Association between socioeconomic status and health behaviour change before and after non-communicable disease diagnoses: a multicohort study

Danyang Wang*, Xiaochen Dai*, Shiva Raj Mishra, Carmen C W Lim, Rodrigo M Carrillo-Larco, Emmanuela Gakidou, Xiaolin Xu

Summary
Background Behavioural risk factors of non-communicable diseases (NCDs) are socially patterned. However, the direction and the extent to which socioeconomic status (SES) influences behaviour changes before and after the diagnosis of NCDs is not clearly understood. We aimed to investigate the influence of SES on behaviour changes (physical inactivity and smoking) before and after the diagnosis of major NCDs.

Methods In this multicohort study, we pooled individual-level data from six prospective cohort studies across 17 countries. We included participants who were diagnosed with either diabetes, cardiovascular disease, chronic lung disease, or cancer after recruitment. Participants were surveyed every 2 years. Education and total household wealth were used to construct SES. We measured behaviour changes as whether or not participants continued or initiated physical inactivity or smoking after NCD diagnosis. We used multivariable logistic regression models to estimate odds ratios (ORs), prevalence ratios (PRs), and 95% CIs for the associations between SES and continuation or initiation of unfavourable behaviours.

Findings We included 8107 individuals recruited between March, 2002, and January, 2016. Over the 4-year period before and after NCD diagnosis, 886 (60·4%) of 1466 individuals continued physical inactivity and 1018 (68·8%) of 1480 participants continued smoking: 1047 (15·8%) of 6641 participants with physical activity before diagnosis initiated physical inactivity after diagnosis and 132 (2·0%) of 6627 non-smokers before diagnosis initiated smoking after diagnosis. Compared with participants with high SES, those with low SES were more likely to continue physical inactivity [244 (70·3%) of 347 vs 23 (50·0%) of 46; PR 1·41 [95% CI 1·05–1·99]; OR 2·28 [1·18–4·41]), continue smoking (214 [75·4%] of 284 vs 39 [60·9%] of 64; PR 1·27 [1·03–1·59]; OR 2·08 [1·14–3·80]), but also to initiate physical inactivity (188 [26·1%] of 720 vs 47 [7·4%] of 639; PR 3·59 [2·58–4·85]; OR 4·31 [3·02–6·14]).

Interpretation Low SES was associated with continuing or initiating physical inactivity and continuing smoking after NCD diagnosis. Reducing socioeconomic inequality in health behaviour changes should be prioritised and integrated into NCD-prevention programmes.

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Introduction Non-communicable diseases (NCDs) account for 71% of global mortality and disproportionately affect the ageing population.1 To reduce the burden of NCDs, WHO member states developed the Global Action Plan for the Prevention and Control of NCDs in 2013 with aims to reduce mortality from cardiovascular disease, cancer, diabetes, or chronic respiratory diseases by 2025.2 Additionally, the WHO STEPwise Approach to NCD Risk Factor Surveillance was proposed and targeted key behavioural risk factors including physical inactivity and tobacco use,3 which accounted for 7 million deaths in 2020.4 Lifestyle modifications, such as increasing physical activity and smoking cessation, are widely recommended initially after NCD diagnosis.4 Often, NCD diagnosis provides an opportunity for individuals to change their health behaviours.5 Secondary prevention strategies and measures (eg, exercise intervention and smoking cessation) affecting behaviour changes after NCD diagnosis have been shown to be effective and should be emphasised particularly for middle-aged and older adults because they are at higher risk of NCD diagnosis.7,8

Previous cross-sectional studies have suggested that behavioural risk factors of NCDs were strongly associated with socioeconomic status (SES);9 however, less is known about the direction and the extent to which SES might influence longitudinal behaviour changes before and after the diagnosis of NCDs. Examining how individuals respond to NCD diagnoses and any differences therein by SES is crucial to better understand the value of NCD screening programmes, to assess the adequacy of secondary prevention interventions, and to understand disparities in NCD management. Existing studies mostly
Research in context

