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Healthy behaviours and 10-year incidence of diabetes: A population cohort study

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ABSTRACT

Objective. To examine the association between meeting behavioural goals and diabetes incidence over 10 years in a large, representative Swedish population.

Methods. Population-based prospective cohort study of 32,120 individuals aged 35 to 55 years participating in a health promotion intervention in Västerbotten County, Sweden (1990 to 2013). Participants underwent an oral glucose tolerance test, clinical measures, and completed diet and activity questionnaires. Poisson regression quantified the association between achieving six behavioural goals at baseline – body mass index (BMI) <25 kg/m^2, moderate physical activity, non-smoker, fat intake $<30\%$ of energy, fibre intake ≥ 15 g/4184 kJ and alcohol intake ≤ 20 g/day – and diabetes incidence over 10 years.

Results. Median interquartile range (IQR) follow-up time was 9.9 (0.3) years; 2211 individuals (7%) developed diabetes. Only 4.4% of participants met all 6 goals ($n = 1245$) and compared to these individuals, participants meeting 0/1 goals had a 3.74 times higher diabetes incidence (95% confidence interval (CI) = 2.50 to 5.59), adjusting for sex, age, calendar period, education, family history of diabetes, history of myocardial infarction and long-term illness. If everyone achieved at least four behavioural goals, 14.1% (95% CI: 11.7 to 16.5%) of incident diabetes cases might be avoided.

Conclusion. Interventions promoting the achievement of behavioural goals in the general population could significantly reduce diabetes incidence.

Introduction

Trials of intensive lifestyle behaviour interventions targeting individuals with impaired glucose tolerance (IGT) typically promote physical activity and healthy eating and have led to sustained reductions in type 2 diabetes (Gillies et al., 2007; Knowler et al., 2009; Li et al., 2008; Lindstrom et al., 2006). As a large number of people exposed to low risk will experience more adverse events than a small number of people exposed to high risk (Rose, 1985), we expect the majority of incident diabetes cases to arise from the large proportion of the population at low risk, rather than the small proportion at high risk defined by IGT. Population-wide interventions are therefore predicted to exert larger, more cost-effective and sustainable effects on population health than interventions targeting high risk individuals (Rose, 1985). Whether adherence to similar behavioural goals in the general population – i.e. in larger groups of people at lower absolute risk – would reduce diabetes incidence and exert more sustainable effects on population health, than interventions targeting high-risk individuals, is unclear.

Evidence to directly support population-wide lifestyle interventions as cost-effective methods of curbing the rising tide of diabetes come mainly from modelling studies (Jacobs-van der Bruggen et al., 2007; Vijgen et al., 2006). Prospective observational studies have shown independent associations between adhering to individual healthy behaviours and reduced risk of developing diabetes (Cooper et al., 2012; de Munter et al., 2007; Hu et al., 2003; Hu et al., 2001; Koppes et al., 2005; The InterAct Consortium, 2012a; Willi et al., 2007). In one large population-based UK cohort, meeting five behavioural goals was

Abbreviations: DiabNorth, Diabetes Register in Northern Sweden; EPIC-PAQ, European Prospective Investigation into Cancer and Nutrition Physical Activity Questionnaire; FFQ, Food Group Frequency Questionnaire; VIP, Västerbotten Intervention Programme.

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inversely associated with the risk of developing diabetes over four years (Simmons et al., 2006). In the face of a growing burden of disease associated with rising glycaemia levels (Long et al., 2014), an improved understanding of the population impact meeting health behaviour goals might have on diabetes risk could help optimise and refine population-level health interventions.

Data from the Swedish Västerbotten Intervention Programme (VIP) (Norberg et al., 2010; Weinehall et al., 2001) provide a unique opportunity to examine whether adherence to behavioural goals might reduce long-term type 2 diabetes incidence in a pragmatic population-based setting. VIP combines population-based health promotion strategies with invitations for middle-aged inhabitants to attend systematic cardiovascular risk factor screening in primary care. We used data from VIP to (*i*) quantify the number of people meeting each of six behavioural goals focussing on diet, physical activity (PA), smoking and alcohol in the population, (*ii*) assess the association between the achievement of baseline behavioural goals and incident diabetes over ten years and (*iii*) estimate how many cases of diabetes might be avoided if everyone achieved a range of behavioural goals.

