Heliyon 10 (2024) e39706

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

The impact of behavioral risks on cardiovascular disease mortality in China between 1990 and 2019

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A B S T R A C T

Aims: Behavioral risks including tobacco use, alcohol use, low physical activity and dietary risks had been proven to contribute to the pathological process in cardiovascular diseases (CVD). Herein the lethal effects attributable to behavioral risks on CVD in China were investigated.
Methods: Data were obtained from the Global Burden of Disease Study 2019. Joinpoint regression analyses and age-period-cohort models were applied.
Results: In China, the total number of CVD deaths attributable to tobacco use, alcohol use, low physical activity and dietary risks in 2019 was 0.98, 0.19, 0.13 and 1.76 million, with an age-standardized rate of 51.2, 9.9, 8.9 and 101.9 per 100 000 people, respectively. Joinpoint analyses suggested a general favorable trend in age-standardized rate of attributable CVD mortality for tobacco use (average annual percent change [AAPC]: -0.9 %, $P < 0.001$), alcohol use (AAPC: -0.8 %, $P < 0.001$) and dietary risks (AAPC: -1.3 %, $P < 0.001$), but unchanged trend for low physical activity (AAPC: 0.2 %, $P = 0.525$) since 1990. Period effects suggested an improvement in attributable CVD mortality rate across the study period for alcohol use and dietary risks, but more favorable period trends were observed over the past 15 years for tobacco use and before the period 2000–2004 for low physical activity. The patterns for cohort effects differed markedly between men and women. In women, cohort effects revealed an inverted hook-shaped pattern for all these behavioral risks, with the highest risk in cohort born around 1915. In men, the improvement was mainly observed in cohorts born before 1980 for tobacco use and dietary risks, in cohorts born before 1965 for alcohol use, and in cohorts born between 1925 and 1955 for low physical activity.
Conclusion: Behavioral risks, especially the dietary risks, brought out huge burden of CVD in China, and their trajectories differed along with time and genders. Much more priorities should be established to ameliorate the impact of behavioral risks on CVD in China.

1. Introduction

CVD, principally ischemic heart disease (IHD) and stroke, is the leading cause of mortality and a major contributor to disability, and bring about huge health burden globally [1]. Similar situation happened in China, for instance, in 2019, CVD took 46.74 % and 44.26 % of total death in rural and urban respectively in China, taking 313.366 billion RMB yuan for the total hospitalization cost. And it was estimated that there were about 330 million CVD patients in 2020, remarkably increasing from 230 million in 2010 [2]. Therefore, CVD burden should be considered the priority for health improvement in China.

Behavior risks including tobacco use, alcohol use, low physical activity and dietary risks are important precipitating factors in the

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https://doi.org/10.1016/j.heliyon.2024.e39706
Received 14 March 2024; Received in revised form 21 October 2024; Accepted 21 October 2024
Available online 24 October 2024

development of CVD [3]. For instance, smoking, even only one cigarette per day, develops risk of coronary heart disease and stroke much greater than expected [4], and many studies had documented inverse associations of physical activity with incidences and mortality of CVD [5,6]. While behavior risks such as smoking, drinking and sedentary were reported to be prevalent in China. For instance, in 2015, a Chinese national nutrition and chronic disease report indicated a high prevalence of current smoking, harmful drinking, and physical inactivity which were 28.1 %, 9.3 %, and 71.3 %, respectively [7]. However, the mortality of CVD attributed to behavior risks remained unclear in China.

Global Burden of Disease Study concentrated on the assessment of health statistics worldwide, including the burden and the relative risk factors of diseases [8]. Based on the most recent GBD 2019 data, we investigated the long-term trends in burden of CVD attributed to behavior risks in China, to unfold the vicissitude of impacts of behavioral risks on cardiovascular disease, and providing evidences to policy marker in prevention of CVD.