Evidence before this study

Global analysis of changes after onset of non-communicable diseases (NCDs) provides a key insight into the secondary prevention of NCDs across countries. We searched PubMed and Google Scholar from inception to April 30, 2021, using the terms “physical activity”, “smoking”, “lifestyle”, “behavior change”, “education”, “wealth”, “income”, “socioeconomic status”, “chronic conditions onset”, and “non-communicable diseases onset”. We identified several studies from high-income countries, which primarily focused on single health conditions. No compilation of global data on behaviour changes after onset of various NCDs has been undertaken. Moreover, the associations in the context of different methods dealing with indicators of socioeconomic status (SES) have been rarely examined and compared. Therefore, we aimed to examine how behaviours (i.e., physical inactivity and smoking) changed before and after the onset of four NCDs (i.e., diabetes, cardiovascular disease, chronic lung disease, and cancer) targeted in the WHO Global Action Plan, and whether the behaviour changes differed by SES.

Added value of this study

This study provides insight into the socioeconomic inequality in the secondary prevention of NCDs. We found a substantial proportion of participants continued or initiated physical inactivity or continued smoking after NCD onset. Low SES was significantly associated with an increase of four times in the odds of initiating physical inactivity, an increase of more than two times in the odds of continuing physical inactivity and of continuing smoking. We also examined the separate and composite effects of different SES indicators. We found that using a composite measure performed differently (stronger associations of ORs) from using individual components separately when predicting the behaviour changes.

Implications of all the available evidence

WHO called for an equity-based approach in the Global Action Plan for the Prevention and Control of NCDs 2013–2020. The findings from the study are timely for policy makers. The strong dose-response relationship between SES and behaviour changes before and after NCD onset suggests that efforts in reducing socioeconomic inequality in health behaviours could yield considerable gains.

Methods

Study design and participants

In this pooled multicohort study we used data from six prospective cohort studies done in 17 countries (appendix p 2) from the Global Aging, Health, and Policy programme: the US Health and Retirement Study (HRS), the English Longitudinal Study on Ageing (ELSA); the Survey of Health, Ageing and Retirement in Europe (SHARE); the Costa Rican Longevity and Healthy Aging Study (CRELES); the Korean Longitudinal Study of Aging (KLoSA); and the China Health and Retirement Longitudinal Study (CHARLS). These studies are sister studies of the HRS with similar survey protocols. All six studies were 2-yearly longitudinal studies of nationally representative samples of middle-aged and older adults, sharing similar measures of economic status, lifestyle, and health. For this study, we included participants without diabetes, cardiovascular disease, chronic lung diseases, and cancer at baseline; developed one or more of these four diseases before the last follow-up; and completed three consecutive follow-up surveys covering the disease diagnosis. Those with missing data on exposure and outcome variables were excluded. We further excluded participants older than 85 years to avoid potential selection bias due to early death (appendix p 14).

Exposure

SES was the exposure of interest. Previous studies mostly used education, income, and occupation to construct SES. In this study, education was time invariant and modelled as three categories (0, 1, and 2) corresponding to primary, secondary, and tertiary education. Regarding income and occupation, given that most older adults in this study were retirees and had no stable paid work, we chose total household wealth instead of measuring financial status. Total household wealth was time varying and measured at the first
diagnosis of diseases of interest. The measure referred to the sum of all wealth components including residence, vehicles, and savings accounts, excluding other debts at the couple level, and was measured in the local currency of each country. Detailed descriptions of how total household wealth was calculated are shown in the appendix (pp 3–4). We used quartiles of total household wealth in each study to make the measure comparable across studies, with 0 to 3 representing the lowest (quartile 1) to the highest (quartile 4). In SHARE, 12 countries were included. Total household wealth was already harmonised in the same currency (EUR).