Methods

Data source

VIP is primarily a population based intervention programme aimed at reducing premature CVD. VIP invites all Västerbotten County inhabitants to an individual counselling session at their primary health care centre when they turn 40, 50 and 60 years of age and participation rate for follow-up after 10 years is around 75% (Norberg et al., 2011). VIP counselling is based on measured CVD risk factors (blood pressure, lipids, Oral Glucose Tolerance Test (OGTT), BMI and waist circumference), and questionnaire data assessing lifestyle behaviours, and the focus is to promote healthy behaviour. If measurements indicate hypertension, diabetes or hyperlipidemia, individuals are referred to usual care. CVD risk factor and questionnaire data from VIP assessments, including socio-demographic characteristics and health behaviour data, are registered in the VIP database and comprise the exposure data used in this study. DiabNorth links the VIP database to Västerbotten County medical records and the Swedish Prescribed Drug Register to identify all VIP participants who have been clinically diagnosed with diabetes (Rolandsson et al., 2012).

The eligible study population (n = 33,142) comprises individuals aged 40 or 50 years at baseline VIP assessment (Norberg et al., 2010; Weinehall et al., 2001) between 1990 and 2012, who attended at least one additional VIP follow-up assessment and/or are included in the Diabetes Register in Northern Sweden (DiabNorth). Based on the date of participation in VIP and date of diabetes diagnosis, prevalent cases at the time point for VIP assessment and incident cases of diabetes thereafter can be distinguished. Individuals with prevalent diabetes at baseline, defined by OGTT, self-report of diabetes or prescription of diabetes medication at the baseline assessment were excluded (n = 999). Individuals with incident diabetes in the year following baseline VIP assessment were excluded (n = 23). Data were available for 32,120 individuals (ESM Fig. 1). Written informed consent was obtained from VIP participants and DiabNorth; ethical approval was granted by the Regional Ethical Review Board, Umeå University [ref no: Dnr 08-131 M].

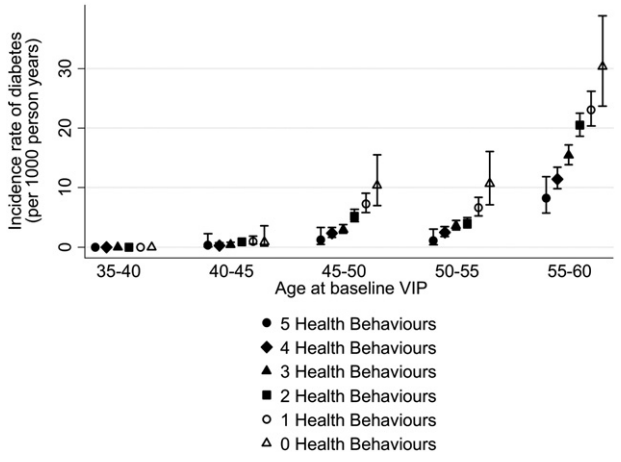

Fig. 1. Incidence of type 2 diabetes over 10-years by age and baseline health behaviour goals. Data are from Västerbotten Intervention Programme participants and presented incidence rates (95% CI) are crude. Tables 2 and 3 present modelled incidence rates by health behaviour goals, adjusted for measured potential confounders.

Incident type 2 diabetes ascertainment

The primary outcome was incident type 2 diabetes between baseline VIP assessment and follow-up over 10 years. Incident cases of diabetes were captured in two ways. Firstly, at VIP assessments by (*i*) OGTT (from capillary plasma): fasting plasma glucose (FPG) ≥ 7.0 mmol/L and/or 2-hour plasma glucose (PG) ≥ 12.2 mmol/L (Alberti and Zimmet, 1998; World Health Organization, 1999), (*ii*) self-report of diabetes or (*iii*) self-report of diabetes medication. For OGTTs, after an overnight fast all participants not known to have diabetes and with fasting plasma glucose (FPG) <7.0 mmol/L, were offered an OGTT according to the World Health Organization (WHO) criteria using a 75 g anhydrous glucose load (World Health Organization, 1999). Secondly, by clinical diagnosis in primary or secondary care and captured in the DiabNorth database. The vast majority, 95%, of the diabetes diagnoses were confirmed according to WHO recommendations (Rolandsson et al., 2012; World Health Organization, 1999).