2. Methods

2.1. Data sources

This study used the China data from the database of Global Burden of Disease Study (GBD) 2019 [8]. In GBD 2019, CVD was identified by the ICD-9 and ICD-10, and the original data for CVD mortality in China were collected from China Disease Surveillance Points and death Registration, and WHO Mortality Database [1]. On the other hand, four modifiable behavioral risks, tobacco use, alcohol use, low physical activity, and dietary risks, were considered to cause CVD deaths [8]. The original data for these behavioral risks in China were largely from national surveys, surveillance data, health statistics, and other scientific literatures [1]. These four risk factors data including number, percentage, and rate in China were extracted from the GBD 2019 dataset for further analysis, and The data source of these risk factors mainly came from Chinese CDC survey on tobacco, alcohol, activity, and nutrition, and some published article (https://ghdx.healthdata.org/gbd-2019/data-input-sources). To capture the maximum population attributable mortality burden, the theoretical minimum risk exposure level (TMREL) was used in GBD 2019, which was a level of risk exposure associated with the minimum mortality risk across outcomes [8]. Meanwhile, to assess the CVD mortality attributable to behavioral risks, in GBD 2019, population attributable fraction (PAF) was used, which represents the proportion of CVD mortality that would be reduced if the behavioral risk exposure reduced to the level of TMREL [8].

All data have been made publicly available on the website of Institute of Health Metrics and Evaluation and can be accessed at http://ghdx.healthdata.org/gbd-results-tool. The GBD 2019 was reviewed and approved by the University of Washington Institutional Review Board, and informed consent was waived because only de-identified, aggregated data were used.

2.2. Statistical analyses

We used joinpoint regression analyses to study the temporal changes in CVD mortality attributable to behavioral risks [9–12]. The method used segmented linear regression to identify the best-fitting point (i.e., "joinpoint") of the long-term trends of mortality, where a statistically significant change occurred [9]. The tests of significance were based on a Monte Carlo Permutation method. The logarithmic transformation of the rates was conducted and the standard errors were calculated based on binomial approximation [9]. Annual percent change (APC) with 95 % confidence interval (CI) was calculated to interpret the rate change per year for each segment between joinpoints. Average annual percent change (AAPC) was calculated as the weighted average of the APCs, with the weights equal to the length of the segments (i.e., the number of years) [12].

The age-period-cohort models were conducted to examine the effects of age, period, and birth cohort on CVD mortality attributable to behavioral risks. Age effects refer to the biological and social changes with aging. Period effects represent changes over time periods that affect all age groups simultaneously (e.g., economic growth, cultural changes, public health policies, or new effective treatments). Cohort effects are related to changes across groups of individuals with the same birth years. To conduct the age-period-cohort models, data were recoded into consecutive 5-year periods from 1990 to 1994 to 2015–2019 and successive 5-year age intervals from 25 to 29 to 80–84 since equal width of the period and age intervals is required for the modeling [13]. Because the CVD mortality attributable to behavioral risks is rare in population under 25 years and all individuals aged 85 years or older were recorded as one group in the GBD database, they were not covered in the analysis [14]. Using the age-period-cohort models, longitudinal age curve, period rate ratios (RRs), and cohort RRs were estimated in our study. The longitudinal age curve indicates the expected age-specific rates in a reference cohort adjusted for period effects [13]. Period (or cohort) RRs represent the risk of age-specific rates in each period (or cohort) relative to reference one adjusted for age and nonlinear cohort (or period) effects [13].

Joinpoint Regression Program Version 4.9.0.0 was used to conduct the joinpoint regression analyses, including APC-IE method to settle collinearity issues [15,16]. All estimable parameters of the age-period-cohort models were derived from the Age-Period-Cohort Web Tool provided by the Biostatistics Branch of National Cancer Institute [13], and Wald chi-square test was used to evaluate the significance of estimated parameters. The level of statistical significance was set at two-sided P values < 0.05.

3. Results

3.1. Trends in CVD mortality attributable to behavioral risks

In 2019, all behavioral risks contributed to 2.44 million CVD deaths in China, and the age-standardized rate of behavioral risks-attributable CVD mortality was 139.5 per 100 000 people. Despite a −25.3 % overall reduction in age-standardized rate of behavioral risks-attributable CVD mortality from 1990 to 2019, the corresponding number increased by 88.2 % as a result of population growth and aging (Fig. 1). The relative proportion of all CVD mortality in China caused by behavioral risks remained generally stable over the study period, and was 50.4 % in 2019 (Fig. 1).

