JDI Journal of Diabetes Investigation Open access
Official Journal of the Asian Association for the Study of Diabetes
ORIGINAL ARTICLE

Improving and maintaining healthy lifestyles are associated with a lower risk of diabetes: A large cohort study

Keisuke Kuwahara[1,2]*, Shuichiro Yamamoto[3], Toru Honda[3], Tohru Nakagawa[3], Hirono Ishikawa[2], Takeshi Hayashi[3], Tetsuya Mizoue[1]

[1]National Center for Global Health and Medicine, Tokyo, Japan, [2]Teikyo University Graduate School of Public Health, Tokyo, Japan, and [3]Hitachi, Ltd, Ibaraki, Japan

Keywords
Adherence to healthy lifestyles over time, Cohort study, Diabetes prevention

***Correspondence**
Keisuke Kuwahara
Tel.: +81-3-3964-1211
Fax: +81-3-3964-1058
E-mail address:
kkuwahara@med.teikyo-u.ac.jp

J Diabetes Investig 2022; 13: 714–724

doi: 10.1111/jdi.13713

ABSTRACT

Aims: It is well known that healthy lifestyles measured at one time-point are inversely associated with diabetes risk. The impact of transitions in combined lifestyles in real settings remains unknown.

Materials and Methods: The trajectory patterns of combined lifestyles over three years were identified using group-based trajectory modeling in 26,647 adults in Japan. Two types of indices (not having the unhealthy lifestyle [easy goal] and having healthiest lifestyles [challenging goal]) were developed using five lifestyle factors: smoking, alcohol consumption, exercise, sleep duration, and body weight control. This index was calculated using the yearly total score (0–5; higher score indicated healthier lifestyles). Diabetes was defined by high plasma glucose level, high hemoglobin A1c level, and self-report.

Results: Five trajectory patterns were identified for each index and it was shown that healthier patterns are associated with a lower risk of type 2 diabetes during 6.6 years of average follow-up. For example, with a challenging-goal, compared with a persistently very unhealthy pattern, the adjusted hazard ratios (95% confidence intervals) were 0.65 (0.59, 0.73), 0.50 (0.39, 0.64), 0.43 (0.38, 0.48), and 0.33 (0.27, 0.41) for 'persistently unhealthy', 'improved from unhealthy to moderately healthy', 'persistently moderately healthy', and 'persistently mostly healthy' patterns, respectively.

Conclusions: Our data reinforce the importance of improving and maintaining health-related lifestyles to prevent diabetes.

BACKGROUND

Diabetes is a growing social issue worldwide. In 2017, diabetes affected 451 million people[1] and accounted for at least one million deaths[2]. Diabetes is also the fourth leading cause of disability[3], posing a huge economic burden[4]. In addition, recent data suggest that diabetes may elevate the risk of COVID-19 severity and related mortality[5,6]. Given that the prevalence of diabetes may keep increasing[1] and that most diabetics (80%) live in low- and middle-income countries[1], there is an urgent need to establish feasible cost-effective strategies that prevent or delay diabetes development. To date, many studies have explained the relationship between distinct health-related lifestyles (e.g., smoking[7], alcohol use[8], physical activity[9], body weight control[10], and sleep[11]) and diabetes. Nonetheless, given that unhealthy lifestyles tend to co-exist[12], it is important to understand how a combination of (un)healthy lifestyles affects diabetes risk.

According to recent systematic reviews[13,14], some observational studies have investigated the compound association of different lifestyles with diabetes onset. However, several issues remain to be addressed. First, although lifestyles may change over time, no observational study explains the association of combined lifestyles trajectory patterns with diabetes yet. Such an examination would help to forecast the results of lifestyle changes consequent to the COVID-19 pandemic[15–17]. Second, existing definitions of health-related lifestyles, such as smoking, alcohol, physical activity, diet, and body weight control[13], do not clearly account for the updated goal-setting theory[18], which

Received 3 July 2021; revised 12 November 2021; accepted 15 November 2021

could help to foster behavior change. According to this theory, setting an appropriate goal (e.g., 'not too challenging') is important to motivate a change of behavior. Thus, when determining the criteria to develop an index of health-related lifestyles, the ability to attain a goal and difficulty of a task should be considered[18], because setting challenging goals may cause harm[18]. Since unhealthy lifestyles co-exist[12], it would be practical to set short-term (easy) goals to quit unhealthy lifestyles and mid- to long-term (more challenging) goals to implement healthier lifestyles. Third, most data are derived from Western countries[13]; data are scarce in Asia[13], where obesity levels are rising[19] and so is the associated burden due to diabetes[20]. As Asians may be more susceptible to obesity than are Caucasians[21], updated evidence is needed to help understand the changing situation. Fourth, only one study examined this topic among workers (specifically, nurses)[22], even though workers' health is critically important for the sustainable development of societies[23]. Lastly, although a tailored message is important for behavior change[24], evidence for the creation of a tailored message is sparse (e.g., data according to glycemic conditions, a key determinant of diabetes[25], and work-related conditions).

To address the abovementioned issues, we developed a lifestyle index that considers the simplicity and difficulty of a task. Thereafter, we identified longitudinal trajectory patterns of combined healthy lifestyles and examined their association with type 2 diabetes onset among workers with diverse characteristics including varying glycemic conditions in Japan.

PARTICIPANTS AND METHODS

Study settings

We performed a large cohort study using longitudinal data of workers in Japan from a sub-study of the Japan Epidemiology Collaboration on Occupational Health (J-ECOH). The present data were collected during annual health check-ups performed in each fiscal year from 2006 to 2017 at one large-scale company. The company's annual health check-up comprised a physical examination and a detailed questionnaire on lifestyles, working conditions, and health. In Japan, workers are required to receive a health examination annually under the Industrial Safety and Health Act. Based on the national ethical guidelines, we announced and explained about the J-ECOH Study and its implementation at the company; workers could refuse the use of their data for research. Ethical approval of the study procedure including a waiver for the need of informed consent was obtained at the National Center for Global Health and Medicine, Japan.

