Walking speed and the risk of type 2 diabetes: a systematic review and meta-analysis

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ABSTRACT

Objective To investigate the association between walking speed and the risk of type 2 diabetes.

Design Systematic review and meta-analysis.

Data sources PubMed, Scopus, CENTRAL and Web of Science to 30 May 2023.

Eligibility criteria for selecting studies We included cohort studies that explored the association between walking speed and the risk of type 2 diabetes in adults. We used random-effects meta-analyses to calculate relative risk (RR) and risk difference (RD). We rated the credibility of subgroup differences and the certainty of evidence using the Instrument to assess the Credibility of Effect Modification ANalyses (ICEMAN) and Grading of Recommendations Assessment, Development and Evaluation (GRADE) tools, respectively.

Results Ten cohort studies were included. Compared with easy/casual walking (<3.2 km/hour), the RR of type 2 diabetes was 0.85 (95% CI 0.70 to 1.00); RD=0.86 (95% CI 1.72 to 0) fewer cases per 100 patients; n=4, GRADE=low) for average/normal walking (3.2–4.8 km/hour), 0.76 (95% CI 0.65 to 0.87); RD=1.38 (95% CI 2.01 to 0.75) fewer cases per 100 patients; n=10, GRADE=low) for fairly brisk walking (4.8–6.4 km/hour) and 0.61 (95% CI 0.49 to 0.73; RD=2.24 (95% CI 2.93 to 1.55) fewer cases per 100 patients; n=6, GRADE=moderate) for brisk/striding walking (>6.4 km/hour). There was no significant or credible difference across subgroups based on adjustment for the total volume of physical activity and time spent walking per day. Dose–response analysis suggested that the risk of type 2 diabetes decreased significantly at a walking speed of 4 km/h and above.

Conclusions Low to moderate certainty evidence, mainly from studies with a high risk of bias, suggests that walking at faster speeds is associated with a graded decrease in the risk of type 2 diabetes.

PROSPERO registration number CRD42023432795.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Frequent walking is associated with a lower risk of type 2 diabetes.
⇒ It is not clear what walking speed is needed to reduce the risk of type 2 diabetes.

WHAT THIS STUDY ADDS

⇒ Walking at faster speeds (4–8 km/hour) was associated with a graded decrease in the risk of type 2 diabetes.
⇒ The results remained significant in the subgroups of studies that controlled for the total volume of physical activity and time spent walking per day.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ While current strategies to increase total walking time are beneficial, it may also be reasonable to encourage people to walk at faster speeds to further increase the health benefits of walking.

INTRODUCTION

Type 2 diabetes is a progressive chronic disease, recognised as one of the most common metabolic disorders worldwide.[1] People with type 2 diabetes are at greater risk of several microvascular and macrovascular complications and a reduced life expectancy.[2 3] Currently, the number of adults worldwide with diabetes is 537 million and this is predicted to increase to 783 million by 2045.[4 5]

Physical activity and structured exercise programmes are essential parts of type 2 diabetes prevention programmes[6] and can exert favourable effects on glycaemic control in patients with type 2 diabetes.[7] A meta-analysis of cohort studies indicated that being physically active was associated with a 35% lower risk of type 2 diabetes in the general population.[8] Of note, the results suggested that frequent walking was associated with a 15% lower risk of developing type 2 diabetes.[8] Walking is a simple and inexpensive type of physical activity and is associated with several social, mental and physical health benefits.[9] Evidence suggests that regular walking may be associated with a lower risk of all-cause mortality[10 11] and cardiovascular events,[12] and that a greater number of steps per day may be associated with a lower risk of premature death.[13]

In addition to the time spent walking, walking speed, defined as the speed at which someone habitually walks, may predict death and disability. Walking speed is a sensitive and reliable measure of overall health condition and a vital sign for functional capacity.[14 15] Evidence suggests that faster gait speed can lead to a greater physiological response[9] and, thus, may be associated with more favourable health benefits than slow walking.

In recent years, there has been a particular interest in the association between walking speed and the risk of multiple health outcomes. A previous meta-analysis of eight cohort studies suggested that, compared with the slowest walking speed (median=1.6 km/hour), the fastest walking speed (median=5.6 km/hour) was associated with a 44% lower risk of stroke and that each 1 km/hour increase in walking speed was associated with a 13% lower risk.[16] Other meta-analyses of cohort

studies also suggested that a faster walking speed may be associated with lower risks of disability,[17] dementia,[18] cardiovascular disease[19] and all-cause mortality.[20]

Previous research has indicated that time spent walking per day is associated with a lower risk of type 2 diabetes.[8] However, it is not clear what level of walking speed is needed to reduce the risk of type 2 diabetes. To our knowledge, systematic reviews and meta-analyses are lacking on the association between different walking speeds and the risk of type 2 diabetes. Therefore, we conducted a systematic review and meta-analysis of cohort studies of the association between walking speed and the risk of developing type 2 diabetes in adults.

METHODS

We conducted the meta-analysis following guidelines outlined in the Cochrane Handbook for systematic reviews[21] and the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Handbook,[22] and reported it according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement for systematic reviews of interventions.[23] The protocol of the present systematic review was registered with PROSPERO (CRD42023432795).[24]

Systematic search

PubMed/Medline, Scopus, CENTRAL and Web of Sciences were searched from inception until May 2023. Based on our search strategy (online supplemental eTable 1), two authors (AE and M-SZ) independently performed the literature search and screened the titles and abstracts. Then, the full texts of relevant articles and the reference lists of relevant meta-analyses were screened. There was no restriction on language, date or publication status.