VIP health assessments, measurements and questionnaires

VIP assessments include risk factor screening at participants' local health centre (Norberg et al., 2010). Height and weight were measured by nurses with the participant wearing light clothing. BMI was calculated as weight (in kg) divided by the square of height (in metres). Blood pressure (BP) was measured twice with a mercury sphygmomanometer and the mean value used (Ng et al., 2012a). Serum total cholesterol was analysed from venous blood samples (Ng et al., 2012b).

All VIP participants completed the 'Västerbotten Intervention Programme Questionnaire' at all assessments, which captures information on socio-demographics, tobacco and snuff use, family history of diabetes, history of myocardial infarction and long-term illness lasting ≥6 months. Physical activity was assessed by a previously validated brief questionnaire (the short EPIC-PAQ) (The Interact Consortium, 2012b). A total physical activity index, similar to the Cambridge physical activity index, ranked individuals into 4 groups (inactive, moderately inactive, moderately active, active) based on the cross-tabulation of occupation and exercise (Wareham et al., 2002). A binary physical activity variable was derived, categorizing individuals as low active (inactive and moderately active from the total activity index), or at least moderately active (moderately active or active). A modified and validated version of the Northern Sweden Food Group Frequency Questionnaire (FFQ) assessed diet and alcohol intake (Johansson et al., 2002) and daily energy/nutrient intakes were calculated as detailed (Bergstrom et al., 1991).

Statistical analysis

All analyses were performed using Stata (version 13.1) software. Behavioural goals were chosen based on the benefits afforded to high risk individuals meeting similar goals in diabetes prevention studies (Knowler et al., 2002; Tuomilehto et al., 2001), and the reported benefits of light/moderate alcohol consumption (Howard et al., 2004; Koppes et al., 2005) and not using tobacco (Willi et al., 2007) on diabetes progression. Six dichotomous behaviour variables were derived according to the achievement of baseline goals: BMI <25 kg/m^2, moderately physical activity, total fat intake <30% of total energy, fibre intake ≥15 g/4184 kJ, non-smoker/snuff user and light/moderate daily alcohol intake of greater than 0 g and less than 20 g per day (Swedish recommendations are not to exceed 20 g per day http://www.vr.se/English/). For all behaviours, the unhealthy behaviour was the reference category. A *health behaviour score* was constructed, for which participants scored 1 point for each of the six health behaviours they achieved, with a higher score reflecting healthier lifestyles.

We used t-tests to examine whether there were any differences in baseline characteristics between individuals with and without follow-up data at 10 years. Poisson regression models calculated crude rate and hazard ratios (HR) with 95% CI for the association between baseline behavioural goals and incident diabetes. Age and calendar period comprised the underlying time-scales in all

models. For attained age, person time was calculated from age at baseline assessment to age at first report of diabetes, or censor date (29th of January 2013, the last recorded VIP assessment), whichever came first. For calendar period, person time was calculated from date of study entry to first report of diabetes, or censor date. For analyses of individual health behaviour goals, Model 1 examined whether any of the six goals were independently associated with incident diabetes. In Model 2, stepwise forward regression identified those baseline health behaviours that were most strongly associated with incident diabetes and only those behaviours that improved model fit, determined via Wald tests, were included. Model 3 additionally adjusted for family history of diabetes, history of myocardial infarction and long-term illness lasting ≥6 months. A similar analytic approach investigated the association between the health behaviour score and diabetes risk.

The population attributable fraction (PAF) estimated the proportion of diabetes cases that could have been prevented in the population if everyone adhered to behavioural goals, adjusting for all measured confounders (Model 3). To test the robustness of estimates, sensitivity analyses (*i*) omitting alcohol abstainers and (*ii*) calculating the reduction in relative risk for each 1.5 kg/m^2 difference in BMI – roughly equal to a 5% reduction in weight for most people – were carried out (Simmons et al., 2006).

