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# Physical Activity Patterns Over 10 Years in Relation to Body Mass Index and Waist Circumference: The Whitehall II Cohort Study

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**Objective:** Physical activity patterns over 10-years in relation to changes in body mass index (BMI) and waist circumference (WC) were examined.

**Design and Methods:** Participants (4,880, mean age 49.3 years at baseline) from the Whitehall II cohort study were included. Self-reported physical activity and anthropometric data were collected at baseline (1991) and twice during follow-up (1997 and 2002).

**Results:** At baseline, meeting established guidelines for physical activity, particularly through vigorous activity, was associated with lower WC (multivariable adjusted *B* compared to not meeting the guidelines  $-2.08$  cm, 95% CI,  $-1.39$ ,  $-0.75$ ) and BMI ( $-0.34$  kg/m<sup>2</sup>,  $-0.10$ ,  $-0.59$ ). Based on repeat data, “high adherence” to the guidelines compared to “rare adherence” over follow-up was associated with lower BMI (adjusted difference,  $-0.43$  kg/m<sup>2</sup>, 95% CI,  $-0.79$ ,  $-0.08$ ) and WC ( $-2.50$  cm, 95% CI,  $-3.46$ ,  $-1.54$ ) at follow-up. Compared to participants that remained stable between 1997 and 2002 (change of  $<2.5$  h/week), those that reported an increase in moderate-vigorous physical activity of at least 2.5 h/week displayed lower BMI ( $-0.40$  kg/m<sup>2</sup>, 95% CI,  $-0.71$ ,  $-0.08$ ) and WC ( $-1.10$  cm, 95% CI,  $-1.95$ ,  $-0.75$ ).

**Conclusion:** Regular physical activity, confirmed by repeated assessments, is associated with relatively favorable levels of adiposity markers after 10 years follow-up.

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## Introduction

According to the World Health Organization, the number of overweight and obese adults worldwide is projected to reach 2.3 billion and 700 million, respectively, by 2015. Obesity is multifactorial in its etiology. Although there is popular belief from the general public and media that physical inactivity is one of the most important factors in the obesity epidemic, evidence linking physical activity and weight gain or obesity is mixed. A recent review concluded that lower levels of physical activity are not associated with subsequent excess weight gain or obesity (1). In addition, data from randomized controlled trials suggest that the treatment of overweight and obese individuals with exercise training alone does not result in any sub-

stantial weight loss (2), although such training may be important in maintaining weight loss (3).

The methodological shortcomings of studies in this field hamper data interpretation. For example, adherence to exercise programs in controlled trials is often poor. There are also large variations in methodology between observational studies (1)—the cross-sectional design of some of them (4), and the use of single baseline measures of physical activity (5) makes it impossible to account for changing patterns over time. An additional reason for the mixed findings is the possible bidirectional nature of the association between physical activity and adiposity markers, although few studies have explored this.

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We hypothesized that much of the health benefits from exercise are established through chronic training adaptations (6) which can be more reliably determined by repeated assessments of physical activity over time rather than by a single measurement at one point in time. Thus, in the present study, we examined the association between physical activity patterns over 10 years in relation to body mass index (BMI) and waist circumference (WC) using a well characterized population based cohort study. Few studies have attempted to quantify changes in adiposity markers in relation to the current physical activity recommendations (at least 2.5 h per week moderate to vigorous physical activity) (7), which formed the second aim of this study. Lastly, we examined possible bi-directional associations by analyzing the relationship between weight gain and future activity levels.

## Methods

### Participants

Participants were drawn from the Whitehall II cohort study (8), an on-going prospective cohort study that consists of 10,308 participants (6,895 men and 3,413 women, mean [SD] age on date of first screening, 44.4 ± 6.1 years) recruited from the British civil service in 1985 in order to investigate social and occupational influences on cardiovascular disease (CVD) risk. The baseline medical examination (Phase 1) took place during 1985/1988, and subsequent phases have alternated between questionnaire alone (Phases 2, 4, 6, and 8) and phases including both a medical examination and a questionnaire (Phases 1, 3, 5, 7, and 9). For the purposes of the present study, Phase 3 (1991/1993) was regarded as the “baseline” when WC and detailed dietary measures were first undertaken, with two subsequent visits, Phases 5 (1997/1999) and 7 (2002/2004), as the follow-up. The mean follow-up time between Phases 3 and 7 was 11.3 years (range, 9.5-12.9 years). Participants gave full informed written consent to participate in the study and ethical approval was obtained from the University College London Hospital committee on the Ethics of Human Research.