Previous studies as well as our preliminary analysis (appendix p 5) suggested that education and wealth might reflect different components of SES and thus might not be exchangeable. However, SES has been estimated previously by summing various socioeconomic indicators. Given this inconsistency, SES in this study was measured in two ways: (1) using different combinations of education and total household wealth, assuming non-exchangeability between education and total household wealth, and (2) using the summed score (ranging 0–5) of education level (0, 1, or 2) and total household wealth quartiles (0, 1, 2, or 3), assuming exchangeability between education and total household wealth. As for the summed score of SES, smaller values indicated lower SES. To make the analyses more efficient, we further categorised the summed SES score into four groups of low (0), lower-middle (1–2), upper-middle (3–4) and high SES (5).

Outcomes
The outcomes of interest were changes in physical inactivity and current smoking 2 years before and 2 years after diagnosis of four major NCDs. The diagnosis of NCDs was defined as the first report of one or more diagnoses of diabetes, cardiovascular disease (including heart disease and stroke), chronic lung disease, and cancer. We chose the four diseases because they are targeted in the WHO Global Action Plan, account for around 50% of disability-adjusted life-years from NCDs, and are mostly lifestyle-related, thus amenable to secondary prevention. Although participants reported their behaviours in the same survey in which they first reported the diagnosis of NCDs, identifying which came first was difficult. Therefore, physical inactivity and current smoking (coded as yes and no) from the surveys just before and after the first NCD diagnosis were used to assess behaviour changes. These behaviour changes were categorised as continuation (yes to yes), cessation (yes to no), initiation (no to yes), and never (no to no). Among these four behaviour changes, continuation and initiation were further aggregated as unfavourable changes and the other two as favourable changes. Detailed harmonisation strategies are shown in the appendix (pp 3–4).

Covariates
Covariates were assessed at the survey when participants first reported any diagnosis of the four diseases. Among the variables available in the surveys, we selected candidate covariates to adjust for in the model on the basis of review of the literature and empirical associations of candidate covariates with SES and behaviour changes. The selected candidate covariates were age, sex (male and female), countries (17 countries; appendix p 2), marital status (married or living together, separated or divorced, widowed, and never married), BMI, drinking status (less than weekly drinking, and weekly drinking or more), hypertension (yes and no), and psychological disorders (yes and no). BMI was categorised as underweight (<18·5 kg/m²), healthy weight (18·5–24·9 kg/m²), overweight (25·0–29·9 kg/m²), and obese (≥30·0 kg/m²).

Once the candidate covariates were decided, we used a directed acyclic graph (appendix pp 15–16) based on previous evidence to choose the minimally sufficient adjustment set (MSAS). According to the directed acyclic graph, only age, sex, and country were confounders and thus included in the MSAS; all the other candidate covariates were likely to be mediators or colliders between SES and behaviour changes (appendix pp 15–16).

Statistical analysis
We summarised characteristics of the participants at the survey of NCD diagnosis by SES score and by behaviour changes. Between-group differences were explored using the χ² test. McNemar’s tests were used to explore whether the behaviour of physical inactivity and current smoking changed significantly before and after NCDs diagnosis.

To investigate the associations between SES and continuing or initiating unfavourable behaviours, we used multivariable logistic regressions to estimate prevalence ratios (PRs) with 95% CIs and odds ratios (ORs) with 95% CIs. First, we examined the associations of education, total household wealth, summed score, and 12 combinations of education and total household wealth with physical inactivity changes among three populations: (1) the odds of initiating (vs never) physical inactivity among participants with physical activity before disease diagnosis, (2) the odds of continuing (vs cessation) physical inactivity among participants with physical inactivity before disease diagnosis, and (3) the odds of initiating or continuing (vs never or cessation) physical inactivity among all participants regardless of their behaviour status before disease diagnosis. Second, we re-ran the models to examine the associations between socioeconomic indicators with current smoking changes among non-smokers before disease diagnosis, smokers before disease diagnosis, and all participants. For each analysis, we ran both a crude model that only included the exposures of interest and an adjusted model that additionally adjusted for the MSAS.