Study selection and eligibility criteria

According to our a priori protocol,[24] we searched for studies that (1) had a longitudinal observational design with follow-up, including prospective and retrospective cohorts, nested case–control and case–cohort studies; (2) included a general population of adults aged ≥18 years; (3) considered walking speed, either measured by timed walking-pace test or self-reported, as an exposure; (4) considered the incidence of type 2 diabetes during follow-up as an outcome and (5) reported multivariable-adjusted effect size (relative risk (RR), risk ratio or HR) of type 2 diabetes across categories of walking speed. Retrospective case–control and cross-sectional studies, patient-based cohorts, as well as studies conducted on pregnant or breastfeeding women, were excluded.

Data extraction

Data extraction was conducted by two reviewers (M-SZ and AE), working independently and in duplicate. Disagreements were resolved by consulting the first author (AJ). Characteristics that were extracted from each study were: author name, study name, population country, number of participants and cases, age range or mean age, the proportion of women, exposure and outcome identification methods, follow-up duration, degree of statistical adjustment and reported effect estimates.

Risk of bias assessment

Risk of bias assessments was performed using the ROBINS-I tool.[25] Two reviewers (AE and M-SZ) independently performed the risk of bias assessments, with disagreements resolved through consensus when necessary. The domains of the ROBINS-I tool include assessment of potential biases due to confounding, selection of participants, exposure and outcome assessment, misclassification during follow-up, missing data and selective reporting of the results.

Statistical analysis

We used a random-effects model (DerSimonian and Laird method)[26] to calculate summary RRs and 95% CIs. HRs were considered equal to RRs.[27] According to our a priori protocol,[24] we performed pairwise meta-analyses to calculate RRs and 95% CIs of type 2 diabetes across categories of walking speed compared with the lowest speed as a reference. We first categorised walking speed into four prespecified categories[28 29]: easy or casual (<2 miles or 3.2 km/hour), average or normal (2–3 miles or 3.2–4.8 km/hour), fairy brisk (3–4 miles or 4.8–6.4 km/hour) and very brisk or brisk/striding (>4 miles or >6.4 km/hour). Second, we assigned each RR from the original cohorts to its corresponding predefined category.[30 31] If more than one category of walking speed from an original study fell into the same group in our meta-analysis, we pooled RRs using a fixed-effects model and used the pooled RR for that group. Conversely, if one category of walking speed from an original cohort covered more than one category in our meta-analysis, we assigned the RR of that category by its median. For studies in which the reference category was not the lowest one, we recalculated the RRs, assuming the lowest category as reference, according to the method by Hamling.[32 33] For studies that reported effect estimates across either sex, we combined sex-specific estimates using a fixed-effects model and used the combined effect estimate in the meta-analysis to include each cohort study only once in the meta-analysis. For studies that reported gait speed as steps/min, we converted steps/min to metres/min considering the average step length for men and women as 0.762 m and 0.670 m, respectively.[34 35] As compared with the lowest walking speed (easy or casual), summary RRs and 95% CIs of type 2 diabetes for all other categories of walking speed were estimated using a random-effects model.[26] To calculate the absolute risk (risk difference (RD)), we used the following formula: RD=baseline risk (RR−1).[36] Baseline risk was considered the average event rate in the included cohort studies. Publication bias was assessed using Egger's test[37] and by inspection of the funnel plots[21] when ≥10 studies were available. Heterogeneity was assessed using the Cochrane Q test and quantified by the I^2 statistic.[38 39]

To identify potential sources of heterogeneity in the data, we conducted influence analysis by removing one study at a time and performed prespecified and post hoc subgroup analyses. As per our a priori protocol,[24] we performed subgroup analyses when ≥5 studies were available for each association. P values for subgroup differences were generated using Cochran's Q test.[40] We performed prespecified subgroup analyses based on adjustment for the total volume of physical activity and time spent walking per day (yes vs no) and methods which were used for assessment of walking speed and diagnosis of type 2 diabetes (objective methods vs self-reported). We performed post hoc subgroup analyses based on the risk of bias (moderate vs serious), geographical region (USA, Europe and Asia), sex (male, female, both), follow-up duration (<8 (median) vs ≥8 years), number of events (<1000 (median) vs ≥1000) and adjustment (yes vs no) for smoking status, body mass index, alcohol drinking, blood pressure/hypertension and parenteral history of type 2 diabetes. We used the Instrument to assess the Credibility of Effect Modification ANalyses (ICEMAN) in our subgroup analyses.[41] The

domains of the ICEMAN tool and how to judge each domain are presented in online supplemental eTable 2. Finally, we performed dose–response meta-analyses to clarify the shape of the dose–response relationship and estimated the RR for each 1 km/hour increase in walking speed. We performed non-linear dose–response meta-analysis using a one-stage weighted mixed-effects meta-analysis.[42] We modelled walking speed by using restricted cubic splines with three knots of the distribution (10%, 50% and 90%).[43] For studies that did not report the number of participants and cases across categories of walking speed, we divided the number of participants by the number of categories to estimate the approximate number of participants in each category and calculated the approximate number of cases per category from the RRs using a similar method, as has previously been described.[44] Statistical analyses were conducted using STATA software, V.17.0. $P<0.05$ was considered statistically significant.

Grading the evidence

Two authors (AJ and M-SZ) judged the certainty of evidence according to the updated GRADE tool.[22 45] A detailed description of the GRADE domains is provided in online supplemental eText 1. We considered a 2% absolute risk reduction (20 fewer per 1000 patients), proposed by the GRADE working group for non-fatal outcomes,[46] as the threshold for minimally important difference. We adapted a recently published GRADE minimally contextualised approach to rate imprecision based on minimally important difference.[47 48] Accordingly, we considered whether the point estimate of effect size was greater than or less than the minimally important difference and whether the 95% CI overlapped with that threshold.

Equity, diversity and inclusion statement

The authors of the present meta-analysis were chosen on merit and came from a diverse range of backgrounds, occupations and levels of seniority. We also included studies from across the globe to increase the generalisability of the findings.