Results

A total of 32,120 middle-aged individuals from Västerbotten County aged 35 to 55 years at baseline were included in these analyses. Just over half of the participants were women (53.1%) and belonged to an intermediate social class (52.8%). Just under half the cohort were overweight or obese (48.2%). Table 1 shows baseline characteristics by type 2 diabetes status. Over a median (IQR) follow-up period of 9.9 (0.3) years, 2211 individuals (7%) developed type 2 diabetes (6.84 per 1000 person years at risk; 95% CI = 6.56 to 7.13).

Having a BMI of <25 kg/m^2, being at least moderately active and not using tobacco (never or former smoker/snuff user), were independently and inversely associated with the incidence of type 2 diabetes over 10 years, adjusting for age, sex, calendar period and education status at baseline (Table 2. RR = 0.35, 95% CI = 0.31 to 0.38; RR = 0.84, 95% CI = 0.77 to 0.92 and RR = 0.86, 95% CI = 0.79 to 0.94, respectively). Mutually adjusting for all three health behaviours did not qualitatively change the inverse associations between those behaviours and diabetes risk (Models 2 and 3, Table 2).

The more health behaviour goals met at baseline, the lower the rate of developing type 2 diabetes over the following 10 years (Fig. 1, Table 3; *p*-value for trend ≤0.001). Only 100 people did not meet any health behaviour goal at baseline, so individuals with a health behaviour score of 0 or 1 were combined. Compared to individuals who met 6 health behaviour goals at baseline VIP health assessment (n = 1245, 4.4%), those achieving 0/1 behaviour goals (n = 1097, 3.9%) had a 3.74 times higher rate (95% CI = 2.50 to 5.59) of developing type 2 diabetes, adjusted for all measured confounders (Model 2, Table 3).

Table 1
Association between participant characteristics at baseline health assessment and incidence of type 2 diabetes — the Västerbotten Intervention Programme, 1990 to 2013, n = 32,120.

Characteristic	Category/units	Participant numbers		Crude odds ratio[a] (95% CI)	P_{trend}
		All	Incident diabetes (%)		
Socio-demographic					
Sex	Women	17,060	982 (5.8)	1	0.0001
	Men	15,060	1229 (8.2)	1.46 (1.33 to 1.60)	
Age[b]	35 to 39.9 years	5120	265 (5.2)	1	0.0001
	40 to 44.9	10,817	550 (5.1)	0.99 (0.85 to 1.14)	
	45 to 49.9	6308	559 (8.9)	1.79 (1.54 to 2.10)	
	50 to 54.9	9875	837 (8.5)	1.70 (1.47 to 1.96)	
Education[c]	Basic	6555	593 (9.0)	1	0.0001
	Medium	16,839	1184 (7.0)	0.85 (0.77 to 0.95)	
	High	8481	401 (4.7)	0.58 (0.50 to 0.66)	
Marital status	Single	2572	240 (9.3)	1	0.0001
	Married/partner	26,790	1729 (6.4)	0.65 (0.59 to 0.78)	
	Divorced/separated/widow	2461	216 (8.8)	0.95 (0.78 to 1.16)	
Clinical					
Total cholesterol	mmol/L	31,769	2177 (6.8)	1.12 (1.07 to 1.16)	0.0001
Systolic BP	mmHg	31,641	2175 (6.9)	1.04 (1.03 to 1.04)	0.0001
Diastolic BP	mmHg	31,630	2172 (6.9)	1.06 (1.05 to 1.06)	0.0001
History T2DM[d]		31,677	2178 (6.9)	1.99 (1.82 to 2.17)	0.0001
History MI[e]		31,816	2181 (6.9)	2.72 (1.66 to 4.48)	0.0001
Long-term sick[f]		28,972	1903 (6.6)	1.48 (1.31 to 1.67)	0.0003
Achievement of health behaviour goals					
BMI	≥25 kg/m^2	15,358	1637 (10.7)	1	0.0001
	<25 kg/m^2	16,484	546 (3.3)	0.31 (0.28 to 0.34)	
Physical activity[g]	Low active	15,956	1173 (7.3)	1	0.0002
	At least moderate	15,157	930 (6.1)	0.84 (0.77 to 0.92)	
Fibre	<15 g/4184 kJ	9601	686 (7.1)	1	0.0048
	≥15 g/4184 kJ	20,263	1307 (6.4)	0.87 (0.79 to 0.96)	
Fat	<30% of total energy intake	22,407	1508 (6.7)	1	0.99
	≥30% of total energy intake	7456	485 (6.5)	1.00 (0.90 to 1.12)	
Alcohol	>20 g/day and abstainers	1901	148 (7.8)	1	0.06
	>0 g and ≤20 g/day	27,963	1845 (6.6)	0.84 (0.71 to 1.01)	
Tobacco	Current user	10,314	817 (7.9)	1	0.0001
	Never/former user	21,166	1359 (6.4)	0.82 (0.75 to 0.90)	