For each behavioral risk, dietary risks accounted for the largest proportion of behavioral risks-attributable CVD mortality, resulting in 1.76 million CVD deaths in 2019. The age-standardized rate of dietary risks-attributable CVD mortality in 2019 was 101.9 per 100 000 people. The total number of CVD deaths attributable to tobacco use, alcohol use and low physical activity in 2019 was 0.98, 0.19 and 0.13 million, with an age-standardized rate of 51.2, 9.9 and 8.9 per 100 000 people, respectively. Of all CVD mortality in China in 2019, 36.8 % was caused by dietary risks, while the corresponding proportion was 18.5 % for tobacco use, 3.6 % for alcohol use and 3.2 % for low physical activity.

Table 1 shows joinpoint analyses on the temporal changes in age-standardized rate of CVD mortality attributable to each behavioral risk in China. Between 1990 and 2019, there was a general favorable trend in age-standardized rate of attributable CVD mortality for tobacco use (AAPC: -0.9 %, $P < 0.001$), alcohol use (AAPC: -0.8 %, $P < 0.001$) and dietary risks (AAPC: -1.3 %, $P < 0.001$), but unchanged trend for low physical activity (AAPC: 0.2 %, $P = 0.525$). Nevertheless, four to six segmented trends were identified for these behavioral risks though joinpoint analyses, indicating the changes were fluctuating over the study period (Table 1). For example, the age-standardized rate of tobacco use-attributable CVD mortality remained stable before 1998 (APC: -0.2 %, $P = 0.095$), then increased by 1.2 % per year from 1998 to 2003 ($P < 0.001$), followed by four different levels of downward trends (all $P < 0.05$, Table 1).

3.2. Age-specific and cohort-based variation

To conduct the age-period-cohort analyses, the mortality and population data were assigned into consecutive 5-year periods from 1990 to 1994 to 2015–2019 and successive 5-year age groups from 25 to 29 to 80–84, consisting of 17 birth cohorts. Fig. 2 and Table S1 (Table S1 was show in Supplementary material) show descriptive analyses on the age-specific and cohort-based variation of CVD mortality attributable to each behavioral risk in China from 1990 to 2019. As Fig. 2A though 2D shows, the attributable CVD mortality rate increased with age group for each behavioral risk, and the patterns persisted across study periods. Between 1990-1994 and 2015–2019, a decreasing trend in attributable CVD mortality rate was observed for tobacco use, alcohol use and dietary risks, while no discernible change was found for low physical activity. Fig. 2E through 2H shows that, across birth cohorts, the change in attributable CVD mortality rate was unsteady for old age groups. For example, at least one rebound of attributable CVD mortality rate was noted for groups aged 80–84 years for each behavioral risk. However, relatively steady downtrend was found for younger age groups for tobacco use, alcohol use and dietary risks (Fig. 2).

3.3. Age-period-cohort effects

Fig. 3 and Table S2 (Table S2 was show in Supplementary material) shows the age, period, and cohort effects on CVD mortality attributable to each behavioral risk in China from 1990 to 2019. As expected, the longitudinal age curves suggested an increasing attributable CVD mortality rate with age for each behavioral risk, and the steepest increase was found for dietary risks (Fig. 3A). By sex, similar patterns were found between men (Fig. 3D) and women (Fig. 3G) for each behavioral risk, with higher attributable CVD mortality rates in men than in women.

Period effects suggested that the CVD mortality rate attributable to dietary risks had the greatest improvement in China across the study period (Fig. 3B), and the improvement was more noticeable in women (Fig. 3E and H). For alcohol use, the RRs for period effects tended to decrease, suggesting an improvement across the study period (Fig. 3B). For tobacco use, more favorable period trends were observed over the past 15 years (Fig. 3B). The patterns were similar between men and women for alcohol use and tobacco use (Fig. 3E and H). For low physical activity, more favorable period trends were observed before the period 2000–2004. Then, the period trends

