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Active commuting, commuting modes and the risk of diabetes: 14-year follow-up data from the Hisayama study

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ABSTRACT

Aims/Introduction: We aimed to investigate the association of active commuting (cycling or walking to work), as well as the association of the individual commuting modes, with the risk of diabetes in a prospective cohort of community-dwelling adults in Japan.

Material and Methods: A total of 1,270 residents aged 40–79 years were followed up for a median of 14 years. Active commuting was defined as either cycling or walking to work. A Cox proportional hazards model was used to examine the association of active commuting with the risk of diabetes. Associations for different forms of active commuting (cycling, walking and mixed modes of cycling or walking with non-active components) were also examined.

Results: During the follow-up period, 191 participants developed diabetes. Active commuting was associated with a lower risk of diabetes than non-active commuting after adjustment for potential confounders (hazard ratio [HR] 0.54, 95% confidence interval [CI] 0.31–0.92). With regard to the commuting modes, the risk of diabetes was significantly lower in individuals who commuted by cycling alone (HR 0.46, 95% CI 0.22–0.98), and tended to be lower in individuals who commuted by walking alone (HR 0.14, 95% CI 0.02–1.02) compared with that in individuals with non-active commuting. Meanwhile, no significant associations were observed for the mixed mode of walking and non-active commuting (HR 1.69, 95% CI 0.77–3.71).

Conclusions: Active commuting, particularly that consisting exclusively of cycling or walking, was associated with a reduced risk of diabetes. Our findings support a public health policy that promotes the choice of active commuting for the prevention of diabetes.

INTRODUCTION

Increased total daily activity levels or physical activities during leisure time have been consistently suggested to be important for slowing down or preventing the onset of diabetes[1–3]. For middle-aged adults, incorporating cycling or walking into commuting to and from work (i.e., active commuting[4]) has been recommended to increase daily physical activity levels, as middle-aged individuals typically lack leisure-time exercise habits[5,6]. Thus, understanding the impact of active commuting on diabetes risk is of substantial clinical interest. However, to the best of our knowledge, just five prospective cohort studies have examined the association between active commuting and risk of diabetes, with four studies showing significant

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associations[7–10] and the other one showing none[11]. Furthermore, none of the relevant studies[7–13] differentiated bicycling from walking by querying participants about their use of bicycling and walking separately. This is an important omission, as commuting behaviors often combine two or more forms. Indeed, a large study showed that the effects of active commuting on the incidence of cardiovascular disease and cancer varied depending on whether the commuting consisted of cycling alone, walking alone or a mixed mode of active and non-active commuting[14]. To date, however, the associations of different forms of active commuting with diabetes have not yet been tested.

In the present study, we investigated the association of active commuting with the risk of developing diabetes in a prospective cohort of community-dwelling adults in Japan. We also assessed whether the associations of active commuting with diabetes risk differ by the form of active commuting (cycling, walking or either/both in combination with non-active commuting).

MATERIALS AND METHODS

Population

A population-based prospective study of cardiovascular disease and its risk factors has been underway since 1961 in the town of Hisayama, a suburb of the Fukuoka metropolitan area on Kyushu Island, Japan. Hisayama borders Fukuoka City, the sixth-largest city in Japan and the capital city of Fukuoka Prefecture, approximately 10 km east of the Fukuoka city center. Mountains and forests occupy 70% of the area of Hisayama , and the residential areas are concentrated in the southwestern part of the town near Fukuoka City. There is no train station in the town, but a nearby station can be reached in approximately 15 min by car or within 30 min by bus. From that train station, residents can go to Fukuoka City without transfer. According to the 2015 Population Census, more than half of the town's resident workers commute out of town[15].

We used data from a screening survey carried out in 1988 for the present study. A detailed description of this survey was published previously[16,17]. Figure 1 shows the flow diagram. Briefly, 2,587 residents out of 3,227 residents aged between 40 and 79 years consented to participate in the baseline examination (participation rate 80.2%). Among them, 107 participants who did not complete the 75-g oral glucose tolerance test, 297 participants who had diabetes at baseline and two participants who died before the start of follow up were excluded. Of the remaining 2,181 participants, 865 who did not have a job at the baseline and one participant with no information on commuting mode were further excluded from the analysis. The remaining 1,315 participants were followed up prospectively from December 1988 to November 2002. Finally, 107 participants who did not undergo re-examinations during follow up were excluded, leaving a sample of 1,208 participants. Of the 1,208 participants analyzed, 842 commuted to work, and the remaining 366 worked at home.