Odds ratios for continuous/categorical exposures represent the odds of developing diabetes per 1 unit/categorical increase in the exposure.
[a] Adjusted for age and sex.
[b] At time of first VIP survey.
[c] Completion of years in school: low ≤9; medium 10–12 and high ≥13 years.
[d] Self-reported nuclear family history of type 2 diabetes at baseline.
[e] Self-reported history of myocardial infarction.
[f] Self-reported long-term sickness lasting 6 months or more.
[g] Validated index based on cross-tabulation of occupational and leisure time activity (The Interact Consortium, 2012b).

Table 2
Numbers achieving individual health behaviour goals at baseline health survey and association of each goal with incidence of type 2 diabetes among middle-aged inhabitants of Västerbotten County Sweden, 1990 to 2013 (n = 32,120).

Characteristic	Health score	n	D	Y	Rate (95% CI)	Model 1	Model 2	Model 3
						Rate ratio (95% CI)	Rate ratio (95% CI)	Rate ratio (95% CI)
BMI								
Overweight/obese	0	15,358	1637	154	10.66 (10.15 to 11.18)	1	1	1
Not overweight/obese	1	16,484	546	167	3.27 (3.01 to 3.56)	0.35 (0.31 to 0.38)[c]	0.34 (0.31 to 0.38)[c]	0.36 (0.32 to 0.40)[c]
Physical activity								
Low active	0	15,956	1173	161	7.31 (6.90 to 7.73)	1	1	1
At least moderate	1	15,157	930	153	6.10 (5.72 to 6.50)	0.84 (0.77 to 0.92)[c]	0.89 (0.82 to 0.97)[a]	0.89 (0.81 to 0.98)[a]
Fibre								
<15 g/4184 kJ	0	9601	686	97	7.10 (6.59 to 7.65)	1	–	–
≥15 g/4184 kJ	1	20,263	1307	203	6.44 (6.10 to 6.79)	0.95 (0.86 to 1.04)	–	–
Fat								
≥30% total energy	0	22,408	1508	225	6.70 (6.37 to 7.05)	1	–	–
<30% total energy	1	7456	485	75	6.49 (5.94 to 7.10)	0.98 (0.88 to 1.09)	–	–
Alcohol								
>20 g/day and abstainers	0	2350	148	19	7.79 (6.63 to 9.15)	1	–	–
>0 g and ≤20 g/day	1	27,514	1845	280	6.57 (6.28 to 6.90)	0.90 (0.76 to 1.07)	–	–
Tobacco								
Current user	0	10,314	817	104	7.89 (7.37 to 8.45)	1	1	1
Never/former user	1	21,166	1359	213	6.37 (6.04 to 6.72)	0.86 (0.79 to 0.94)[c]	0.85 (0.77 to 0.93)[b]	0.84 (0.76 to 0.93)[c]

Rates represent the incidence of developing diabetes per 1000 person years at risk and rate ratios for each behaviour represents the risk of developing diabetes per categorical increase in the health score.
Model 1: Adjusted for sex, age, calendar period and education. Model 2: As for Model 1, and mutually adjusted for achieving BMI, tobacco and physical activity goals. Model 3: As for Model 2 and additionally adjusted for family history of diabetes, history of myocardial infarction and self-reported long-term illness lasting at least 6 months.
D, type 2 diabetes event; Y, person-years at risk (per 1000).
[a] $p \leq 0.05$.
[b] $p \leq 0.001$.
[c] $p \leq 0.0001$.