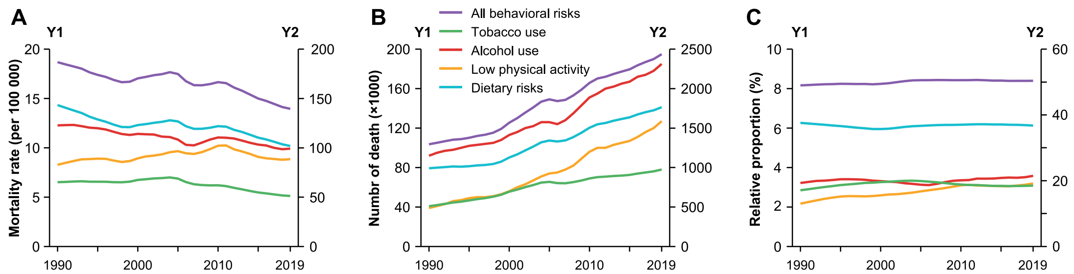

Fig. 1. Trends in age-standardized rates, total number, and relative proportion of CVD mortality attributable to behavioral risks in China, 1990–2019.
(A) Age-standardized rates; (B) Total number; (C) Relative proportion. CVD, cardiovascular disease. Y1 axis was for alcohol use and low physical activity. Y2 axis was for behavioral risks, tobacco use and dietary risks. Relative proportion indicated the proportion of all CVD mortality in China caused by behavioral risks.

Table 1
The APC and AAPC in age-standardized rate of CVD mortality attributable to each behavioral risk in China, 1990–2019.

Segments	ASMR (/100 000)		
	Year	APC, (95 % CI)	*P* value
Tobacco use			
Trend 1	1990–1997	−0.2 % (−0.3 %, 0.0 %)	0.095
Trend 2	1998–2003	1.2 % (0.9 %, 1.6 %)	<0.001
Trend 3	2004–2006	−3.8 % (−5.1 %, −2.4 %)	<0.001
Trend 4	2007–2010	−0.8 % (−1.4 %, −0.1 %)	0.029
Trend 5	2011–2014	−2.7 % (−3.4 %, −2.1 %)	<0.001
Trend 6	2015–2019	−1.7 % (−2.1 %, −1.3 %)	<0.001
AAPC, (95 % CI)	1990–2019	−0.9 % (−1.1 %, −0.7 %)	<0.001
Alcohol use			
Trend 1	1990–2003	−0.9 % (−1.0 %, −0.7 %)	<0.001
Trend 2	2004–2006	−2.7 % (−5.3 %, 0.0 %)	0.053
Trend 3	2007–2009	3.0 % (0.4 %, 5.7 %)	0.028
Trend 4	2010–2019	−1.4 % (−1.6 %, −1.2 %)	<0.001
AAPC, (95 % CI)	1990–2019	−0.8 % (−1.2 %, −0.5 %)	<0.001
Low physical activity			
Trend 1	1990–1993	1.8 % (−0.2 %, 3.9 %)	0.081
Trend 2	1994–1997	−1.2 % (−4.0 %, 1.8 %)	0.410
Trend 3	1998–2010	1.2 % (1.0 %, 1.5 %)	<0.001
Trend 4	2011–2015	−2.5 % (−3.7 %, −1.4 %)	<0.001
Trend 5	2016–2019	−0.2 % (−1.9 %, 1.5 %)	0.796
AAPC, (95 % CI)	1990–2019	0.2 % (−0.4 %, 0.7 %)	0.525
Dietary risks			
Trend 1	1990–1997	−2.3 % (−2.4 %, −2.2 %)	<0.001
Trend 2	1998–2003	0.9 % (0.7 %, 1.1 %)	<0.001
Trend 3	2004–2006	−2.4 % (−3.2 %, −1.6 %)	<0.001
Trend 4	2007–2010	0.3 % (0.0 %, 0.7 %)	0.085
Trend 5	2011–2019	−2.2 % (−2.3 %, −2.1 %)	<0.001
AAPC, (95 % CI)	1990–2019	−1.3 % (−1.4 %, −1.2 %)	<0.001

APC, annual percent change; AAPC, average annual percent change; CVD, cardiovascular disease; ASMR, age-standardized mortality rate; CI, Confidence interval.

