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Title: Association of self-reported walking pace with type 2 diabetes incidence in the UK Biobank prospective cohort study

Running title: Walking pace and risk of type 2 diabetes

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#### Abstract

(247 words) Objective: To investigate the association between self-reported walking pace and type 2 diabetes (T2D) incidence and whether it differed by physical activity levels and walking time.

Patients and Methods:162,155 participants (mean age 57.1 years, $54.9 \%$ women) from the UK Biobank prospective study, recruited between 2006 and 2010, were included in the study. Walking pace was self-reported and classified as brisk, average or slow. Total physical activity and walking time were self-reported using IPAQ. Association between walking pace and T2D incidence, and the potential moderating role of physical activity and walking time, were investigated using Cox-proportional hazards models.

Results: The median follow-up was 7.4 (IQR: $6.7 ; 8.2$ ) years. There were 4,442 participants who developed T2D during the follow-up period. In the fully adjusted model (sociodemographics, diet, BMI and physical activity), average (HR, 1.28; 95\% $\mathrm{Cl}, 1.14$ to 1.44 ) and slow walking pace (HR, $1.91 ; 95 \% \mathrm{CI}, 1.62$ to 2.24 ) were associated with a higher T2D risk compared to brisk walking among women. Among men, average (HR, 1.28; $95 \% \mathrm{Cl}, 1.17$ to 1.40 ) and slow (HR, $1.73 ; 95 \% \mathrm{Cl}, 1.50$ to 1.99) walking pace were also associated with higher T2D risk. Compared to slow walkers, brisk walkers have the same diabetes incidence rate 18.6 and 16.0 yearslater, for women and men, respectively.

Conclusion: Average and slow walking pace was associated with a higher risk of incident T2D in both men and women, independently of major confounding factors, with the associations consistent across different physical activity levels and walking time.


keywords: Gait; Type 2 diabetes; walking pace; walking

## Introduction

Type 2 diabetes (T2D) is a current major public health challenge linked to a higher risk of non-communicable diseases, such as cardiovascular diseases (CVD), chronic kidney disease and premature death. People were affected by T2D, accounting for $6.2 \%$ worldwide in $2017^{1}$. Moreover, people with T2D live, on average, 4 to 10 years less than those without ${ }^{2}$. There is emerging evidence on the role of lifestyle in preventing T2D as well as preventing the complications and comorbidities associated with $\mathrm{T}_{2} \mathrm{D}^{2}$.

Physical activity is a key lifestyle factor for the prevention and treatment of $\mathrm{T}_{2} \mathrm{D}^{2}$. Existing evidence from randomized controlled trials and prospective cohort studies highlight the beneficial effect of physical activity on T2D. However, most of this evidence is based on total physical activity or leisure-time physical activity ${ }^{3,4}$, with less evidence available for specific forms of physical activity such as walking, and the importance of people's habitual walking pace ${ }^{5,67}$. Recent studies have suggested that a low walking pace is a strong predictor of poorer health outcomes, including cardiovascular, respiratory diseases, cancer and all-cause mortality ${ }^{8,9}$. Despite this, most of the evidence on walking pace and T2D risk comes from cross-sectional studies ${ }^{10}$, with the few existing prospective studies having a relatively small sample size. Many did not address whether the associations were independent of total physical activity ${ }^{6,7,11-14}$. It is, therefore, unclear whether any association between walking pace and T2D is consistent among people with different physical activity levels and walking times ${ }^{3,15}$. Such information will be useful to optimize walking-based interventions for T2D and to identify people who are at higher T2D risk. Therefore, to address these gaps in the literature, the aim of this study was to investigate the association between self-reported walking pace and risk of T2D and whether this
association differs by total physical activity and walking time in the UK Biobank, a large prospective cohort study.

## Methods

## Study cohort

The UK Biobank recruited >502,000 participants between 2006 and 2010 (5.5\% response rate, men and women were age 37-73 years) from the general population ${ }^{16}$. Participants attended 1 of 22 assessment centres across England, Wales, and Scotland ${ }^{17}$. At the assessment centres, they completed an electronically signed consent, and detailed information regarding their sociodemographics and lifestyles with physical measurements ${ }^{17}$. Analyses for the current study were conducted in participants of the UK Biobank cohort, who had available records for T2D incidence from primary care records, the exposure of interest (self-reported walking pace) and all covariates. Participants with prevalent type 1, type 2 diabetes or undiagnosed diabetes $(\mathrm{HbA} 1 \mathrm{c} \geqslant 48 \mathrm{mmol} / \mathrm{mol})$ at the baseline assessment were excluded from the study.

## Ethical Approval

The UK Biobank study was approved by the North West Multi-Centre Research Ethics Committee (Ref 11/NW/0382 on June 17, 2011) and all participants provided written informed consent to participate in the UK Biobank study. The study protocol is available online (http://www.ukbiobank.ac.uk/). This research has been conducted using the UK Biobank resource under application number 7155.

## Outcome

Incident T2D was derived from linkage to primary care data in UK Biobank. Records were extracted for $45 \%$ of the UK Biobank cohort ( 228,495 participants). The end of
coverage (extract date) was May 2017 for Scotland, September 2017 for Wales and August 2017 for England. Detailed linkage procedures are described elsewhere ${ }^{18}$. We defined incident T2D as primary care diagnosed with ICD-10 (international classification of diseases, $10^{\text {th }}$ revision) code E11. READ codes used in the primary care data were converted into ICD-10 codes using UK Biobank's look-up table.

## Exposure

Participants self-reported their usual walking pace on a touch-screen questionnaire at the baseline assessment visit. The question asked was "How would you describe your usual walking pace?" and they could select one of the three following options: brisk ( $>4$ miles/hour), average (3-4 miles/hour) or slow walking pace (<3 miles/hour), as described elsewhere ${ }^{8,9}$. Walking pace in the present study was categorized into brisk, average and slow pace.