Patient and public involvement

Patients and the public were not involved in the development of this work.

RESULTS

Literature search and study selection process

Online supplemental eFigure 1 shows the systematic search and study selection process. After the exclusion of 638 duplicates and an additional 1684 records that were not eligible according to our inclusion criteria, we read the full text of 84 records; of those, 10 cohort studies were considered eligible for inclusion. Online supplemental eTable 3 presents the list of studies (n=74) that were excluded based on the review of the full texts with reasons for exclusions.

Characteristics of cohort studies

Ten prospective cohort studies with 18 410 cases among 508 121 participants proved eligible for the present meta-analysis (table 1).[28 29 49–56] The included cohort studies were conducted in the USA,[28 29 50 52–55] Japan[51 56] and the UK[49] and were published between 1999 and 2022. All studies were population-based cohort studies. Two cohorts were conducted in females,[29 54] two in males [28 56] and the remaining cohort studies in both males and females, wherein the proportion of females was between 52% and 73%. The follow-up duration of the cohort studies ranged from 3 to 11.1 years (median 8 years). Five cohort studies measured walking speed by timed walking-pace tests,[50 51 53 55 56] while the other five studies used self-reported questionnaires.[28 29 49 52 54] Seven cohorts used objective methods such as blood glucose measurement or linkage to medical records to ascertain cases of type 2 diabetes,[49–53 55 56] and three cohorts used self-reported questionnaires, which were validated by medical records and laboratory measures.[28 29 54] All studies controlled for age, sex and smoking status in their multivariable analyses, nine for alcohol drinking,[28 29 49–51 53–56] six for blood pressure/hypertension,[29 51–53 55 56] six for the total volume of physical activity,[29 49 51 53–55] five for body mass index,[28 49 51 55 56] four for time spent walking or step count per day[29 49 54 55] and four for the parental history of diabetes.[28 29 54 56] Three cohort studies were rated to have a moderate risk of bias based on the ROBINS-I tool,[51 53 55] and the other seven studies were rated to have a serious risk of bias.[28 29 49 50 52 54 56] The main reasons for the serious risk of bias were biases due to confounding and assessment of walking speed (online supplemental eTable 4).

Meta-analysis

Average or normal walking

Four cohort studies with 6520 cases of type 2 diabetes among 160 321 participants reported information on average or normal walking.[28 29 50 54] Compared with easy or casual walking (<2 miles or 3.2 km/hour), participants with average or normal walking (2–3 miles or 3.2–4.8 km/hour) were at a 15% lower risk of type 2 diabetes (RR=0.85, 95% CI 0.70 to 1.00, I^2=69%; RD=0.86 (95% CI 1.72 to 0) fewer cases per 100 patients; GRADE=low) (online supplemental eFigure 2). In the influence analysis removing each study at a time, the RR became significant when the Black Women's Health Study[54] was excluded from the analysis (RR=0.79, 95% CI 0.65 to 0.92; I^2=46%) (online supplemental eFigure 3).

Fairly brisk walking

Ten cohort studies with 18 410 cases among 508 121 participants reported information on fairly brisk walking.[28 29 49–56] Those with fairly brisk walking (3–4 miles/hour or 4.8–6.4 km/hour) were at a 24% lower risk of type 2 diabetes compared with those with easy or casual walking (RR=0.76, 95% CI 0.65 to 0.87, I^2=90%; RD=1.38 (95% CI 2.01 to 0.75) fewer cases per 100 patients, GRADE=low) (figure 1). The pooled RR remained significant and ranged from 0.73 (95% CI 0.62 to 0.83) to 0.79 (95% CI 0.70 to 0.88) in the influence analysis removing each study at a time (online supplemental eFigure 4).

Table 2 presents the subgroup analyses based on the study and participants' characteristics, and online supplemental eTable 5 presents the subgroup difference credibility assessment by the ICEMAN tool. We found two subgroup differences with moderate credibility based on methods that were used for the walking speed assessment and diagnosis of type 2 diabetes. As predicted in our a priori protocol, we found statistically significant stronger associations in cohort studies that used self-reported methods to assess walking speed and diagnosis of type 2 diabetes. Of note, the RRs were similar in a subgroup analysis based on whether or not studies controlled for the total volume of physical activity or time spent walking per day (table 1). The subgroup analyses suggested that additional adjustment for body mass index attenuated the results slightly. There was also a significant group difference by geographical region, where studies conducted in the USA and Europe indicated stronger associations than those conducted in Asia; however, the limited number of studies from Europe and Asia makes interpretation of these

Table 1 Characteristics of cohort studies included in the meta-analysis of walking speed and the risk of type 2 diabetes