### Physical activity assessment

Physical activity was assessed at Phases 3, 5, and 7 using a self-reported questionnaire. At Phase 3, the physical activity assessment consisted of three questions about duration and frequency per week spent at light, moderate, and vigorous intensity physical activity. At Phases 5 and 7, the physical activity questions consisted of 20 items on frequency and duration of participation in walking, cycling, sports, gardening, housework, and home maintenance (9). For each item, the participants were required to provide the total number of hours spent in that activity over the past 4 weeks. Each activity was assigned a metabolic equivalent (MET) value by using a compendium of activity energy costs. One MET value reflects the intensity of the activity relative to lying quietly. We classified the intensity of physical activity by using the MET value and recoded it as light physical activity for values less than 3 METs (e.g., dish washing), moderate physical activity for values ranging from 3 to 5.9 (e.g., brisk walking, weeding), and vigorous physical activity for values of 6 or greater (e.g., jogging, sports, mowing). Frequency and duration of each activity were combined to compute hours per week of moderate to vigorous physical activity. The 20-item self-reported physical activity questionnaire is a modified version of the widely used and validated Minnesota leisure-time physical activity questionnaire

(10). This questionnaire has demonstrated excellent test-retest reliability—Spearman rank correlation coefficients 0.79-0.88 for total activity and ranging 0.69-0.86 among the light, moderate, and heavy intensity subcategories (11). In addition, the self-reported physical activity measure has demonstrated predictive validity for mortality in the Whitehall II study (12), and was recently validated against objective accelerometry measures in this sample (13). Physical activity (moderate-vigorous h/week) measured at Phase 3 was correlated with physical activity measured at Phases 5 and 7, as previously reported (14), suggesting moderate stability.

We categorized participants according to whether they adhered to the physical activity guidelines (at least 2.5 h per week moderate to vigorous physical activity) that have predictive validity for coronary heart disease (7,15). Participants that achieved at least 2.5 h per week moderate to vigorous physical activity were additionally categorized into largely moderate (vigorous < 75 min/week) or largely vigorous activity (vigorous ≥ 75 min/week).

### Adiposity markers assessment (Phases 3, 5, and 7)

The clinical examinations were performed based on standard operating protocols. Participants' body weight was measured in light clothing and without shoes using Soehnle and Tanita electronic scales, and height was measured using a Stadiometer with the Frankfort plane in the horizontal position. BMI was calculated as [weight (kilograms)/height (meters) squared]. WC was measured twice to the nearest millimeter mid-way between the iliac crest and lower rib using a measuring tape held at 600 g tension using a spring balance. An average of the first two measurements was used in the present analyses although if the first and second reading differed by more than 3 cm a third reading was taken and an average of the two nearest values used.

### Covariates

Data on age, civil service employment grade (a measure of socioeconomic status, SES), smoking (past/former/current), and self-reported chronic illness (yes/no) were drawn from the questionnaire at Phase 3 (1991/1993). Furthermore, dietary intake in kilojoules per day was estimated from the food frequency questionnaire that has been previously validated in the Whitehall II cohort (16). Dietary patterns were identified using cluster analysis (PROC FASTCLUS, SAS Institute 1988) and four clusters emerged (Healthy; Continental; British sweet; Unhealthy) (17).

### Statistical analysis

Adherence to physical activity guidelines was first considered at one time point—Phase 3—and was examined in relation to change in adiposity markers between Phases 3-7. We adopted a linear mixed models approach and fitted both the intercept and slope as random effects, allowing individuals to have differences in adiposity markers at baseline and different rates of change over the follow-up. The model included terms for baseline physical activity, time (Phase 3 corresponds to time 0, Phase 5 to time 1, and Phase 7 to time 2 so that coefficients associated with time correspond to a 5 year change), and an interaction term between physical activity and time to estimate the association between baseline physical activity and change in BMI and WC over the follow-up. This model also

**TABLE 1** Descriptive characteristics of the sample at each phase (*n* = 4,880)<sup>a</sup>

|                                      | Phase 3      | Phase 5     | Phase 7     |
|--------------------------------------|--------------|-------------|-------------|
| Age (years)                          | 49.3 ± 5.9   | 55.6 ± 6.0  | 61.1 ± 6.0  |
| % men                                | 71.5         |             |             |
| % low grade employees                | 11.0         |             |             |
| % smokers                            | 11.3         | 8.6         | 6.3         |
| % Chronic illness                    | 33.4         | 48.9        | 60.5        |
| % meeting PA guidelines <sup>b</sup> | 52.5         | 88.2        | 86.1        |
| % unhealthy diet pattern             | 31.4         |             |             |
| Energy intake (kJ/day)               | 1,501 ± 2531 |             |             |
| BMI (kg/m <sup>2</sup> )             | 25.1 ± 3.5   | 26.0 ± 3.9  | 26.6 ± 4.2  |
| Waist circumference (cm)             | 85.5 ± 11.3  | 90.5 ± 11.6 | 93.2 ± 12.1 |

<sup>a</sup>Data presented as Means ± standard deviations unless indicated.