Participants

As shown in Figure 1, first, we extracted the data of participants aged 30–64 years who attended an annual health check-up between April 2009 and March 2010, which marked the fiscal year 2009 and the study's baseline; 43,025 workers (36,208 men and 6,817 women) met this criterion. Then, we excluded 9,380 workers due to missing information regarding diabetes

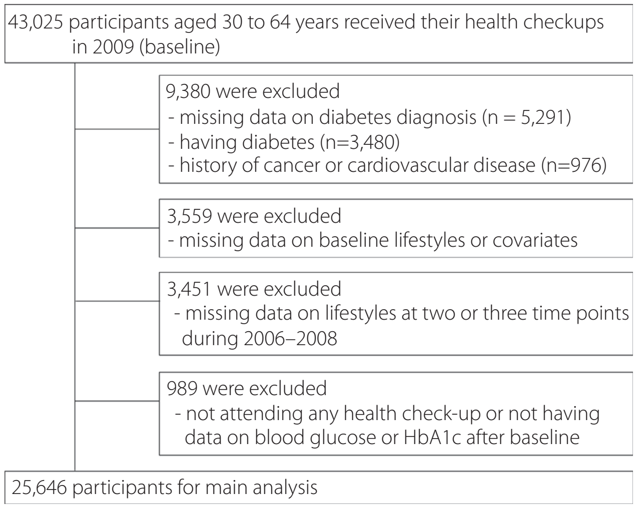

Figure 1 | A flowchart of participants selection.

diagnosis (n = 5,291), presence of diabetes (determined by fasting or random plasma glucose, hemoglobin A1c (HbA1c) levels, ongoing anti-diabetic drug therapy, and self-reported history of diabetes; n = 3,480), or history of cancer or cardiovascular disease (n = 976). Of the remaining participants, 3,559 were excluded due to a lack of baseline data on lifestyle factors or covariates. Further, 3,451 participants were excluded due to missing data on health-lifestyles at two or three time points during 2006–2008. Lastly, 989 participants who did not attend any subsequent health check-up or who did not have data on plasma glucose or HbA1c levels in a subsequent health examination were excluded from the dataset. As a result, the data of 25,646 workers aged 30–64 years (mean: 45.3 years) were included in the main analysis.

Measurement of lifestyles

Participants self-reported smoking habits, alcohol consumption, sleep duration, and exercise. Smoking status was reported as never smoker, past smoker, or current smoker. Participants reported the frequency and volume of alcohol consumed per occasion; we calculated the daily alcohol consumption expressed in *go* (a unit of Japanese *sake*, 1 *go* approximately corresponds to 23 g of ethanol). Sleep duration was self-reported as sleep lasting <5, 5 to <6, 6 to <7, and 7 h or longer per day. This type of question, which has been commonly employed in observational studies[26,27], has shown good correlation with sleep duration objectively recorded sleep duration[28]. The volume of leisure-time exercise (metabolic equivalent [MET]-hours per week) was calculated using information on exercise type (20 items) and its frequency and duration as described previously[29]. The present physical activity questionnaire is similar to the validated physical activity questionnaire[30]. Body mass index (BMI, kg/m^2) was calculated using data on objectively measured body height (m) and weight (kg).

Development of lifestyle index

We developed an *a priori* lifestyle index comprising smoking habits, alcohol consumption, sleep duration, exercise performed, and body weight control. These variables were defined according to recent evidence on risk factors of type 2 diabetes[7–11], existing index for diabetes prevention[13], and feasibility and simplicity of use in occupational settings. One point was assigned to each low-risk factor; otherwise, zero points were assigned. Therefore, the total score of the index ranged from 0 (unhealthy lifestyles) to 5 (healthy lifestyle). This index was calculated each year from 2006 to 2009, yielding a maximum of four time points for the index.

We developed two types of indices (A and B) by changing the cutoff for sleep and exercise. Index A comprised challenging goals: no smoking and no heavy alcohol use, gaining sufficient sleep, performing recommended level of exercise, and avoiding obesity. 'No smoking' was defined as such if the participant had never smoked or had quit smoking. We determined ethanol consumption of <46 and <23 g per day as the cutoffs for 'no heavy alcohol use' for men and women, respectively. As evidence of the association between alcohol and diabetes is limited, especially in Asian women[8,31], and as there is no consensus regarding the definition of 'heavy alcohol use', we determined the above mentioned cutoffs using data from systematic reviews[8,31], a recent report[32], and the national health promotion strategy in Japan for non-communicable diseases[33]. 'Sufficient sleep' was defined as 7 h or longer per day according to a systematic review[11] and previous studies in working populations, who rarely exhibit long sleep durations[34]. 'Meeting the recommended level of exercise' was defined as having ≥7.5 MET-hours per day (which approximately corresponds to World Health Organization (WHO)'s recommendation)[35]. Lastly, healthy body weight was determined as a BMI <25.0 kg/m^2 according to the relationship between obesity level and diabetes[36,37]. Index B comprised easier goals; we changed the definition of exercise to engaging in some leisure-time exercise (>0 MET-hours per week) in harmony with the WHO's new guideline that states, 'start by doing small amounts of physical activity, gradually increasing frequency, intensity and duration over time'[35]. Avoiding sleep deprivation was defined as sleeping ≥5 h/day, based on the results of a systematic review[11]. For sensitivity analysis of index A, we also developed an index C, wherein we defined BMI as a range from 18.5 to 25.0 kg/m^2, which is commonly recommended for general health[36]. We assigned zero points for underweight (<18.5 kg/m^2) and obesity (≥25.0 kg/m^2).

Measurement of outcome (type 2 diabetes)

We confirmed new type 2 diabetes cases using data derived during the fiscal years from 2010 to 2017. A participant was categorized as diabetic if their fasting plasma glucose was ≥126 mg/dL (7.0 mmol/L), random plasma glucose was ≥200 mg/dL (11.1 mmol/L), HbA1c was ≥6.5% (48 mmol/mol), or self-report of being currently under medical treatment for diabetes[38].

Other variables

History of disease, family history of diabetes, and work-related factors including overtime work, shift work, job position, and duration of walking to and from work were self-reported as explained previously[29]. Participants were termed hypertensive if their blood pressure was defined as ≥140/90 mmHg or they were on anti-hypertensive therapy. Prediabetes was defined according to the criteria presented by American Diabetes Association[38].

Statistical analysis

We applied group-based trajectory modeling to identify the longitudinal lifestyle patterns using four time points (from 2006 to 2009). The details of this procedure have been described previously[39]. In short, we first determined the number of groups based on model fit using Bayesian information criteria (BIC) and our objective (to investigate the relationship between lifestyle patterns and diabetes). After fixing the group number, we identified the combination of trajectory shapes showing the best BIC. Accordingly, we classified the participants without diabetes into groups showing similar trajectories of healthy lifestyles. We calculated the average posterior probability of assigning participants to each trajectory group; a probability of 70% or higher indicates good discrimination in classifying people into different groups. We named the lifestyle patterns according to the level of healthy lifestyle scores and the shape of the longitudinal changes in the score. The descriptive results of participant characteristics according to the adherence patterns of healthy lifestyles are shown as percentages and means for categorical and continuous variables, respectively.