## Covariates

Sex and education were self-reported at baseline; age was calculated from dates of birth and baseline assessment; ethnicity was self-reported at baseline and was categorized as white, South Asian, Mixed and Chinese. Deprivation Index, an areabased measure of socioeconomic status, was derived from the postal code of residence using the Townsend deprivation score ${ }^{19}$.

Anthropometric measurements were obtained by trained personnel following standard operating procedures and using calibrated equipment ${ }^{20}$. Body mass index (BMI) was calculated from body weight (in kilograms; kg ) divided by square of height (in meters; m) based on World Health Organization's criteria.

Smoking status was categorised into never, former, and current. Fruit and vegetable, red meat, and processed meat intake were recorded by using a touch screen questionnaire asking the reported frequency of consumption at baseline. Alcohol
intake was self-reported and categorised into daily/almost daily, 3-4 times a week, once or twice a week, 1-3 times a month, special occasions only and never. Sedentary behaviour was self-reported, derived from combined TV viewing, leisure PC screen time and driving time in hours per day ${ }^{21}$. Sleep duration was self-reported and categorised as short sleep, normal sleep and long sleep. Prevalent diseases that were medically diagnosed were self-reported at baseline.

Physical activity and walking time were based on the International Physical Activity Questionnaire (IPAQ) short form ${ }^{21}$, with participants reporting the frequency and duration of walking, moderate and vigorous activity undertaken in a typical week. Total physical activity was computed as the sum of walking, moderate and vigorous activity, measured as metabolic equivalent of task (MET), and people were defined as physically inactive if total physical activity $<600$ MET-min/week ${ }^{22}$. Additional details about these measurements can be found in the UK Biobank online protocol ${ }^{20}$.

## Statistical Analysis

Descriptive characteristics of the cohort were presented by categories of self-reported walking pace and sex. Continuous variables were presented as mean and standard deviation (SD), whereas categorical variables were presented as the number of observations and their respective percentage.

Cox-proportional hazard models were used to investigate the associations between self-reported walking pace (slow, average and brisk pace (reference category)) and incident T2D for men and women, separately. The results are reported as hazard ratios (HR) together with $95 \%$ confidence intervals ( $95 \% \mathrm{CI}$ ). To minimise reverse causation, the analyses were conducted with a 2-year landmark period, excluding events in the first two years of the follow-up period, and excluded all participants with prevalent type 1 , type 2 diabetes orundiagnosed type 2 diabetes ( $\mathrm{HbA} 1 \mathrm{c} \geq 48 \mathrm{mmol} / \mathrm{mol}$ ), at the
baseline assessment, as well as those with missing data on walking pace, physical activity, walking time and covariates.

We ran four models that included an increasing number of covariates: model 0 (minimally adjusted) included age, ethnicity, deprivation index, and education. Model 1 (lifestyle model) was adjusted as in model 0 but also included smoking, fruit and intake of fruit and vegetable, red meat, processed meat, and alcohol, total sedentary time and sleep time. Model 2 (BMI model) was adjusted as in model 1 but also included BMI. Model 3 (fully adjusted) was similar to model 2 but was additionally adjusted for total physical activity. All of the four models included walking pace as the exposure variable.

Interaction analyses were conducted to investigate whether the association between walking pace and risk of subsequent T2D differed by total physical activity level and walking time. An interaction between walking pace category and total physical activity and walking time coded as tertiles were added to the Cox-regression analyses, which used brisk walking pace and high physical activity tertile as the reference group (Brisk pace/High PA). These analyses were adjusted for model 3 but excluded total physical activity as covariates.

We calculated rate advancement periods (RAPs) ${ }^{23}$ to estimate the number of additional chronologic years that would be required to yield the equivalent risk rate of T2D incidence among individuals who reported a slow walking pace compared to those who reported a brisk walking pace. We divided the coefficient of incidence for those individuals in the slow walking pace category referent to individuals in the brisk walking category by the coefficient for incidence associated with each yearly increase in age, as described elsewhere ${ }^{24}$.

We checked the proportional hazard assumption by a test based on Schoenfeld residuals. Statistical analyses were performed using the statistical software STATA 16 (StataCorp LP). Associations were regarded as significant when $P<.05$.

## Results

This study included 162,155 ( 73,084 men and 89,071 women) participants with complete data for T2D incidence, walking pace and covariates. The median follow-up period was 7.4 years (interquartile range: 6.7 to 8.2 ). Over the follow-up, 4,442 participants developed T2D (2,645 men and 1,797 women).

The primary cohort characteristics by walking pace categories are presented in Table 1. In summary, brisk walkers were younger, more affluent, had higher education levels than those who reported a slow walking pace. In terms of lifestyle, brisk walkers were leaner, consumed less alcohol and processed meat, ate more fruit and vegetables, spent less time in sedentary behaviours, were more active and had higher levels of grip strength than slow walkers. A higher proportion of brisk walkers reported being never smokers and had normal sleep hours (7 to $9 \mathrm{~h} /$ day) than slow walkers (Table 1). Cohort characteristics by sex are presented in Supplementary Tables S1 and S2.

