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Active commuting and the risk of obesity, hypertension and diabetes: a systematic review and meta-analysis of observational studies

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ABSTRACT

Active commuting may hold a potential for preventing adverse health outcomes. However, evidence of the association of active commuting and the risk of health outcomes remains debatable. The current study systematically and quantitatively summarised research findings on the association between active commuting and the risk of the mentioned health outcomes. We comprehensively searched four databases (PubMed, EMBASE, Web of Science and Open Grey) from inception to 2 August 2020 for observational studies investigating the associations among adult population. Summary relative risks (RRs) and 95% CIs were estimated for the association. Heterogeneity was investigated using Cochran's *Q* test and the I^2 statistic. Restricted cubic splines were used to evaluate linear and nonlinear relations. The search yielded 7581 initial references. We included 28 articles in the meta-analysis. Compared with inactive commuting, active commuting reduced the risk of obesity (RR=0.88, 95% CI 0.83 to 0.94, I^2=69.1%), hypertension (RR=0.95, 95% CI 0.87 to 1.04, I^2=82.2%) and diabetes (RR=0.82, 95% CI 0.76 to 0.90, I^2=44.5%). Restricted cubic splines showed linear associations between active commuting and obesity, hypertension and diabetes ($P_{nonlinearity}$=0.640; $P_{nonlinearity}$=0.886; $P_{nonlinearity}$=0.099). As compared with the lowest active commuting group, the risk of obesity, hypertension and diabetes in the highest active commuting group were reduced by 13% (95% CI 0.82 to 0.93, I^2=65.2%); 6% (95% CI 0.86 to 1.02, I^2=75.2%) and 19% (95% CI 0.73 to 0.91, I^2=49.8%) respectively. Active commuting seemed to be associated with lower risk of obesity, hypertension and diabetes. However, the results should be interpreted cautiously because this meta-analysis was based solely on observational studies.

PROSPERO registration number CRD42020202723.

Key questions

What is already known?

- The results of previous systematic review disclosed that active commuting might reduce the risk of diabetes.

What are the new findings?

- Active commuting seemed to be associated with lower risk of obesity, hypertension, and diabetes.
- Linear associations between active commuting and obesity, hypertension, and diabetes.
- Different types of active commuting such as commute on foot or by bicycle are related to reduced obesity, hypertension, and diabetes.

What do the new findings imply?

- Health professionals, stakeholders and policy planners are called to improve infrastructure in such a way that it supports a healthy lifestyle, promotes active commuting as a part of national and global strategies for the prevention of these adverse health.

INTRODUCTION

While the world is in rapid epidemiological and demographic transitions, noncommunicable diseases (NCDs) continues to be one of the leading causes of deaths, contributing to 73.4% of mortality in the year 2017.[1] Moreover, NCDs have been reported to increasingly cause morbidity, disability and hence reduces the quality of lives.[2–4] NCDs including obesity, hypertension and diabetes are expanding threats to global health despite the fact that some of their behavioural risk factors can be substantially avoidable.[5] This increased prevalence of NCDs may be attributed primarily to changes in people's lifestyles as well as technological advancements.[6] Therefore, multisectoral, innovative and targeted interventions are urgently needed to manage the high burden and the vast impact of NCDs.

Although large and consistent evidences suggested that physical activity is vital for the health and well-being of the public,[7–11] the prevalence of physical activity continues declines in worldwide with the massive adoption of private motorised transport in

addition to an increasing rate of sedentary occupations and busy life schedules.[12] Commuting actively on foot or by bicycle in general offers a comparatively more effective way of integrating physical activity into a sedentary lifestyle.[13] Laverty *et al* suggested that active commuting decreased the risk of obesity, hypertension and diabetes[14] whereas Hu *et al* revealed contradicting findings.[15] To the best of our knowledge, there are no meta-analyses conducted on the association of active commuting and risk of obesity and hypertension to date. There is only one recent systematic review that included four studies to evaluate the association between active commuting and diabetes incidence.[16] However, up to eight more observational studies[14 17–25] have been published on the associations of active commuting and risk of diabetes, showing inconsistent results. Moreover, the dose–response meta-analyses on the association of active commuting and obesity, hypertension and diabetes are also underexplored in the existing scientific literature. In addition, it is not clear whether other types of active commuting such as commute on foot or by bicycle are related to reduced obesity, hypertension and diabetes.

We, therefore, conducted a comprehensive meta-analysis to examine whether active commuting is independently associated with the reduced risk of obesity, hypertension and diabetes, based on observational studies.

METHODS

Search strategy

We reported our meta-analysis in accordance to the meta-analysis of observational studies in epidemiology) statement[26] and registered our protocol on 30 August 2020. We systematically searched through PubMed, EMBASE, Web of Science and Open Grey databases from inception to 2 August 2020, without language restrictions, with terms related to active commuting, obesity, hypertension and diabetes. The summary of search strategy and results are shown in online supplemental table 1. In addition, the reference lists of eligible studies for additional articles were also reviewed to avoid missing any relevant publication.

Patient and public involvement

Patients were not involved in this study.

Study selection

Two researchers (QL and YM) independently screened, titles and abstracts of identified citations from EndNote library and, subsequently, the full texts of potentially eligible studies. Any disagreement was resolved through discussion and consensus with the principal investigator (JW). Studies were included if (1) they were population-based studies, (2) the study participants were adults (aged ≥18 years), (3) the exposure was active commuting (including walking and bicycling, bicycling and walking), and the outcome was obesity (defined by body mass index (BMI), or waist circumstance (WC)), hypertension or diabetes, (4) they reported ORs, relative risks (RRs) or HRs with 95% CIs, (5) for dose–response meta-analysis, at least three levels of active commuting at baseline were provided, active commuting level-specific obesity, hypertension or diabetes, and enough participants or sufficient data to derive these data. If multiple articles based on the same study were published, we chose the most informative one or with the largest sample size or the longest time of follow-up. We excluded letters, comments, reviews, meta-analyses and ecological studies. We also excluded studies performed on children or adolescents. In addition, studies that considered other obesity index, as waist-to-height ratio and those that considered visceral fat as the exposure, rather than BMI or WC, were excluded. Moreover, studies with insufficient data were excluded.