<sup>b</sup>Meeting physical activity (PA) guidelines (at least 2.5 h moderate to vigorous physical activity per week).

included covariates that were selected *a priori* based on their documented association with both physical activity and adiposity markers (1). Interaction between each covariate—including gender and physical activity were examined and found to be statistically non-significant. To examine the effects of long-term physical activity exposure over the three assessments, participants were categorized as “Rarely” meeting guideline (once or less through follow-up); “Sometimes” (on two phases); “Always” (on all three follow-up phases). We fitted general linear models to examine the association between long-term physical activity exposure (number of times meeting the guideline over follow-up) and adiposity markers at follow-up, adjusting for age at baseline and follow-up, gender, smoking, employment grade, dietary pattern, energy intake, and chronic illness at baseline. We also investigated associations

between concomitant changes in physical activity (defined as the difference in hours/week of moderate to vigorous activity between Phases 5 and 7) and adiposity markers at Phase 7 using general linear models, making the same adjustments as described above. In supplementary analyses, we additionally examined the associations between long-term physical activity exposure and risk of incident obesity (defined as BMI ≥ 30 kg/m<sup>2</sup>) and incident central obesity (waist ≥102 cm in men, ≥88 cm in women) using binary logistic regression. All analyses were conducted using SPSS version 20 (SPSS, Chicago, IL) using two-sided tests with a significance level *P* < 0.05.

## Results

At Phase 3 (baseline), 7,899 participants had data on all variables although after excluding participants with missing data through follow-up the final analytic sample comprised 4,880 participants (3,489 men and 1,391 women). Participants excluded were slightly older (50.0 vs. 49.3 years, *P* < 0.001), less physically active (3.2 vs. 3.6 h/week moderate to vigorous physical activity, *P* < 0.001), and had higher BMI (25.6 vs. 25.1 kg/m<sup>2</sup>, *P* < 0.001) compared with those included. However, these absolute differences in characteristics between the groups were very small, only attaining statistical significance owing to the large sample size. Characteristics of the analytic sample at each phase are displayed in Table 1. On average, there was an increase in both BMI and WC from baseline to 10 year follow-up: mean BMI increased from 25.1 to 26.6 kg/m<sup>2</sup> (*P* < 0.001) with 52.2% of the sample demonstrating an increase of at least 5% BMI; mean WC increased from 85.5 to 93.2 cm (*P* < 0.001).

### Baseline physical activity and change in adiposity markers

Meeting the physical activity guideline at baseline was associated with a lower baseline WC and BMI after adjustments for covariates, but the differences were accentuated in participants that undertook

**TABLE 2** Linear mixed models to examine the association of meeting physical activity guidelines at baseline with BMI and waist circumference over 10-year follow-up

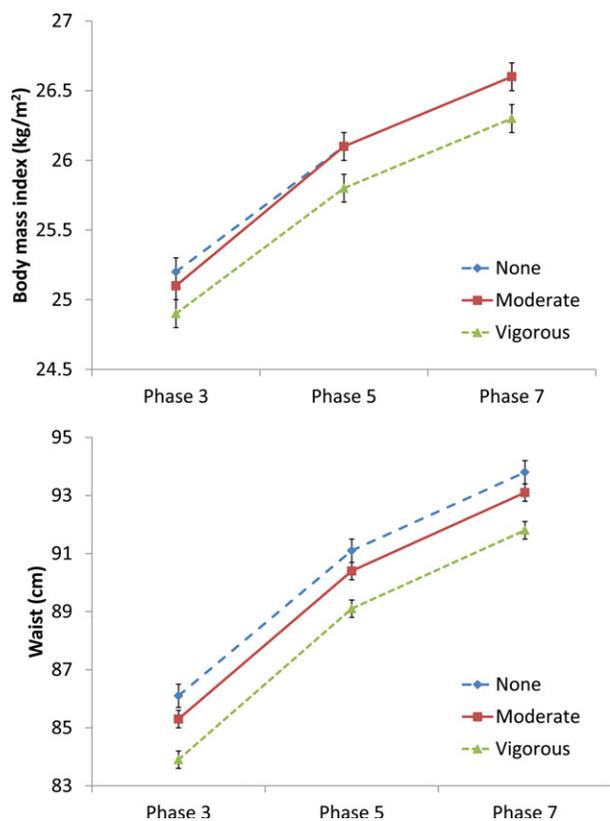
| Baseline physical activity           | BMI                 |                     | Waist circumference |                     |
|--------------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                      | <i>B</i> (95% CI)   |                     | <i>B</i> (95% CI)   |                     |
|                                      | Model 1             | Model 2             | Model 1             | Model 2             |
| <b>Cross-sectional analysis</b>      |                     |                     |                     |                     |
| Vigorous                             | 0 (Reference)       | 0 (Reference)       | 0 (Reference)       | 0 (Reference)       |
| Moderate                             | 0.32 (0.06, 0.57)   | 0.32 (0.05, 0.58)   | 1.55 (0.85, 2.25)   | 1.53 (0.82, 2.25)   |
| None                                 | 0.49 (0.24, 0.73)   | 0.34 (0.10, 0.59)   | 2.43 (1.77, 3.09)   | 2.08 (1.39, 2.75)   |
| <b>Longitudinal analysis (slope)</b> |                     |                     |                     |                     |
| Vigorous                             | 0 (Reference)       | 0 (Reference)       | 0 (Reference)       | 0 (Reference)       |
| Moderate                             | −0.02 (−0.09, 0.05) | −0.03 (−0.09, 0.04) | 0.05 (−0.19, 0.29)  | 0.009 (−0.24, 0.25) |
| None                                 | −0.02 (−0.08, 0.05) | −0.01 (−0.08, 0.05) | 0.06 (−0.19, 0.29)  | 0.08 (−0.15, 0.21)  |