The association between walking pace and incident T2D is presented in Figure 1. There was a dose-response association between walking pace and T2D risk across all models. For women, using a minimally adjusted model (adjusted for sociodemographics factors) risk of T2D was 2-times (HR, 2.04; 95\% CI, 1.82 to 2.29) and 4.8 -times (HR, $4.82 ; 95 \% \mathrm{Cl}, 4.13$ to 5.61 ) higher for average and slow women compare to brisk walkers, respectively. For men, T2D risk was 1.7-times (HR, 1.71; $95 \% \mathrm{CI}, 1.56$ to 1.87 ) and 3.1 -times ( $\mathrm{HR}, 3.14$; $95 \% \mathrm{CI}, 2.74$ to 3.60 ) higher among average and slow walkers compared to brisk walkers. When the analyses were
additionally adjusted for lifestyle factors (Model 1), the magnitude of the associations was slightly attenuated for both men and women but remained significant (Figure 1). Further adjustment for BMI (Model 2) attenuated the magnitude of the associations considerably but remained significant. Among women compared to brisk walkers, average and slow walkers had 29\% (HR, 1.29; 95\% CI, 1.15 to 1.45) and 94\% (HR, $1.94 ; 95 \% \mathrm{CI}, 1.65$ to 2.27 ) higher risks of T2D, respectively. For men, average and slow walkers had $29 \%$ (HR, 1.29 ; $95 \% \mathrm{CI}, 1.18$ to 1.41 ) and $80 \%(H R, 1.80 ; 95 \% \mathrm{CI}$, 1.57 to 2.07 ) higher risk of T2D, respectively. Further adjustment for total physical activity (Model 3) did not alter the associations (Figure 1).

The interactions of walking pace with total physical activity and walking time are shown in Figure 2 and Supplemental Table S3 and S4. Although no significant interactions were observed for walking pace with either total physical activity or total walking time, T2D risk increased in a dose-response manner among average and slow pace walkers when their physical activity levels decreased. Similar results were observed when walking pace was presented by walking time (Figure 2).

The RAP analysis revealed that slow walkers have higher T2D incidence rates than brisk walkers. For brisk walkers to yield similar incidence rates to those observed for slow walkers, they would be 18.6 and 16.0 years older, for women and men, respectively. Incident rates for average versus slow walkers are presented in Table 2.

## Discussion

The main finding of this study is that, compared to brisk walking, average and slow walking pace were associated with a higher incidence of T2D in both men and women, independent of sociodemographics, diet, adiposity, and physical activity level. Among people with average and slow walking paces, high levels of physical activity did not
attenuate the excess T2D risk attributable to slow walking pace. We also provide evidence that, on average, slow walkers will experience equivalent T2D incidence rate as brisk walkers, but this will occur $\sim 18$ and $\sim 16$ years earlier for women and men, respectively. Future studies are needed to verify whether self-reported walking pace could be a useful marker to identify those individuals who are more likely to develop T2D, especially if we consider that current evidence suggests that walking pace could improve cardiovascular disease risk prediction ${ }^{9}$.

There are a few prospective studies that investigated the association of walking pace with incident T2D ${ }^{7,11,12}$, which were generally consistent with our findings. The Nurses' Health Study investigated the association between walking pace and T2D risk in 70,102 women aged $40-60$ years who were followed up for eight years ${ }^{11}$. They found that people with normal (or average) and brisk (or very brisk) walking pace were at a lower risk of T2D (relative risk (RR), $0.72 ; 95 \% \mathrm{CI}, 0.62$ to 0.85 and $0.41,95 \% \mathrm{Cl}, 0.33$ to 0.52 , respectively) compared to those with a slow walking pace ${ }^{11}$. However, the authors reported that after adjusting for BMI, although the association between brisk walking pace and T2D risk was attenuated (RR, $0.59 ; 95 \% \mathrm{Cl}, 0.47$ to 0.73 ), the association for average walking pace was no longer present (RR, $0.86 ; 95 \% \mathrm{CI}, 0.73$ to 1.01$)^{11}$. This disagrees with our findings as the associations between average-pace walkers and T2D risk was independent of BMI. Another study conducted in 37,918 men aged 40 to 75 years, who were free of diabetes, CVD, and cancer at baseline reported a strong association between walking pace and risk of T2D independent of time spent walking ${ }^{12}$. After adjusting for age, smoking, family history of T2D, alcohol intake and diet, the risk ratios for normal, brisk and very brisk pace were $0.68,0.46$ and 0.39 , respectively, compared to those who reported an easy or casual pace ${ }^{12}$. Recently, another study conducted in 197,825 non-diabetic Japanese people,
reported that brisk walking pace was inversely associated with a lower probability of T2D (odds ratio: $0.93 ; 95 \% \mathrm{Cl}, 0.88$ to 0.98$)^{7}$. However, when the associations were stratified by sex, age and BMI, brisk walking was associated with a lower risk of T2D only in participants aged $<65$, with $\mathrm{BMI}>25 \mathrm{~kg} / \mathrm{m}^{2}$ and who were men ${ }^{7}$. Our findings confirmed the inverse association between walking pace and T2D risk, independently of BMI and total physical activity. However, we also provide further evidence that the association between walking pace and T2D risk is also independent of walking time. This has important implications as the detrimental association between slow walking pace and risk of T2D is not attenuated by high levels of physical activity. Previous studies looking at the association of walking pace with other health outcomes such as CVD, cancer, respiratory diseases, and premature mortality, have also reported that slow walking pace is a strong risk factor independent of other major risk factors such as poor lifestyle and adiposity, 8,25 . These studies have also reported that slow walkers are more likely to be pre-frail or frail ${ }^{26,27}$ and have low cardiorespiratory fitness ${ }^{28,29}$. However, it is not certain whether walking pace is a causal factor or a marker of risk. Because total physical activity was adjusted in the analysis, the walking pace could be an indicator of overall physical capability/health status. However, it is also possible that higher intensity of physical activity (as indicated by walking faster) will confer a greater benefit in diabetes risk reduction ${ }^{30}$, which warrants further research.