Assuming that the association between meeting behavioural goals and diabetes is causal, the proportion of diabetes cases that might be prevented in the population (PAF) rose as the number of behavioural goals met by individuals increased (Table 4). If all participants met at least 2 health behaviour goals at baseline, 1.5% of diabetes cases might have been prevented and this rose to 34.4% if everyone met all 6 goals (Table 4. 95% CI = 1.1 to 2.0% and 27.9 to 42.4%, respectively). Among the sub-group of individuals achieving 0/1 healthy behaviours at baseline, the attributable fractions associated with a healthy lifestyle was even more pronounced (Table 4). Those meeting more behavioural goals at baseline were more likely to be female, belong to a higher socioeconomic category, be married and without a family history of diabetes compared to those who had met fewer health behaviours (χ^2 test for trend, all $p < 0.001$; data not shown).

Sensitivity analyses omitting abstainers (n = 1761) did not qualitatively change the results (Model 1: RR, 95% CI = 0.99, 0.67 to 1.47). In terms of differences in baseline weight, the incidence of diabetes increased by 14% for every 1.5 kg/m^2 higher BMI, adjusting for all measured confounders (RR = 1.14, 95% CI = 1.13 to 1.15).

Discussion

In this representative population-based cohort of 32,120 middle-aged individuals, over half met at least 4 out of 6 behavioural goals encompassing diet, physical activity, alcohol and tobacco use. Diabetes incidence over 10 years of follow-up was inversely associated with the number of behavioural goals achieved at baseline. Individuals with a BMI of <25 kg/m^2, who reported being at least moderately physically active and who did not use tobacco had a significantly lower risk of developing type 2 diabetes over a decade of follow-up, compared to individuals who were obese/overweight, were not active or used tobacco. These associations were independent of measured confounders including age, socioeconomic status, long term illness, family history of diabetes and a history of myocardial infarction. The PAFs we report allow us to predict what would happen to the burden of diabetes in Sweden if we were to implement interventions that lead to population-wide increases in the adoption and adherence to health behaviours. This includes the scenarios in which the population adhered to all six health behaviours, down to at least two health behaviours.

Table 3
Health behaviour score and incidence of type 2 diabetes over a 10 year follow-up period among middle-aged inhabitants of Västerbotten County Sweden, 1990 to 2013 (n = 28,343).

Heath score	n	D	Y	Rate (95% CI)	Model 1	Model 2
					Rate ratio (95% CI)	Rate ratio (95% CI)
6	1245	37 (3.0)	12.5	2.95 (2.14 to 4.07)	1	1
5	5069	211 (4.2)	51.0	4.13 (3.61 to 4.73)	1.31 (0.93 to 1.86)	1.45 (0.98 to 2.13)
4	8454	460 (5.4)	84.9	5.42 (4.95 to 5.94)	1.73 (1.24 to 2.42)	1.97 (1.36 to 2.86)
3	8169	612 (7.5)	81.8	7.49 (6.92 to 8.10)	2.24 (1.60 to 3.12)	2.49 (1.72 to 3.61)
2	4452	420 (9.4)	44.5	9.43 (8.57 to 10.38)	2.68 (1.91 to 3.76)	2.97 (2.04 to 4.32)
0 or 1	1097	139 (12.7)	11.0	12.68 (10.74 to 14.98)	3.52 (2.44 to 5.07)	3.74 (2.50 to 5.59)
P_{trend}					<0.0001	<0.0001

Rates represent the incidence of developing diabetes per 1000 person years at risk and rate ratios represent the risk of developing diabetes per 1 unit increase in the health behaviour score.
Model 1: Adjusted for sex, age, calendar period and education. Model 2: As for Model 1, and additionally adjusted for family history of diabetes, history of myocardial infarction and self-reported long-term illness lasting at least 6 months.
D, type 2 diabetes event (%); Y, person-years at risk (per 1000).