*B* coefficient represents differences in BMI (kg/m<sup>2</sup>) and waist circumference (cm) between the groups (“None” represents participants that do not meet physical activity guideline at baseline; “moderate” represents participants that meet physical activity guidelines largely through moderate activity [>150 min/week]; “vigorous” represents participants that meet physical activity guidelines through vigorous activity [>75 min/week]).

Model 1; adjusted for age, gender.

Model 2; adjusted for age, gender, smoking, employment grade, diet pattern, energy intake, chronic illness.

The slope reflects the physical activity by time interaction term.



**FIGURE 1** The association between physical activity at baseline and changes in BMI (upper panel) and WC (lower panel) over 10 years. “None” represents participants that do not meet physical activity guideline at baseline; “moderate” represents participants that meet physical activity guidelines largely through moderate activity (>150 min/week); “vigorous” represents participants that meet physical activity guidelines through vigorous activity (>75 min/week). The means (SE) are adjusted for age, sex, smoking, employment grade, chronic illness, diet pattern, and calorie intake.

at least 75 min/week of vigorous activity (Table 2). In order to further investigate independent contributions of different types of activity (light, moderate, vigorous), we ran linear regression models using Phase 3 data, and found that only vigorous activity (h/week) remained significantly associated with BMI ( $B = -0.08$ , 95% CI,  $-0.15, -0.01$ ) and waist ( $B = -0.43$ , 95% CI,  $-0.62, -0.24$ ) after mutual adjustment for light and moderate activity and all covariates. Baseline physical activity was not associated with change in BMI or WC over follow-up (Table 2, Figure 1), suggesting that the difference in adiposity markers as a function of physical activity persisted but did not increase across time.

### Habitual physical activity over 10 years and adiposity markers at follow up

In comparison to participants that rarely adhered to physical activity guidelines through follow-up, the high adherence group had lower BMI ( $B$  coefficient =  $-0.43$  kg/m<sup>2</sup>, 95% CI,  $-0.79, -0.08$ ) and WC ( $B$  coefficient =  $-2.50$  cm, 95% CI,  $-3.46, -1.54$ ) at follow-up, after adjustment for age, gender, smoking, employment grade, diet pattern, energy intake, and chronic illness (Table 3). A

dose–response pattern ( $P$ -trend < 0.01) was evident in that participants who “sometimes” met the guidelines had lower BMI/WC than those “rarely” meeting the guidelines. The lowest levels of adiposity markers were seen in those “always” meeting guidelines.

We performed several sensitivity analyses. Firstly, missing values for covariates were imputed (SPSS multiple imputation procedure) using nine imputations based on maximum likelihood estimates. Essentially, there were minimal differences between the original results and those using the imputed data set (see Supporting Information Table 1). Second, we excluded participants reporting long-standing illness at baseline although the effect estimates remained unchanged. For example, in the healthy sub-sample ( $n = 3,223$ ), comparison to participants that rarely adhered to physical activity guidelines through follow-up, the high adherence group had lower BMI ( $B$  coefficient =  $-0.48$  kg/m<sup>2</sup>, 95% CI,  $-0.91, -0.06$ ) and WC ( $B$  coefficient =  $-2.34$  cm, 95% CI,  $-3.51, -1.16$ ). In further analyses, we examined associations with incident obesity (Supporting Information Table 2). After removing obese participants at baseline there were 499 incident cases of obesity (defined as BMI  $\geq 30$  kg/m<sup>2</sup>) and 828 cases of central obesity (waist  $\geq 102$  cm in men,  $\geq 88$  cm in women) at Phase 7 follow-up. Participants that always met the physical activity guidelines were at lower risk of incident central obesity (odds ratio = 0.71, 95% CI, 0.54, 0.92) after adjusting for covariates. There was no association when examining incident obesity as defined from BMI.