Author, year, country	Cohort name (follow-up, years)	Participants/ cases	Age range (median or mean)	% female	Assessment of walking speed	Diagnosis of type 2 diabetes	Walking speed categories	Relative risk (95%CI)	Adjustments
Hu *et al*,[29] 1999 USA	Nurse's Health Study (8)	70 102/1419	40–65	100	Self-reported using mailed questionnaires	Self-reported, confirmed by laboratory measures	<3.2 km/hour 3.2–4.8 km/hour >4.8 km/hour	1.00 0.86 (0.73 to 1.01) 0.59 (0.47to 0.73)	Age, smoking status, alcohol drinking, menopausal status, parental history of diabetes, history of hypertension, history of high cholesterol level and time spent walking per day
Hu *et al*,[28] 2001 USA	Health Professionals' Follow-up Study (10)	37 918/1058	40–75	0	Self-reported using mailed questionnaires	Self-reported, confirmed by laboratory measures	<2 miles/hour 2–2.9 miles/hour 3–3.9 miles/hour >4 miles/hour	1.00 0.68 (0.58 to 0.85) 0.46 (0.39 to 0.59) 0.39 (0.31 to 0.51)	Age, smoking status, parental history of diabetes, alcohol drinking, body mass index and intakes of fatty acids and dietary fibres
Nakanishi *et al*,[56] 2004 Japan	Japanese male cohort (7)	2924/168	30–59 (46.5)	0	A 1-day activity record during an ordinary weekday	Blood glucose measurement	<4.68 km/hour 4.68–6.28 km/hour	1.00 0.87 (0.71 to 1.03)	Age, family history of diabetes, alcohol consumption, cigarette smoking, body mass index, weekly energy expenditure on physical exercise, systolic blood pressure, HDL cholesterol and triglycerides at study entry
Krishnan *et al*,[54] 2009 USA	Black Women's Health Study (10)	45 668/2928	21–69	100	Self-reported using questionnaires	Self-reported, validated by medical records	<2 km/hour 2–3.2 km/hour 3.2–4.8 km/hour >4.8 km/hour	1.00 1.12 (0.96 to 1.28) 0.99 (0.85 to 1.13) 0.74 (0.62 to 0.86)	Age, time period, family history of diabetes, years of education, family income, marital status, cigarette use, alcohol use, energy intake, coffee consumption, vigorous activity, television watching and walking
Joseph *et al*,[52] 2016 USA	Multi-Ethnic Study of Atherosclerosis (11.1)	5829/655	>18 (61.8)	54	Self-reported using questionnaires	Newly using hypoglycaemic medications or having fasting glucose ≥7 mmol/L (126 mg/dL) at one of four subsequent examinations	<2 miles/hour 2–4 miles/hour >4 miles/hour	1.00 0.76 (0.64 to 0.91) 0.67 (0.54 to 0.74)	Age, race, gender, education, current occupation status, study site, current smoking, systolic blood pressure and current hypertension medication use
Iwasaki *et al*,[51] 2021 Japan	Specific Health Check and Guidance System (3)	167 684/6229	40–74 (63.7)	61	Measured by trained staff at visits	Fasting plasma glucose ≥126 mg/dL or glycosylated haemoglobin ≥6.5%	80 m/min 100 m/min	1.00 0.93 (0.88 to 0.98)	Age, sex, body mass index, blood pressure, smoking status, alcohol drinking, weight gain and daily exercise
Boonpor *et al*,[49] 2022 UK	UK Biobank (7.4)	162 155/4442	37–73 (57)	55	A touch-screen questionnaire	Linkage to primary care data in the UK Biobank	Women: <3 miles/hour 3–4 miles/hour >4 miles/hour Men: <3 miles/hour 3–4 miles/hour >4 miles/hour	1.00 0.78 (0.69 to 0.88) 0.52 (0.44 to 0.62) 1.00 0.78 (0.71 to 0.85) 0.58 (0.50 to 0.67)	Age, ethnicity, deprivation index, education, smoking, fruit and vegetable intake, red meat intake, processed meat intake, alcohol intake, total sedentary time, sleep time, body mass index and time spent walking per day
Cuthbertson *et al*,[50] 2022 USA	Hispanic Community Health Study/ Study of Latinos (6)	6633/1115	18–75 (39)	52	Actical accelerometer during waking hours for 1 week	1. Self-reported use of diabetic medication, or 2. Laboratory-tested fasting plasma glucose >126 mg/dL, non-fasting plasma glucose of >200 mg/dL, 2-hour postload oral glucose tolerance test >200 mg/dL, or glycosylated haemoglobin ≥6.5%	<60 steps/min 60–80 steps/min 80–100 steps/min >100 steps/min	1.00 0.86 (0.64 to 1.16) 0.75 (0.55 to 1.02) 0.56 (0.35 to 0.89)	Age, sex, Latino background by field centre, education, married/ partner status, employment, years in the USA, self-rated general health, mobility limitations, cigarette pack years, alcoholic drinks per week, energy intake, AHEI-2010 and accelerometer wear time

Continued

Table 1 Continued

Author, year, country	Cohort name (follow-up, years)	Participants/ cases	Age range (median or mean)	% female	Assessment of walking speed	Diagnosis of type 2 diabetes	Walking speed categories	Relative risk (95%CI)	Adjustments
Kaplan *et al*,[53] 2022 USA	Framingham Heart Study (10.8)	4066/240	53.9	56	Actical version B-1 accelerometer, positioned above the iliac crest and worn for 7 days	1. A physician diagnosis of diabetes and the use of diabetes medications, based on self-reported information obtained at an annual telephone follow-up or an in-person cohort examination, or 2. Measured glycaemic traits at a follow-up study examination	0–90 steps/min 90–140 steps/min 140–200 steps/ min >200 steps/min	1.00 1.29 (0.88 to 1.88) 1.33 (0.86 to 2.04) 0.88 (0.53 to 1.46)	Age, sex, employment status, marital status, education, body mass index, lipid lowering treatment, hypertension, aspirin use, smoking status, alcohol drinking, diet quality and total physical activity
Master *et al*,[55] 2022 USA	All of the US Research Program (4)	5142/156	>18 (56.7)	73	Wearing the Fitbit for at least 10 hours per day and reporting at least 100 steps per day for 2 days	Electronic health records	<100 steps/min >100 steps/min	1.00 0.76 (0.58 to 0.98)	Age, race, sex, coronary artery disease, cancer, body mass index, systolic blood pressure, education level, smoking, alcohol use and step count per day

AHEI, Alternative Healthy Eating Index; HDL, high-density lipoprotein cholesterol.

subgroup results unclear.[41] We did not find evidence of publication bias with Egger's test (p=0.20), Begg's test (p=0.28) or by inspection of the funnel plot (online supplemental eFigure 5).