We calculated person-time using the date of the baseline check-up and the date of diagnosis with diabetes at a subsequent health check-up or the date of the last check-up. We employed Cox regression to obtain hazard ratios and 95% confidence intervals (CIs) of diabetes onset according to longitudinal lifestyle patterns. First, we adjusted for sex and age (years, continuous) at baseline in model 1. In the next model, we further adjusted for hypertension (yes or no), a family history of diabetes (yes or no), job position (high or others), monthly overtime work (<45, 45–59, 60–79, 80–99, and ≥100 h), physical activity at work (sedentary, standing or walking, and fairly physically active), shift work status (yes and no), walking during commute to and from work (<20, 20–39, and ≥40 min). In model 3, we additionally adjusted for baseline HbA1c level (%, continuous) as a potential mediator. Model 4 was adjusted for all covariates in model 2 and baseline BMI; it was performed as a sensitivity analysis because obesity is a strong predictor of diabetes and obesity levels largely differ as per lifestyle patterns. We repeated the analyses according to demographic factors, obesity level, glycemic condition, family history of diabetes, and work-related factors. To compare the relative risk between the 'improving' group and the 'persistently mostly healthy' group, we repeated the main analysis with treating the 'improving' group as reference category. *P* values (two-sided) less than 0.05

were considered as statistically significant. Stata version 14.2 (Stata Corp, College Station, TX, USA) was employed for data analysis.

RESULTS

When using lifestyle index A (challenging goal), we identified five longitudinal lifestyle patterns as illustrated in Figure 2 and Table S1. The posterior probability of assigning participants to each group was sufficiently high for all patterns; all probabilities were >90% except for that of assigning participants to the 'improved' group (82%). Participants who engaged in healthier lifestyles tended to be women and did not have hypertension and obesity. They were slightly less likely to engage in shift work and long overtime work, whereas they were more likely to engage in sedentary work and have a high-rank job position. They also tended to walk during commuting (Table 1). Similar results were observed when using index B (Figure S1 and Table S2) and index C (data omitted).

During the 169,309 person-years, 2,223 developed type 2 diabetes (8.7%). Table 2 shows the association of longitudinal lifestyle patterns and diabetes risk when using lifestyle index A. Participants with healthier lifestyles clearly showed a significantly lower risk of developing diabetes. This relationship was not changed after adjustment for demographic and work-related factors. Relative to a persistently 'unhealthy' pattern, the adjusted hazard ratios (95% CIs) were 0.65 (0.59, 0.73) for persistently 'unhealthy' pattern, 0.50 (0.39, 0.64) for 'improved to moderately healthy' pattern, 0.43 (0.38, 0.48) for persistently 'moderately healthy' pattern, and 0.33 (0.27, 0.41) for persistently 'nearly completely healthy' pattern. Additional adjustment for baseline HbA1c level attenuated the relationship; the corresponding values were 1.00 (reference), and for the lifestyle patterns in the same order as mentioned above, 0.79 (0.71, 0.89), 0.69 (0.53, 0.89), 0.68 (0.60, 0.77), and 0.57 (0.46, 0.70), respectively. Adjustment for baseline BMI in addition to factors in model 2 showed similar results to those from model 3. When the 'improving' group was treated as reference, the 'persistently mostly healthy' group showed a significantly reduced risk of diabetes (Table S3).

As demonstrated in Figures 3 and 4, subgroup analyses showed that the associations between the longitudinal lifestyle patterns with diabetes risk were mostly consistent across varying characteristics, such as age, sex, obesity level, glycemic status, occupational physical activity, shift work, overtime work hours, job position, and tendency to walk during commute.

When we used lifestyle index B (easier goal), the tendency of the results was similar to that obtained from index A, as shown in Table S4 and Figures S2 and S3. When we changed the cut-off of BMI (lifestyle index C), the results were materially unchanged from those obtained using the lifestyle index A (data not shown).

DISCUSSION

In this longitudinal analysis of the working population, adherence to healthier lifestyles over time was substantially associated with a smaller risk of diabetes across diverse subgroups of the study population. This trend was stable irrespective of the goal's difficulty. This is the first observational study to clarify longitudinal lifestyle patterns in real world settings and its relationship with diabetes risk.

Our results, of a significantly decreased risk of type 2 diabetes associated with healthier lifestyle patterns, corroborate existing studies that showed that persons who engaged in healthier lifestyles at baseline exhibit a lower risk of diabetes[13]. However, these studies were limited in the nature of the study design; they measured lifestyles only at one-time point[22,40–43] although

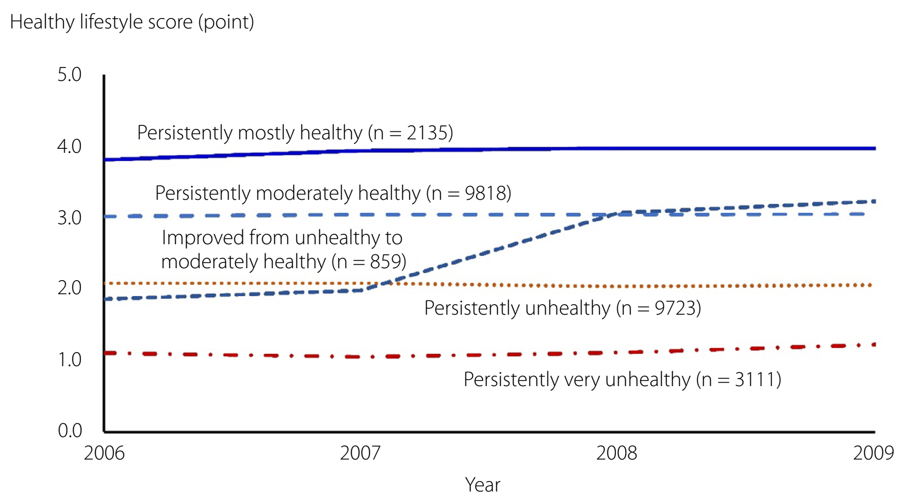

Figure 2 | Longitudinal adherence patterns to healthy lifestyles (index A, challenging goal). Data are shown as average sores of healthy lifestyles according to trajectory patterns.