The present study included a large number of participants, which provided a sufficient sample size to undertake the analysis, particularly on the subgroup analysis by physical activity level. This provides novel insight into the association's consistency across different physical activity levels. The measurement of walking pace is of low cost, easy to administer and would, therefore, be relatively simple to implement into
clinical practice for risk prediction/stratification. The previous studies concluded that the age at diagnosis of T2D was early, particularly $\leqslant 40$ years ${ }^{31,32}$. Our finding found that individuals who reported a slow walking pace will develop T2D earlier than those who had brisk walking pace. Therefore, assuming causality, brisk walking pace should be promoted among adults to reduce the risk of developing T2D. Although our study used self-reported usual walking pace, which may be more prone to self-reported bias, evidence suggests that self-reported walking pace is a very strong predictor of health and a good proxy of gait speed ${ }^{33}$. However, our study has limitations. The UK Biobank is not representative of the general population of the UK, including sociodemographic, physical, lifestyle and health-related characteristics of the general population. Although absolute risk would not be applicable to the general population, exposuredisease risk estimates should be generalisable ${ }^{34,35}$. The observational nature of the study does not allow us to infer causality, however, evidence from randomised control trials (RCT) has shown beneficial effects of brisk walking on preventing T2D and improving glycaemic control in people with diabetes ${ }^{36}$. Reverse causation may still be possible even though a 2-years landmark analysis was conducted and individuals with diabetes at baseline were excluded.

## Conclusions

This study provides evidence that walking pace, especially slow pace, was associated with a higher incident T2D in both men and women, independently of key confounding factors, particularly adiposity and total physical activity. Self-reported walking pace may be a useful marker to identify people who are at high risk of developing T2D, which warrants further research.

## Conflicts of Interest

No potential conflicts of interest relevant to this article were reported.

## CRediT author statement

Jirapitcha Boonpor: Conceptualization, formal analysis, investigation, data curation and writing-original draft; Frederick K. Ho: conceptualization, writing-original draft preparation, writing-Review \& Editing, and Supervision. Stuart R Gray: conceptualization, writing-original draft preparation, writing-Review \& Editing, and Supervision; Carlos-Celis-Morales: conceptualization, data curation, writing-original draft preparation, writing-Review \& Editing, and Supervision.

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Table 1. Cohort characteristics by self-reported walking pace categories

| Characteristics | Slow pace | Average pace | Brisk pace |
| :---: | :---: | :---: | :---: |
| Participants ( n ) | 8,164 | 83,181 | 70,810 |
| Age, years (mean, SD) | 58.8 (7.7) | 57.1 (8.0) | 55.3 (8.1) |
| Townsend Deprivation Index, n (\%) |  |  |  |
| Lower deprivation | 1,839 (22.5) | 27,976 (33.6) | 25,868 (36.5) |
| Middle deprivation | 2,435 (29.8) | 28,684 (34.5) | 24,685 (34.9) |
| Higher deprivation | 3,890 (47.7) | 26,521 (31.9) | 20,257 (28.6) |
| Ethnicity, n (\%) |  |  |  |
| White | 7,474 (91.6) | 79,551 (95.6) | 68,972 (97.4) |
| Mixed | 186 (2.3) | 938 (1.1) | 688 (1.0) |
| South Asian | 338 (4.1) | 1,582 (1.9) | 595 (0.8) |
| Black | 127 (1.6) | 867 (1.0) | 456 (0.6) |
| Chinese | 39 (0.5) | 243 (0.3) | 99 (0.1) |
| Education, n (\%) |  |  |  |
| College or University degree | 2,182 (39.8) | 29,539 (44.0) | 32,411 (51.5) |
| A levels/AS levels or equivalent | 721 (13.2) | 8,725 (13.0) | 8,737 (13.9) |
| O levels/GCSEs or equivalent | 1,579 (28.8) | 18,371 (27.3) | 14,474 (23.0) |
| SEs or equivalent/NVQ or HND or HNC | 1,000 (18.2) | 10,576 (15.7) | 7,296 (11.6) |
| Smoking status, n (\%) |  |  |  |
| Never | 3,722 (45.6) | 45,379 (54.6) | 41,447 (58.5) |
| Previous | 3,062 (37.5) | 29,161 (35.1) | 23,411 (33.1) |
| Current | 1,380 (16.9) | 8,641 (10.4) | 5,952 (8.4) |
| Sleep categories, n (\%) |  |  |  |
| Normal (7-9 h per day) | 5,146 (63.0) | 62,381 (75.0) | 54,196 (76.5) |
| Short sleep (<7 h per day) | 2,550 (31.2) | 19,518 (23.5) | 16,008 (22.6) |
| Long sleep (>9 h per day) | 468 (5.7) | 1,282 (1.5) | 606 (0.7) |
| Diets \& Lifestyles |  |  |  |


| Alcohol intake, n (\%) |  |  |  |
| :---: | :---: | :---: | :---: |
| Daily or almost daily | 1,308 (16.0) | 16,493 (19.8) | 15,935 (22.5) |
| 3-4 times a week | 1,260 (15.4) | 19,214 (23.1) | 19,234 (27.2) |
| Once or twice a week | 1,882 (23.1) | 22,439 (27.0) | 18,575 (26.2) |
| 1-3 times a month | 965 (11.8) | 9,518 (11.4) | 7,357 (10.4) |
| Special occasions only | 1,438 (17.6) | 9,365 (11.3) | 5,889 (8.3) |
| Never | 1,311 (16.1) | 6,150 (7.4) | 3,819 (5.4) |
| Process meat intake, portion/week (mean, SD) | 2 (1.1) | 1.89 (1.1) | 1.73 (1.1) |
| Fruit and vegetable intake, g/day (mean, SD) | 316.4 (211.4) | 324.1 (188.6) | 352.9 (194.6) |
| Red meat intake, portion/week (mean, SD) | 2.2 (1.6) | 2.2 (1.4) | 2.0 (1.4) |
| Total Sedentary time, $\mathrm{h} /$ day (mean, SD) | 5.5 (2.6) | 5.1 (2.2) | 4.7 (2.1) |
| Total physical activity, MET-hr/week (mean, SD) | $\begin{aligned} & \hline 2,007.5 \\ & (2,436.8) \end{aligned}$ | $\begin{gathered} \hline 2,828.0 \\ (3,052.5) \end{gathered}$ | $\begin{gathered} \hline 3,117.1 \\ (3,187.1) \end{gathered}$ |
| Grip strength (kg) | 26.3 (11.1) | 30.4 (10.9) | 32.2 (10.8) |
| Systolic blood pressure, mmHg (mean, SD) | 139.7 (18.9) | 139.1 (18.8) | 136.2 (18.5) |
| Adiposity |  |  |  |
| Waist circumference, cm (mean, SD) | 97.3 (14.3) | 90.8 (12.7) | 85.8 (11.8) |
| $\mathrm{BMI}, \mathrm{kg} / \mathrm{m}^{2}$ (mean, SD) | 30.4 (6.1) | 27.7 (4.5) | 25.8 (3.7) |
| BMI category, n (\%) |  |  |  |
| Underweight ( $<18.5 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 38 (0.5) | 305 (0.4) | 504 (0.7) |
| Normal ( $18.5-24.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 1,382 (16.9) | 22,971 (27.6) | 31,854 (45.0) |
| Overweight ( $25-29.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 2,852 (34.9) | 38,041 (45.7) | 29,869 (42.2) |
| Obese ( $\geq 30.0 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 3,892 (47.7) | 21,864 (26.3) | 8,583 (12.1) |