Brisk/striding walking

Six cohorts with 10 438 cases of type 2 diabetes among 262 269 participants reported information on brisk/striding walking (>4 miles or 6.4 km/hour).[28 49 50 52–54] The RR of type 2 diabetes was 0.61 (95% CI 0.49 to 0.73, I^2=81%; RD=2.24 (95% CI 2.93 to 1.55) fewer cases per 100 patients, GRADE=moderate) (figure 2). The RR remained significant and ranged from 0.57 (95% CI 0.46 to 0.69) to 0.66 (95% CI 0.54 to 0.78) when removing each cohort study at a time (online supplemental eFigure 6). Online supplemental eTable 6 presents the results of the subgroup analyses. We found two significant subgroup differences, where cohorts with a serious risk of bias reported a stronger association than those with a moderate risk of bias (RRs: 0.57 vs 1.05) and studies conducted in males reported a stronger association than those conducted in females (RR: 0.46 vs 0.75); however, the credibility of subgroup differences was rated low (online supplemental eTable 7). The results of the studies that reported the RRs both with and without adjustment for body mass index suggested that an additional adjustment for body mass index attenuated the strength of the association by 24%. There was no significant or credible subgroup difference by adjustment for the total physical activity or time spent walking per day.

Dose–response meta-analysis

Nine cohorts with 18 254 cases among 502 979 participants reported information for dose–response meta-analyses.[28 29 49–54 56] Each 1 km/hour increase in walking speed was associated with a 9% lower risk of type 2 diabetes in the linear dose–response analysis (RR: 0.91, 95% CI 0.88 to 0.94; I^2=87%, online supplemental eFigure 7). Dose–response analysis suggested a monotonic inverse association, wherein the risk of type 2 diabetes did not change significantly until reaching a walking speed of 4 km/hour (equal to 87 steps/min for men and 100 steps/min for women; $RR_{4km/hour}$= 0.86, (95% CI 0.74 to 0.99) and then decreased linearly up to a walking speed of 8 km/hour ($P_{non\text{-}linearity}$=0.10, $P_{dose\text{–}response}$<0.001; figure 3). Point-specific RRs of type 2 diabetes for different walking speeds are indicated in table 3.

Grading the evidence

We applied a minimally contextualised approach introduced by the GRADE working group to rate the certainty of the evidence.[47] The certainty of the evidence was rated low for average/normal and fairly brisk walking due to downgrades for very serious risk of bias, serious imprecision and serious inconsistency (online supplemental eTable 8). The certainty of the evidence was rated moderate for brisk/striding walking due to a double downgrade for a very serious risk of bias and an upgrade for the dose–response gradient. Of note, the magnitude of the absolute effect for brisk/striding walking surpassed the threshold set as the minimally important difference (20 fewer cases per 1000 patients),[46] suggesting that brisk/striding walking can exert an important reduction in the risk of type 2 diabetes.

DISCUSSION

In the present meta-analysis of prospective cohort studies, we gathered existing evidence on the association between walking speed and the risk of type 2 diabetes in adults. Our findings

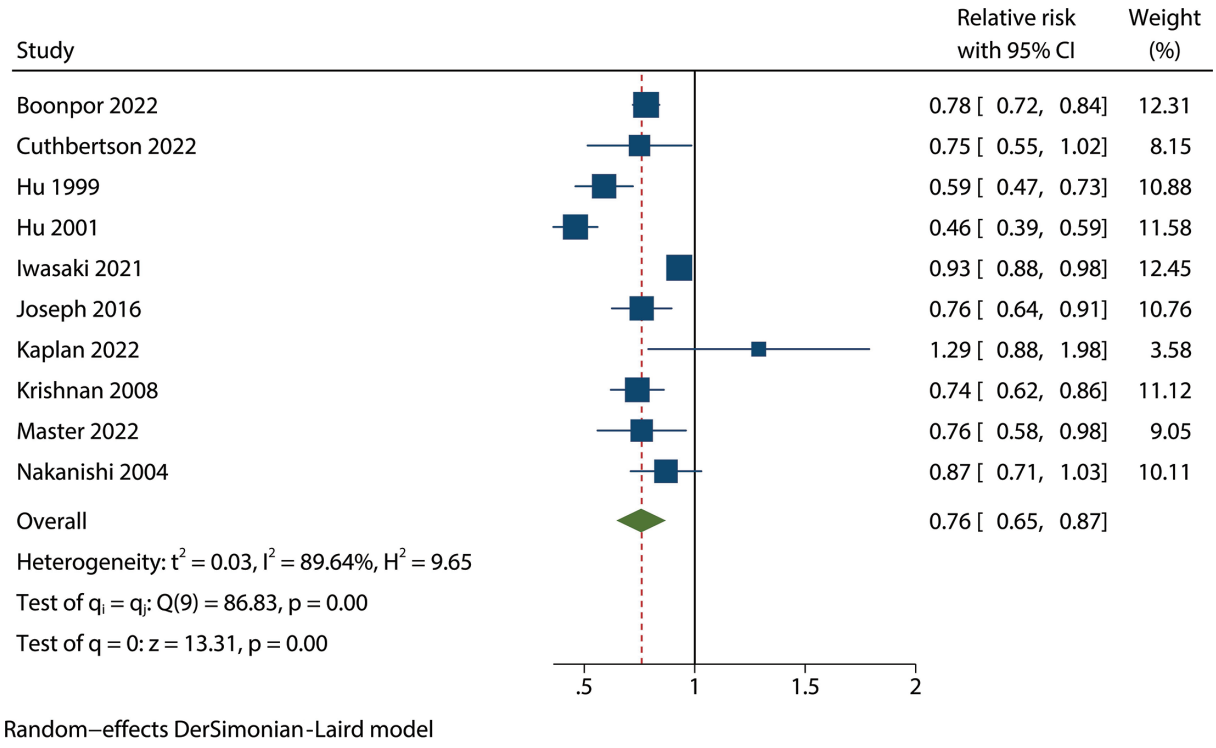

Figure 1 Relative risk of type 2 diabetes for fairly brisk walking compared with easy/casual walking.

from low certainty evidence suggested that average and fairly brisk walking were modestly associated with a lower risk of type 2 diabetes. We also found evidence of moderate certainty that brisk/striding walking was associated with a 39% lower risk of type 2 diabetes, equal to 2.24 fewer cases per 100 patients, surpassing the threshold set as the minimally important difference. Each 1 km/hour increase in walking speed was also associated with a 9% lower risk of type 2 diabetes.