### Concomitant change in physical activity and adiposity markers

We were able to compute a physical activity change score between Phases 5 and 7 when the same questionnaire was used to assess this behavior and related these data to BMI/WC at follow-up (Table 4). Compared to participants that remained stable, those that reported an increase in physical activity of at least 2.5 h/week displayed lower BMI at follow-up ( $B$  coefficient =  $-0.40$  kg/m<sup>2</sup>, 95% CI,  $-0.71, -0.08$ ) and WC ( $B$  coefficient =  $-1.10$  cm, 95% CI,  $-1.95, -0.25$ ) after adjustment for a range of covariates that included diet and energy intake. Participants that reported a reduction in physical activity did not differ significantly from those that remained stable.

We also investigated the possibility of reverse causation such that weight gain may lead to reduced physical activity. Using mixed models, we examined the association between weight gain and physical activity, defined as study members who gained at least 5% in BMI between Phases 3 and 5, with the level of physical activity at Phase 5 and changes in physical activity between Phases 5 and 7. Compared with participants that remained stable or lost weight, the weight gainers displayed lower levels of moderate to vigorous physical activity (h/week) at Phase 5 ( $B$  coefficient =  $-1.27$ , 95% CI,  $-1.95, -0.58$ ) after adjusting for multiple covariates assessed at Phase 3. However, there was no association between weight gain and change in activity over Phases 5–7 ( $B = 0.43$ , 95% CI,  $-0.29, 1.15$ ;  $P = 0.24$ ).

### Discussion

The economic burden of obesity is growing (18) and obesity is recognized as a global epidemic (19), although the determinants remain poorly understood. This study took advantage of the rare availability

**TABLE 3** Adjusted coefficients (95% CI) for habitual physical activity over 10 years on adiposity markers at follow up (n = 4,880)

|   | BMI                  |                      | Waist circumference  |                      |
|---|----------------------|----------------------|----------------------|----------------------|
|   | Model 1              | Model 2              | Model 1              | Model 2              |
| Meeting physical activity guidelines <sup>a</sup> | B (95% CI)           | B (95% CI)           | B (95% CI)           | B (95% CI)           |
| Rarely (n = 761)                                  | 0 (Reference)        | 0 (Reference)        | 0 (Reference)        | 0 (Reference)        |
| Sometimes (n = 729)                               | -0.37 (-0.73, -0.01) | -0.28 (-0.64, 0.08)  | -1.54 (-2.52, -0.55) | -1.28 (-2.26, -0.31) |
| Always (n = 2,90)                                 | -0.59 (-0.94, -0.23) | -0.43 (-0.79, -0.08) | -2.90 (-3.86, -1.94) | -2.50 (-3.46, -1.54) |
| P-trend   | 0.004                | 0.051                | <0.001               | <0.001               |

B coefficient represents differences in BMI (kg/m<sup>2</sup>) and waist circumference (cm) between the groups.

<sup>a</sup>Meeting physical activity guidelines (at least 2.5 h MVPA per week); "Rarely" includes meeting guideline once or less through follow-up; "sometimes" on two phases; "always" on all three follow-up phases. Model 1; adjusted for age, gender.

Model 2; adjusted for age, age at follow-up, gender, smoking, employment grade, chronic illness, diet pattern, calorie intake.

of repeated assessments over a 10-year follow-up period in the British Whitehall II study to examine the associations between physical activity and adiposity markers. Previous results in this area are equivocal, but many studies relied on a single baseline measure of physical activity and have not considered the bidirectional nature of this association. Importantly, we found that repeated assessments of physical activity were a stronger predictor of adiposity markers than simply using a single baseline assessment. In addition, an increase in physical activity equivalent to the current physical activity guidelines (2.5 h/week) was associated with lower adiposity markers at follow-up. This is one of the few studies to specifically quantify changes in adiposity markers in relation to the current physical activity recommendations. We were, however, unable to examine all aspects of the physical activity recommendations, such as strength and flexibility training as well as minimum duration of a bout of activity, as such things are difficult to examine using self-report.