Data extraction

Two researchers (QL and YM) independently conducted eligibility and quality assessment and extracted data from eligible studies by using standard data extraction form. Any disagreement was resolved via discussion and consensus with the principal investigator (JW). From each eligible article, we extracted the first author, publication year, study site, the study title, study design, sample size, number of cases, duration of follow-up, sex, mean or median age range of study participants, exposure variables, method used for assessing exposure, definition and assessment of interested outcomes, comparison categories and relevant effect sizes of comparison categories together with 95% CIs and confounding variables adjusted for the statistical analysis. When the data were reported for men and women separately, we considered each part as a distinct study. If an included study reported several risk estimates, we extracted the fully adjusted effect sizes.

Quality assessment

The methodological quality of the cross-sectional studies included was assessed using an 11-item checklist recommended by Agency for Healthcare Research and Quality.[27] An item would be scored '0' if it was answered 'no' or 'unclear'. When an item was answered 'yes', then it scored '1'. Scores of 0–3, 4–7 and 8–11 were categorised as low, moderate and high quality, respectively (online supplemental table 3). We used the Newcastle-Ottawa Scale (NOS)[28] to assess the quality of the included cohort studies, in which a study is judged based on section (four items), comparability (two items) and outcome (three items). The score of NOS was ranging from 0 to 9. Articles' quality was assessed as follows: poor quality=0–3; fair quality=4–6; good quality=7–9 (online supplemental table 4).

Data synthesis and analysis

The units of active commuting reported as min/day were converted to min/week for the dose–response meta-analyses. For studies reporting risk estimates relative to the active commuting, the risk estimates were

recalculated by setting the inactive commuting as the reference. We assumed that the HRs/ORs were approximately equal to the RRs for studies reporting HRs/ORs for active commuting.[29] The missing number of cases in each category was calculated by using the reported RRs and number of total cases.[30] If the number of exposed participants was not reported for each category, categories were assumed to be equal size.[30] For each study, the median or mean active commuting in each category was assigned to the corresponding RRs.[30] If the median or mean active commuting per category was not provided, the midpoint of the lower and upper boundaries in each category was used as the mean active commuting exposure.[30] The interval width was assumed to be the same as the closest category if the highest or lowest category for active commuting was open ended.[31]

If an article reported data separately for different categories of active commuting, we used the random-effects model to calculate article-specific RRs, then used the calculated article-specific RRs in the meta-analysis for the association of active commuting versus inactive commuting. Summary RRs and 95% CIs for obesity, hypertension or diabetes for the highest versus lowest level of active commuting were estimated by using a random-effects model.[32] We used the generalised least squares regression to estimate study-specific dose–response associations[33] and the random-effects model to pool the study-specific dose–response RRs.[32] Study-specific RRs estimates were calculated for per 60 min/week increase in active commuting. Moreover, we included studies reporting risk estimates for at least three exposure levels and obesity, hypertension, diabetes or to examine possible linear or nonlinear dose–response associations by modelling active commuting with restricted cubic splines, with three knots at the 25th, 50th and 75th percentiles of the distribution. The p value for nonlinearity ($P_{\text{nonlinearity}}$) was calculated by testing the null hypothesis that the coefficient of the second spline is equal to 0.[29]

Cochran's Q test and the I^2 statistic[34] were used to test for heterogeneity. p<0.1 was considered statistically significant for the Q statistic while I^2 values of approximately 25%, 50% and 75% were considered low, moderate and high heterogeneity, respectively. Subgroup analyses were stratified by sex, region (Asia, Africa, Europe, America and Oceania), study design (cross-sectional study and cohort study), active commuting (walking and bicycling, bicycling and walking), outcome assessment (self-reported, measured and doctor diagnosis) and adjustments (eg, age, sex, smoking, alcohol consumption, energy intake and physical activity). We performed a sensitivity analysis by excluding one study at a time to evaluate whether the removal of studies with weak internal validity, high selection bias, inappropriate consideration for confounders and inappropriate data collection methods influenced the pooled effect size. Publication bias (small study effect) was evaluated by the funnel plots for asymmetry and formally used Egger's linear regression test.[35] Trim and fill method used to correct the publication bias if publication bias was detected. All analyses were performed with Stata V.12.1 (Stata Corp, College Station, Texas, USA). All tests were two sided, p<0.05 was considered statistically significant.

RESULTS

Characteristics of included studies

Of 7581 initial references, we retrieved 28 full-text articles for meta-analysis (figure 1). A total of 21 articles (128 331 participants) reported the association between active commuting and obesity; 13 articles (251 948 participants) provided the association between active commuting and hypertension; 13 articles (176 229 participants) reported the association between active commuting and diabetes. Details of the characteristics of the included studies are presented in online supplemental table 2. All studies were graded as having good quality. Details of the quality assessment of the cross-sectional studies are presented in online supplemental table 3 and the cohort studies in online supplemental table 4.

Association of active commuting and obesity

We included 16 articles (39 studies) that provided the association between active commuting and obesity. Compared with inactive commuting, active commuting reduced the risk of obesity (RR=0.88, 95% CI 0.83 to 0.94, I^2=69.1%) (figures 2 and 3). Sensitivity analysis suggested that the pooled risk was substantially unchanged after excluding one study at a time (data not shown). Both Eegg's test (p=0.292) and funnel plots (online supplemental figure 1) indicated no evidence of publication bias. For subgroup analyses, the size or direction of the pooled estimates was robust in most results. However, the RR of the association between active commuting and obesity for Oceania was 1.02 (95% CI 0.55 to 1.89) (table 1). A total of 21 articles (49 studies) were included to explore the association of highest versus lowest active commuting and obesity. As compared with the lowest active commuting group, with the highest active commuting, the risk of obesity was reduced by 13% (95% CI 0.82 to 0.93, I^2=65.2%) (figures 2 and 3). The pooled risk was substantially unchanged by sensitivity analysis (data not shown). There is no evidence of asymmetry by funnel plots hence suggesting no publication bias (online supplemental figure 2). Publication bias was not found by Eegg's test too (p=0.928). Moreover, we pooled four articles (11 studies) to analyse the dose–response association. For each 60 min/week increase in active commuting, the risk of obesity was reduced by 1% (RR=0.99, 95% CI 0.94 to 1.03, I^2=70.6%) (figures 2 and 3). Sensitivity analysis suggested that the pooled risk was substantially unchanged after excluding one study at a time (data not shown). Publication bias was investigated by the Egger's test (p=0.039) and funnel plot indicated that the publication bias might underestimate the effect of active commuting on obesity (online supplemental figure 3). The trim and fill method showed that