Table 1 | Baseline characteristics according to lifestyle patterns (index A, challenging goal)

Characteristics in 2009	Longitudinal adherence patterns to healthy lifestyles				
	Persistently very unhealthy	Persistently unhealthy	Improved from unhealthy to moderately healthy	Persistently moderately healthy	Persistently mostly healthy
No. of participants	3,111	9,723	859	9,818	2,135
Age, year	45.4 (7.7)	44.9 (8.0)	45.2 (8.1)	45.2 (8.2)	46.9 (8.9)
Men, *n* (%)	3,007 (96.7)	9,001 (92.6)	823 (95.8)	7,678 (78.2)	1,817 (85.1)
No smoking, *n* (%)	351 (11.3)	3,685 (37.9)	628 (73.1)	8,746 (89.1)	2,090 (97.9)
No heavy drinking, *n* (%)	2,123 (68.2)	8,686 (89.3)	828 (96.4)	9,455 (96.3)	2,085 (97.7)
Exercise ≥7.5 MET-h/week, *n* (%)	269 (8.6)	1,060 (10.9)	437 (50.9)	2,089 (21.3)	1,619 (75.8)
Sleeping ≥7 h/day, *n* (%)	103 (3.3)	431 (4.4)	151 (17.6)	708 (7.2)	600 (28.1)
BMI <25.0 kg/m^2, *n* (%)	958 (30.8)	6,162(63.4)	742 (86.4)	8,953 (91.2)	2,090 (97.9)
BMI, kg/m^2	26.1 (3.4)	23.9 (3.4)	23.3 (2.4)	22.2 (2.4)	21.9 (1.9)
Hypertension, *n* (%)	688 (22.1)	1,570 (16.1)	144 (16.8)	1,217 (12.4)	292 (13.7)
HbA1c, %	5.7 (0.3)	5.6 (0.3)	5.6 (0.3)	5.6 (0.3)	5.6 (0.3)
Family history of diabetes, *n* (%)	515 (16.6)	1,434 (14.7)	141 (16.4)	1,453 (14.8)	318 (14.9)
Shift work, *n* (%)	655 (21.1)	1,973 (20.3)	152 (17.7)	1,424 (14.5)	247 (11.6)
Overtime work ≥45 h/month, *n* (%)	969 (31.1)	3,102 (31.9)	243 (28.3)	2,727 (27.8)	508 (23.8)
Higher job position, *n* (%)	694 (22.3)	2,039 (21.0)	211 (24.6)	2,185 (22.3)	554 (25.9)
Sedentary work, *n* (%)	1,778 (57.2)	5,742 (59.1)	542 (63.1)	6,473 (65.9)	1,431 (67.0)
<20 min of walking to and from work, *n* (%)	1,649 (53.0)	5,232 (53.8)	450 (52.4)	5,066 (51.6)	1,069 (50.1)

Data are shown as mean (SD) or number (%). BMI, body mass index; HbA1c, hemoglobin A1c.

Table 2 | Association of lifestyle patterns and type 2 diabetes (index A, challenging goal)

	Longitudinal adherence patterns to healthy lifestyles				
	Persistently v2ery unhealthy	Persistently unhealthy	Improved from unhealthy to moderately healthy	Persistently moderately healthy	Persistently mostly healthy
N	3,111	9,723	859	9,818	2,135
Cases, *n* (%)	492 (15.8)	960 (9.9)	68 (7.9)	595 (6.1)	108 (5.1)
Person-years	19,778	64,378	5,740	65,599	13,813
Incidence-rate/1,000	24.9	14.9	11.8	9.1	7.8
Model 1†	1 (reference)	0.62 (0.56, 0.69) $P < 0.001$	0.48 (0.37, 0.62) $P < 0.001$	0.39 (0.35, 0.44) $P < 0.001$	0.30 (0.24, 0.37) $P < 0.001$
Model 2‡	1 (reference)	0.65 (0.59, 0.73) $P < 0.001$	0.50 (0.39, 0.64) $P < 0.001$	0.43 (0.38, 0.48) $P < 0.001$	0.33 (0.27, 0.41) $P < 0.001$
Model 3§	1 (reference)	0.79 (0.71, 0.89) $P < 0.001$	0.69 (0.53, 0.89) $P = 0.004$	0.68 (0.60, 0.77) $P < 0.001$	0.57 (0.46, 0.70) $P < 0.001$
Model 4¶	1 (reference)	0.84 (0.75, 0.93) $P = 0.002$	0.73 (0.57, 0.95) $P = 0.019$	0.72 (0.63, 0.82) $P < 0.001$	0.58 (0.47, 0.72) $P < 0.001$

Data are shown as hazard ratio (95% confidence intervals). †Adjusted for age (years, continuous) and sex at baseline. ‡Adjusted for factors in model 1 plus baseline hypertension, family history of diabetes, shift work, overtime work, job position, occupational physical activity, and time spent in walking during commuting. §Further adjusted for baseline HbA1c (%, continuous). ¶Adjusted for factors in model 2 plus baseline BMI (kg/m^2, continuous).

lifestyles may change over time, or two time points[44], which may not capture the transitions precisely. Our approach of detecting longitudinal adherence patterns to healthy lifestyles could help to identify target populations for lifestyle interventions to prevent or delay the development of diabetes at a population level.

Most of the identified lifestyle patterns showed that lifestyles remained stable over 3 years; only one showed improved lifestyles. Notably, this pattern showed a lower risk of diabetes than those that had comparable lifestyles at the start of the lifestyle observation (fiscal year 2006) but did not show any improvements in lifestyles. This finding is in part supported by