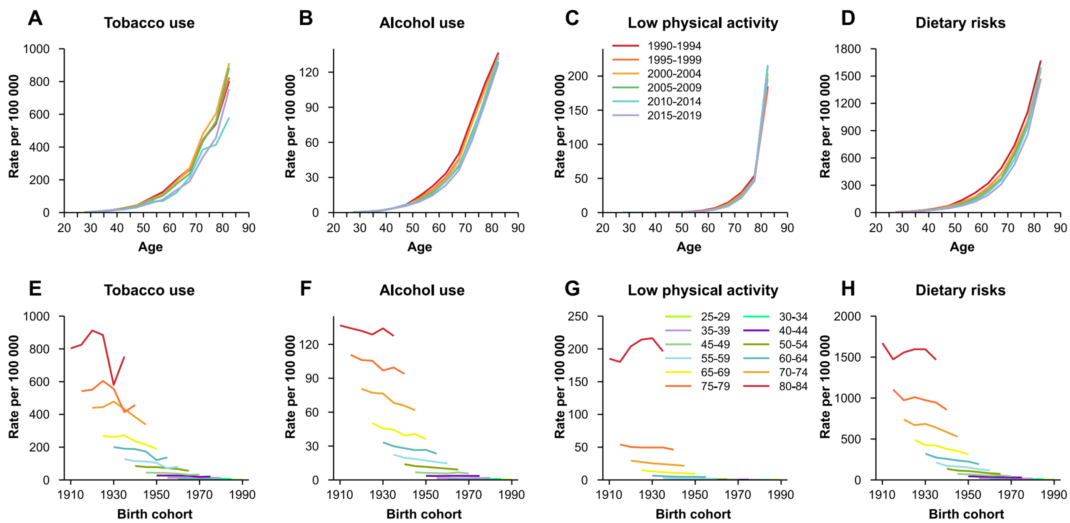

Fig. 2. Age-specific and cohort-based variation of CVD mortality attributable to each behavioral risk in China, 1990–2019.
(A through D) -specific rates of CVD mortality attributable to tobacco use, alcohol use, low PA, and dietary risks by period from 1990 to 2019; (E through H) Cohort-specific rates of CVD m Age mortality attributable to tobacco use, alcohol use, low physical activity, and dietary risks by age group from 1990 to 2019. CVD, cardiovascular disease.

were flat in women (Fig. 3H), but reversed in men (Fig. 3E).

The patterns for cohort effects differed markedly between men and women (Fig. 3C, F and 3I). In women, the RRs for cohort effects revealed an inverted hook-shaped pattern for all the four behavioral risks, with the highest risk in cohort born around 1915 (Fig. 3I). In men, the progressive improvement in attributable CVD mortality rate was observed in cohorts born before 1980 for tobacco use and dietary risks, then the improvement appears to have stalled (Fig. 3F). The progressive improvement was also found in cohorts of men