Table 4
The proportion of diabetes cases that might be prevented if all individuals achieved at least the number of preventive health behaviour goals indicated at baseline, the Västerbotten Intervention Programme, 1990 to 2013, n = 28,485.

Goals met[a]	Population attributable fraction % (95% CI)	
	Whole population[b]	Population achieving 0/1 goals[c]
2 goals	1.5 (1.1 to 2.0)	39.2 (26.9 to 49.5)
3 goals	5.9 (4.6 to 7.1)	26.2 (20.1 to 31.8)
4 goals	14.1 (11.7 to 16.5)	51.4 (43.4 to 58.4)
5 goals	25.8 (21.7 to 29.6)	58.2 (50.3 to 64.9)
6 goals	34.4 (27.9 to 42.4)	65.6 (57.6 to 72.1)

Adjusted for sex, age, calendar period, education, self-reported family history of diabetes, history of myocardial infarction and long-term illness lasting 6 months or more. Assuming causality between meeting health behaviour goals and diabetes, PAFs show the percentage of diabetes cases that might be prevented if all participants achieved at least the number of health behaviours indicated at baseline.

[a] The number of preventive health behaviour goals achieved at baseline by self-report.

[b] The proportion of diabetes cases that might be prevented in the Västerbotten County if all participants achieved at least the number of preventive health behaviour goals indicated.

[c] The proportion of diabetes cases in unhealthy individuals (achieving 0 or 1 goals at baseline) that might be prevented if all unhealthy participants achieved the number of preventive goals indicated.

For example, we estimated that 14.1% (PAF) of all diabetes cases might be avoided in the population if everyone achieved at least 4 health behaviour goals. Interventions that promote the achievement of behavioural goals in the general population could significantly reduce the burden of diabetes incidence.

Whether health behaviour interventions decrease diabetes incidence on a population level, i.e. in large groups of people at lower absolute risk, is not clear. Carefully conducted observational analyses examining whether adherence to key behaviours reduce diabetes risk in well-characterised cohorts can help elucidate whether behavioural interventions can decrease population-wide diabetes incidence and advance our understanding of the population impact of living a healthy life. One previous empirical study suggested that individuals who met more of a set of five diabetes prevention goals, similar to those outlined here were less likely to develop diabetes, with the two goals most strongly inversely associated with diabetes incidence comprising a BMI of less than 25 kg/m^2 and being moderately active (Simmons et al., 2006). Consistency in those behaviours most strongly inversely associated with reduced diabetes risk over different geographic locations and time periods suggests that having a healthy body composition and being physically active may represent key goals to target in population preventive strategies. An inverse association between never/former tobacco use and diabetes incidence was found, adding further support for the health benefits of not using tobacco (Rimm et al., 1995). In addition to reduced diabetes risk, meeting similar health behaviour goals is associated with a range of health benefits, including reductions in cardiovascular disease, premature death (Khaw et al., 2008), cancer (Vergnaud et al., 2013) and cognitive decline (Anton et al., 2013).

Our results suggest that the biggest effects on reducing diabetes risk came from having a healthy body composition, being moderately physically active and not using tobacco. However, is it realistic to expect adherence to such healthy behaviours in the general population? Extrapolating from the original EPAQ2 validation study, we expect the difference in measured PAEE between PA categories used here to approximate 920 and 730 kJ/day in men and women, respectively. In terms of BMI, the mean (95% CI) BMI of those with and without a healthy body composition (<25 kg/m^2) was 22.6 kg/m^2 (22.6 to 22.6 kg/m^2) and 28.3 (28.3 to 28.4 kg/m^2), respectively. This equates to a net difference (95% CI) in BMI of 5.7 kg/m^2 (5.6 to 5.8 kg/m^2) between those who had a healthy body composition and those who did not, which was associated with a 58% reduction in diabetes risk over 10 years. Increases in weight during middle-age are well documented and given the difficulty in reducing/maintaining weight in trials (Turk et al., 2009), such large effects will be difficult to achieve and sustain in a real-world setting. Our findings emphasise the huge potential for small changes in health behaviour to contribute to a reduction in population risk, but also the difficulty in motivating people to meet and maintain behavioural goals.