We did subgroup analyses by age, sex, NCDs, and study to explore variation in the association of SES with
continuing or initiating unfavourable behaviours among different population subgroups. For all the subgroup analyses, we used the categorised summed score of SES as the exposure and adjusted for the MSAS covariates. We further meta-analysed the study-specific ORs of SES on continuing or initiating unfavourable behaviours to get pooled estimates using random effects models and assess the between-study heterogeneity with the $I^2$ statistic.

CRELES was excluded from the meta-analysis because of complete separation of outcome by SES (zero count of outcome for certain SES level; appendix p 6).

To examine the robustness of our results, we did two sensitivity analyses that adjusted for additional covariates and used multiple imputation to account for missing data. After carefully studying the candidate covariates, we constructed the directed acyclic graph and identified the MSAS for adjustment. Although we believe that the other candidate covariates were either colliders or potential mediators and thus should not be adjusted for, the relationship between these covariates and SES could be complex. Instead of being affected by SES, these covariates might also affect SES. Therefore, in the first sensitivity analysis, we adjusted for MSAS plus marital status and psychological disorders and adjusted for all candidate covariates to assess whether the results were sensitive to the decision of not adjusting for additional covariates. Second, because of missing data (particularly for physical inactivity in CHARLS), we used two different two-level multiple imputation methods to impute the missing data—ie, Amelia22 and multiple imputation by chained equations.23 For each method, the missing data were imputed five times, with estimates from each of the

| Overall (n=8107) | Socioeconomic status* | p value† |
|------------------|-----------------------|---------|
|                  | Low (n=1067)          | Lower-middle (n=3446) | Upper-middle (n=2909) | High (n=685) |
| Age, years       |                       |         |                       |             |
| 45–54            | 674 (8.3%)            | 93 (8.7%) | 322 (9.3%) | 222 (7.7%) | 36 (5.3%) | 0.0008 |
| 55–64            | 2556 (31.5%)          | 302 (28.3%) | 1114 (32.3%) | 907 (31.2%) | 233 (34.0%) | .. |
| 65–74            | 3017 (37.2%)          | 377 (33.3%) | 1223 (35.5%) | 1143 (39.3%) | 274 (40.0%) | .. |
| 75–85            | 1860 (22.9%)          | 295 (27.6%) | 787 (22.8%) | 636 (21.9%) | 142 (20.7%) | .. |
| Sex              |                       |         |                       |             |
| Male             | 3569 (44.0%)          | 371 (34.8%) | 1421 (41.2%) | 1356 (46.6%) | 421 (61.5%) | <0.0001 |
| Female           | 4538 (56.0%)          | 696 (65.2%) | 2025 (58.8%) | 1553 (53.4%) | 264 (38.5%) | .. |
| Marital status   |                       |         |                       |             |
| Married or partnered | 5657 (70.0%) | 542 (50.8%) | 2237 (65.2%) | 2299 (79.4%) | 579 (84.5%) | <0.0001 |
| Separated or divorced | 799 (9.9%) | 165 (15.5%) | 426 (12.4%) | 171 (5.9%) | 37 (5.4%) | .. |
| Widowed           | 1303 (16.1%)          | 303 (28.4%) | 615 (17.9%) | 341 (11.8%) | 44 (6.4%) | .. |
| Never married     | 319 (3.9%)            | 56 (5.3%) | 155 (4.5%) | 83 (2.9%) | 25 (3.6%) | .. |
| Body-mass index, kg/m² |         |         |                       |             |
| <18.5            | 182 (2.6%)            | 38 (4.4%) | 84 (2.9%) | 52 (2.1%) | 8 (1.3%) | <0.0001 |
| 18.5–24.9        | 2064 (29.9%)          | 285 (33.1%) | 778 (26.6%) | 780 (26.0%) | 221 (34.8%) | .. |
| 25.0–29.9        | 2639 (38.2%)          | 289 (33.6%) | 1084 (37.1%) | 1017 (30.3%) | 249 (41.4%) | .. |
| ≥30.0            | 2026 (29.3%)          | 249 (28.9%) | 978 (33.4%) | 676 (26.8%) | 123 (20.5%) | .. |
| Drinking status  |                       |         |                       |             |
| Less than weekly drinking | 4758 (60.5%) | 752 (74.7%) | 2254 (67.5%) | 1504 (52.8%) | 248 (36.6%) | <0.0001 |
| Weekly drinking or more | 3112 (39.5%) | 255 (25.3%) | 1084 (32.5%) | 1343 (47.2%) | 461 (64.1%) | .. |
| Hypertension     | 4913 (60.7%)          | 658 (61.8%) | 2208 (64.2%) | 1675 (57.6%) | 372 (54.3%) | <0.0001 |
| Psychological disorders | 1306 (16.2%) | 307 (19.6%) | 585 (17.2%) | 430 (14.8%) | 342 (51.3%) | <0.0001 |
| Major NCDs       |                       |         |                       |             |
| Diabetes         | 2442 (30.2%)          | 340 (31.9%) | 1125 (32.0%) | 792 (27.2%) | 176 (25.7%) | <0.0001 |
| Cardiovascular disease | 3480 (42.9%) | 482 (45.3%) | 1476 (42.8%) | 1250 (43.0%) | 271 (39.6%) | 0.14 |
| Chronic lung diseases | 1214 (15.0%) | 212 (19.9%) | 569 (16.5%) | 377 (13.0%) | 56 (8.2%) | <0.0001 |
| Cancer           | 1546 (19.1%)          | 143 (13.4%) | 538 (15.6%) | 655 (22.5%) | 130 (19.7%) | <0.0001 |