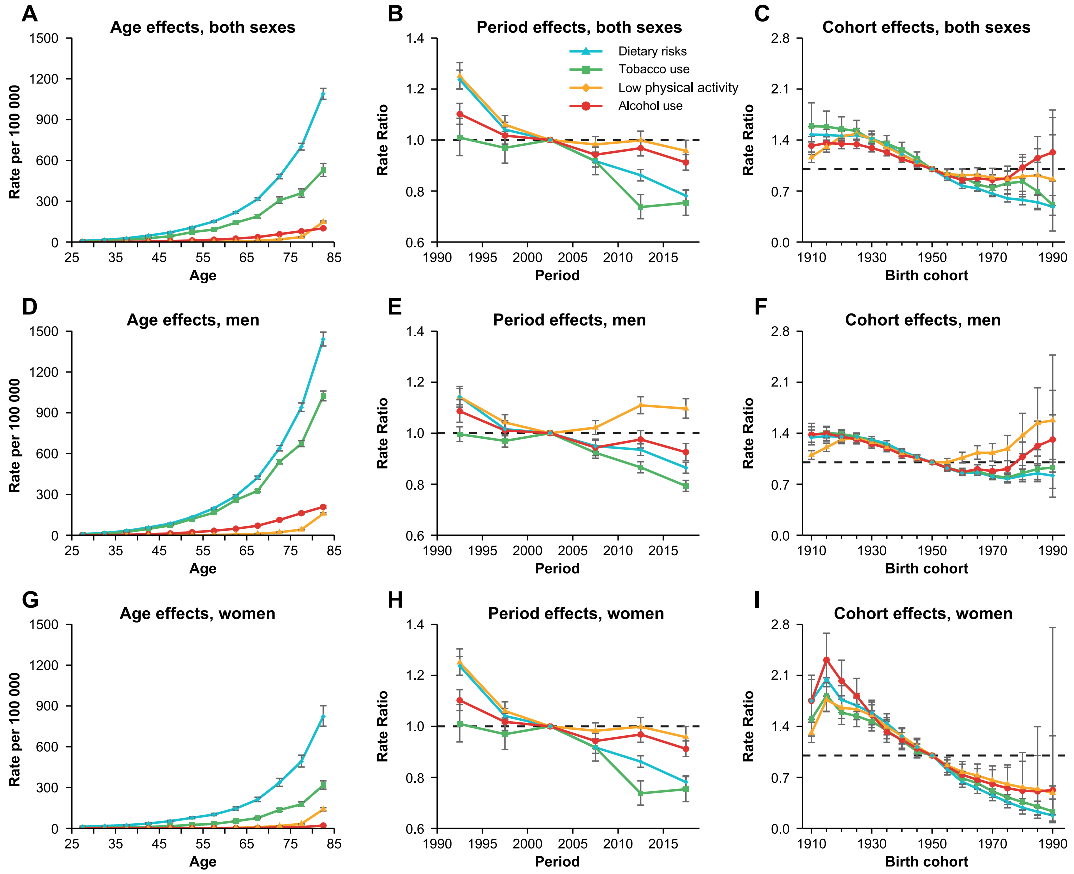

Fig. 3. Parameter estimates of age, period, and cohort effects on CVD mortality attributable to each behavioral risk in China, 1990–2019. (A, D, and G) Fitted longitudinal age curves of attributable CVD mortality rate for each behavioral risk. (B, E, and H) Relative risk of each period compared with the reference (period 2000–2004) adjusted for age and nonlinear cohort effects. (C, F, and I) Relative risk of each cohort compared with the reference (cohort 1945–1954) adjusted for age and nonlinear period effects. Error bars represent the 95 % confidence intervals.

born before 1965 for alcohol use, then upward cohort trends were observed (Fig. 3F). The pattern of cohort effects for low physical activity was more complex in men, with two upward trends were noted, and the improvement in attributable CVD mortality rate was only observed in cohorts born between 1925 and 1955 (Fig. 3F).

4. Discussion

In our study, we found out that in China, behavioral risks brought about huge CVD mortality and which accounted almost 50 % of all CVD mortality from 1990 to 2019. And there was a decrease in age-standardized rate of behavioral risks attributable CVD mortality in recent years, however it was mainly due to the population growth and aging in China [17]. And it was indicated that dietary risks accounted for the largest proportion among behavior risks. Furthermore, our study also analyzed the Age-Period-Cohort effects and their variations of behavior risks, providing dynamic monitoring information for the policy-makers in prevention of CVD.

Dietary risks were important preventable risk factors for non-communicable diseases, and many previous studies provided potential causal relationship between specific dietary factors (diet high in red meat, sodium, trans fatty acids, etc.) and CVD [18,19]. Our results showed that in spite of a slightly favored trend for dietary risks, it still remained the biggest villain among all the four behavior risks. According to China National Nutrition Surveys, the percentage of intake from fat increased to 32.9 % in 2012 from 18.4 % in 1982, and it also reported an animal-based diets shift in dietary structure, but the intakes of eggs and fish remained at a low level, implying challenges in not only obesity but also CVD and diabetes from unhealthy diet structure in China.[19] Moreover, China National Nutrition Surveys 2009 reported that the sodium and potassium intakes were 4.7 g and 1.8 g per day, respectively, which were far from meeting the WHO recommendations, thus relating to hypertension [20]. The sugar-sweetened beverages consumption also surged in recent years in China, increasing the risk of coronary heart diseases and hypertension [21–23]. Considering that ameliorations in diet risks were relatively economical, it was vital to improve the diet structure in China for CVD prevention. Therefore, healthier food options and eating patterns at a Chinese dining table are crucial, and it is of great benefit to promoting healthy diet through creating a supportive environment for the promotion of nutrition knowledge, and integrating nutrition services into the primary health care system [20].