Data is presented as mean and SD for continuous variables and as frequency and \% for categorical variables.

SD, standard deviation; g, gram; h, hour; MET, metabolic equivalent task; cm, centimetre; kg , kilogram; mmHg , millimetre of mercury; BMI, body mass index; m , metre

Table 2. Advance Rate Period (RAP) for incident T2D in women and men by selfreported walking pace category

|  | RAP for T2D incidence (95\% CI) |  |
| :--- | :---: | :---: |
| Walking pace | Women | Men |
| category |  |  |
| Brisk pace (Ref.) | Ref. | Ref. |
| Average pace | $7.2(4.6 ; 8.9)$ | $7.2(5.4 ; 8.6)$ |
| Slow pace | $18.6(17.1 ; 19.6)$ | $16.0(14.0 ; 17.4)$ |

Estimate based on HRs shown for model 3 in Figure 1.

Figure 1. Association between self-reported walking pace and type 2 diabetes incidence in women and men.

Data are presented as hazard ratio (HR) and $95 \% \mathrm{Cl}$ by self-reported walking pace categories. Brisk walkers were the reference group (Ref.). Model 0 (minimally adjusted) included age, ethnicity, deprivation index, and education. Model 1 was adjusted as in model 0 but also included smoking, fruit and vegetable intake, red meat intake, processed meat intake, alcohol intake, total sedentary time and sleep time. Model 2 was adjusted as in model 1 but also included body mass index (BMI). Model 3 (fully adjusted) was similar to model 2 but was additionally adjusted for total physical activity (PA).

Figure 2. Association of self-reported walking pace with diabetes risk by total physical activity and walking time levels in women and men.

Data is presented as hazard ratio (HR) and $95 \% \mathrm{Cl}$. Brisk walkers with high levels of physical activity or walking time were set as the reference group (Ref.). The analyses were adjusted age, ethnicity, deprivation index, education, smoking, fruit and vegetable intake, red meat intake, processed meat intake, alcohol intake, total sedentary time, sleep time and BMI.

## SUPPLEMENTARY MATERIAL

Supplementary Table S1. Cohort characteristics by self-reported walking pace category in women.

| Characteristics | Slow pace | Average pace | Brisk pace |
| :---: | :---: | :---: | :---: |
| Women | 4,567 | 45,627 | 38,877 |
| Age, years (mean, SD) | 58.2 (7.6) | 56.9 (7.9) | 55.1 (8.0) |
| Townsend Deprivation Index, n (\%) |  |  |  |
| Lower deprivation | 1,034 (22.6) | 15,249 (33.4) | 13,985 (36.0) |
| Middle deprivation | 1,441 (31.6) | 15,816 (34.7) | 13,617 (35.0) |
| Higher deprivation | 2,092 (45.8) | 14,562 (31.9) | 11,275 (29.0) |
| Ethnicity, n (\%) |  |  |  |
| White | 4,161 (91.1) | 43,704 (95.8) | 37,801 (97.2) |
| Mixed | 120 (2.6) | 555 (1.2) | 431 (1.1) |
| South Asian | 183 (4.0) | 735 (1.6) | 280 (0.7) |
| Black | 76 (1.7) | 480 (1.1) | 300 (0.8) |
| Chinese | 27 (0.6) | 153 (0.3) | 65 (0.2) |
| Education, n (\%) |  |  |  |
| College or University degree | 1,290 (40.2) | 16,153 (43.7) | 17,214 (50.2) |
| A levels/AS levels or equivalent | 452 (14.1) | 5,107 (13.8) | 5,073 (14.8) |
| O levels/GCSEs or equivalent | 957 (29.8) | 11,094 (30.0) | 8,802 (25.7) |
| SEs or equivalent/NVQ or HND or HNC | 514 (16.0) | 4,638 (12.5) | 3,225 (9.4) |
| Smoking status, n (\%) |  |  |  |
| Never | 2,458 (53.8) | 27,289 (59.8) | 23,827 (61.3) |
| Previous | 1,470 (32.2) | 14,358 (31.5) | 12,133 (31.2) |
| Current | 639 (14.0) | 3,980 (8.7) | 2,917 (7.5) |
| Sleep categories, n (\%) |  |  |  |
| Normal (7-9 h per day) | 2,893 (63.4) | 34,276 (75.1) | 29,906 (76.9) |