We are not aware of any previous systematic review and meta-analysis on the association between walking speed and the risk of type 2 diabetes. A previous meta-analysis of eight prospective cohort studies suggested that compared with walking at an average speed of 1.6 km/hour, walking at an average speed of 5.6 km/hour was associated with a 44% lower risk of stroke.[16] Another meta-analysis of nine cohort studies suggested that compared with the lowest walking speed, the fastest walking speed was associated with a 47% lower risk of all-cause mortality in older adults.[20] Similar findings were found in a meta-analysis of 17 cohort studies, where the highest versus the lowest walking speed was associated with a 47% lower risk of cognitive decline and a 40% lower risk of dementia.[18] A recent individual participant data meta-analysis of 11 British cohorts indicated that compared with participants with slow walking, those with average and brisk/fast walking were at 20% and 24% lower risk of all-cause mortality and 24% and 21% lower risk of cardiovascular mortality, respectively.[57]

Potential mechanisms

There are several explanations for why walking at a fast speed is associated with a lower risk of type 2 diabetes. Most importantly, walking speed is an important indicator of overall health status and, indeed, is a vital sign for functional capacity.[14] Apparently healthy people who can walk briskly are more likely to participate in daily physical activity programmes.[58 59] Second, faster walking speed is associated with better cardiorespiratory fitness[60 61] which, in turn, is associated with a lower risk of type 2 diabetes.[62] Third, there is a positive correlation between walking pace and muscle strength. Muscle loss can result in low-grade systemic inflammation[63] and, thereby, may be associated with a higher risk of type 2 diabetes.[64] Fourth, increased exercise intensity due to faster walking speeds can result in a greater stimulus for physiological functions and better health status.[65] Fifth, intervention studies suggest that brisk walking can result in clinically important reductions in body weight, waist circumference and body fat mass[66] and improvements in insulin sensitivity.[67] The subgroup analyses of studies that reported results both with and without adjustment for body mass index suggested that additional adjustment for body mass index attenuated the strength of the association by 24%, suggesting that nearly a quarter of the risk reduction may be explained by reduced adiposity. This suggests that most of the impact of faster walking speed on type 2 diabetes may be independent of its effects on body weight.

Public health implications

The subgroup analyses of fairly brisk and brisk/striding walking indicated that there was no significant difference across subgroups defined based on whether or not studies adjusted for the total volume of physical activity and time spent walking per day, suggesting that walking pace, independent of the total volume of physical activity or step count per day, may be associated with a lower risk of type 2 diabetes. A recent evaluation within the UK Biobank prospective cohort study also indicated that the inverse associations between average and brisk walking and the risk of type 2 diabetes were consistent across different walking times.[49] This suggests that the speed at which individuals habitually walk may be as important as the total amount of time spent walking. Currently, there is no specific instruction for gait speed in current guidelines.[68–72] However, the 2018 physical activity guidelines for Americans suggested that brisk walking, as being representative of moderate-intensity aerobic activity,

Table 2 Subgroup analyses of the association between fairly brisk walking and the risk of type 2 diabetes

Variables	Cohorts (n)	Relative risk (95% CI)	I^2, $P_{heterogeneity}$	P subgroup difference
All cohorts	10	0.76 (0.65 to 0.87)	90%, <0.001	–
Risk of bias				0.05
Moderate	3	0.91 (0.74 to 1.08)	57%, 0.10	
Serious	7	0.70 (0.59 to 0.81)	84%, <0.001	
Region				<0.001
USA	7	0.70 (0.57 to 0.83)	78%, <0.001	
Europe	1	0.78 (0.72 to 0.84)	–	
Asia	2	0.92 (0.88 to 0.97)	0%, 0.48	
Sex				0.31
Male	3	0.66 (0.46 to 0.86)	93%, <0.001	
Female	3	0.74 (0.59 to 0.89)	76%, 0.02	
Both	5	0.82 (0.71 to 0.93)	63%, 0.02	
Follow-up duration				0.12
<8 years	6	0.83 (0.74 to 0.93)	75%, <0.001	
≥8 years	4	0.68 (0.52 to 0.85)	84%, <0.001	
Number of cases				0.25
<1000	4	0.83 (0.70 to 0.95)	39%, 0.18	
≥1000	6	0.71 (0.56 to 0.86)	94%, <0.001	
Walking speed assessment				0.01
Measured	5	0.88 (0.78 to 0.98)	43%, 0.14	
Self-reported	5	0.67 (0.53 to 0.80)	88%, <0.001	
Type 2 diabetes assessment				0.01
Medical records or measured	7	0.83 (0.75 to 0.92)	72%, <0.001	
Self-reported	3	0.59 (0.43 to 0.76)	84%, <0.001	
Adjustments				
Total physical activity per day				0.47
Yes	6	0.79 (0.67 to 0.91)	84%, <0.001	
No	4	0.70 (0.49 to 0.91)	88%, <0.001	
Time spent walking per day or step count per day				0.48
Yes	4	0.72 (0.46 to 0.81)	56%, 0.08	
No	6	0.80 (0.60 to 1.00)	93%, <0.001	
Body mass index				0.89
Yes	6	0.73 (0.58 to 0.88)	94%, <0.001	
No	6	0.72 (0.56 to 0.87)	89%, <0.001	
Smoking status				–
Yes	10	0.76 (0.65 to 0.86)	88%, <0.001	
No	0	–	–	
Alcohol drinking				–
Yes	10	0.76 (0.65 to 0.86)	88%, <0.001	
No	0	–	–	
Blood pressure				0.22
Yes	6	0.82 (0.68 to 0.96)	83%, <0.001	
No	4	0.68 (0.51 to 0.85)	90%, <0.001	
Family history of diabetes				0.10
Yes	6	0.83 (0.73 to 0.93)	76%, <0.001	
No	4	0.66 (0.48 to 0.83)	87%, <0.001	
Studies that reported relative risk both before and after adjustment for body mass index				0.57
Yes	2	0.69 (0.51 to 0.88)	85%, 0.01	
No	2	0.58 (0.25 to 0.92)	97%, <0.001	

