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Leisure-time cross-country skiing is associated with lower incidence of type 2 diabetes: A prospective cohort study

Running Title: Cross-country skiing and type 2 diabetes

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Abstract

Aims: Cross-country skiing is associated with reduction in risk of adverse vascular outcomes, but its association with type 2 diabetes is uncertain. We aimed to assess the associations between leisure-time cross-country skiing habits and incident type 2 diabetes.

Methods: We analyzed data of 2,483 middle-aged men with no history of diabetes at baseline in the KIHD prospective study. The frequency, average duration, and intensity of leisure cross-country skiing were assessed at baseline using a 12-month physical activity questionnaire. Hazard ratios (HRs) (95% CIs) for type 2 diabetes were estimated.

Results: During a median follow-up of 21.6 years, 539 men developed type 2 diabetes. Type 2 diabetes risk decreased with increasing total volume of cross-country skiing up to 1,215 MET hours/year. In analyses adjusted for several established risk factors, when compared to men with no cross-country skiing activity, the HRs (95% CIs) for type 2 diabetes were 0.75 (0.62-0.92) and 0.59 (0.46-0.76) for men who did 1-200 and >200 MET hours/year of cross-country skiing respectively. Compared to men with no cross-country skiing activity, the corresponding adjusted HRs (95% CIs) for type 2 diabetes were 0.73 (0.60-0.89) and 0.64 (0.50-0.82) for men who did 1-60 and >60 mins/week of cross-country skiing respectively. The associations remained consistent following further adjustment for prevalent comorbidities.

Conclusion: Total volume and duration of leisure-time cross-country skiing are each inversely and independently associated with future type 2 diabetes risk in a male population. Cross-country skiing undertaken as a leisure activity has the potential to promote public health.

KEYWORDS

physical activity, cross-country skiing, high-intensity exercise training, type 2 diabetes

1. INTRODUCTION

Cardiovascular complications remain the leading cause of morbidity and death in patients with type 2 diabetes.[1] The major risk factors implicated in type 2 diabetes development are lifestyle factors, which include obesity, physical inactivity, tobacco smoking, alcohol consumption, and mental stress; the cornerstone for the primary prevention of type 2 diabetes is based on elimination of these risk factors.[2] Physical activity is well established to have important health benefits including the prevention of adverse non-vascular and vascular outcomes such as cancer, cardiovascular disease (CVD) as well as type 2 diabetes.[3-5] High- or vigorous-intensity physical activity may produce more pronounced benefits compared with moderate intensity physical activity.[3,6,7] The beneficial effects of specific types of physical activity on adverse outcomes vary.[8] In a prospective population study that evaluated the differential improvements in life expectancy associated with participation in various sports, findings indicated that various sports were associated with markedly different improvements in life expectancy.[9] Though the importance of physical activity in disease prevention is generally well accepted, knowledge of the relationships between specific physical activity types and major chronic diseases could provide insight into whether a particular physical activity type has more benefits compared to others and also whether harm could occur by performing too much of a particular physical activity type. Cross-country skiing is a seasonal high-intensity physical activity and whole-body aerobic exercise commonly undertaken during the winter. Cross-country skiing is considered to be one of the most demanding of aerobic endurance activities that requires both upper and lower-body work to different extents. Cross-country skiing can be undertaken as a leisure-time activity or long-term endurance competitive sport. Emerging data suggests both types of activity are associated with reduction in the risk of vascular outcomes such as hypertension, CVD, and all-cause mortality.[10-13] Though type 2 diabetes is a vascular disease, the prospective relationship of cross-country skiing with risk of type 2 diabetes is uncertain. Using a large population-based sample of middle-aged Finnish

men without diabetes at baseline, we aimed to assess the associations of the total volume and duration of leisure-time cross-country skiing with the risk of incident type 2 diabetes.