Other behavior risks also attributed great portions to CVD mortality. For instance, results published in 2022 from >512,000 adults in a Chinese prospective cohort indicated that 67.7 % of men and 3.2 % of women (overall 29·4 %) ever smoked regularly, and smoking lead to a high risk of circulatory diseases mortality (HR = 1.10, 95 % CI: 1.08–1.12), while fortunately, along with more and more smoking cessation actions in recent years, preliminary findings from 2018 indicated a slight decrease in smoking prevalence, from 27.7 % to 26.6 % nationwide [24,25], which may be consistent with decline in tobacco use related CVD death. Some effective strategies like package warnings, tobacco tax, and restrictions on tobacco advertising should be enforced in tobacco control in China. While concerning physical activity, 1991–2011 China Health and Nutrition Survey data showed a decline in physical activity for men and women and domestic physical activity for women in China, and it was estimated that low physical activity increased incidence of coronary heart disease and hypertension (RR = 1.45 and 1.30, respectively) [26,27].

We also investigated the age, period, and cohort effects on CVD mortality attributable to each behavioral risk in China. Our results showed higher attributable CVD mortality rates in the aged population and men. Overall, men were more likely to be addicted to smoking and drinking [25,28], and it was also reported that higher sodium in men urine than women [29]. Although women were less physical active than men [30], women had the 29 % higher odds of meeting physical activity targets [31]. Besides, generally, women were more likely to take the primary prevention drug of CVD [31]. Taken together, there remained sex differences in behavior risks related to CVD. Our study also concluded period and cohort effects of each behavior risk, and the relationships between age/cohort and CVD mortality were non-linear, indicating a specific adaptation to different situation. Taken together, targeted health education is more conducive to modifying risk factors, like smoking and alcohol cessation among males, and fostering sports engagement among females.

There are several limitations in our study. Firstly, behavioral risk factors are often relied on self-reported data, affecting accuracy of our results, besides, considering that our study was an ecological study, confounding factors like genetic background, ethnic difference, manners and customs, etc., were not addressed based on such study design. Secondly, China has a huge geographical region with various ethnic groups, and the data of different regions and ethnic groups in China may be not accessible, therefore, geographical and ethnic variability were not fully investigated in our study, and in addition, due to different demographic, socio-economic, and cultural background, restricted extrapolation property existed in other countries. Thirdly, we did not detail every diet risk (for instance, low calcium intakes) to a specific heart disease (for instance, hypertension). At last, our age-period-cohort analysis was performed in periods of multiple five years, which might overlook the variations in age, period and cohort effects.

In conclusion, our study highlighted those behavioral risks, especially the dietary risks, brought out huge burden of CVD in China, which should be a prior in prevention of CVD. Moreover, their trajectories differed along with time, age and genders, indicated specific adaptions implemented to different gender and age.

CRediT authorship contribution statement

Li Gong: Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Data curation. **Tingting Wu:** Writing – review & editing, Validation. **Lei Zhang:** Writing – review & editing, Formal analysis. **Guoqiang Lin:** Writing – review & editing. **Fanyan Luo:** Writing – review & editing, Data curation. **Weiru Zhang:** Writing – review & editing, Methodology. **Wen Zhong:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Data availability statement

Public datasets, Global Burden of Disease Study (GBD) 2019, were analyzed in this study. The data can be found in following website: http://ghdx.healthdata.org/gbd-results-tool. The datasets supporting the conclusions of this article were included within the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We thank the Institute for Health Metrics and Evaluation (IHME) for providing open access. This study was funded by the Science and Technology Innovation Program of Hunan Province (Li Gong, 2021RC2032), and the Natural Science Foundation of Hunan Province (Wen Zhong, 2022JJ40846).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e39706.

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