LTPA discordant twin pairs | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | All pairs, n = 356* | | DZ pairs, n = 229* | | MZ pairs, n = 110* | |
| | | Mean BMI (95% CI) | Coefficient (95% CI), p-value** | Mean BMI (95% CI) | p-Value*** | Mean BMI (95% CI) | p-Value*** | Mean BMI (95% CI) | p-Value*** |
| 1975 | Inactive | 22.0 (21.9, 22.2) | | 21.7 (21.5, 22.0) | | 22.0 (21.7, 22.4) | | 21.2 (20.7, 21.7) | |
| | Active | 21.3 (21.2, 21.4) | | 21.4 (21.1, 21.7) | | 21.5 (21.1, 21.8) | | 21.1 (20.6, 21.6) | |
| | Difference | 0.73 (0.55, 0.90) | 0.37 (0.19, 0.54), $3.1\,e^{-05}$ | 0.36 (0.10, 0.61) | 0.006 | 0.56 (0.21, 0.92) | 0.002 | 0.05 (−0.30, 0.41) | 0.761 |
| 2011 | Inactive | 27.6 (27.3, 27.8) | | 27.2 (26.6, 27.7) | | 27.7 (27.1, 28.4) | | 26.0 (25.2, 26.8) | |
| | Active | 25.4 (25.3, 25.5) | | 25.7 (25.3, 26.1) | | 25.8 (25.3, 26.3) | | 25.3 (24.6, 26.0) | |
| | Difference | 2.15 (1.87, 2.42) | 1.67 (1.42, 1.93.3), $1.3\,e^{-38}$ | 1.46 (0.96, 2.00) | $2.5\,e^{-08}$ | 1.98 (1.30, 2.67) | $3.8\,e^{-08}$ | 0.74 (0.04, 1.43) | 0.039 |
| Change 2011–1975 | Inactive | 5.53 (5.31, 5.75) | | 5.41 (4.99, 5.84) | | 5.70 (5.13, 6.28) | | 4.85 (4.20, 5.49) | |
| | Active | 4.11 (4.00, 4.23) | | 4.31 (3.98, 4.65) | | 4.29 (3.87, 4.70) | | 4.16 (3.87, 4.70) | |
| | Difference | 1.42 (1.18, 1.65) | 1.65 (1.39, 1.90), $3.3\,e^{-37}$ | 1.10 (0.67, 1.53) | $1.0\,e^{-06}$ | 1.42 (0.83, 2.00) | $3.4\,e^{-06}$ | 0.68 (0.05, 1.32) | 0.036 |

Inactive: persistently inactive, mainly inactive, or change from active to inactive during the 35-year follow-up.

Active: persistently active, mainly active, or change from inactive to active during the 35-year follow-up.

LTPA=leisure-time physical activity, DZ=dizygotic, MZ=monozygotic.

*Including those whose weight and height reported in both 1975 and in 2011.

**Linear regression model between mean BMI and long-term LTPA group adjusted for sex and age in 1975. In 2011, adjusted also with BMI in 1975. Twin-pair identity was used as a cluster. Active group as reference group.

***Paired t-test within long-term discordant LTPA groups.

1975, a higher BMI increased mortality among men (adjusted HR 1.22; 95% CI 1.06 to 1.41) but not among women.[65] However, we found no increased risk of death and no decreased participation rate in 2011 among inactive men or women in comparison with those who were active in 1975.

## Conclusions

Persistent leisure-time physical inactivity was quite rare among Finnish adults followed for 35 years over four time points. Every fifth person was persistently active, whereas most changed their LTPA over time. BMI increased more among the persistently inactive and among those who became inactive. LTPA is important in weight management, although familial confounding, likely to be largely genetic in nature, may influence the long-term association between BMI and LTPA.

## Supplementary Data

Supplementary data are available at *IJE* online.

## Funding

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