2. METHODS

The current analysis is based on the Finnish Kuopio Ischemic Heart Disease (KIHD) risk factor study. The study population involved a representative sample of middle-aged men aged 42-61 years living in the city of Kuopio and its surrounding rural communities in Eastern Finland. The study was approved by the Research Ethics Committee of the University of Eastern Kuopio in accordance with the Declaration of Helsinki. Each participant provided written informed consent. This study was performed following the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines for reporting observational studies in epidemiology (**Table S1**). Baseline examinations were performed between March 20, 1984 and December 5, 1989. Full details of recruitment methods and measurements of risk markers have been described previously.[14] Habits of cross-country skiing activity as well as total leisure-time physical activity (LTPA) were assessed using the KIHD 12-month LTPA questionnaire modified from the Minnesota LTPA Questionnaire.[15] Full details of these assessments have been described elsewhere.[12] Briefly, this is a quantitative questionnaire which collects information on the most common leisure-time physical activities of middle-aged Finnish men (conditioning physical activity, e.g. walking, skiing, bicycling, swimming, rowing, ball games, etc and non-conditioning physical activity, e.g. crafts, repairs, building, gardening, hunting, fishing, etc) and is able to assess of all domains of physical activity over the previous year. For each type of physical activity performed, participants were asked to record the frequency (number of sessions per month), average duration (hours and minutes per session), and intensity (scored as 0 for recreational activity, 1 for conditioning activity, 2 for brisk conditioning activity, and 3 for competitive, strenuous exercise). A trained interviewer collected the information. A metabolic equivalent task (MET, or metabolic equivalents of oxygen consumption) score was assigned to the intensity of each physical activity based on its energy cost. One metabolic unit corresponds to an energy expenditure of approximately 1 kcal per kilogram of body weight per hour. Cross-country skiing was assigned an intensity of 9.6 MET. The total volume of cross-country skiing

(MET hours per year) was estimated using the intensity in METs multiplied by the duration. The validity and reproducibility of the KIHD LTPA Questionnaire and the Minnesota LTPA Questionnaire have been reported elsewhere. These data indicate that the KIHD LTPA Questionnaire is reproducible and provides a useful measure of average weekly activity over a 1-year period.[16-18]

An incident case of type 2 diabetes was defined as a fasting plasma glucose (FPG) ≥7.0 mmol/l, a 2 hour glucose tolerance test plasma glucose ≥11.1 mmol/l, or use of glucose-lowering medication according to self-report and by record linkage to the national hospital discharge registry and to the Social Insurance Institution of Finland register for reimbursement of medicine expenses. The hospital registers are maintained by the National Institute for Health and Welfare. For this analysis, men with a prevalent history of diabetes were excluded. Prevalent diabetes was defined as a fasting blood glucose level ≥7.0 mmol/L or clinical diagnosis of diabetes with dietary, oral, or insulin treatment. The final cohort for the present analysis is based on 2,483 men with no missing data on the assessment of cross-country skiing activity, total LTPA, relevant covariates, and incident type 2 diabetes. We calculated multivariable hazard ratios (HRs) with 95% confidence intervals (CIs) using Cox proportional hazard models. Confounders were selected based on their known associations with type 2 diabetes and observed associations with cross-country skiing using the available data[19] and evidence from previous research.[12,13] The shape of the relationship of total volume of cross-country skiing with incident type 2 diabetes was explored using a restricted cubic spline with three knots at user-specified percentiles of the distribution of the exposures in multivariate adjusted models. Formal tests of interaction tests were used to assess for statistical evidence of effect modification by individual characteristics, such as age, body mass index, total LTPA and other risk markers for type 2 diabetes. To minimize biases due to reverse causation, we conducted sensitivity analysis which involved excluding the first five years of follow-up. All statistical analyses were conducted using Stata version 15 (Stata Corp, College Station, Texas, USA).