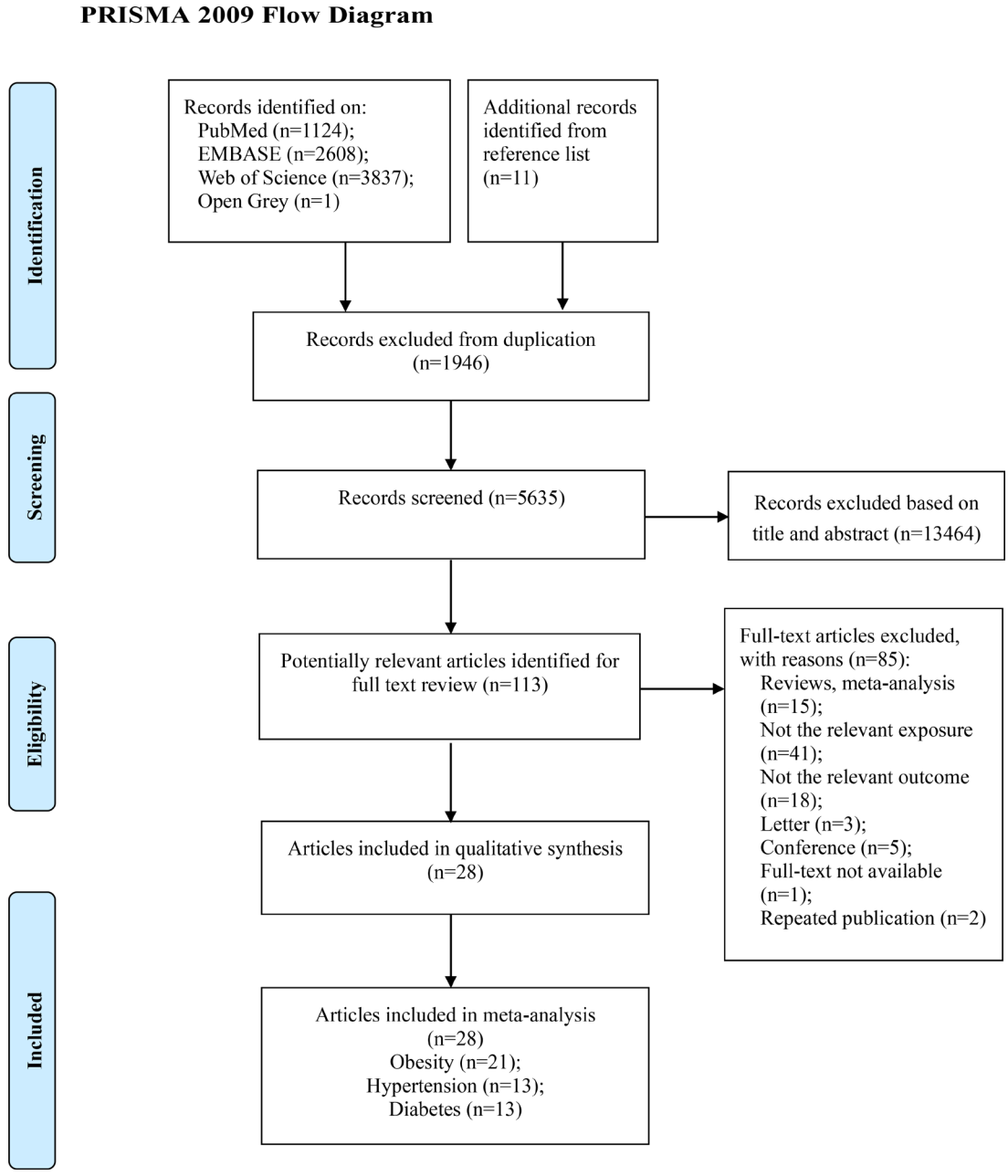

Figure 1 Flowchart of study selection.

the main result was altered (RR=0.92, 95% C: 0.87 to 0.97). For subgroup analyses, the size or direction of the pooled estimates was robust in most results. However, the RR of the association between active commuting and obesity for Asia was 1.05 (95% CI 0.99 to 1.12) and for study without adjustment for alcohol consumption was 1.02 (95% CI 0.87 to 1.19) (table 2). Furthermore, we included four articles (11 studies) in the restricted cubic splines model to indicate a linear association between active commuting and obesity ($P_{\text{nonlinearity}}$=0.640) (online supplemental figure 4).

Association between active commuting and hypertension

We included nine articles (15 studies) that provided the association between active commuting and hypertension. Compared with inactive commuting, active commuting reduced the risk of hypertension (RR=0.95, 95% CI 0.87 to 1.04, I^2=82.2%) (figures 2 and 4). Sensitivity analysis suggested that the pooled risk was substantially unchanged after excluding one study at a time (data not shown). Both Egg's test (p=0.189) and funnel plots (online supplemental figure 5) indicated no evidence of publication bias. For subgroup analyses, the size or direction of the pooled estimates was robust in most results. However, the RR of the association between active commuting and hypertension was 1.13 for women (95% CI 1.07 to 1.20) and 1.08 for men without adjusted for sex (95% CI 1.02 to 1.15) (table 1). To explore the association of highest versus lowest active commuting and hypertension, 13 articles (19 studies) were included. As compared with the lowest active commuting group, with the highest

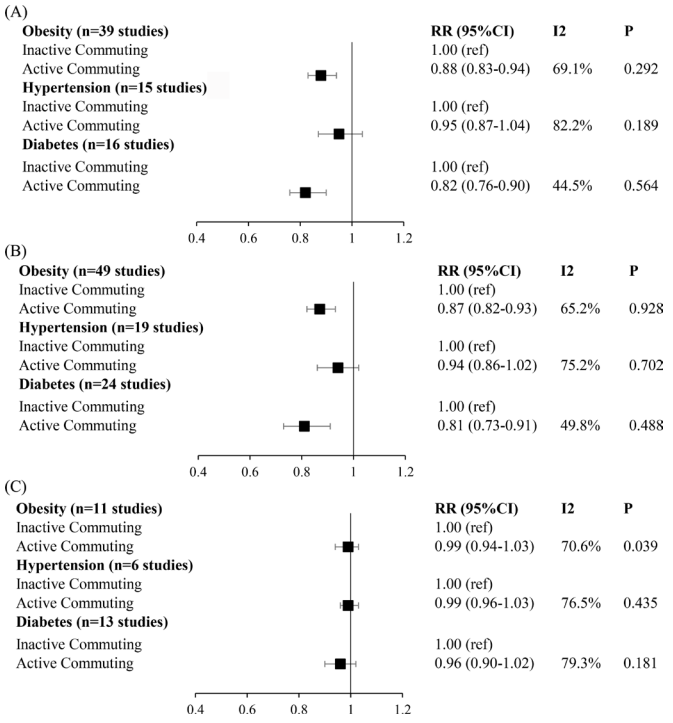

Figure 2 Association between active commuting and obesity, hypertension, and diabetes. (A) active/inactive; (B) high/low; (C) per 60 min/week increase.