| Short sleep (<7 h per day) | 1,439 (31.5) | 10,584 (23.2) | 8,602 (22.1) |
| :---: | :---: | :---: | :---: |
| Long sleep (>9 h per day) | 235 (5.2) | 767 (1.7) | 369 (1.0) |
| Diets \& Lifestyles |  |  |  |
| Alcohol intake, n (\%) |  |  |  |
| Daily or almost daily | 487 (10.7) | 6,946 (15.2) | 7,221 (18.6) |
| 3-4 times a week | 576 (12.6) | 9,109 (20.0) | 9,633 (24.8) |
| Once or twice a week | 1,010 (22.1) | 12,366 (27.1) | 10,571 (27.2) |
| 1-3 times a month | 626 (13.7) | 6,285 (13.8) | 4,725 (12.2) |
| Special occasions only | 1,008 (22.1) | 6,852 (15.0) | 4,238 (10.9) |
| Never | 860 (18.8) | 4,067 (8.9) | 2,489 (6.4) |
| Process meat intake, portion/week (mean, SD) | 1.7 (1.1) | 1.6 (1.0) | 1.4 (1.0) |
| Fruit and vegetable intake, g/day (mean, SD) | 337.3 (204.0) | 345.1 (183.0) | 377.9 (192.8) |
| Red meat intake, portion/week (mean, SD) | 2.1 (1.5) | 2.0 (1.4) | 1.9 (1.3) |
| Total Sedentary time, h/day (mean, SD) | 5.2 (2.4) | 4.7 (2.0) | 4.4 (1.9) |
| Total physical activity, MET-hr/week (mean, SD) | 1,855.9 (2,254.9) | $\begin{aligned} & \hline 2,521.2 \\ & (2,634.2) \end{aligned}$ | $\begin{aligned} & \hline 3,012.9 \\ & (2,952.6) \end{aligned}$ |
| Grip strength (kg) | 19.7 (6.8) | 23.1 (6.0) | 24.8 (5.9) |
| Systolic blood pressure, mmHg (mean, SD) | 138.4 (19.3) | 136.6 (19.3) | 133.1 (19.0) |
| Adiposity |  |  |  |
| Waist circumference, cm (mean, SD) | 93.6 (14.3) | 85.4 (11.6) | 79.7 (9.8) |
| BMI, kg/m² (mean, SD) | 31.1 (6.7) | 27.5 (4.8) | 25.1 (3.8) |
| BMI category, n (\%) |  |  |  |
| Underweight (<18.5 kg/m²) | 22 (0.5) | 238 (0.5) | 431 (1.1) |
| Normal ( $18.5-24.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 784 (17.2) | 14,885 (32.6) | 21,144 (54.4) |
| Overweight ( $25-29.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 1,360 (29.8) | 18,676 (40.9) | 13,404 (34.5) |


| Obese $\left(\geq 30.0 \mathrm{~kg} / \mathrm{m}^{2}\right)$ | $2,401(52.6)$ | $11,828(25.9)$ | $3,898(10.0)$ |
| :--- | :---: | :---: | :---: |

Data is presented as mean and SD for continuous variables and as frequency and \% for categorical variables.

SD, standard deviation; g, gram; h, hour; MET, metabolic equivalent task; cm, centimetre;
kg , kilogram; mmHg, millimetre of mercury; BMI, body mass index; m, metre

Supplementary Table S2. Cohort characteristics by self-reported walking pace category in men.

| Characteristics | Slow pace | Average pace | Brisk pace |
| :---: | :---: | :---: | :---: |
| Men | 3,597 | 37,554 | 31,933 |
| Age, years (mean, SD) | 59.5 (7.6) | 57.4 (8.1) | 55.5 (8.2) |
| Townsend Deprivation Index, n (\%) |  |  |  |
| Lower deprivation | 805 (22.4) | 12,727 (33.9) | 11,883 (37.2) |
| Middle deprivation | 994 (27.6) | 12,868 (34.3) | 11,068 (34.7) |
| Higher deprivation | 1,798 (50.0) | 11,959 (31.8) | 8,982 (28.1) |
| Ethnicity, n (\%) |  |  |  |
| White | 3,313 (92.1) | 35,847 (95.5) | 31,171 (97.6) |
| Mixed | 66 (1.8) | 383 (1.0) | 257 (0.8) |
| South Asian | 155 (4.3) | 847 (2.3) | 315 (1.0) |
| Black | 51 (1.4) | 387 (1.0) | 156 (0.5) |
| Chinese | 12 (0.3) | 90 (0.3) | 34 (0.1) |
| Education, n (\%) |  |  |  |
| College or University degree | 892 (39.3) | 13,386 (44.3) | 15,197 (53.1) |
| A levels/AS levels or equivalent | 269 (11.9) | 3,618 (12.0) | 3,664 (12.8) |
| O levels/GCSEs or equivalent | 622 (27.4) | 7,277 (24.1) | 5,672 (19.8) |
| SEs or equivalent/NVQ or HND or HNC | 486 (21.4) | 5,938 (19.7) | 4,071 (14.2) |
| Smoking status, n (\%) |  |  |  |
| Never | 1,264 (35.1) | 18,090 (48.2) | 17,620 (55.2) |
| Previous | 1,592 (44.3) | 14,803 (39.4) | 11,278 (35.3) |
| Current | 741 (20.6) | 4,661 (12.4) | 3,035 (9.5) |
| Sleep categories, n (\%) |  |  |  |
| Normal (7-9 h per day) | 2,253 (62.6) | 28,105 (74.8) | 24,290 (76.1) |
| Short sleep (<7 h per day) | 1,111 (30.9) | 8,934 (23.8) | 7,406 (23.2) |
| Long sleep (>9 h per day) | 233 (6.5) | 515 (1.4) | 237 (0.7) |
| Diets \& Lifestyles |  |  |  |