can reduce the risk of chronic disease and other adverse health outcomes.[73] Our results therefore provide some support for the incorporation of walking speed into physical activity guidelines.

The magnitude of the absolute risk reduction in the analysis of brisk/striding walking was also larger than the threshold set by the GRADE working group as the minimally important difference for non-fatal outcomes (2 fewer cases per 100 patients),[46] suggesting that brisk/striding walking can result in an important reduction in the risk of type 2 diabetes. However, it is unclear whether walking speed is an indicator of health status or a causal factor. If confirmed by future trials, the findings of the present meta-analysis may indicate that while strategies to increase total

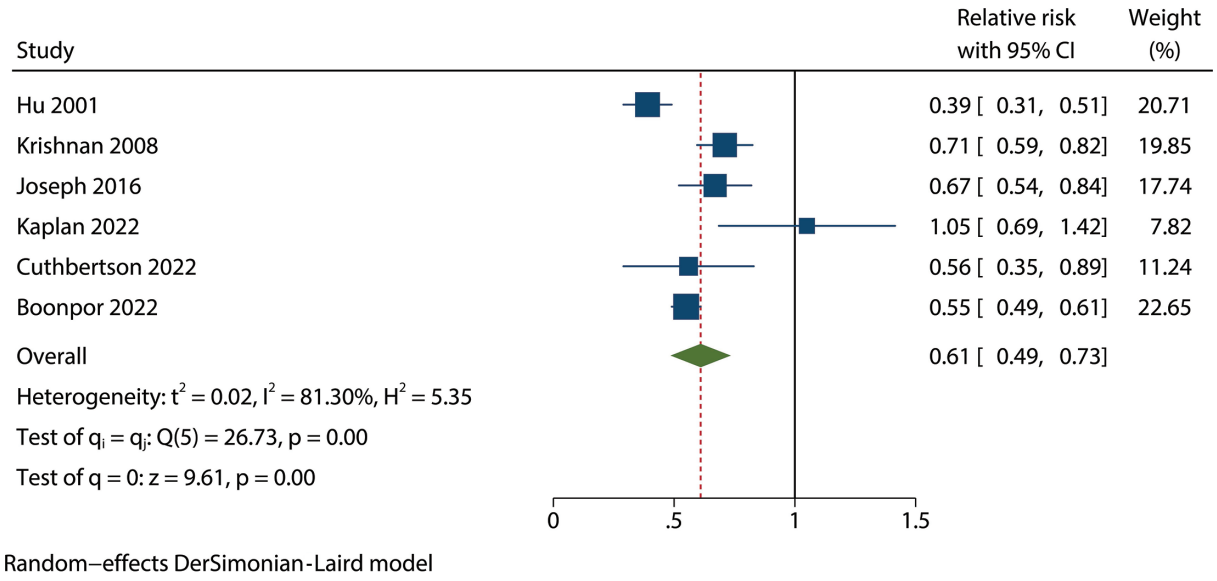

Figure 2 Relative risk of type 2 diabetes for brisk/striding walking compared with easy/casual walking.

walking time, which is currently a priority, are beneficial, it might also be reasonable to encourage people to walk at faster speeds, based on the capability of the individuals, to further increase the health benefits of walking. It is possible that faster walking, as being representative of a high intensity of physical activity, will have more favourable effects on diabetes risk reduction than slow walking.[74] The non-linear dose–response meta-analysis reported supportive evidence, where the risk of type 2 diabetes decreased proportionally with the increase in walking speed up to 8 km/hour. Conversely, if these findings are not confirmed by future trials and, thus, are indicated not to be causal, the findings suggest that walking speed may be a valuable tool to predict the future risk of type 2 diabetes in adults.

Our subgroup analyses of fairly brisk walking also indicated that there was a significant and credible subgroup difference based on the method of walking speed assessment, where cohort studies that used timed walking-pace tests reported a weaker association than those that used self-reported questionnaires. This should be considered when interpreting the magnitude of the association between fairly brisk walking and the risk of type 2 diabetes. However, the results remained statistically significant in the subgroup of cohorts which used time walking-pace tests.