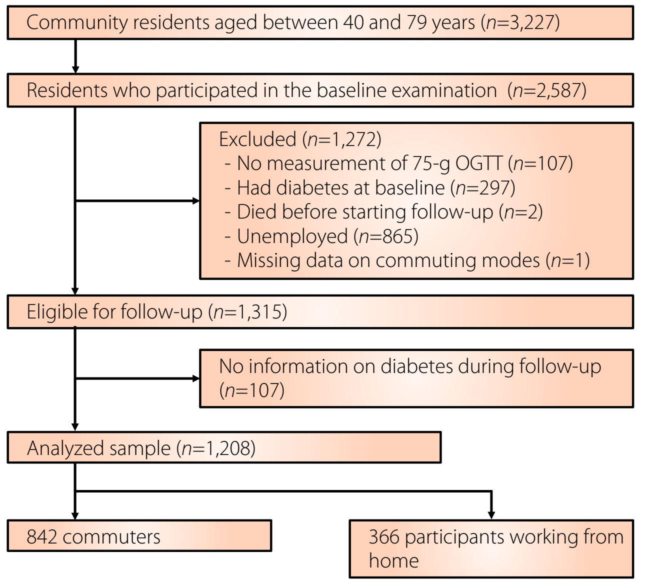

Figure 1 | Flow diagram of study inclusion and exclusion.

Ethical considerations

This study was carried out with the approval of the Kyushu University Institutional Review Board for Clinical Research. Written or oral informed consent was obtained from the study participants.

Follow-up survey of diabetes

The study participants were monitored at yearly health examinations. In the baseline and follow-up examinations, the study participants underwent the 75-g oral glucose tolerance test between 08.00 and 10.30 hours after an overnight fast of at least 12 h. Blood for the glucose assay was obtained by venipuncture into tubes containing sodium fluoride at fasting and 2-h post-load, and was separated into plasma and blood cells within 20 min. Plasma glucose concentrations were determined by the glucose-oxidase method. According to the World Health Organization 1998 criteria, diabetes was defined as fasting plasma glucose of ≥7.0 mmoL/L (126 mg/dL) and/or 2-h post-load glucose of ≥11.1 mmoL/L (200 mg/dL), and/or the use of antidiabetic medication at one examination[18]. New-onset cases were also identified by reviewing medical records and collecting information on diabetes medication use.

Definition of active commuting

Participants were asked to report whether they worked at home (no commuting) or used any of five commuting modes: cycling, walking, public transport, car or motorbike. Multiple responses were allowed. We defined active commuting as a commuting mode to and from work that included either cycling or walking. We defined non-active commuting as commuting by public transportation, car, motorcycle or any combination of these means. Based on these definitions, we initially derived three commuting categories: non-active commuting, active commuting or work at home.

To further consider the associations separately for cycling, walking and their combinations with non-active commuting, we grouped participants into the following five mutually exclusive categories according to a previous report from the UK Biobank[14]: non-active; cycling (cycling only or cycling plus walking); walking only; mixed-mode cycling (cycling plus non-active); and mixed-mode walking (walking plus non-active). Two participants used both cycling and walking; of those, one used cycling and walking only, and the other used cycling, walking and public transportation. In accordance with the aforementioned classification, these participants were categorized into the cycling group, and the mixed-mode cycling group, respectively.