active commuting, the risk of hypertension was reduced by 6% (95% CI 0.86 to 1.02, I^2=75.2%) (figures 2 and 4). The pooled risk was substantially unchanged by sensitivity analysis (data not shown). Publication bias was not found by Eegg's test (p=0.702) and funnel plots (online supplemental figure 6). Moreover, we pooled five articles (six studies) to analyse the dose–response association. For each 60 min/week increase in active commuting, the risk of hypertension was reduced by 1% (RR=0.99, 95% CI 0.96 to 1.03, I^2=76.5%) (figures 2 and 4). Sensitivity analysis suggested that the pooled risk was substantially unchanged after excluding one study at a time (data not shown). Publication bias was not investigated by the Egger's test (p=0.435) and funnel plots (online supplemental figure 7). For subgroup analyses, the size or direction of the pooled estimates was robust in most results. However, the RR of the association between active commuting and hypertension for women was 1.03 (95% CI 1.01 to 1.06) (table 2). Furthermore, we included five articles (six studies) in the restricted cubic splines model to indicate a linear association between active commuting and hypertension ($P_{\text{nonlinearity}}$=0.886) (online supplemental figure 8).

Association between active commuting and diabetes

We included nine articles (16 studies) that provided the association between active commuting and diabetes. Compared with inactive commuting, active commuting was found to reduce the risk of diabetes (RR=0.82, 95% CI 0.76 to 0.90, I^2=44.5%) (figures 2 and 5). Sensitivity analysis suggested that the pooled risk was substantially

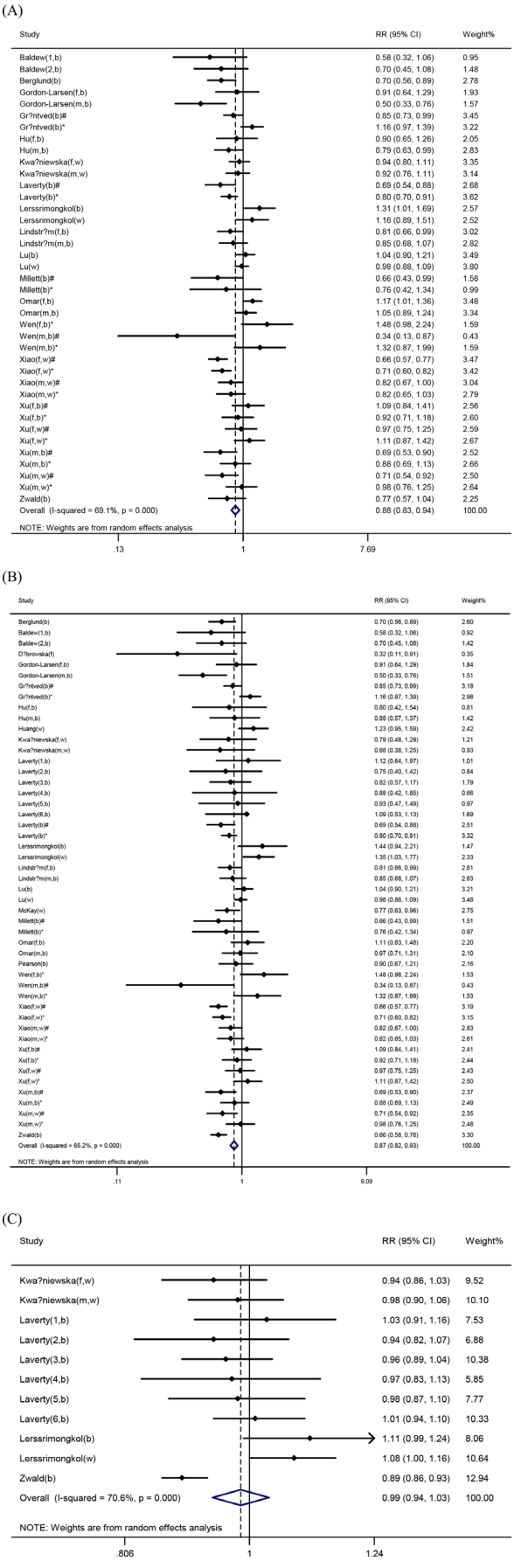

Figure 3 Forest plot summary of associations between active commuting and obesity. (A) active/inactive; (B) high/low; (C) per 60 min/week increase.

Table 1 Subgroup analyses of active commuting and risk of obesity, hypertension and diabetes