Data are n (%), unless otherwise indicated. Characteristics were assessed at the survey when participants first reported the diagnosis of any diseases of interest. NCD=non-communicable disease. *Socioeconomic status was constructed as the summed score (ranging 0–5) of education level (0, 1, or 2) and total household wealth quartiles (0, 1, 2, or 3), and categorised into four groups of low (0), lower-middle (1–2), upper-middle (3–4), and high socioeconomic status (5). $\chi^2$ tests were used to compare differences of categorical variables presented as n (%). Body-mass index in the English Longitudinal Study on Ageing, the Costa Rican Longevity and Healthy Aging Study, and the China Health and Retirement Longitudinal Study was based on physically measured data whereas the US Health and Retirement Study, the Survey of Health, Ageing and Retirement in Europe, and the Korean Longitudinal Study of Aging used self-reported data.

Table 1: Characteristics of participants by socioeconomic status at the survey of NCD diagnosis
## Table 2: Characteristics of participants at the survey of NCD diagnosis by behaviour changes (n=8107)

| Characteristics                          | Participants with physical activity before disease diagnosis (n=6641) | Participants with physical inactivity before disease diagnosis (n=1466) | Non-smokers before disease diagnosis (n=6627) | Smokers before disease diagnosis (n=1018) |
|------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------|----------------------------------------|
| **Age, years**                           |                                                                   |                                                                |                                             |                                        |
| 45–54                                    | 477 (8.5%)                                                       | 73 (10%)                                                      | 472 (7.3%)                                   | 15 (11.4%)                             |
| 55–64                                    | 1882 (33.6%)                                                    | 268 (25.6%)                                                   | 1869 (28.8%)                                 | 44 (33.3%)                             |
| 65–74                                    | 2159 (38.6%)                                                    | 353 (33.7%)                                                   | 2477 (38.1%)                                 | 51 (38.6%)                             |
| 75–85                                    | 1076 (19.2%)                                                    | 353 (33.7%)                                                   | 167 (22.6%)                                  | 41 (31.8%)                             |
| **Sex**                                  |                                                                   |                                                                |                                             |                                        |
| Male                                     | 2697 (48.2%)                                                    | 397 (7.9%)                                                    | 2705 (41.6%)                                 | 80 (60.6%)                             |
| Female                                   | 2897 (51.8%)                                                    | 650 (62.1%)                                                   | 3790 (58.4%)                                 | 52 (39.4%)                             |
| **Education**                            |                                                                   |                                                                |                                             |                                        |
| Primary                                  | 1562 (27.9%)                                                    | 465 (44.4%)                                                   | 2188 (37.1%)                                 | 49 (37.1%)                             |
| Secondary                                | 2809 (50.2%)                                                    | 463 (44.2%)                                                   | 3042 (46.8%)                                 | 59 (44.7%)                             |
| Tertiary                                 | 1223 (21.9%)                                                    | 119 (11.4%)                                                   | 1265 (19.5%)                                 | 46 (34.7%)                             |
| **Total household wealth**               |                                                                   |                                                                |                                             |                                        |
| Quartile 1 (lowest)                      | 1251 (22.4%)                                                    | 343 (32.8%)                                                   | 1542 (23.7%)                                 | 35 (26.5%)                             |
| Quartile 2                               | 1307 (24.4%)                                                    | 293 (28.0%)                                                   | 1606 (24.7%)                                 | 45 (34.1%)                             |