Covariates

Blood pressure was obtained three times using a mercury sphygmomanometer with the participant in a sitting position after resting for at least 5 min; the average values were used in the analyses. Hypertension was defined as a systolic blood pressure of ≥140 mmHg and/or a diastolic blood pressure of ≥90 mmHg, and/or current treatment with antihypertensive agents. Serum total cholesterol, high-density lipoprotein cholesterol, and triglycerides were determined enzymatically. The height and weight of each participant, wearing light clothes without shoes, were recorded and body mass index (kg/m^2) was calculated. Each participant completed a self-administered questionnaire covering current occupations, medical history, antidiabetic and antihypertensive treatments, current drinking, smoking, and leisure-time regular exercise habits. Occupation was classified as either manual work or non-manual work. Diabetes in first-degree relatives was taken to show a family history of diabetes. Drinking and smoking habits were classified as either current use or not. Individuals engaging in sports at least three times per week during their leisure time were categorized as having a regular exercise habit. Data on nutritional intakes were obtained using a 70-item semiquantitative food frequency questionnaire regarding food intake[19,20]. Intakes of daily total energy and dietary nutrients were calculated using the 4th revision of the Standard Tables of Food Composition in Japan[21].

Statistical analysis

All analyses were carried out using SAS version 9.4 (SAS Institute, Cary, NC, USA). Descriptive statistics were computed according to the commuting status. The group difference was tested by linear or logistic regression by replacing the group with dummy variables with the non-active commuting group as a reference. Serum triglycerides values were presented as the median with interquartile range in descriptive statistics, and were transformed using the log function to correct for the skewed distribution for parametric tests. There were no missing values on all covariates.

A Cox proportional hazards model was used to examine the association between commuting status and the risk of developing diabetes, with the non-active commuting group serving as a reference. Potential confounders, including age, sex, manual work, family history of diabetes, body mass index, hypertension, serum total cholesterol, serum high-density lipoprotein cholesterol, serum triglycerides (log-transformed), current smoking, current drinking, leisure-time regular exercise habits and daily total energy intake, were adjusted in a multivariable model. Additional analyses to compare commuting mode categories (cycling, walking only, mixed-mode cycling and mixed-mode walking) were carried out in the participants who commuted to work (n = 842), with adjustment for the same covariates. A sensitivity analysis that adjusted for dietary nutrients that were potentially associated with diabetes was carried out. In addition, another sensitivity analysis that excluded participants who developed diabetes within the first 3 years from the baseline was carried out to elucidate the possibility of reverse causality.

RESULTS

Baseline characteristics of the study sample are shown in Table 1. The active commuters were older, less likely to be men, and had lower fasting plasma blood glucose, diastolic blood pressure and serum triglycerides levels than the non-active commuters. In terms of lifestyle behaviors, the active commuters had a lower proportion of people with current smoking, current drinking and leisure time exercise habits, and a lower dietary energy intake and higher intakes of carbohydrate, fat, and saturated fatty acids. The participants who worked at home were older, less likely to be men and more likely to be manual workers compared with the non-active commuters. The work-at-home participants also had higher systolic blood pressure, but lower diastolic blood pressure; lower serum high-density lipoprotein cholesterol levels; a lower proportion of current smokers and drinkers; higher intakes of dietary carbohydrate, vegetables, vitamin C and magnesium; and a lower intake of dietary fat and saturated fatty acids.

During the median 14-year follow-up period (interquartile range 13–14 years), 191 participants developed diabetes. Table 2 shows the hazard ratios (HRs) and 95% confidence intervals (95% CIs) of developing diabetes across the commuting statuses. The active commuting group had a significantly lower age- and sex-adjusted HR compared with the non-active commuting group (HR 0.54, 95% CI 0.32–0.93). The association was unchanged after adjusting for potential confounders (HR 0.54, 95% CI 0.31–0.92). There was no evidence of significant difference in the risk of developing diabetes between the work-at-home group and the non-active commuting group.

The numbers of participants in the cycling, walking only, mixed-mode cycling and mixed-mode walking groups were 112, 44, 6 and 27, respectively. Baseline characteristics of the study sample according to this category are shown in Table S1. Table 3 shows the association of each commuting mode with the development of diabetes. Both the cycling and the walking-

Table 1 | Baseline characteristics of study participants according to commuting status