Subgroups	Number of studies	Obesity			Number of studies	Hypertension			Number of studies	Diabetes		
		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P
Sex												
Men and women	14	0.89 (0.79 to 0.99)	70.8%	<0.0001	9	0.87 (0.78 to 0.97)	77.6%	<0.0001	8	0.77 (0.66 to 0.90)	64.0%	0.007
Men	12	0.84 (0.76 to 0.93)	55.6%	0.008	3	1.02 (0.97 to 1.09)	0.0%	0.610	4	0.97 (0.82 to 1.14)	0.0%	0.957
Women	13	0.93 (0.82 to 1.07)	77.7%	<0.0001	3	1.13 (1.07 to 1.20)	0.0%	0.805	4	0.81 (0.68 to 0.96)	0.0%	0.710
Region												
Asia	21	0.88 (0.81 to 0.96)	67.9%	<0.0001	6	0.93 (0.73 to 1.18)	81.2%	<0.0001	8	0.91 (0.80 to 1.03)	10.1%	0.352
Africa	1	0.70 (0.45 to 1.08)	–	–	–	–	–	–	–	–	–	–
Europe	11	0.90 (0.81 to 1.00)	72.9%	<0.0001	6	0.93 (0.83 to 1.04)	72.1%	0.003	7	0.79 (0.69 to 0.91)	41.1%	0.117
America	3	0.72 (0.53 to 0.99)	58.3%	0.091	3	0.98 (0.84 to 1.15)	91.4%	<0.0001	1	0.69 (0.59 to 0.80)	–	–
Oceania	3	1.02 (0.55 to 1.89)	74.7%	0.019	–	–	–	–	–	–	–	–
Expose												
Active commuting	18	0.91 (0.84 to 1.00)	63.9%	<0.0001	9	1.05 (0.96 to 1.15)	75.8%	<0.0001	7	0.89 (0.76 to 1.04)	58.8%	0.024
Bicycling	10	0.78 (0.69 to 0.87)	57.6%	0.012	3	0.72 (0.54 to 0.97)	78.4%	0.010	5	0.74 (0.67 to 0.82)	0.0%	0.425
Walking	11	0.95 (0.83 to 1.08)	69.4%	<0.0001	3	0.85 (0.78 to 0.94)	0.0%	0.724	4	0.80 (0.64 to 1.00)	29.1%	0.237
Outcome assessment												
Self-reported	29	0.90 (0.77 to 1.06)	78.3%	<0.0001	2	0.81 (0.71 to 0.94)	0.0%	0.605	2	0.58 (0.43 to 0.77)	0.0%	0.610
Measured	10	0.88 (0.82 to 0.94)	65.5%	<0.0001	11	1.01 (0.93 to 1.10)	80.8%	<0.0001	9	0.88 (0.77 to 1.01)	50.5%	0.040
Doctor diagnosis	–	–	–	–	2	0.62 (0.42 to 0.93)	60.8%	0.110	5	0.77 (0.70 to 0.85)	0.0%	0.547
Obesity												
General obesity	27	0.88 (0.81 to 0.96)	68.7%	<0.0001	–	–	–	–	–	–	–	–
Abdominal obesity	12	0.88 (0.79 to 0.97)	71.2%	<0.0001	–	–	–	–	–	–	–	–
Adjustment												
Age												
Yes	39	0.88 (0.83 to 0.94)	69.1%	<0.0001	15	0.95 (0.87 to 1.04)	82.2%	<0.0001	16	0.82 (0.74 to 0.90)	44.5%	0.029
No	–	–	–	–	–	–	–	–	–	–	–	–
Sex												
Yes	14	0.89 (0.79 to 0.99)	70.8%	<0.0001	9	0.87 (0.78 to 0.97)	77.6%	<0.0001	8	0.77 (0.66 to 0.90)	64.0%	0.007
No	25	0.88 (0.81 to 0.96)	68.8%	<0.0001	6	1.08 (1.02 to 1.15)	29.6%	0.213	8	0.89 (0.79 to 1.00)	0.0%	0.810
Smoking												

Continued

Table 1 Continued

Subgroups	Number of studies	Obesity			Number of studies	Hypertension			Number of studies	Diabetes		
		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P
Yes	22	0.90 (0.83 to 0.97)	57.7%	<0.0001	10	0.94 (0.83 to 1.07)	81.0%	<0.0001	9	0.80 (0.72 to 0.89)	29.5%	0.183
No	17	0.87 (0.78 to 0.97)	77.9%	<0.0001	5	0.97 (0.88 to 1.08)	81.0%	<0.0001	7	0.81 (0.66 to 0.99)	55.9%	0.034
Alcohol												
Yes	22	0.85 (0.79 to 0.92)	60.5%	<0.0001	10	0.97 (0.87 to 1.07)	81.6%	<0.0001	9	0.81 (0.74 to 0.89)	5.4%	0.390
No	17	0.93 (0.84 to 1.03)	73.2%	<0.0001	5	0.93 (0.78 to 1.10)	82.9%	<0.0001	7	0.79 (0.65 to 0.97)	67.7%	0.005
Energy intake												
Yes	20	0.89 (0.82 to 0.97)	71.0%	<0.0001	6	0.89 (0.76 to 1.04)	81.6%	<0.0001	9	0.81 (0.74 to 0.89)	5.4%	0.390
No	19	0.87 (0.79 to 0.97)	68.6%	<0.0001	9	0.99 (0.89 to 1.09)	81.4%	<0.0001	7	0.79 (0.65 to 0.97)	67.7%	0.005
Physical activity												
Yes	32	0.89 (0.82 to 0.96)	67.1%	<0.0001	11	0.95 (0.85 to 1.06)	79.2%	<0.0001	14	0.84 (0.76 to 0.93)	39.8%	0.062
No	7	0.86 (0.74 to 1.00)	79.0%	<0.0001	4	0.96 (0.84 to 1.10)	85.0%	<0.0001	2	0.58 (0.43 to 0.77)	0.0%	0.610

unchanged after excluding one study at a time (data not shown). Both Eegg's test (p=0.564) and funnel plots (online supplemental figure 9) indicated no evidence of publication bias. For subgroup analyses, the RR of the association between active commuting and diabetes was 0.97 for men (95% CI 0.82 to 1.14), 0.91 for Asia (95% CI 0.80 to 1.03), 0.89 for walking and bicycling (95% 0.76–1.04) and 0.88 for measured diabetes (95% CI 0.77 to 1.01) (table 1). A total of 13 articles (24 studies) were included to explore the association of highest versus lowest active commuting and diabetes. As compared with the lowest active commuting group, with the highest active commuting, the risk of diabetes was reduced by 19% (95% CI 0.73 to 0.91, I^2=49.8%) (figures 2 and 5). The pooled risk was substantially unchanged by sensitivity analysis (data not shown). Publication bias was not found by Eegg's test (p=0.488) and funnel plots (online supplemental figure 10). Moreover, we pooled seven articles (13 studies) to analyse the dose–response association. For each 60 min/week increase in active commuting, the risk of diabetes was reduced by 4% (RR=0.96, 95% CI 0.90 to 1.02, I^2=79.3%) (figures 2 and 5). Sensitivity analysis suggested that the pooled risk was substantially unchanged after excluding one study at a time (data not shown). Publication bias was not investigated by the Egger's test (p=0.181) and funnel plots (online supplemental figure 11). For subgroup analyses, the size or direction of the pooled estimates was robust in most results (table 2). Furthermore, we included seven articles (13 studies) in the restricted cubic splines model to indicate a linear association between active commuting and diabetes ($P_{\text{nonlinearity}}$=0.099) (online supplemental figure 12).