3. RESULTS

Baseline characteristics of 2,483 study participants without a known history of diabetes at baseline are shown in **Table 1**. The overall mean (standard deviation, SD) age of at baseline was 53 (5) years. The baseline median (interquartile range, (IQR); minimum to maximum values) total volume and duration of cross-country skiing was 42.5 (0.0-195.0; 0-3,375) MET hours per year and 60 (60-90; 10-480) minutes per week respectively. Total volume of cross-country skiing was moderately strongly and positively correlated with total LTPA (r = 0.36). A total of 539 incident type 2 diabetes events (annual rate 11.6/1000 person-years at risk, 95% confidence interval (CI) 10.7 to 12.7) were recorded during a median (interquartile range) follow-up of 21.6 (14.3-23.8) years. A restricted cubic spline curve showed a nonlinear relationship of total volume of cross-country skiing with risk of type 2 diabetes (*p*-value for nonlinearity<0.001); the risk of type 2 diabetes decreased with increasing total volume of cross-country skiing up to 1,215 MET hours/year, beyond which there was no further decrease in risk (**Figure S1**).

Compared to men with no cross-country skiing activity, the age-adjusted HRs (95% CIs) for incident type 2 diabetes were 0.70 (0.58 to 0.85) and 0.49 (0.38 to 0.61) for men who did 1-200 and >200 MET hours per year of cross-country skiing respectively (**Table 2**). Following progressive adjustment for several conventional risk factors and other potential confounders, the corresponding HRs (95% CIs) were minimally attenuated to 0.75 (0.62 to 0.92) and 0.59 (0.46 to 0.76) for 1-200 and >200 MET hours per year of cross-country skiing respectively (**Table 2**). The HRs (95% CIs) remained unchanged on further adjustment for prevalent conditions such as CVD and cancer, 0.76 (0.63 to 0.93) and 0.59 (0.46 to 0.76) for 1-200 and >200 MET hours per year of cross-country skiing respectively.

In analysis that adjusted for age, compared to men with no cross-country skiing activity, the HRs (95% CIs) of incident type 2 diabetes were 0.65 (0.54 to 0.78) and 0.55 (0.44 to 0.69) for men who did 1-60 and >60 mins per week of cross-country skiing (**Table 2**). The corresponding HRs (95% CIs) were 0.73 (0.60 to 0.89) and 0.64 (0.50 to 0.82) following further adjustment for several confounders. On additional adjustment for prevalent CVD and cancer, the corresponding HRs (95% CIs) remained

unchanged: 0.74 (0.61 to 0.91) and 0.64 (0.50 to 0.81) respectively.

The HRs (95% CIs) for the associations of both total volume and duration of cross-country skiing with incident type 2 diabetes remained unchanged when the analyses were not adjusted for total LTPA (**Table S2**). Furthermore, all associations were qualitatively similar in analyses that excluded the first five years of follow-up (**Table 3**).

Figure 1 shows the associations of total volume and average duration of cross-country skiing with incident type 2 diabetes in clinically relevant subgroups. Except for evidence of statistically significant interactions by socioeconomic status (SES) on the associations of total volume and duration of cross-country skiing with type 2 diabetes, there was no evidence of effect modification on the associations by other relevant clinical characteristics. Higher total volume and duration of cross-country skiing were each associated with reduced risk of type 2 diabetes in men with lower SES, but not in men with higher SES.

4. DISCUSSION

In this prospective study of the associations of leisure-time cross country skiing habits with risk of type 2 diabetes in middle-aged Finnish men, the findings showed that total volume and average duration of cross-country skiing were each inversely and independently associated with future risk of type 2 diabetes. The risk of type 2 diabetes decreased with increasing total volume of cross-country skiing up to 1,215 MET hours/year in a dose-response manner, with no further decrease in risk beyond this value. Therefore, it seems that most benefits of cross-country skiing in the prevention of type 2 diabetes may be achieved when the total amount in METhours/year of cross-country skiing is increased from a low to moderate level. Furthermore, the associations were not modified by levels or categories of relevant risk markers, except for statistically significant evidence of effect modification by SES. Higher total volume and duration of cross-country skiing were each associated with reduced risk of type 2 diabetes in men with lower SES, but not in men with higher SES; these findings reflect the observation that men with lower SES were more physically active (Table 1). Though numerous reports have consistently demonstrated various vigorous-intensity physical activity types to be associated with reduced incidence of type 2 diabetes,[4] this is the first comprehensive evaluation of the

nature and magnitude of the association of leisure-time cross-country with the risk of type 2 diabetes. Cross-country skiing has also been shown to be protective of hypertension, CVD outcomes and all-cause mortality.[10-13]