	Commuting modes		
	Non-active commuting n = 653	Active commuting n = 189	Work at home n = 366
Age (years)	50.5 (6.8)	52.0 (7.4)*	59.7 (9.7)*
Men (%)	62.2	23.3*	48.4*
Manual work (%)	19.1	21.7	73.5*
Fasting plasma glucose (mmol/L)	5.5 (0.5)	5.3 (0.4)*	5.5 (0.5)
2 h post-load plasma glucose (mmol/L)	6.4 (1.6)	6.4 (1.4)	6.6 (1.6)
Family history of diabetes (%)	8.3	5.8	6.3
Systolic blood pressure (mmHg)	128.7 (18.0)	127.6 (18.0)	131.2 (18.9)*
Diastolic blood pressure (mmHg)	79.8 (11.4)	77.0 (11.7)*	76.6 (11.0)*
Hypertension (%)	31.9	29.6	37.7
Serum total cholesterol (mmol/L)	5.3 (1.0)	5.3 (1.0)	5.2 (1.1)
Serum HDL cholesterol (mmol/L)	1.3 (0.3)	1.4 (0.3)	1.3 (0.3)*
Serum triglycerides (mmol/L)†	1.08 (0.78–1.65)	0.90 (0.71–1.21)*	1.10 (0.78–1.55)
Body mass index (kg/m^2)	23.2 (2.9)	22.9 (3.0)	22.9 (3.0)
Current smoking (%)	33.1	18.0*	21.6*
Current drinking (%)	47.3	23.3*	30.9*
Leisure-time exercise habit (%)	8.9	2.7*	7.7
Total energy intake (kcal/day)	1,820 (433)	1,694 (405)*	1,817 (429)
Dietary carbohydrate intake (g/1,000 kcal)	134.1 (19.4)	139.0 (17.5)*	141.1 (18.4)*
Dietary protein intake (g/1,000 kcal)	32.0 (5.5)	32.4 (4.6)	32.4 (5.5)
Dietary fat intake (g/1000 kcal)	28.6 (6.4)	30.0 (6.4)*	27.6 (6.1)*
Dietary vegetable intake (g/1,000 kcal)	132.0 (63.7)	137.9 (60.7)	152.7 (72.9)*
Dietary vitamin C intake (mg/1,000 kcal)	40.8 (18.2)	42.7 (15.3)	51.0 (22.4)*
Dietary magnesium intake (mg/1,000 kcal)	99.9 (21.3)	101.0 (24.3)	104.0 (22.3)*
Dietary saturated fatty acid intake (g/1,000 kcal)	7.6 (2.2)	8.1 (2.4)*	7.2 (2.2)*
Dietary polyunsaturated fatty acid intake (g/1,000 kcal)	9.4 (2.9)	9.6 (2.6)	9.1 (2.8)

Values are means (standard deviations) or frequencies except where noted. *P < 0.05 vs the non-active commuting group. †Data are presented as median and interquartile range. HDL, high-density lipoprotein.

Table 2 | Association between active commuting and risk of developing diabetes

Commuting modes	Events/participants	Crude incidence, per 1,000 person-years	Age- and sex-adjusted		Multivariable-adjusted	
			HR (95% CI)	P	HR (95% CI)	P
Non-active commuting	116/653	14.2	1.0 (ref)		1.0 (ref)	
Active commuting	16/189	6.7	0.54 (0.32–0.93)	0.03	0.54 (0.31–0.92)	0.02
Work at home	59/366	13.5	0.92 (0.64–1.31)	0.62	0.84 (0.56–1.24)	0.37

The multivariable model was adjusted for age, sex, manual work, family history of diabetes, body mass index, hypertension, serum total cholesterol, serum high-density lipoprotein cholesterol, serum triglycerides (log-transformed), current smoking, current drinking, leisure-time exercise habit and daily energy intake. CI, confidence interval; HR, hazard ratio.

only groups showed a reduced risk of diabetes compared with the non-active commuting group (HR 0.46, 95% CI 0.22–0.98 for the cycling group; HR 0.14, 95% CI 0.02–1.02 for the walking-only group), although the estimate in the walking-only group did not reach statistical significance, probably due to the small number of diabetes cases in this group. In contrast, mixed-mode walking was not significantly associated with the risk of diabetes (HR 1.69, 95% CI 0.77–3.71). Because there were just six participants in the mixed-mode cycling group in the analyzed population, we could not estimate the association for the mixed-mode cycling group.