DISCUSSION

Based on 28 original articles, we conducted this meta-analysis to assess the association between active commuting and obesity, hypertension and diabetes by comparing active commuting to inactive commuting. We also compared the highest to lowest categories and conducted linear or nonlinear dose–response analyses. The risk of obesity, hypertension and diabetes decreased by 12%, 5% and 18%, respectively, for active commuting group compared with inactive commuting. Linear associations were found in the association between active commuting and the risk of above health outcomes.

Previous review[36] described the association between active transport and obesity. We systematically and quantitatively summarised earlier investigations on the association between active commuting and obesity. Our results suggest that people who were engaged in active commuting had a significantly reduced risk of obesity. Similar findings were observed in a cross-sectional survey from UK Biobank which revealed an independent association between active commuting and reduced BMI in mid-life.[37] An online survey involving 1450 participants also described that three bicycling trips per week were associated with 31% less risk of obesity.[38] Furthermore,

Table 2 Dose–response subgroup analyses of active commuting and risk of obesity, hypertension and diabetes.

Subgroups	Obesity				Hypertension				Diabetes			
	Number of studies	RR (95% CI)	I^2	P	Number of studies	RR (95% CI)	I^2	P	Number of studies	RR (95% CI)	I^2	P
Sex												
Men and women	9	0.99 (0.93 to 1.05)	76.2%	<0.0001	3	0.99 (0.93 to 1.06)	74.6%	0.019	2	0.98 (0.92 to 1.05)	0.0%	0.523
Men	1	0.94 (0.86 to 1.03)	–	–	2	0.95 (0.84 to 1.07)	83.0%	0.015	10	0.88 (0.80 to 0.96)	80.6%	<0.0001
Women	1	0.98 (0.90 to 1.06)	–	–	1	1.03 (1.01 to 1.06)	–	–	1	0.48 (0.24 to 0.97)	–	–
Region												
Asia	4	1.05 (0.99 to 1.12)	28.7%	0.240	2	0.98 (0.80 to 1.19)	88.8%	0.003	5	1.01 (0.92 to 1.11)	67.7%	0.015
Africa	2	1.00 (0.93 to 1.07)	65.5%	0.647	–	–	–	–	2	1.02 (0.92 to 1.14)	0.0%	0.788
Europe	3	0.97 (0.92 to 1.02)	0.0%	0.768	1	0.99 (0.95 to 1.03)	–	–	4	0.89 (0.80 to 0.99)	19.6%	0.292
America	2	0.92 (0.85 to 0.99)	0.0%	0.089	3	1.00 (0.96 to 1.04)	82.9%	0.003	2	0.89 (0.85 to 0.94)	0.0%	0.743
Expose												
Active commuting	11	0.99 (0.94 to 1.03)	70.6%	<0.0001	6	0.99 (0.96 to 1.03)	76.5%	0.001	10	0.97 (0.90 to 1.05)	74.5%	<0.0001
Bicycling	–	–	–	–	–	–	–	–	1	0.90 (0.85 to 0.95)	–	–
Walking	–	–	–	–	–	–	–	–	2	0.98 (0.77 to 1.25)	79.9%	0.026
Outcome assessment												
Self-reported	–	–	–	–	–	–	–	–	6	1.02 (0.97 to 1.07)	22.8%	0.262
Measured	11	0.99 (0.94 to 1.03)	70.6%	<0.0001	6	0.99 (0.96 to 1.03)	76.5%	0.001	4	0.94 (0.86 to 1.02)	56.6%	0.075
Doctor diagnosis	–	–	–	–	–	–	–	–	3	0.77 (0.55 to 1.08)	44.2%	0.167
Obesity												
General obesity	8	0.98 (0.92 to 1.04)	68.4%	0.002	–	–	–	–	–	–	–	–
Abdominal obesity	3	1.00 (0.92 to 1.09)	67.1%	0.048	–	–	–	–	–	–	–	–
Adjustment												
Age												
Yes	11	0.99 (0.94 to 1.03)	70.6%	<0.0001	6	0.99 (0.96 to 1.03)	76.5%	0.001	13	0.96 (0.90 to 1.02)	79.3%	<0.0001
No	–	–	–	–	–	–	–	–	–	–	–	–
Sex												
Yes	9	0.99 (0.93 to 1.05)	76.2%	<0.0001	2	1.00 (0.88 to 1.15)	86.5%	0.006	10	0.98 (0.92 to 1.05)	80.6%	<0.0001
No	2	0.96 (0.91 to 1.02)	0.0%	0.502	4	1.00 (0.96 to 1.03)	73.2%	0.011	3	0.77 (0.56 to 1.06)	37.6%	0.201
Smoking												
Yes	11	0.99 (0.94 to 1.03)	70.6%	<0.0001	4	0.97 (0.91 to 1.03)	74.8%	0.008	12	0.97 (0.91 to 1.04)	78.7%	<0.0001

Continued

Table 2 Continued

Subgroups	Number of studies	Obesity			Number of studies	Hypertension			Number of studies	Diabetes		
		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P		RR (95% CI)	I^2	P
No	–	–	–	–	2	1.01 (0.99 to 1.04)	70.3%	0.066	1	0.88 (0.80 to 0.97)	–	–
Alcohol												
Yes	8	0.98 (0.94 to 1.01)	0.0%	0.915	4	1.00 (0.96 to 1.03)	73.2%	0.011	9	0.98 (0.91 to 1.05)	77.8%	<0.0001
No	3	1.02 (0.87 to 1.19)	93.2%	<0.0001	2	1.00 (0.88 to 1.15)	86.5%	0.006	4	0.89 (0.77 to 1.04)	43.0%	0.153
Energy intake												
Yes	2	0.96 (0.91 to 1.02)	0.0%	0.502	–	–	–	–	1	0.90 (0.85 to 0.95)	–	–
No	9	0.99 (0.93 to 1.05)	76.2%	<0.0001	6	0.99 (0.96 to 1.03)	76.5%	0.001	12	0.97 (0.91 to 1.04)	75.2%	<0.0001
Physical activity												
Yes	11	0.99 (0.94 to 1.03)	70.6%	<0.0001	3	0.98 (0.90 to 1.08)	77.7%	0.011	12	0.97 (0.91 to 1.04)	78.7%	<0.0001
No	–	–	–	–	3	1.00 (0.96 to 1.04)	82.9%	0.003	1	0.88 (0.80 to 0.97)	–	–