| Alcohol intake, n (\%) |  |  |  |
| :---: | :---: | :---: | :---: |
| Daily or almost daily | 821 (22.8) | 9,547 (25.4) | 8,714 (27.3) |
| 3-4 times a week | 684 (19.0) | 10,105 (26.9) | 9,601 (30.1) |
| Once or twice a week | 872 (24.2) | 10,073 (26.8) | 8,004 (25.1) |
| 1-3 times a month | 339 (9.4) | 3,233 (8.6) | 2,632 (8.2) |
| Special occasions only | 430 (12.0) | 2,513 (6.7) | 1,651 (5.2) |
| Never | 451 (12.5) | 2,083 (5.6) | 1,330 (4.2) |
| Process meat intake, portion/week (mean, SD) | 2.30 (1.1) | 2.22 (1.0) | 2.08 (1.1) |
| Fruit and vegetable intake, g/day (mean, SD) | 289.8 (217.7) | 298.6 (192.0) | 322.6 (192.6) |
| Red meat intake, portion/week (mean, SD) | 2.4 (1.7) | 2.3 (1.5) | 2.2 (1.5) |
| Total Sedentary time, h/day (mean, SD) | 5.8 (2.7) | 5.5 (2.3) | 5.1 (2.2) |
| Total physical activity, MET-hr/week (mean, SD) | $\begin{gathered} 2,199.9 \\ (2,637.6) \end{gathered}$ | $\begin{gathered} 3,200.7 \\ (3,457.6) \end{gathered}$ | $\begin{gathered} 3,243.9 \\ (3,447.0) \end{gathered}$ |
| Grip strength (kg) | 34.7 (9.8) | 39.4 (8.5) | 41.3 (8.3) |
| Systolic blood pressure, mmHg (mean, SD) | 141.4 (18.4) | 142.2 (17.7) | 140.0 (17.1) |
| Adiposity |  |  |  |
| Waist circumference, cm (mean, SD) | 102.0 (12.7) | 97.3 (10.6) | 93.2 (9.5) |
| $\mathrm{BMI}, \mathrm{kg} / \mathrm{m}^{2}$ (mean, SD) | 29.5 (5.1) | 28.0 (4.0) | 26.6 (3.4) |
| BMI category, n (\%) |  |  |  |
| Underweight ( $<18.5 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 16 (0.4) | 67 (0.2) | 73 (0.2) |
| Normal ( $18.5-24.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 598 (16.6) | 8,086 (21.5) | 10,710 (33.5) |
| Overweight ( $25-29.9 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 1,492 (41.5) | 19,365 (51.6) | 16,465 (51.6) |
| Obese ( $\geq 30.0 \mathrm{~kg} / \mathrm{m}^{2}$ ) | 1,491 (41.5) | 10,036 (26.7) | 4,685 (14.7) |

Data is presented as mean and SD for continuous variables and as frequency and \% for categorical variables.

SD, standard deviation; g, gram; h, hour; MET, metabolic equivalent task; cm, centimetre;
kg , kilogram; mmHg, millimetre of mercury; BMI, body mass index; m, metre

Supplementary Table S3. Association of T2D incidence and self-reported walking pace by tertiles of total physical activity

|  |  | Model 0 |  | Model 1 |  | Model 2 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Walking pace categories | Physical <br> Activity <br> Tertiles | HR (95\% CI) | $P$-value | HR (95\% CI) | $P$-value | HR (95\% CI) | $P$-value |
| Women |  |  |  |  |  |  |  |
| Brisk pace | High | 1.00 (Ref) |  | 1.00 (Ref) |  | 1.00 (Ref) |  |
|  | Middle | 1.18 (0.92;1.52) | . 185 | 1.20 (0.93; 1.54) | . 160 | 1.14 (0.89; 1.46) | . 311 |
|  | Low | 1.31 (1.01; 1.69) | . 037 | 1.30 (1.01; 1.69) | . 043 | 1.17 (0.90; 1.51) | . 238 |
| Average pace | High | 2.27 (1.84; 2.80) | <. 001 | 2.07 (1.68; 2.55) | <. 001 | 1.37 (1.11; 1.69) | . 004 |
|  | Middle | 2.44 (1.99; 3.00) | <. 001 | 2.20 (1.79; 2.71) | <. 001 | 1.39 (1.12; 1.71) | . 002 |
|  | Low | 2.47 (2.00; 3.04) | <. 001 | 2.24 (1.82; 2.76) | <. 001 | 1.56 (1.27; 1.93) | <. 001 |
| Slow pace | High | 3.49 (2.40; 5.07) | <. 001 | 2.70 (1.85; 3.93) | <. 001 | 1.61 (1.03; 2.19) | . 035 |
|  | Middle | 5.71 (4.30; 7.59) | <. 001 | 4.36 (3.27; 5.82) | <. 001 | 2.11 (1.58; 2.83) | <. 001 |
|  | Low | 5.98 (4.65; 7.54) | <. 001 | 4.61 (3.61; 5.89) | <. 001 | 2.23 (1.74; 2.87) | <. 001 |
|  |  | $P$-interaction | . 559 | $P$-interaction | . 614 | $P$-interaction | . 293 |
| Men |  |  |  |  |  |  |  |


| Brisk pace | High | 1.00 (Ref) |  | 1.00 (Ref) |  | 1.00 (Ref) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Middle | 1.15 (0.94; 1.40) | . 169 | 1.16 (0.95; 1.42) | . 138 | 1.14 (0.93; 1.39) | . 212 |
|  | Low | 1.42 (1.17; 1.72) | <. 001 | 1.40 (1.15; 1.71) | . 001 | 1.30 (1.07; 1.59) | . 008 |
| Average pace | High | 1.84 (1.55; 2.18) | <. 001 | 1.74 (1.46; 2.06) | <. 001 | 1.38 (1.16; 1.64) | <. 001 |
|  | Middle | 1.92 (1.61; 2.27) | <. 001 | 1.82 (1.53; 2.16) | <. 001 | 1.40 (1.17; 1.66) | <. 001 |
|  | Low | 2.40 (2.03; 2.83) | <. 001 | 2.24 (1.90; 2.65) | <. 001 | 1.62 (1.37; 1.92) | <. 001 |
| Slow pace | High | 2.71 (1.97; 3.74) | <. 001 | 2.27 (1.64; 3.13) | <. 001 | 1.46 (1.06; 2.02) | . 021 |
|  | Middle | 3.44 (2.63; 4.49) | <. 001 | 2.80 (2.14; 3.67) | <. 001 | 1.77 (1.35; 2.33) | <. 001 |
|  | Low | 3.59 (2.88; 4.48) | <. 001 | 3.00 (2.40; 3.75) | <. 001 | 1.89 (1.51; 2.37) | <. 001 |
|  |  | $P$-interaction | . 410 | $P$-interaction | . 378 | $P$-interaction | . 639 |