The sensitivity analysis showed that the observed association did not materially change after further adjustment for dietary intakes of carbohydrate, protein, fat, vegetables, vitamin C, magnesium, and saturated and polyunsaturated fatty acids (Table S2). Also, the exclusion of diabetes patient that occurred

Table 3 | Hazard ratios for developing diabetes by commuting modes among 842 participants who commuted to work

Commuting modes	Events/participants	Crude incidence, per 1,000 person-years	Age- and sex-adjusted		Multivariable-adjusted	
			HR (95% CI)	*P*	HR (95% CI)	*P*
Non-active commuting	116/653	14.2	1.00 (ref)		1.00 (ref)	
Cycling	8/112	5.6	0.51 (0.24–1.06)	0.07	0.46 (0.22–0.98)	0.04
Walking only	1/44	1.8	0.16 (0.02–1.17)	0.07	0.14 (0.02–1.02)	0.053
Mixed-mode cycling	0/6	0.0	–		–	
Mixed-mode walking	7/27	21.9	1.44 (0.67–3.10)	0.36	1.69 (0.77–3.71)	0.19

The multivariable model was adjusted for age, sex, manual work, family history of diabetes, body mass index, hypertension, serum total cholesterol, serum high-density lipoprotein cholesterol, serum triglycerides (log-transformed), current smoking, current drinking, leisure-time exercise habit and daily energy intake. Commuting modes were obtained with allowance for multiple responses and were coded as mutually exclusive categories; one participant who used cycling and walking was categorized into cycling, and one participant who used cycling, walking, and public transportation was categorized into mixed-mode cycling. CI, confidence interval; HR, hazard ratio.

within 3 years of follow up did not change the results substantially (Table S3).

DISCUSSION

In the present study, we showed that the risk of diabetes was reduced in Japanese community-dwelling adults who actively commuted to work. In addition, we showed that the risk of diabetes was decreased in both cycling-alone and walking-alone commuters, whereas we did not find a significant association of mixed-mode commuting with the risk of diabetes. As active commuting is likely to be controlled not only by individual effort, but also by social and environmental factors, such as corporate commuting rules and land-use policies of cities[4,22–24], interventions on social and environmental factors to promote active commuting might contribute to a reduction in the number of people with diabetes and, ultimately, to a reduction in mortality from chronic diseases at a population level.

The present study consistently showed that active commuting was associated with a reduced risk of diabetes. Although previous studies generally showed a favorable association of active commuting with diabetes, the research methods varied among these studies, with some considering only walking or only cycling[9–11], and the follow-up periods were relatively short[8,9,11]. In addition, two of the previous studies were carried out with Japanese employees of a single company[9,11]. In contrast, in the present study we used data from community residents with a long-term follow-up period of >10 years, and examined the associations between diabetes and cycling, walking or either activity in combination with non-active commuting modes; the present results provide new evidence of an association between active commuting and decreased risk of diabetes.

In previously reported cross-sectional studies, active commuting was reported to be associated with better glucose and lipid metabolism[25–27], anthropometry measures[12,25,28–30], and exercise tolerance[25]. In contrast, in observational longitudinal studies with a short- or medium-term follow up, the association of active commuting with anthropometry was inconsistent, and the effect size was limited[31–33]. A 12-month randomized controlled trial in 73 hospital workers failed to show a favorable effect of an active commuting intervention on anthropometry or cardiovascular risk factors[34], but another study on the same trial found a significant improvement in exercise tolerance[35]. Even a small increase in cardiorespiratory fitness has been shown to significantly reduce the development of diabetes[36]. Therefore, it can be inferred that active commuting might contribute to a long-term reduction in the risk of obesity and diabetes development, mainly through an increment in exercise capacity.

Among the active commuting modes assessed herein, cycling was associated with a reduced risk of diabetes. There is strong evidence that cycling contributes to an improvement in physical fitness, and moderate evidence that cycling is associated with favorable cardiovascular risk factor profiles[37]. A prospective association of cycling to work with the risk of diabetes has only been reported in one study of a Danish cohort[10]. To our knowledge, there have been no prior studies comparing cycling and walking to work in relation to the risk of diabetes. The present study is thus the first to show a favorable association between cycling and the development of diabetes in Asian people.