The difficulties and costs of identifying people with impaired fasting glucose (IFG)/IGT, coupled with the low uptake of intensive interventions in the high risk identified (Ruge et al., 2007) mean that traditional individual-level intensive preventive approaches which focus on targeting the high-risk minority are likely to be insufficient to combat the growing burden of hyperglycaemia (Rose, 1985). Thus, interventions targeting the wider collective determinants of elevated blood glucose levels are needed to complement intensive individual approaches in order to drive a downward shift in the population distribution of glycaemia (Rose, 1985). Lessons can be learned from the success of tobacco cessation strategies, where a combination of individual- (West et al., 2013; West et al., 2000) and collective- (Jha and Chaloupka, 2000) level interventions have likely contributed to the halving of smoking prevalence in the UK in recent decades, from 45% in 1974 to 20% in 2011 (Office for National Statistics, 2011). Indeed, many tobacco cessation interventions could be adapted to address other modifiable risk factors, such as BMI and diet (Adeyi et al., 2007; Mercer et al., 2003). Combined with population-level interventions to increase activity (NHS Health Development Agency, 2005), individual-level behaviour change programmes (Bravata et al., 2007), may represent one way of increasing activity on a population-wide scale. Mass exposure controls, such as population health promotion programmes (Finnish Diabetes Association, 2003; Norberg et al., 2010) or fiscal strategies for unhealthy foods (Briggs et al., 2013) could change cultural norms and may exert additional effects on population health.

A major strength of this study is the prospective population-based design, comprising 32,120 individuals followed for a decade. VIP is integrated into primary care which enabled efficient data collection, long-term follow-up and generalisability to similar locations. The vast majority of diabetes diagnoses were confirmed via OGTT and care was taken to exclude prevalent undiagnosed diabetes cases. Use of standard operating procedures alongside a regular training programme for VIP personal ensured robust measurements across primary care centres and over time. Limitations include the use of self-report to ascertain the health behaviour exposure which may introduce some misclassification of the true exposure. However, since questionnaires were completed before diabetes ascertainment such misclassification, if introduced, is likely to be random and dilute true associations. The high rate of VIP goal achievement could be driven by a 'healthy participant effect'. However, VIP participation rates were excellent for a population-based programme – 56% in 1995 to ≥66% since 2005 (Norberg et al., 2012) – and evidence to support a social selection bias was not found in previous VIP studies (Norberg et al., 2012), consistent with the non-differential distribution of health behaviours by VIP participation status, but we cannot confirm this.

Conclusions

Type 2 diabetes incidence was inversely associated with the number of behavioural goals achieved in this representative middle-aged Swedish population. The healthy behaviours identified as most strongly associated with reduced diabetes risk included having a healthy body composition, being at least moderately active and not using tobacco. These data demonstrate the potential for population-based prevention approaches targeting obesity, physical activity, tobacco use and diet to control the rising burden of diabetes and highlights the need for additional strategies to address the growing burden of disease associated with unhealthy lifestyles.

Author contributions

GHL did the analyses, interpreted the data, and drafted and critically revised the manuscript. RKS and SJG conceived the study question, interpreted the data and drafted and critically revised the manuscript. LW coordinated the VIP and data collection from 1990 to 2007, interpreted the data and critically revised the manuscript. MN coordinated the VIP and data collection from 2008 to present, interpreted the data and critically revised the manuscript. OR coordinated the DiabNorth and data collection from 2002 to present, interpreted the data and critically revised the manuscript. EF and PW interpreted the data and critically revised the manuscript. All authors had access to all of the data. All authors can take responsibility for the integrity of the data and the accuracy of the analysis.

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Competing interests

The first author Gráinne H. Long declares no conflicts of interest but has recently joined Roche Products Ltd. The first author states that all of the works contained in this manuscript were carried out during his employment as a Career Development Fellowship at the Medical Research Council's Epidemiology Unit at the University of Cambridge. The other authors declared no competing interests.

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Appendix A. Supplementary

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2014.12.013.

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