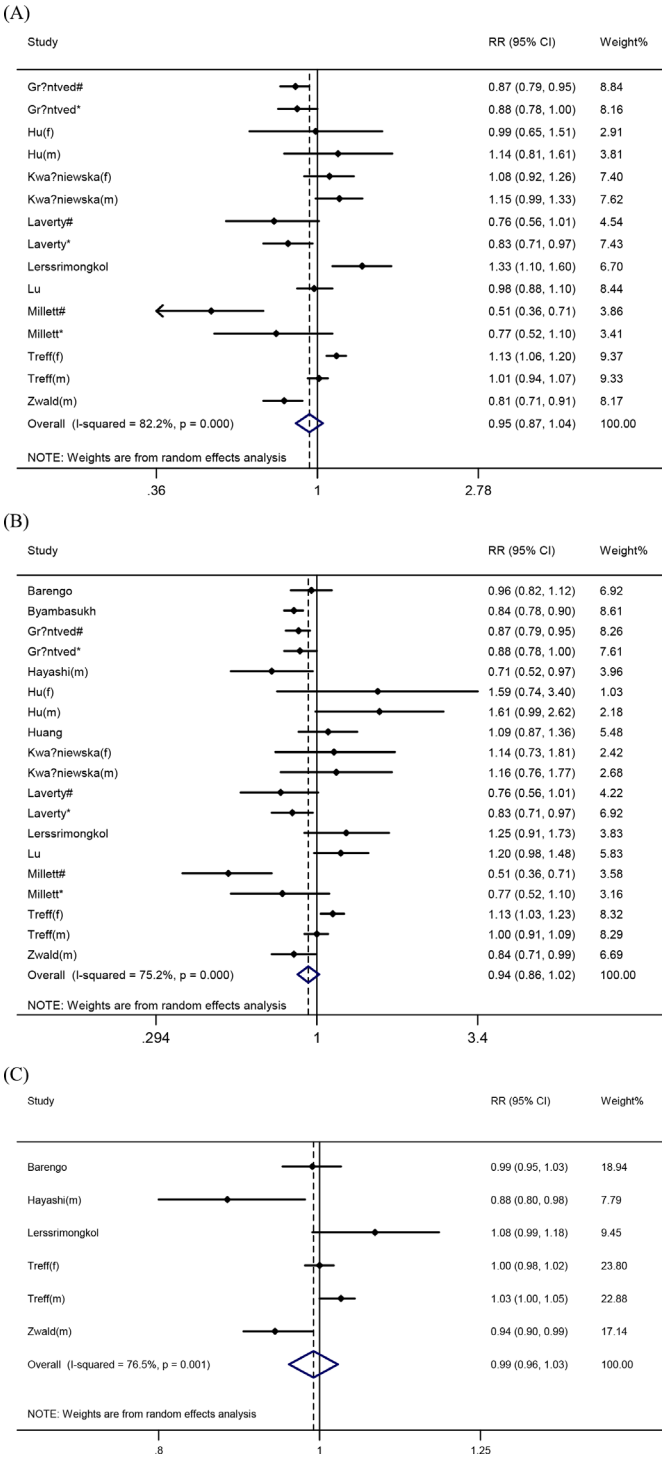

Figure 4 Forest plot summary of associations between active commuting and hypertension. (A) active/inactive; (B) high/low; (C) per 60 min/week increase.

we discovered that, when compared with the lowest active commuting category, the highest active commuting category reduced the risk of obesity by 13%. Furthermore, we discovered that the active commuting–obesity relationship was linear. Obese condition is typically accumulated over a long period of time, resulting from a chronic positive energy balance due to daily caloric intake that exceeds energy expenditure. However, the overall caloric intake has

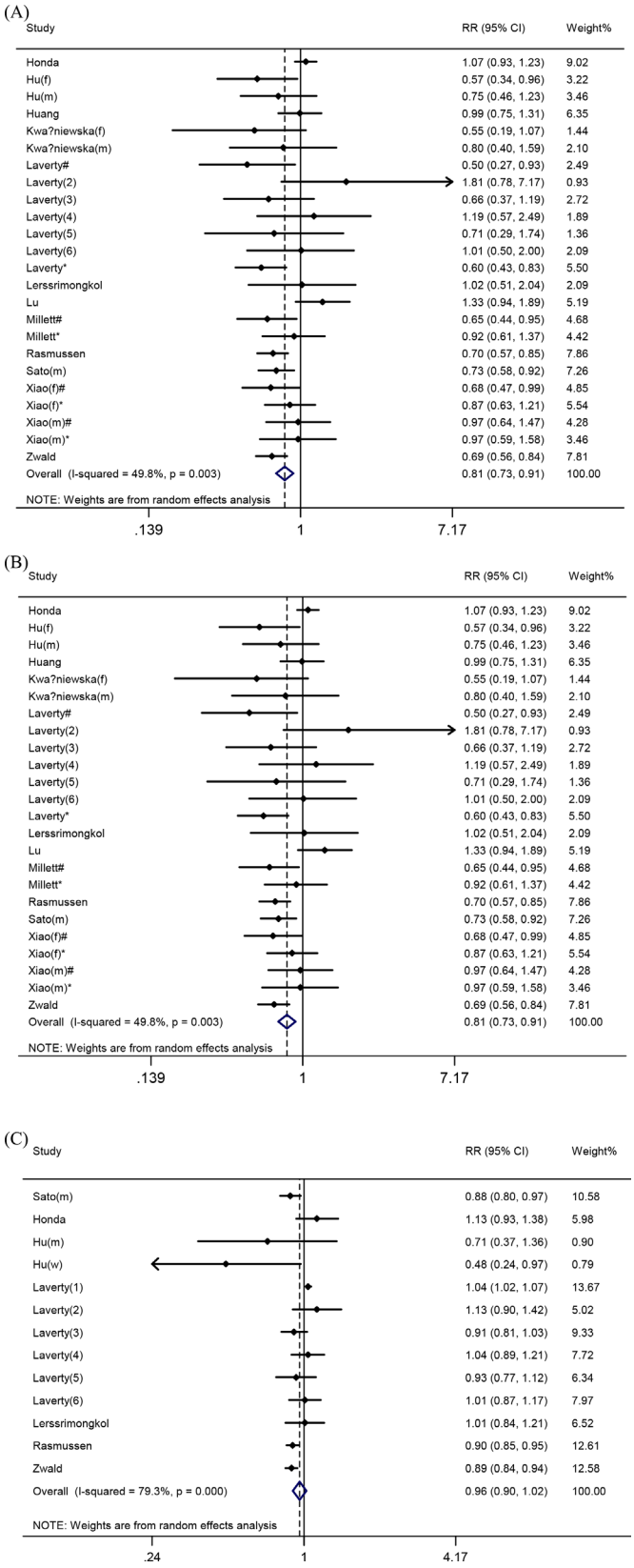

Figure 5 Forest plot summary of associations between active commuting and diabetes. (A) active/inactive; (B) high/low; (C) per 60 min/week increase.