We also observed a lower risk of diabetes when walking was used solely, whereas mixed-mode walking was not associated with diabetes. The present finding was in line with a previous study on cardiovascular disease and cancer outcomes[14]. In the present study, mixed-mode walkers mostly used this commuting modality in combination with public transportation. A previous study in the USA showed that people who lived near a station or whose workplace was close to a metro area tended to choose mixed-mode active commuting[38]. Furthermore, a previous study showed that solely-active commuters spent a longer time in physical activity during commuting than mixed-mode commuters[39]. These studies suggested that mixed-mode commuters traveled relatively short distances to the nearest stop or station, which resulted in the active time being short. In addition, the mixed-mode commuter might tend to spend more time sitting on the bus or train, and thus any reduction in diabetes risk associated with the active portion of the commute might be offset by the longer sedentary time[40,41]. However, given the small number of diabetes cases in the current study, we cannot draw clear conclusions on the effectiveness of mixed-mode commuting; further investigation on this subject is warranted.

The recent coronavirus disease 2019 pandemic has increased the number of people telecommuting[42]. Telecommuting is important for infection control, but in contrast, it has also been reported to be associated with worsening glycated hemoglobin levels in diabetes patients, suggesting a contribution of changes in commuting modes[43]. Based on the findings of the present study, we could speculate an increase in diabetes risk due to a decrease in commuting activities, especially for those who were active commuters before the coronavirus disease 2019 pandemic. Risk–benefit analysis, long-term monitoring of those who switched to telecommuting and alternative strategies to promote physical activity are required.

The present study had several strengths. First, it was carried out with community residents, and therefore the diversity of occupations and employment statuses within the study population might increase the generalizability of the results. In addition, commuting behavior is influenced not only by personal preferences and workplace rules, but also by environmental factors[44]. Unveiling the health effects of active commuting in a regionally restricted cohort should be valuable when formulating recommendations for land-use policies that might improve commuting environments. Furthermore, the relatively long follow-up period compared with previous studies and the use of a sensitivity analysis excluding those who developed diabetes in a short period reduced the possibility of reverse causality. In addition, an oral glucose tolerance test-based accurate diagnosis of diabetes could lessen the possibility of misclassification at both baseline and follow up.

Limitations should also be noted. First, the small number of analyzed participants precluded further investigations, such as analyses of more detailed combinations of commuting modes, categorization of commuting time and subgroup analyses. Second, we could not investigate the dose–response association in relation to the intensity or distance of commuting activities: commuting distance might have been confounding, because it can influence the choice of commute modes. Third, the baseline year was 1988, and attitudes toward active commuting might have changed in recent times; in particular, awareness of the health benefits of cycling might have increased. Fourth, there is a possibility that attitudes toward healthy living might confound the association. However, we observed that the association between active commuting and diabetes was unchanged after adjusted for smoking, drinking, regular exercise habits and daily energy intake, and even after adjusting for dietary intakes of macronutrients and vegetables. Therefore, this possibility is not high. Fifth, as the present study was carried out in one town, its generalizability is limited.

In conclusion, the present study showed that active commuting is associated with a lower risk of developing diabetes in Japanese community residents. This study supports the notion that promoting cycling and walking to work is an effective means of reducing diabetes in the community. The findings of this study need to be further elaborated in future experimental studies to prevent diabetes by promoting active commuting, both through behavioral interventions in individuals, and land-use policy that includes the construction of sidewalks and bicycle paths.

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DISCLOSURE

The authors declare no conflict of interest.

Approval of the research protocol: This study was carried out with the approval of the Kyushu University Institutional Review Board for Clinical Research.

Informed consent: Written or oral informed consent was obtained from the study participants.

Registry and the registration no. of the study/trial: N/A.

Animal studies: N/A.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 | Baseline characteristics of study participants according to commuting categories.

Table S2 | Association between active commuting and risk of developing diabetes among commuters with an additional adjustment for dietary intakes of macronutrients and vegetables.

Table S3 | Association between active commuting and risk of developing diabetes among commuters after excluding participants who developed diabetes in the first 3 years.