Our findings are consistent with several contemporary studies that have taken similar approaches to the present analyses (20-23). For example, in participants from The Coronary Artery Risk Development in Young Adults (CARDIA) study, those maintaining high levels of habitual activity over 20 years of follow-up demonstrated lower gains in BMI and WC (20). In a Dutch study of men and

women aged between 26 and 66 years at baseline, those who increased their physical activity (30 extra min/day of moderate activity) over a 5-year period had less gain in WC (21). In a sample of participants from the Women's Health Study, physical activity was assessed five times over 12 years follow-up and women expending less than 7.5 MET hours per week gained 0.12 kg compared with women expending 21 or more MET hours per week (22). In slight contrast to our findings, the European Prospective Investigation into Cancer and Nutrition (EPIC) showed an association between a single measure of physical activity at baseline and changes in adiposity markers over 5-year follow-up (5). In sub-group analysis those associations were only observed in younger men and women (<50 years), which may explain the discrepancies with our findings as we studied older adults, aged 49 years on average at baseline. However, these differences may also be explained by variations in the measurement of physical activity.

In the present study, physical activity was more consistently associated with WC than with BMI. Regional visceral fat depots may be of greater importance than measures of overall adiposity such as BMI. This is supported by various exercise training studies showing that exercise reduces levels of visceral adiposity in the absence of weight loss (24,25). In a recent sub-study of the Whitehall II cohort,

**TABLE 4** Adjusted coefficients (95% CI) for physical activity change on adiposity markers at phase 7

|                                       | BMI at phase 7       |                      | WC at phase 7        |                      |
|---------------------------------------|----------------------|----------------------|----------------------|----------------------|
|                                       | Model 1              | Model 2              | Model 1              | Model 2              |
| Physical activity change <sup>a</sup> | B (95% CI)           | B (95% CI)           | B (95% CI)           | B (95% CI)           |
| Decrease (n=1907)                     | -0.22 (-0.55, 0.11)  | -0.19 (-0.53, 0.14)  | -0.11 (-1.01, 0.80)  | -0.11 (-1.02, 0.81)  |
| Stable (n = 1118)                     | 0 (Reference)        | 0 (Reference)        | 0 (Reference)        | 0 (Reference)        |
| Increase (n = 1855)                   | -0.44 (-0.75, -0.13) | -0.40 (-0.71, -0.08) | -1.19 (-2.03, -0.36) | -1.10 (-1.95, -0.25) |
| P-trend                               | 0.001                | 0.001                | <0.001               | <0.001               |

B coefficient represents differences in BMI (kg/m<sup>2</sup>) and waist circumference (cm) between the groups.

<sup>a</sup>Physical activity change calculated from Phases 5 through 7. A decrease/increase represents a change of at least 2.5 h/week of moderate to vigorous physical activity. Model 1; adjusted for age, gender, and h/week of moderate to vigorous physical activity at Phase 5.

Model 2; adjusted for age, gender, hrs/wk of moderate to vigorous physical activity at phase 5, smoking, employment grade, diet pattern, calorie intake, chronic illness.

we demonstrated an association between objectively assessed physical activity and pericardial fat, independently of BMI (26).

We did not specifically assess sedentary behavior, although recent work showed no association between sedentary behavior and risk of future obesity in the Whitehall II study (27). Some previous studies using accelerometry based measures have observed detrimental, linear associations of sedentary time with WC after controlling for physical activity (28,29), although in other studies the associations did not persist after adjusting for physical activity (26,30-32). Thus, there is limited evidence to suggest a distinct effect of sedentary behavior beyond that due to lack of exercise *per se*. In addition, some evidence suggests that the direction of the association is more likely to be from obesity to physical inactivity. One might speculate, for example, that weight gain may lead to physical exertion becoming uncomfortable. In a sample of healthy adults, BMI and fat mass at baseline predicted sedentary behavior at 5.6 years follow-up (33). In a large British cohort weight gain of 0.5-2 kg per year was associated with physical inactivity at 10 years follow-up (34). In the present study, we found limited evidence for an association between weight gain and subsequent change in physical activity level. Nevertheless, this association may have been imprecise due to regression dilution bias as physical activity was measured with larger error than the adiposity markers (35).