| Quartile 3                               | 1433 (25.6%)                                                    | 237 (22.6%)                                                   | 1643 (25.3%)                                 | 28 (21.2%)                             |
| Quartile 4 (highest)                     | 1543 (27.6%)                                                    | 174 (16.6%)                                                   | 1704 (26.2%)                                 | 24 (18.2%)                             |
| **Marital status**                       |                                                                   |                                                                |                                             |                                        |
| Married or partnered                     | 4061 (72.9%)                                                    | 659 (63.2%)                                                   | 4377 (64.9%)                                 | 156 (12.0%)                            |
| Separated or divorced                    | 547 (9.8%)                                                      | 121 (11.6%)                                                   | 549 (8.5%)                                   | 15 (11.5%)                             |
| Widowed                                  | 743 (13.3%)                                                     | 220 (21.1%)                                                   | 1105 (16.2%)                                 | 13 (10.0%)                             |
| Never married                            | 219 (3.9%)                                                      | 43 (4.1%)                                                     | 238 (3.7%)                                   | 4 (3.1%)                              |
| **Body-mass index, kg/m²**               |                                                                   |                                                                |                                             |                                        |
| <18.5                                    | 99 (1.7%)                                                       | 39 (4.5%)                                                      | 130 (2.3%)                                   | 4 (3.1%)                              |
| 18.5–24.9                                | 1332 (23.7%)                                                    | 281 (27.3%)                                                   | 1556 (28.0%)                                 | 41 (33.5%)                             |
| 25–29.9                                  | 1989 (34.4%)                                                    | 288 (33.1%)                                                   | 2518 (38.9%)                                 | 45 (35.1%)                             |
| ≥30                                      | 1384 (23.8%)                                                    | 262 (30.1%)                                                   | 1707 (30.8%)                                 | 23 (23.0%)                             |
| **Drinking status**                      |                                                                   |                                                                |                                             |                                        |
| Less than weekly drinking                | 2959 (54.2%)                                                    | 695 (70.0%)                                                   | 3892 (61.6%)                                 | 63 (50.0%)                             |
| Weekly drinking or more                 | 2502 (45.8%)                                                    | 298 (30.0%)                                                   | 2424 (38.4%)                                 | 63 (50.0%)                             |
| **Hypertension**                         |                                                                   |                                                                |                                             |                                        |
| No                                       | 2292 (41.0%)                                                    | 373 (35.7%)                                                   | 2488 (38.3%)                                 | 51 (38.6%)                             |
| Yes                                      | 3293 (59.0%)                                                    | 622 (64.3%)                                                   | 4002 (61.7%)                                 | 56 (50.4%)                             |
| **Psychological disorders**              |                                                                   |                                                                |                                             |                                        |
| No                                       | 4772 (85.4%)                                                    | 813 (79.3%)                                                   | 5476 (85.1%)                                 | 770 (75.8%)                            |
| Yes                                      | 816 (14.6%)                                                    | 213 (20.7%)                                                   | 961 (14.9%)                                  | 246 (24.2%)                            |