not changed as dramatically over the years,[39] suggesting that other factors responsible for the overall reduction of energy expenditure may be playing a significant role and in fact may be the major contributors, for the current obesity epidemic. In support to this concept, occupation-related physical activity has declined significantly over the past 50 years,[40] providing evidence that reduced occupation-related physical activity including commuting may play a major role in determining a chronic positive energy balance. Previous research has established that socioeconomic status is an independent predictor of the mode of commuting, resulting in disparities in its accessibility and use.[14] Furthermore, the choice of commute mode is related to gender status, possibly because men are more likely than women to walk or cycle further to reach railway stations, which are typically more dispersed spatially.[37] Further research using longitudinal data and quasiexperimental study designs are warranted in order to closely understand causal pathways and processes. Our findings warrant more interventions to promote active commuting as a population-level policy response for prevention of obesity.

The association of active commuting with hypertension we found in the pooled analysis suggested a protective effect, but the result was not statistically significant. This result was not a surprise given that this analysis might have been underpowered to detect an effect given the limited number of studies available or the low prevalence of walking and cycling to work in the general population, which eventually may have reduced the statistical power for analysis. In addition, there were a very limited number of studies, which included energy intake and socioeconomic status as confounding variables in the multivariable models[14] which may have introduced a possible limitation in the interpretation of the results. Furthermore, other unmeasured or unobserved confounding factors (eg, early life conditions) may have played a potential role,[41] of which the included studies did not account for. More researches should be conducted to investigate the association between active commuting and hypertension. Whereas, in our analyses, both commuting by bicycling and walking showed a statistically significant effect on hypertension. The definition of active commuting was not consistent across studies. For instance, inability to differentiate between the different types of public transport taken and the public transport category also including people who reported mixed modes of motorised travel and active commuting, a situation which might lead to unstable results. Future studies need a better definition of active commuting in terms of type, duration, intensity, frequency as well as better standardisation of the methods used to evaluate active commuting.

Our results support those of a previous meta-analysis of including four studies—that cycling to work was significant reduction in diabetes risk.[16] This may deduce that cycling to work, independent of the type of commuting, had a lower risk of diabetes. Our findings also suggest that walking to work reduced the risk of diabetes. With fast economic development and transition, the building of motor-vehicle-oriented transport infrastructure allocated increasingly more financial and material resources. However, this consistently reduces space left for pedestrians and riders. It is also supposed that active commuting practices could be discouraged due

to stress, tension from unsafe road condition and fear of inhaling polluted air. Even so, we found a substantial association between active commuting and diabetes. We believe that active commuting reduces sedentary time[42] and hence impacting insulin resistance.[43] Other mechanisms should be tested in future studies.

The findings suggested that more efforts should be invested in strategizing ways to improve active commuting practices. Various approaches such as publicity programmes to encourage active commuting, improve infrastructure to make roads safer, reduce air pollution, extending cycling networks and financial incentives and behavioural change should be emphasised and adopted worldwide. Meanwhile, policymakers must concentrate on how to integrate active commuting into urban life.[16] Companies should consider offering bonuses or incentives to employees who actively commute to and from work in order to encourage this practice and create healthier and more productive employees. In addition, supporting infrastructure such as showers, changing rooms, lockers, bicycles and others should be installed to encourage active commuting.

This meta-analysis has several strengths. First, it included a large number of participants and cases that allowed us to quantitatively assess the association between active commuting and risk of obesity, hypertension and diabetes, thus making it more statistically powerful than any single study. Second, we employed a dose–response analysis to evaluate the linear and nonlinear associations. In addition, we considered categories of active commuting, including bicycle cycling and walking on foot to the working place. These data provide a comprehensive insight into the association between active commuting and risk of the selected health outcomes based on the current evidence.

Our study also had several potential limitations. First, the active commuting practice was self-reported by participants, an event which might had invited recall bias and social desirability bias during data collection. This may have overestimated the true association between active commuting and obesity, hypertension and diabetes. Second, information on the severity of reported chronic conditions was not available. Our results should be interpreted with caution as it is likely that these conditions might be less severe in most participants in the study sample who were able to meet the guidelines. Third, there was a possibility of publication bias in the meta-analysis that looked at the associations between active commuting for 60 min per week and the risk of obesity. Fourth, although we adjusted our analyses with a number of potential confounders, there may be other unmeasured confounding factors that were not captured and could have affected the magnitude of the association between active commuting and the selected chronic diseases. Some studies did take dietary consumption into account and others did not consider total physical activity as covariates, which could affect the independent association of active commuting and obesity, hypertension and diabetes. Fifth, some studies in this review did not report sufficient information to be included in the dose–response meta-analysis, which might limit the statistical power to detect an association. Sixth, our findings should be interpreted with caution because they are based entirely on observational studies, which are prone to reverse causality bias. Seventh, we discovered significant heterogeneity across studies in our meta-analysis, but we failed to find the source of heterogeneity using the subgroup analysis. Finally, it is noteworthy that the association is not significant for 60 min/week increase in active commuting, but it is significant in the highest versus lowest meta-analysis. We assumed that a small number of studies were included to examine the dose–response relationship, and that moderate to high heterogeneity was observed, which could lead to results that are not robust. Furthermore, we believe that the threshold for active commuting has yet to be discovered in future studies.

CONCLUSIONS

Our meta-analysis indicates that active commuting may decrease the risk of obesity, hypertension and diabetes. Health professionals, stakeholders and policy planners are called to improve infrastructure in such a way that it supports a healthy lifestyle, promotes active commuting as a part of national and global strategies for the prevention of these adverse health outcomes.

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