A notable strength of this study is the repeated measures over a 10-year follow-up period in a well characterized cohort. This allowed us to track changes in physical activity, adiposity markers, and other important clinical variables. Self-reported measures of physical activity are prone to reporting bias although the questionnaire used at Phases 5 and 7 in the present study is well validated and has demonstrated convergent validity in predicting mortality in the Whitehall II study (12). In addition, among a sub-cohort of 394 Whitehall II participants, we recently demonstrated that self-reported physical activity was associated with objectively (accelerometry) assessed activity at 10-year follow-up across various activity categories (13). In the present study, we did observe an upward trend in physical activity that might be accounted for by lack of agreement between the different questionnaires used at Phases 3 and 5. This upward trend might also be explained by the fact many participants from Whitehall II were in the transition to retirement during this period. This is consistent with recent data from the GAZEL cohort 4 years before and 4 years after retirement showing that leisure-time physical activity increased by 36% in men and 61% in women during the transition to retirement (36). Attempting to account for the confounding effects of dietary intake is crucial in this area, although many previous studies have made little or no adjustment. Indeed, it is notoriously difficult to estimate energy intake from self-reported dietary questionnaires. Detailed dietary data were only available at baseline. However, our analyses were adjusted for dietary pattern in order to account for the quality of nutritional intake that is arguably a more meaningful variable in relation to health outcomes (37,38). The observed association between adherence to physical activity guidelines and adiposity markers was modest but may have clinical relevance. The difference in WC between participants that consistently adhered to the physical activity guidelines and those that were inactive over the 10 years follow-up was 2.50 cm (3.46-1.54) after accounting for confounding factors. This equated to  $\approx 32\%$  of the total gain in WC between baseline and follow-up. However, these effect estimates were likely to be imprecise because of measurement errors in the exposure variable.

In summary, among a sample of middle-older aged adults, habitual physical activity over 10 years was associated with lower markers of adiposity, although a single assessment of activity at baseline did not capture these effects to the same extent. Increases in physical activity were associated with lower gains in BMI and WC, after accounting for a range of covariables including indicators of dietary behaviors. **O**

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## References

1. Summerbell CD, Douthwaite W, Whittaker V, et al. The association between diet and physical activity and subsequent excess weight gain and obesity assessed at 5 years of age or older: a systematic review of the epidemiological evidence. *Int J Obes (Lond)* 2009;33 (Suppl 3):S1-S92.
2. Södlerlund A, Fischer A, Johansson T. Physical activity, diet and behaviour modification in the treatment of overweight and obese adults: a systematic review. *Perspect Public Health* 2009;129:132-142.
3. Mekary RA, Feskanich D, Hu FB, Willett WC, Field AE. Physical activity in relation to long-term weight maintenance after intentional weight loss in premenopausal women. *Obesity (Silver Spring)* 2010;18:167-174.
4. Williams PT, Pate RR. Cross-sectional relationships of exercise and age to adiposity in 60,617 male runners. *Med Sci Sports Exerc* 2005;37:1329-1337.
5. Ekelund U, Besson H, Luan J, et al. Physical activity and gain in abdominal adiposity and body weight: prospective cohort study in 288,498 men and women. *Am J Clin Nutr* 2011;93:826-835.
6. Williams PT. Relationship of distance run per week to coronary heart disease risk factors in 8283 male runners. The National Runners' Health Study. *Arch Intern Med* 1997;157:191-198.
7. Department of Health. *Start active, Stay Active: A Report on Physical Activity from the Four Home Countries' Chief Medical Officers*. London: Department of Health. 2011. [http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH\\_128209](http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_128209). Accessed on October 25, 2012.
8. Marmot M, Brunner E. Cohort profile: the Whitehall II study. *Int J Epidemiol* 2005;34: 251-256.
9. Singh-Manoux A, Hillsdon M, Brunner E, Marmot M. Effects of physical activity on cognitive functioning in middle age: evidence from the Whitehall II prospective cohort study. *Am J Public Health* 2005;95:2252-2258.
10. Taylor HL, Jacobs DR Jr, Schucker B, Knudsen J, Leon AS, Debacker G. A questionnaire for the assessment of leisure time physical activities. *J Chronic Dis* 1978; 31:741-755.
11. Folsom AR, Jacobs DR Jr, Caspersen CJ, Gomez-Marin O, Knudsen J. Test-retest reliability of the Minnesota Leisure Time Physical Activity Questionnaire. *J Chronic Dis* 1986;39:505-511.
12. Sabia S, Dugravot A, Kivimaki M, Brunner E, Shipley MJ, Singh-Manoux A. Effect of intensity and type of physical activity on mortality: results from the Whitehall II cohort study. *Am J Public Health* 2012;102:698-704.
13. Hamer M, Kivimaki M, Steptoe A. Longitudinal patterns in physical activity and sedentary behaviour from mid-life to early old age: a sub-study of the Whitehall II cohort. *J Epidemiol Community Health* 2012;66:1110-1115.
14. Hamer M, Sabia S, Batty GD, et al. Physical activity and inflammatory markers over 10 years: follow-up in men and women from the Whitehall II cohort study. *Circulation* 2012;126:928-933.
15. Sattelmair J, Pertman J, Ding EL, Kohl HW III, Haskell W, Lee IM. Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation* 2011;124:789-795.