Data are n (%), unless otherwise indicated. Characteristics were assessed at the survey when participants first reported the diagnosis of any disease of interest. *Body-mass index in the English Longitudinal Study on Ageing, the Costa Rican Longevity and Healthy Aging Study, and the China Health and Retirement Longitudinal Study was based on physically measured data whereas the US Health and Retirement Study, the Survey of Health, Ageing and Retirement in Europe, and the Korean Longitudinal Study of Aging used self-reported data. *χ² tests were used to compare differences of categorical variables presented as n (%). We considered continuing or not initiating an unfavourable behaviour (eg, never) after NCD diagnosis as behaviour changes as well.
five complete datasets pooled using Rubin’s rules (appendix pp 7–8).²

In this study, all tests were two-sided, and the type I error α was set to be 0·05. Statistical analyses were done using SAS (version 9.4) and R (version 4.0.3). This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Role of the funding source
The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results
Of 217 370 participants recruited at baseline between March, 2002, and January, 2016, we included 8107 (3·7%) participants with three consecutive surveys and newly diagnosed with at least one of four major NCDs. 4025 (49·6%) participants were from the UK and 12 other European countries, 3278 (40·4%) were from the USA and Costa Rica, and 804 (9·9%) were from South Korea and China (appendix p 2). The mean age at diagnosis of NCDs was 67·11 years (SD 8·89) and 4538 (56·0%) participants were female and 3569 (44·0%) were male (table 1). Participants with high SES at disease diagnosis were less likely to report diabetes or chronic lung diseases, but more likely to report cancer, compared with those with low SES at diagnosis (table 2). Those who continued or initiated physical inactivity after disease diagnosis were more likely to have lower education whereas those who continued or initiated smoking were more likely to have less total household wealth (table 2).

The distributions of physical inactivity and smoking before and after NCD diagnosis were significantly different (table 2) and we found between-group heterogeneity (appendix pp 17–18). Before NCD diagnosis, 6641 (81·9%) of 8107 participants were physically active and 6627 (81·7%) participants were non-smokers (table 2). Throughout the 4-year period, 1047 (15·8%) of 6641 participants with physical activity initiated physical inactivity and 132 (2·0%) of 6627 non-smokers initiated smoking. We also found a substantial proportion of people who continued physical inactivity (886 [60·4%] of 1466) or smoking (1018 [68·8%] of 1480) after NCD diagnosis (table 2).

Compared with those with tertiary education or in the highest quartile of total household wealth, the prevalence and odds of continuing or initiating physical inactivity after NCD diagnosis were significantly higher for those with primary education level or in the lowest quartile of total household wealth in the MSAS-adjusted models (tables 3, 4). For example, the ORs of continuing physical inactivity were 1·71 (tertiary education vs primary education; 95% CI 1·35–2·18) and 2·59 (highest wealth quartile vs lowest wealth quartile; 2·08–3·23). The ORs and PRs of continuing or initiating smoking slightly increased as the education level or total household wealth declined, but no significant associations between these measures were observed (tables 3, 4). The summed SES score had a dose-response relationship with continuing or initiating physical inactivity (tables 3, 4). Among those who were physically active before disease diagnosis, low SES (vs high) was associated with a PR of 3·59 (2·58–4·85) and OR of 4·31 (3·02–6·14) of initiating physical inactivity after disease diagnosis (tables 3, 4). Among those who were physically inactive before NCD diagnosis, low SES (vs high) was associated with a PR of 1·41 (1·05–1·99) and an OR of 2·28 (1·18–4·41) of continuing physical inactivity after disease diagnosis (tables 3, 4).