Data is presented as hazard ratio (HR) and $95 \% \mathrm{Cl}$ by self-reported walking pace and total physical activity tertiles. Brisk walkers with high levels of physical activity were set as the reference group (Ref.). Models were adjusted incrementally, Model 0 (minimally adjusted) included age, ethnicity, deprivation index, and education. Model 1 was adjusted as in model 0 but also included smoking, fruit and vegetable intake, red meat intake, processed meat intake, alcohol intake, total sedentary time and sleep time. Model 2 (fully adjusted) was adjusted as in model 1 but also included body mass index (BMI).

Supplementary Table S4. Association of T2D incidence and self-reported walking pace by tertiles of walking time.

|  |  | Model 0 |  | Model 1 |  | Model 2 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Walking pace categories | Walking time tertiles | HR (95\% CI) | $P$-value | HR (95\% CI) | $P$-value | HR (95\% CI) | $P$-value |
| Women |  |  |  |  |  |  |  |
| Brisk pace | High | 1.00 (Ref) |  | 1.00 (Ref) |  | 1.00 (Ref) |  |
|  | Middle | 1.23 (0.96; 1.57) | . 098 | 1.24 (0.98; 1.59) | . 079 | 1.20 (0.94; 1.53) | . 146 |
|  | Low | 1.21 (0.94; 1.56) | . 148 | 1.21 (0.94; 1.56) | . 146 | 1.13 (0.87; 1.45) | . 366 |
| Average pace | High | 2.18 (1.77; 2.68) | <. 001 | 2.00 (1.62; 2.46) | <. 001 | 1.34 (1.08; 1.65) | . 007 |
|  | Middle | 2.39 (1.94; 2.93) | <. 001 | 2.10 (1.71; 2.57) | <. 001 | 1.35 (1.10; 1.66) | . 004 |
|  | Low | 2.33 (1.91; 2.86) | <. 001 | 2.16 (1.76; 2.65) | <. 001 | 1.51 (1.23; 1.86) | <. 001 |
| Slow pace | High | 4.09 (2.96; 5.66) | <. 001 | 3.09 (2.23; 4.29) | <. 001 | 1.55 (1.11; 2.15) | . 010 |
|  | Middle | 5.36 (4.26; 6.73) | <. 001 | 4.08 (3.24; 5.15) | <. 001 | 2.03 (1.60; 2.58) | <. 001 |
|  | Low | 5.58 (4.21; 7.39) | <. 001 | 4.35 (3.28; 5.78) | <. 001 | 2.17 (1.63; 2.90) | <. 001 |
|  |  | $P$-interaction | . 462 | $P$-interaction | . 504 | $P$-interaction | . 420 |
| Men |  |  |  |  |  |  |  |
| Brisk pace | High | 1.00 (Ref) |  | 1.00 (Ref) |  | 1.00 (Ref) |  |


|  | Middle | $1.08(0.89 ; 1.30)$ | .446 | $1.09(0.90 ; 1.32)$ | .365 | $1.06(0.88 ; 1.28)$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | Low | $1.11(0.92 ; 1.34)$ | .263 | $1.11(0.92 ; 1.33)$ | .298 | $1.04(0.86 ; 1.25)$ | .713 |
| Average pace | High | $1.81(1.55 ; 2.12)$ | $<.001$ | $1.71(1.46 ; 2.01)$ | $<.001$ | $1.26(1.07 ; 1.48)$ | .006 |
|  | Middle | $1.83(1.55 ; 2.15)$ | $<.001$ | $1.73(1.47 ; 2.04)$ | $<.001$ | $1.30(1.10 ; 1.53)$ | .002 |
|  | Low | $1.86(1.59 ; 2.18)$ | $<.001$ | $1.73(1.47 ; 2.03)$ | $<.001$ | $1.34(1.14 ; 1.57)$ | .001 |
| Slow pace | High | $2.39(1.94 ; 2.93)$ | $<.001$ | $2.26(1.73 ; 2.95)$ | $<.001$ | $1.44(1.10 ; 1.89)$ | .007 |
|  | Middle | $3.09(2.35 ; 4.05)$ | $<.001$ | $2.52(1.92 ; 3.31)$ | $<.001$ | $1.56(1.18 ; 2.06)$ | .002 |
|  | Low | $3.44(2.81 ; 4.20)$ | $<.001$ | $2.79(2.28 ; 3.42)$ | $<.001$ | $1.72(1.40 ; 2.11)$ | $<.001$ |
|  |  | -interaction | .333 | $P$-interaction | .308 | $P-$ interaction | .895 |

Data are presented as hazard ratio (HR) and $95 \% \mathrm{Cl}$ by self-reported walking pace and total physical activity tertiles. Brisk walkers with high levels of walking time were set as the reference group (Ref.). Models were adjusted incrementally; Model 0 (minimally adjusted) included age, ethnicity, deprivation index, and education. Model 1 was adjusted as in model 0 but also included smoking, fruit and vegetable intake, red meat intake, processed meat intake, alcohol intake, total sedentary time and sleep time. Model 2 (fully adjusted) was adjusted as in model 1 but also included body mass index (BMI).