Cross-country skiing is a very high-intensity aerobic physical activity which places increased demands on cardiovascular function and metabolism, hence improving their efficiency. As cross-country skiing involves upper body exercise to various extents in addition to a high aerobic power, the ability to ski indicates the ability to perform high rate aerobic exercise and muscle work which employs the whole body.[20] Cross-country skiing is one of the most demanding aerobic endurance exercises that require upper and lower-body workouts to different extents. Cross-country skiing may reduce the risk of type 2 diabetes via the pathways exerted by physical activity and these include improvement in energy balance and reduction in adiposity,[21] improvement in insulin sensitivity and glycaemic control,[22,23] and anti-inflammatory effects.[24] There is a possibility that since cross-country skiing is only possible during the winter period, its protective effect on type 2 diabetes may reflect the high level of physical activity over the years and healthy lifestyle of cross-country skiers.[11] However, our analyses accounted for total LTPA, which suggests a possibility that the effects of cross-country skiing might be independent and direct. Findings add to the growing body of evidence that cross-country skiing undertaken as a leisure activity has the potential to promote public health. Leisure cross-country skiing is an enjoyable activity that can be taken up by individuals to overcome the physical activity deficits during winter and is loaded with several health benefits.

Strengths of the current investigation include the large-scale population-based prospective cohort design with inclusion of men who were representative of the general population; the long follow-up period; and comprehensive adjustment for confounders. The results should be interpreted with caution given the observational design; the inability to generalise the findings to women and other populations; and potential misclassification of the main exposure and physical activity habits (i.e., under- or over-estimation of physical activity level), because they were self-reported.

CONCLUSION

Total volume as well as duration of leisure time cross-country skiing are each inversely and independently associated with future risk of type 2 diabetes in a middle-aged Caucasian male population.

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DECLARATIONS AND CONSENT

Ethical approval was obtained from the Research Ethics Committee of the University of Eastern Kuopio. The study was conducted in accordance with the principles of the 1996 Helsinki Declaration. Written informed consent was obtained for all participants.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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COMPETING INTERESTS

The authors declare that they have no competing interests in this section.

AUTHORSHIP

S.K.K. performed data analyses; interpretation; drafting of the manuscript; and critical revision of the manuscript for intellectual content. J.K., S.K., and J.A.L. are principal investigators and contributed to the study design; data collection; and critical revision of the manuscript for intellectual content. A.V. contributed to data acquisition; data management; and critical revision of the manuscript for intellectual content. S.Y.J. and R.S.D. contributed to interpretation and critical revision of the manuscript for intellectual content. T.H.M. and J.A.L. supervised study and performed critical revision of the manuscript for intellectual content.

S.K.K. and J.A.L. are the guarantors of this work, and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

REFERENCES

1. Zheng Y, Ley SH, Hu FB. Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. *Nat Rev Endocrinol.* 2018;14(2):88-98.

2. Bhattacharya PK, Roy A. Primary prevention of diabetes mellitus: current strategies and future trends. *Italian Journal of Medicine.* 2016;11(1):15-22.

3. Chomistek AK, Cook NR, Flint AJ, Rimm EB. Vigorous-intensity leisure-time physical activity and risk of major chronic disease in men. *Med Sci Sports Exerc.* 2012;44(10):1898-1905.

4. Aune D, Norat T, Leitzmann M, Tonstad S, Vatten LJ. Physical activity and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis. *Eur J Epidemiol.* 2015;30(7):529-542.