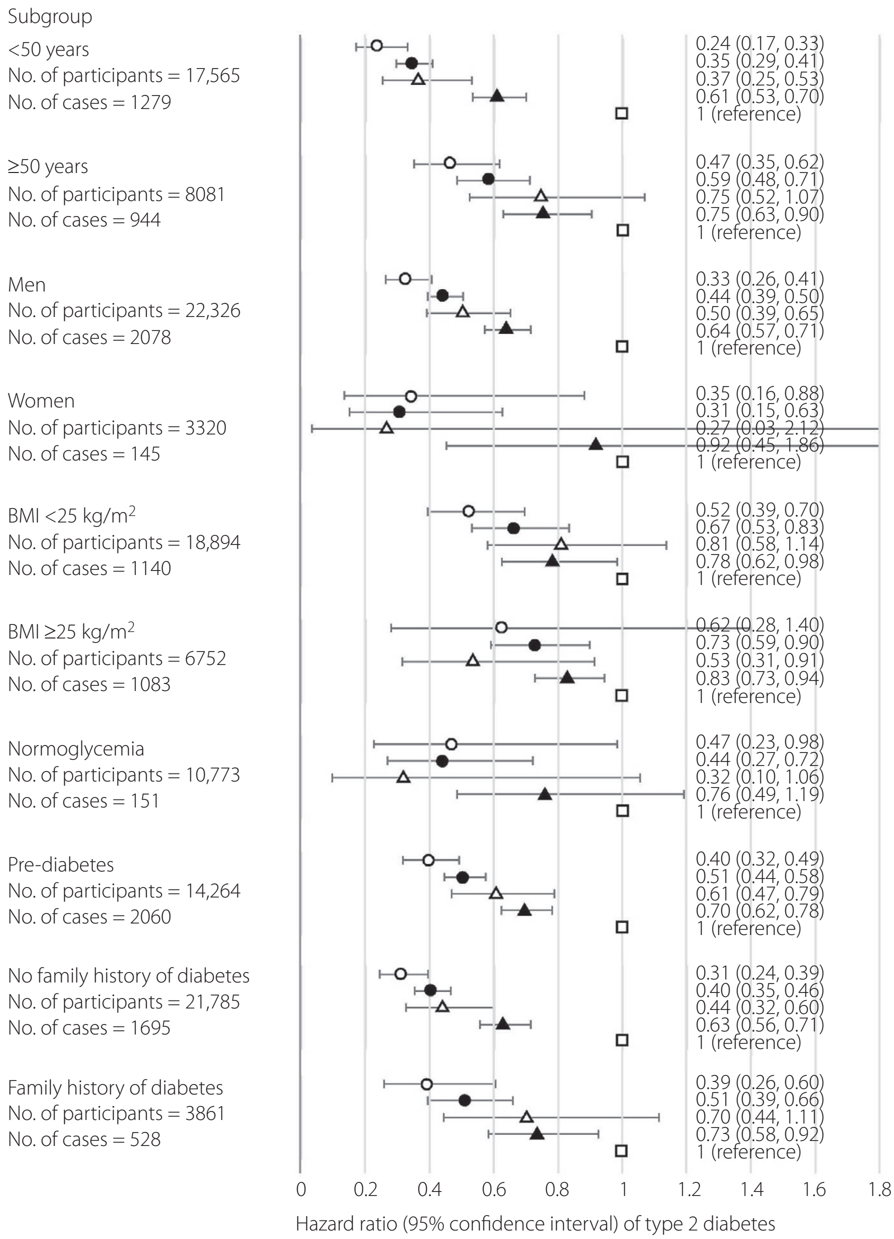

Figure 3 | Subgroup analyses by age, sex, obesity, glycemic status, and family history of diabetes (index A, challenging goal). Data are adjusted for factors in model 2. White circle indicates persistently mostly healthy pattern, black circle indicates persistently moderately healthy pattern, white triangle indicates improved from unhealthy to moderately healthy pattern, black triangle indicates persistently unhealthy pattern, and white square indicates persistently very unhealthy pattern (reference group).

a recent finding from an observational study[45] showing that positive changes in lifestyles between two time points were associated with an 8% lower odds of incident diabetes. Our findings in lifestyle change seem different from the findings in China showing overall worsening lifestyle factors and greater diabetes burden[46]. Given that a longer diabetes duration may increase the risk of other diseases, such as cancer[47], and that majority of the people have potential to make lifestyles healthier, additional efforts are warranted to improve lifestyles at individual and population levels.

In the present analyses, although some subgroups with fewer incident cases showed ambiguous tendencies, the beneficial relationship of healthier lifestyle patterns with diabetes risk was mostly consistent across the diverse characteristics of participants. Similarly, previous observational studies showed that reduced risk associated with healthier lifestyles at baseline was

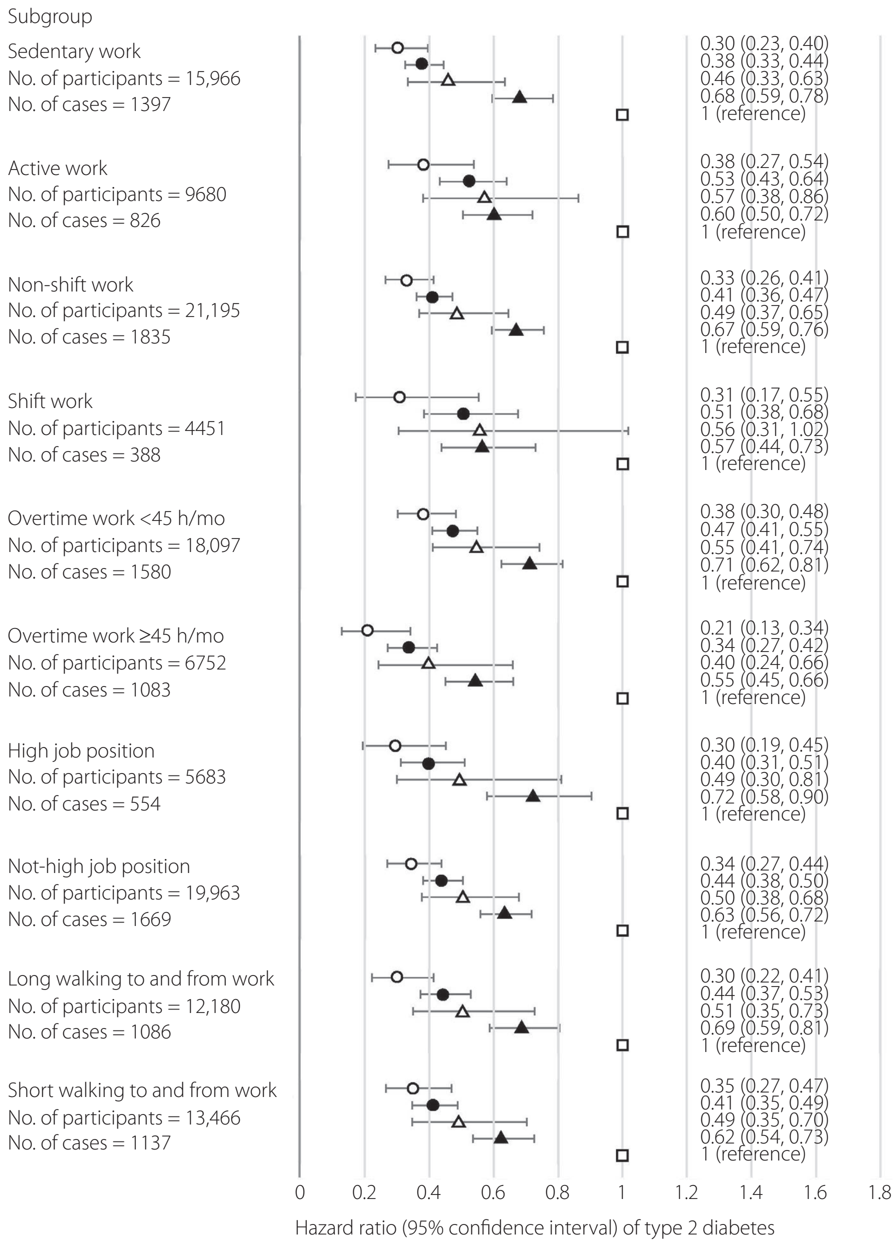

Figure 4 | Subgroup analyses by work-related factors (index A, challenging goal). Data are adjusted for factors in model 2. White circle indicates persistently mostly healthy pattern, black circle indicates persistently moderately healthy pattern, white triangle indicates improved from unhealthy to moderately healthy pattern, black triangle indicates persistently unhealthy pattern, and white square indicates persistently very unhealthy pattern (reference group).