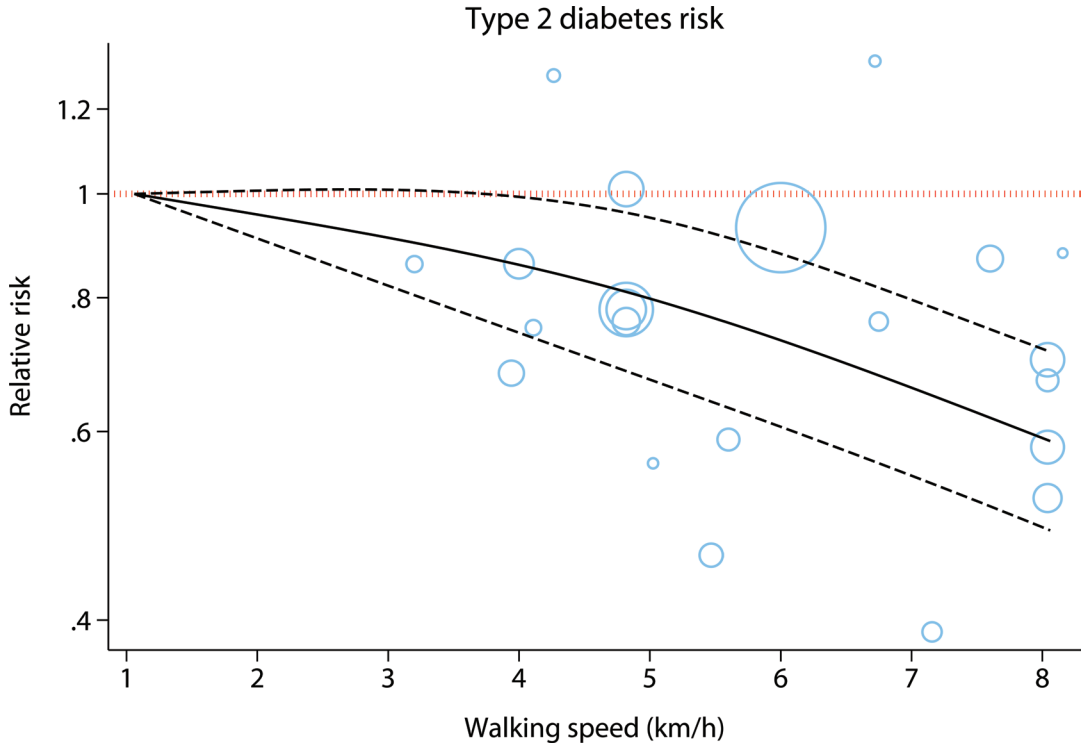

Figure 3 Dose–response association between walking speed and the risk of type 2 diabetes. The solid line represent non-linear dose–response and dashed lines represent 95% CI. Circles represent relative risk point estimates for walking speed category from each study with circle size proportional to inverse of SE.

Table 3 The relative risk of type 2 diabetes for different walking speeds obtained from the non-linear dose–response meta-analysis

Walking speed (km/hour)	1 (Ref)	2	3	4	5	6	7	8
Steps/min (average)	22 (M)/25 (F)	44 (M)/50 (F)	66 (M)/75 (F)	87 (M)/100 (F)	109 (M)/125 (F)	131 (M)/150 (F)	153 (M)/175 (F)	175 (M)/200 (F)
Relative risk (95% CI)	1.00	0.96 (0.91 to 1.01)	0.91 (0.82 to 1.01)	0.86 (0.74 to 0.99)	0.80 (0.67 to 0.95)	0.73 (0.61 to 0.88)	0.66 (0.55 to 0.80)	0.59 (0.49 to 0.72)

F, female; M, male.

In addition, the subgroup analyses of brisk/striding walking did not indicate such a significant subgroup difference. Nevertheless, the self-reported approaches to assess walking pace should be further investigated in future studies to reach more confident conclusions.

Dose–response association

Our dose–response analyses indicated a monotonic inverse association, wherein the risk did not change significantly until walking speed of 4 km/hour. The risk of type 2 diabetes decreased linearly within walking speed of 4–8 km/hour. Subject to the limitations, such as aggregation bias, our results suggested that the slowest walking speed to reduce the risk of type 2 diabetes is about 4 km/hour, equal to 87 steps/min for men and 100 steps/min for women and that faster gait speeds may confer additional benefits in a dose-dependent manner.

Strengths and limitations

The present meta-analysis has some strengths, which may increase the generalisability of the findings. Based on our strictly reported a priori approach,[24] we included cohort studies, which allows us to consider the temporal sequence of exposure and outcome and which are less affected by recall and selection biases than retrospective case–control studies, and increases the likelihood of causality. Based on previous research,[28 29] we created a priori-defined walking speed categories and performed random-effects meta-analyses to assess the association between different walking speeds and the risk of type 2 diabetes. We also performed several subgroup analyses, assessed the credibility of subgroup differences using the recently developed ICEMAN tool, calculated both relative and absolute risks and rated the certainty of evidence using the GRADE approach.

There were also several shortcomings which need further evaluation in future research and should be considered when interpreting the results. First, most of the studies included in the present review were rated as having a serious risk of bias and there were significant differences across subgroups defined by study risk of bias. The most important biases were due to inadequate adjustment for potential confounders and the methods used for walking speed assessment and diagnosis of type 2 diabetes. However, the subgroup analyses indicated persistent inverse associations across subgroups defined by important effect modifiers. Second, our findings could have been subject to reverse causality bias since participants with faster walking speed are more likely to perform more physical activity and have better cardiorespiratory fitness, greater muscle mass and better health status. However, the subgroup analyses of fairly brisk and brisk/striding walking indicated that there were no significant subgroup differences by follow-up duration and that the significant inverse associations remained stable in the subgroup of cohort studies with a follow-up duration of >10 years. This suggests that the impact of reverse causation is less likely to have affected the result as it would most likely have the most impact early in the follow-up. Third, although the subgroup analyses by adjustment for the total volume of physical activity or time spent per day did not indicate significant subgroup differences, the potential impacts of residual confounding should be considered.

CONCLUSION

To conclude, the present meta-analysis of cohort studies suggested that fairly brisk and brisk/striding walking, independent of the total volume of physical activity or time spent walking per day, may be associated with a lower risk of type 2 diabetes in adults. While current strategies to increase total walking time are beneficial, it may also be reasonable to encourage people to walk at faster speeds to further increase the health benefits of walking.

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Contributors AJ conceptualised and designed the study, drafted the initial manuscript, coordinated and supervised data collection, analysed the data and reviewed and revised the manuscript. AE and M-SZ screened articles, abstracted data, drafted the manuscript and reviewed and provided relevant intellectual content. DA critically revised the manuscript. AJ was responsible for the overall content as guarantor. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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