5. Howard RA, Freedman DM, Park Y, Hollenbeck A, Schatzkin A, Leitzmann MF. Physical activity, sedentary behavior, and the risk of colon and rectal cancer in the NIH-AARP Diet and Health Study. *Cancer Causes Control.* 2008;19(9):939-953.

6. Williams PT. Reductions in incident coronary heart disease risk above guideline physical activity levels in men. *Atherosclerosis.* 2010;209(2):524-527.

7. Lee IM, Paffenbarger RS, Jr. Associations of light, moderate, and vigorous intensity physical activity with longevity. The Harvard Alumni Health Study. *American journal of epidemiology.* 2000;151(3):293-299.

8. Oja P, Kelly P, Pedisic Z, et al. Associations of specific types of sports and exercise with all-cause and cardiovascular-disease mortality: a cohort study of 80 306 British adults. *Br J Sports Med.* 2016.

9. Schnohr P, O'Keefe JH, Holtermann A, et al. Various Leisure-Time Physical Activities Associated With Widely Divergent Life Expectancies: The Copenhagen City Heart Study. *Mayo Clin Proc.* 2018;93(12):1775-1785.

10. Hallmarker U, Asberg S, Michaelsson K, et al. Risk of Recurrent Stroke and Death After First Stroke in Long-Distance Ski Race Participants. *Journal of the American Heart Association.* 2015;4(10):e002469.

11. Hallmarker U, Lindback J, Michaelsson K, et al. Survival and incidence of cardiovascular diseases in participants in a long-distance ski race (Vasaloppet, Sweden) compared with the background population. *Eur Heart J Qual Care Clin Outcomes.* 2018;4(2):91-97.

12. Laukkanen JA, Laukkanen T, Kunutsor SK. Cross-country skiing is associated with lower all-cause mortality: A population-based follow-up study. *Scand J Med Sci Sports.* 2018;28(3):1064-1072.

13. Kunutsor SK, Makikallio TH, Kauhanen J, et al. Leisure-time cross-country skiing is associated with lower incidence of hypertension: a prospective cohort study. *J Hypertens.* 2019.

14. Kunutsor SK, Khan H, Laukkanen JA. Serum albumin concentration and incident type 2 diabetes risk: new findings from a population-based cohort study. *Diabetologia.* 2015;58(5):961-967.

15. Taylor HL, Jacobs DR, Jr., Schucker B, Knudsen J, Leon AS, Debacker G. A questionnaire for the assessment of leisure time physical activities. *J Chronic Dis.* 1978;31(12):741-755.

16. Folsom AR, Jacobs DR, Jr., Caspersen CJ, Gomez-Marin O, Knudsen J. Test-retest reliability of the Minnesota Leisure Time Physical Activity Questionnaire. *J Chronic Dis.* 1986;39(7):505-511.

17. Lakka TA, Salonen JT. The physical activity questionnaires of the Kuopio Ischemic Heart Disease Study (KIHD): A collection of physical activity questionnaires for health related research. *Medicine & Science in Sports & Exercise.* 1997;29.

18. Lakka TA, Salonen JT. Intra-person variability of various physical activity assessments in the Kuopio Ischaemic Heart Disease Risk Factor Study. *Int J Epidemiol.* 1992;21(3):467-472.

19. Groenwold RH, Klungel OH, Grobbee DE, Hoes AW. Selection of confounding variables should not be based on observed associations with exposure. *Eur J Epidemiol.* 2011;26(8):589-593.

20. Sandbakk O, Holmberg HC. Physiological Capacity and Training Routines of Elite Cross-Country Skiers: Approaching the Upper Limits of Human Endurance. *Int J Sports Physiol Perform.* 2017;12(8):1003-1011.

21. Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB. Changes in diet and lifestyle and long-term weight gain in women and men. *N Engl J Med.* 2011;364(25):2392-2404.

22. Boule NG, Haddad E, Kenny GP, Wells GA, Sigal RJ. Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus: a meta-analysis of controlled clinical trials. *JAMA.* 2001;286(10):1218-1227.