consistent according to age, sex, obesity level, and family history of diabetes[41,43]. Controlled trials have shown that multifaceted lifestyle interventions are an effective and economical approach to prevent diabetes among pre-diabetic adults[48,49], a group at high risk of developing diabetes[25]. This observational study provides additional evidence that such associations are observed regardless of glycemic status and work-related conditions in real world settings. Our results, together with available data, suggest that it would not be too late to start healthy lifestyles for diabetes prevention, even under high risk conditions.

Regarding the present finding that the health-related lifestyles were relatively stable over three years, although we do not have data on the reason for not improving lifestyle, prior studies reported that many people do not have the motivation to change unhealthy lifestyles[50–54], possibly due to cost and lack of time as barriers[51,53]. Nonetheless, intervention studies have shown that lifestyle modification may be possible for working adults[55]. However, most of the individuals with unhealthy lifestyles are not target of such programs. Since 2008, the national health guidance program, which mainly targets individuals having metabolic syndrome for lifestyle improvements, has started in Japan. In our study, the prevalence of metabolic syndrome was below 25% even in the persistently very unhealthy lifestyle group during 2008–2009 (Table S5). Thus, such intervention programs are expected to be implemented at scale.

There are some strengths in the present study. Investigation of longitudinal adherence patterns to lifestyles using repeatedly measured data from a large-scale dataset enabled us to detect detailed patterns. The long follow-up duration could help detect a sufficient number of incident cases of type 2 diabetes according to lifestyle patterns. Additionally, diabetes was defined by objectively measured blood glucose and HbA1c; this was beneficial because exclusively self-reporting diabetes would lead to an underestimation of its onset.

This study also has some limitations. First, dietary information[56] was not included in the lifestyle index, although we included body weight control (defined by BMI), which is important for chronic disease prevention[57]. Instead, we included sleep duration, which is associated with diabetes risk[11] but has not been considered in the previous studies[13]. Second, we did not consider the lifestyles during the follow-up period. Another approach is required to consider the exposure status during follow-up. Third, residual or unmeasured confounding factors may have affected the results, although we adjusted for many variables. Lastly, our participants were adults working at a large-scale company in Japan and the proportion of women was small. As the company's culture may influence the employees' lifestyles, the generalizability of our findings to populations with a different background are unclear. Nonetheless, the extracted lifestyle patterns are in line with existing knowledge on lifestyle; the characteristics of the present participants who engaged in healthier lifestyles (e.g., more women; higher job position; physically healthy; not engaging in shift work, physically demanding work, and long working hours) were in accordance with existing knowledge[58–62]. In addition, prior studies reported that health-related lifestyles were relatively stable for the majority of adults[63–66].

In conclusion, the present real-world data suggest that improving lifestyles and maintaining healthier lifestyles would help to prevent type 2 diabetes even in pre-diabetic adults or older individuals. Multiple interventions to maintain healthier lifestyles should be made at the individual, organizational or community, and societal levels to reduce future burden due to chronic diseases, such as type 2 diabetes.

ACKNOWLEDGMENTS

The authors are thankful to Dr Toshiteru Okubo (National Institute of Occupational Safety and Health, Japan) for scientific support on the implementation of the J-ECOH Study, Ms Maki Konishi (National Center for Global Health and Medicine) for her management of data, and Ms Rika Osawa (National Center for Global Health and Medicine) for her support with administrative issues.

FUNDING

The present study is supported by the Industrial Health Foundation, JSPS KAKENHI (Grant numbers 25293146, 16K21379, and 19K10671), a fund from National Center for Global Health and Medicine (28-Shi-1206), and the Industrial Disease Clinical Research Grants (150903-01). The funding bodies did not engage in determining the study design, collecting data, analyzing the data, interpreting the results, drafting the manuscript, or submitting the manuscript for publication.

DISCLOSURE

We have no conflict of interest relating to this study. S. Yamamoto, T. Nakagawa, T. Honda, and T. Hayashi are occupational physicians in the participating company.

Approval of the research protocol: March 5, 2021, No. NCGM-G-001140-19. This is the latest approved number for J-ECOH Study.

Informed consent: N/A.

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

Animal studies: N/A.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Based on the national ethical guidelines, we announced and explained about J-ECOH Study and its implementation at the company; workers could refuse the use of their data for research. Ethical approval of the study procedure including a waiver for the need of informed consent was obtained at the National Center for Global Health and Medicine, Japan.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to restrictions regarding research participant privacy. However, the data can be requested by academic researchers for non-commercial research; inquiries and applications can be made to Department of Epidemiology and Prevention, Center for Clinical Sciences, National Center for Global Health and Medicine, Tokyo, Japan (Dr Mizoue, mizoue@hosp.ncgm.go.jp).

REFERENCES

1. Cho NH, Shaw JE, Karuranga S, *et al*. IDF diabetes atlas: global estimates of diabetes prevalence for 2017 and projections for 2045. *Diabetes Res Clin Pract* 2018; 138: 271–281.
2. GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; 392: 1736–1788.
3. GBD 2017 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence,

prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; 392: 1789–1858.
4. Bommer C, Sagalova V, Heesemann E, *et al*. Global economic burden of diabetes in adults: projections from 2015 to 2030. *Diabetes Care* 2018; 41: 963–970.
5. Gregory JM, Slaughter JC, Duffus SH, *et al*. COVID-19 severity is tripled in the diabetes community: a prospective analysis of the pandemic's impact in type 1 and type 2 diabetes. *Diabetes Care* 2021; 44: 526–532.
6. McGurnaghan SJ, Weir A, Bishop J, *et al*. Risks of and risk factors for COVID-19 disease in people with diabetes: a cohort study of the total population of Scotland. *Lancet Diabetes Endocrinol* 2021; 9: 82–93.
7. Akter S, Goto A, Mizoue T. Smoking and the risk of type 2 diabetes in Japan: a systematic review and meta-analysis. *J Epidemiol* 2017; 27: 553–561.
8. Knott C, Bell S, Britton A. Alcohol consumption and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of more than 1.9 million individuals from 38 observational studies. *Diabetes Care* 2015; 38: 1804–1812.
9. Smith AD, Crippa A, Woodcock J, *et al*. Physical activity and incident type 2 diabetes mellitus: a systematic review and dose-response meta-analysis of prospective cohort studies. *Diabetologia* 2016; 59: 2527–2545.
10. Abdullah A, Peeters A, de Courten M, *et al*. The magnitude of association between overweight and obesity and the risk of diabetes: a meta-analysis of prospective cohort studies. *Diabetes Res Clin Pract* 2010; 89: 309–319.
11. Shan Z, Ma H, Xie M, *et al*. Sleep duration and risk of type 2 diabetes: a meta-analysis of prospective studies. *Diabetes Care* 2015; 38: 529–537.
12. Pampel FC, Krueger PM, Denney JT. Socioeconomic disparities in health behaviors. *Annu Rev Sociol* 2010; 36: 349–370.
13. Zhang Y, Pan X-F, Chen J, *et al*. Combined lifestyle factors and risk of incident type 2 diabetes and prognosis among individuals with type 2 diabetes: a systematic review and meta-analysis of prospective cohort studies. *Diabetologia* 2020; 63: 21–33.
14. Schlesinger S, Neuenschwander M, Ballon A, *et al*. Adherence to healthy lifestyles and incidence of diabetes and mortality among individuals with diabetes: a systematic review and meta-analysis of prospective studies. *J Epidemiol Community Health* 2020; 74: 481–487.
15. Tison GH, Avram R, Kuhar P, *et al*. Worldwide effect of COVID-19 on physical activity: a descriptive study. *Ann Intern Med* 2020; 173: 767–770.
16. Clay JM, Parker MO. Alcohol use and misuse during the COVID-19 pandemic: a potential public health crisis? *Lancet Public Health* 2020; 5: e259.
17. Klemperer EM, West JC, Peasley-Miklus C, *et al*. Change in tobacco and electronic cigarette use and motivation to quit in response to COVID-19. *Nicotine Tob Res* 2020; 22: 1662–1663.
18. Swann C, Rosenbaum S, Lawrence A, *et al*. Updating goal-setting theory in physical activity promotion: a critical conceptual review. *Health Psychol Rev* 2021; 15: 34–50.
19. NCD Risk Factor Collaboration. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet* 2017; 390: 2627–2642.
20. Nanditha A, Ma RCW, Ramachandran A, *et al*. Diabetes in Asia and the Pacific: implications for the global epidemic. *Diabetes Care* 2016; 39: 472–485.
21. Yabe D, Seino Y, Fukushima M, *et al*. beta cell dysfunction versus insulin resistance in the pathogenesis of type 2 diabetes in East Asians. *Curr Diab Rep* 2015; 15: 602.
22. Hu FB, Manson JE, Stampfer MJ, *et al*. Diet, lifestyle, and the risk of type 2 diabetes mellitus in women. *N Engl J Med* 2001; 345: 790–797.
23. World Health Organization. Health in 2015: from MDGs, Millennium Development Goals to SDGs, Sustainable Development Goals. Geneva: World Health Organization; 2015. https://apps.who.int/iris/handle/10665/200009 Accessed November 25, 2021.
24. Schmid KL, Rivers SE, Latimer AE, *et al*. Targeting or tailoring? *Mark Health Serv* 2008; 28: 32–37.
25. Tabak AG, Herder C, Rathmann W, *et al*. Prediabetes: a high-risk state for diabetes development. *Lancet* 2012; 379: 2279–2290.
26. Lu Y, Sugawara Y, Zhang S, *et al*. Changes in sleep duration and the risk of incident dementia in the elderly Japanese: the Ohsaki Cohort 2006 Study. *Sleep* 2018; 41: zsy143.
27. Ikehara S, Iso H, Date C, *et al*. Association of sleep duration with mortality from cardiovascular disease and other causes for Japanese men and women: the JACC study. *Sleep* 2009; 32: 295–301.
28. Lockley SW, Skene DJ, Arendt J. Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. *J Sleep Res* 1999; 8: 175–183.
29. Kuwahara K, Honda T, Nakagawa T, *et al*. Associations of leisure-time, occupational, and commuting physical activity with risk of depressive symptoms among Japanese workers: a cohort study. *Int J Behav Nutr Phys Act* 2015; 12: 119.
30. Matthews CE, Shu XO, Yang G, *et al*. Reproducibility and validity of the Shanghai Women's Health Study physical activity questionnaire. *Am J Epidemiol* 2003; 158: 1114–1122.
31. Seike N, Noda M, Kadowaki T. Alcohol consumption and risk of type 2 diabetes mellitus in Japanese: a systematic review. *Asia Pac J Clin Nutr* 2008; 17: 545–551.
32. Holst C, Becker U, Jorgensen ME, *et al*. Alcohol drinking patterns and risk of diabetes: a cohort study of 70,551 men and women from the general Danish population. *Diabetologia* 2017; 60: 1941–1950.