16. Brunner E, Stallone D, Juneja M, Bingham S, Marmot M. Dietary assessment in Whitehall II: comparison of 7 d diet diary and food-frequency questionnaire and validity against biomarkers. *Br J Nutr* 2001;86:405-414.
17. Hamer M, Witte DR, Mosdøl A, Marmot MG, Brunner EJ. Prospective study of coffee and tea consumption in relation to risk of type 2 diabetes mellitus among men and women: the Whitehall II study. *Br J Nutr* 2008;100:1046-1053.
18. James WPT. WHO recognition of the global obesity epidemic. *Int J Obesity* 2008;32:S120-S126.
19. Butland B, Jebb S, Kopelman P, et al. *Foresight: Tackling Obesity: Future Choices—Project Report*. London, UK: Government Office for Science; 2007.
20. Hankinson AL, Daviglius ML, Bouchard C, et al. Maintaining a high physical activity level over 20 years and weight gain. *JAMA* 2010;304:2603-2610.
21. May AM, Bueno-de-Mesquita HB, Boshuizen H, Spijkerman AM, Peeters PH, Verschuren WM. Effect of change in physical activity on body fatness over a 10-y period in the Doetinchem Cohort Study. *Am J Clin Nutr* 2010;92:491-499.
22. Lee IM, Djoussé L, Sesso HD, Wang L, Buring JE. Physical activity and weight gain prevention. *JAMA* 2010;303:1173-1179.
23. Shiroma EJ, Sesso HD, Lee IM. Physical activity and weight gain prevention in older men. *Int J Obes (Lond)* 2012;36:1165-1169.
24. Lee S, Kuk JL, Davidson LE, et al. Exercise without weight loss is an effective strategy for obesity reduction in obese individuals with and without Type 2 diabetes. *J Appl Physiol* 2005;99:1220-1225.
25. van der Heijden GJ, Wang ZJ, Chu ZD, et al. A 12-week aerobic exercise program reduces hepatic fat accumulation and insulin resistance in obese, Hispanic adolescents. *Obesity* 2010;18:384-390.
26. Hamer M, Venuraju SM, Urbanova L, Lahiri A, Steptoe A. Physical activity, sedentary time, and pericardial fat in healthy older adults. *Obesity (Silver Spring)* 2012;20:2113-2117.
27. Pulsford RM, Stamatakis E, Britton AR, Brunner EJ, Hillsdon M. Sitting behaviour and obesity: evidence from the Whitehall II study. *Am J Prev Med* 2013;44:132-138.
28. Healy GN, Wijndaele K, Dunstan DW, Owen N. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes Care* 2008;31:369-371.
29. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. *Eur Heart J* 2011;32:590-597.
30. McQuire KA, Ross R. Sedentary behavior is not associated with cardiometabolic risk in adults with abdominal obesity. *PLoS One* 2011;6:e20503.
31. Ekelund U, Brage S, Griffin SJ, Wareham NJ; ProActive UK Research Group. Objectively measured moderate- and vigorous-intensity physical activity but not sedentary time predicts insulin resistance in high-risk individuals. *Diabetes Care* 2009;32:1081-1086.
32. Stamatakis E, Davis M, Stathi A, Hamer M. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. *Prev Med* 2012;54:82-87.
33. Ekelund U, Brage S, Besson H. Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? *Am J Clin Nutr* 2008;88:612-617.
34. Golubic R, Ekelund U, Wijndaele K, et al. Rate of weight gain predicts change in physical activity levels: a longitudinal analysis of the EPIC-Norfolk cohort. *Int J Obes (Lond)* 2013;37:404-409.
35. Hutcheon JA, Chioloro A, Hanley JA. Random measurement error and regression dilution bias. *BMJ* 2010;340:c2289.
36. Sjösten N, Kivimäki M, Singh-Manoux A, et al. Change in physical activity and weight in relation to retirement: the French GAZEL Cohort Study. *BMJ Open* 2012;2:e000522.
37. Brunner EJ, Mosdøl A, Witte DR, et al. Dietary patterns and 15-y risks of major coronary events, diabetes, and mortality. *Am J Clin Nutr* 2008;87:1414-1421.
38. Quatromoni PA, Copenhafer DL, D'Agostino RB, Millen BE. Dietary patterns predict the development of overweight in women: The Framingham Nutrition Studies. *J Am Diet Assoc* 2002;102:1239-1246.