23. Mayer-Davis EJ, D'Agostino R, Jr., Karter AJ, et al. Intensity and amount of physical activity in relation to insulin sensitivity: the Insulin Resistance Atherosclerosis Study. *JAMA.* 1998;279(9):669-674.

24. Lavie CJ, Church TS, Milani RV, Earnest CP. Impact of physical activity, cardiorespiratory fitness, and exercise training on markers of inflammation. *J Cardiopulm Rehabil Prev.* 2011;31(3):137-145.

TABLE 1 Baseline participant characteristics overall and by levels of total volume of leisure-time cross-country skiing

	Overall	Cross-country skiing exposure		
	N=2,483	0 MET hours/year N=995	1-200 MET hours/year N=883	> 200 MET hours/year N=605
	Mean (SD), median (IQR), or n (%)	Mean (SD), median (IQR), or n (%)	Mean (SD), median (IQR), or n (%)	Mean (SD), median (IQR), or n (%)
Total volume of skiing (MET hours/year)	42.5 (0.0-195.0)	0	72.3 (40.0-120.0)	390.0 (280.0-575.0)
Duration of skiing (mins/week)	60 (60-90)	0	60 (45-60)	90 (60-120)
Questionnaire/Prevalent conditions				
Age at survey (years)	53.0 (5.2)	53.4 (5.0)	52.7 (5.4)	52.8 (5.0)
Alcohol consumption (g/week)	31.4 (6.1-89.8)	32.9 (4.8-115.7)	32.0 (5.8-84.4)	29.0 (7.5-75.4)
Socioeconomic status	8.47 (4.24)	9.57 (3.9)	8.13 (4.17)	7.16 (4.43)
Current smokers	793 (31.9)	424 (42.6)	241 (27.3)	128 (21.2)
History of cardiovascular disease	922 (37.1)	449 (45.1)	277 (31.4)	196 (32.4)
History of cancer	42 (1.7)	16 (1.6)	16 (1.8)	10 (1.7)
Family history of diabetes	674 (27.1)	255 (25.6)	253 (28.7)	166 (27.4)
Physical measurements				
BMI (kg/m^2)	26.8 (3.5)	27.2 (4.0)	26.7 (3.1)	26.4 (3.2)
SBP (mmHg)	134 (17)	135 (18)	133 (16)	133 (17)
DBP (mmHg)	89 (10)	89 (11)	89 (10)	88 (10)
Total LTPA (kcal/day)	285.0 (149.5-477.8)	227.1 (107.6-411.2)	244.5 (136.8-408.9)	444.2 (299.2-669.3)
Lipid markers				
Total cholesterol (mmol/l)	5.91 (1.07)	5.93 (1.08)	5.93 (1.08)	5.84 (1.05)
HDL-C (mmol/l)	1.30 (0.30)	1.28 (0.31)	1.29 (0.31)	1.33 (0.28)
Metabolic and renal markers				
Fasting plasma glucose (mmol/l)	5.21 (0.82)	5.25 (0.82)	5.23 (0.90)	5.13 (0.67)
Serum creatinine (μmol/1)	89.6 (21.0)	89.0 (29.1)	89.2 (13.5)	91.2 (12.2)

BMI, body mass index; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; IQR, interquartile range; LTPA, leisure-time physical activity; SBP, systolic blood pressure

TABLE 2 Associations of total volume and duration of leisure-time cross-country skiing with incident type 2 diabetes

Cross-country skiing exposure	Events/ Total	Model 1		Model 2	
		HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Total volume (MET hours/year)					
0	253 / 995	ref		ref	
1-200	189 / 883	0.70 (0.58 to 0.85)	< 0.001	0.75 (0.62 to 0.92)	0.004
> 200	97 / 605	0.49 (0.38 to 0.61)	< 0.001	0.59 (0.46 to 0.76)	< 0.001
Duration (mins/week)					
0	253 / 995	ref		ref	
1-60	183 / 898	0.65 (0.54 to 0.78)	< 0.001	0.73 (0.60 to 0.89)	0.002
> 60	103 / 590	0.55 (0.44 to 0.69)	< 0.001	0.64 (0.50 to 0.82)	< 0.001