33. Komiyama Y A basic direction for comprehensive implementation of national health promotion, 2012. Available from: https://www.mhlw.go.jp/file/06-Seisakujouhou-10900000-Kenkoukyoku/0000047330.pdf Accessed May 7, 2021.
34. Kita T, Yoshioka E, Satoh H, *et al*. Short sleep duration and poor sleep quality increase the risk of diabetes in Japanese workers with no family history of diabetes. *Diabetes Care* 2012; 35: 313–318.
35. World Health Organization. WHO Guidelines on Physical Activity and Sedentary Behaviour. Geneva: World Health Organization, 2020. https://www.who.int/publications/i/item/9789240015128 Accessed November 25, 2021.
36. Kanazawa M, Yoshiike N, Osaka T, *et al*. Criteria and classification of obesity in Japan and Asia-Oceania. *Asia Pac J Clin Nutr* 2002; 11: S732–S737.
37. Katanoda K, Noda M, Goto A, *et al*. Being underweight in adolescence is independently associated with adult-onset diabetes among women: the Japan Nurses' Health Study. *J Diabetes Investig* 2019; 10: 827–836.
38. American Diabetes Association. 2. Classification and diagnosis of diabetes: standards of medical care in diabetes-2019. *Diabetes Care* 2019; 42(Suppl 1): S13–S28.
39. Kuwahara K, Honda T, Nakagawa T, *et al*. Body mass index trajectory patterns and changes in visceral fat and glucose metabolism before the onset of type 2 diabetes. *Sci Rep* 2017; 7: 43521.
40. Steinbrecher A, Morimoto Y, Heak S, *et al*. The preventable proportion of type 2 diabetes by ethnicity: the multiethnic cohort. *Ann Epidemiol* 2011; 21: 526–535.
41. Mozaffarian D, Kamineni A, Carnethon M, *et al*. Lifestyle risk factors and new-onset diabetes mellitus in older adults: the cardiovascular health study. *Arch Intern Med* 2009; 169: 798–807.
42. Dow C, Balkau B, Bonnet F, *et al*. Strong adherence to dietary and lifestyle recommendations is associated with decreased type 2 diabetes risk in the AusDiab cohort study. *Prev Med* 2019; 123: 208–216.
43. Lv J, Yu C, Guo YU, *et al*. Adherence to a healthy lifestyle and the risk of type 2 diabetes in Chinese adults. *Int J Epidemiol* 2017; 46: 1410–1420.
44. Walther D, Curjuric I, Dratva J, *et al*. Hypertension, diabetes and lifestyle in the long-term – results from a Swiss population-based cohort. *Prev Med* 2017; 97: 56–61.
45. Feldman AL, Long GH, Johansson I, *et al*. Change in lifestyle behaviors and diabetes risk: evidence from a population-based cohort study with 10 year follow-up. *Int J Behav Nutr Phys Act* 2017; 14: 39.
46. Li Y, Wang DD, Ley SH, *et al*. Time trends of dietary and lifestyle factors and their potential impact on diabetes burden in China. *Diabetes Care* 2017; 40: 1685–1694.
47. Tseng CH. Diabetes, metformin use, and colon cancer: a population-based cohort study in Taiwan. *Eur J Endocrinol* 2012; 167: 409–416.
48. Schellenberg ES, Dryden DM, Vandermeer B, *et al*. Lifestyle interventions for patients with and at risk for type 2 diabetes: a systematic review and meta-analysis. *Ann Intern Med* 2013; 159: 543–551.
49. American Diabetes Association. 3. Prevention or delay of type 2 diabetes: standards of medical care in diabetes-2019. *Diabetes Care* 2019; 42(Suppl 1): S29–S33.
50. Marcus BH, Simkin LR, Rossi JS, *et al*. Longitudinal shifts in employees' stages and processes of exercise behavior change. *Am J Health Promot* 1996; 10: 195–200.
51. Nishida Y, Suzuki H, Wang D-H, *et al*. Psychological determinants of physical activity in Japanese female employees. *J Occup Health* 2003; 45: 15–22.
52. Campbell MK, Tessaro I, DeVellis B, *et al*. Tailoring and targeting a worksite health promotion program to address multiple health behaviors among blue-collar women. *Am J Health Promot* 2000; 14: 306–313.
53. Salmon J, Owen N, Crawford D, *et al*. Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. *Health Psychol* 2003; 22: 178–188.
54. Lam T-H, Chan BHY, Chan SKK, *et al*. A prospective study of stage of change for general health promotion action and health-related lifestyle practices among Chinese adults. *Soc Sci Med* 2006; 63: 1846–1856.
55. Saito T, Watanabe M, Nishida J, *et al*. Lifestyle modification and prevention of type 2 diabetes in overweight Japanese with impaired fasting glucose levels: a randomized controlled trial. *Arch Intern Med* 2011; 171: 1352–1360.
56. Erber E, Hopping BN, Grandinetti A, *et al*. Dietary patterns and risk for diabetes: the multiethnic cohort. *Diabetes Care* 2010; 33: 532–538.
57. Shaper AG, Wannamethee SG, Walker M. Body weight: implications for the prevention of coronary heart disease, stroke, and diabetes mellitus in a cohort study of middle aged men. *BMJ* 1997; 314: 1311–1317.
58. Reeves MJ, Rafferty AP. Healthy lifestyle characteristics among adults in the United States, 2000. *Arch Intern Med* 2005; 165: 854–857.
59. Zhang Y-B, Chen C, Pan X-F, *et al*. Associations of healthy lifestyle and socioeconomic status with mortality and incident cardiovascular disease: two prospective cohort studies. *BMJ* 2021; 372: n604.
60. van Amelsvoort LGPM, Jansen NWH, Kand I. Smoking among shift workers: more than a confounding factor. *Chronobiol Int* 2006; 23: 1105–1113.
61. Ham DC, Przybeck T, Strickland JR, *et al*. Occupation and workplace policies predict smoking behaviors: analysis of national data from the current population survey. *J Occup Environ Med* 2011; 53: 1337–1345.
62. Bannai A, Tamakoshi A. The association between long working hours and health: a systematic review of epidemiological evidence. *Scand J Work Environ Health* 2014; 40: 5–18.

63. Oura P, Rissanen I, Junno J-A, *et al*. Lifelong smoking trajectories of Northern Finns are characterized by sociodemographic and lifestyle differences in a 46-year follow-up. *Sci Rep* 2020; 10: 16365.
64. Britton A, Ben-Shlomo Y, Benzeval M, *et al*. Life course trajectories of alcohol consumption in the United Kingdom using longitudinal data from nine cohort studies. *BMC Med* 2015; 13: 47.
65. Gilmour H, Stranges S, Kaplan M, *et al*. Longitudinal trajectories of sleep duration in the general population. *Health Rep* 2013; 24: 14–20.
66. Lounassalo I, Salin K, Kankaanpää A, *et al*. Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review. *BMC Public Health* 2019; 19: 271.

SUPPORTING INFORMATION

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

Table S1 | Prevalence of each component of healthy lifestyles between 2006 and 2009 according to lifestyle patterns (index A, challenging goal)

Table S2 | Baseline characteristics of participants according to adherence patterns of healthy lifestyles during 2006-2009 using lifestyle index B (easier goal)

Table S3 | Main analysis for lifestyle patterns (index A, challenging goal) and diabetes risk when 'improving' group was treated as reference

Table S4 | Hazard ratios of developing type 2 diabetes according to longitudinal adherence patterns to healthy lifestyles using index B (easier goal)

Table S5 | Prevalence of metabolic syndrome in 2008 and 2009 according to lifestyle patterns (index A, challenging goal)

Figure S1 | Adherence patterns of healthy lifestyles over 3 years (during 2006 to 2009) using index B (easier goal).

Figure S2 | Subgroup analyses by age, sex, obesity, glycemic status, and family history of diabetes using lifestyle index B (easier goal).

Figure S3 | Subgroup analyses by work-related factors using lifestyle index B (easier goal).