Model 1: Adjusted for age

Model 2: Model 1 plus body mass index, systolic blood pressure, smoking status, total cholesterol, baseline plasma glucose, high-density lipoprotein cholesterol, alcohol consumption, family history of diabetes, socioeconomic status and total leisure-time physical activity

TABLE 3 Associations of total volume and duration of leisure-time cross-country skiing with incident type 2 diabetes on exclusion of first five years of follow-up

Cross-country skiing exposure	Events/ Total	Model 1		Model 2	
		HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
Total volume (MET hours/year)					
0	202 / 880	ref		ref	
1-200	160 / 824	0.72 (0.59 to 0.89)	0.002	0.74 (0.60 to 0.92)	0.006
> 200	87 / 578	0.52 (0.41 to 0.67)	< 0.001	0.65 (0.49 to 0.84)	0.002
Duration (mins/week)					
0	202 / 880	ref		ref	
1-60	157 / 846	0.67 (0.55 to 0.83)	< 0.001	0.72 (0.58 to 0.90)	0.003
> 60	90 / 556	0.58 (0.45 to 0.75)	< 0.001	0.68 (0.53 to 0.89)	0.005

Model 1: Adjusted for age

Model 2: Model 1 plus body mass index, systolic blood pressure, smoking status, total cholesterol, baseline plasma glucose, high-density lipoprotein cholesterol, alcohol consumption, family history of diabetes, socioeconomic status and total leisure-time physical activity

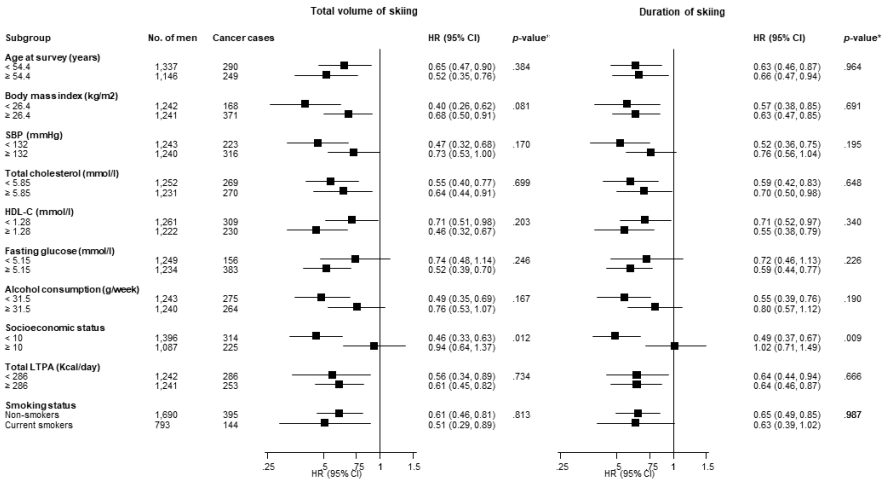

FIGURE 1 Associations of total volume and duration of cross-country skiing with incident type 2 diabetes in clinically relevant subgroups

Models were adjusted for age, body mass index, systolic blood pressure, smoking status, total cholesterol, baseline plasma glucose, high-density lipoprotein cholesterol, alcohol consumption, family history of diabetes, socioeconomic status and total leisure-time physical activity; CI, confidence interval; HDL-C, high-density lipoprotein cholesterol; HR, hazard ratio; LTPA, leisure-time physical activity; SBP, systolic blood pressure; *, *P*-value for interaction; cut-offs used for age, body mass index, systolic blood pressure, total cholesterol, HDL-C, fasting glucose, alcohol consumption, socioeconomic status, and total LTPA are median values.

For total volume of cross-country skiing, HRs are reported comparing > 200 MET hours/year of cross-country skiing with no skiing activity; for duration of cross-country skiing, HRs are reported comparing > 60 minutes of cross-country skiing/week with no skiing activity.