Overall, SES showed a dose-response relationship with the aggregated outcomes of continuing or initiating unfavourable behaviours in both crude and MSAS-adjusted models. Specifically, in the MSAS-adjusted models, low SES (score of 0), with high SES (score of 5) as reference, was associated with increased odds of aggregated outcomes of continuing or initiating physical inactivity 5·33 (95% CI 3·98–7·15) and of continuing or initiating smoking 4·38 (3·14–6·11; tables 3, 4). In low SES strata, the predicted prevalence of aggregated outcomes of continuing or initiating physical inactivity was 35·5% (32·4–38·7) and of continuing or initiating smoking was 4·38 (4·3–7·5% for smoking in high SES strata (tables 3, 4).

We found that different combinations of education and total household wealth had varied ORs on continuing or initiating unfavourable behaviours before and after disease diagnosis (figure 1). The odds of continuing or initiating physical inactivity and continuing smoking varied across different combinations of education and total household wealth, and were highest in those with primary education level only and in the lowest quartile of total household wealth (figure 1). Within the same total household wealth quartiles or education levels, we found gradient increases in ORs on aggregated behavioural outcomes as the other variable (education level or total household wealth quartile) declined (figure 1). The association between SES and the aggregated behavioural outcomes presented similar patterns within each subgroup stratified by age, sex, and type of disease, but we found between-group heterogeneity (appendix pp 9–II). In the meta-analysis, the pooled ORs for the association between SES and the aggregated outcomes of continuing or initiating physical inactivity were 5·15 (low vs high; 95% CI 3·52–7·52), 3·26 (lower-middle vs high;
### Table 3: Associations of socioeconomic indicators with continuing or initiating physical inactivity before and after NCD diagnosis

| Education | Participants with physical activity before disease diagnosis (n=6641) | Participants with physical inactivity before disease diagnosis (n=1466) | All participants (N=8107) |
|-----------|-------------------------------------------------|------------------------------------------------|--------------------------|
|           | Observed prevalence* | Predicted prevalence (95% CI) | PR (95% CI) OR (95% CI) | Observed prevalence+ | Predicted prevalence (95% CI) | PR (95% CI) OR (95% CI) | Observed prevalence‡ | Predicted prevalence (95% CI) | PR (95% CI) OR (95% CI) |
| Primary   | 465/2027 (22.9%) | 161 (13.0–19.9) | 171 (13.5–21.8) | 529/776 (68.2%) | 124 (1.03–1.53) | 1.65 (1.07–2.54) | 994/2803 (35.5%) | 24.6% (22.7–26.5) | 1.72 (1.46–2.03) |
| Secondary | 463/3272 (14.2%) | 134 (10.0–16.3) | 138 (11.1–17.3) | 300/568 (52.8%) | 109 (0.91–1.33) | 1.19 (0.79–1.80) | 763/3840 (19.9%) | 19.5% (18.1–20.9) | 1.37 (1.16–1.60) |
| Tertiary  | 173/1432 (8.9%)  | 98 (8.1–11.8) | 100 (ref) | 52/122 (46.7%) | 100 (ref) | 100 (ref) | 176/1464 (12.0%) | 14.3% (12.3–16.4) | 100 (ref) |

| Total household wealth | Participants with physical activity before disease diagnosis (n=6641) | Participants with physical inactivity before disease diagnosis (n=1466) | All participants (N=8107) |
|------------------------|-------------------------------------------------|------------------------------------------------|--------------------------|
| Quartile 1 (lowest)    | 343/1594 (21.5%) | 196 (14.4–23.8) | 259 (20.8–32.3) | 165/756 (21.9%) | 130 (10.4–1.74) | 1.19 (0.86–1.62) | 517/3350 (15.4%) | 21.0% (18.3–23.8) | 1.26 (1.00–1.58) |
| Quartile 2              | 293/1660 (17.7%) | 181 (14.8–21.9) | 194 (15.6–24.2) | 165/888 (18.7%) | 130 (10.4–1.74) | 1.19 (0.86–1.62) | 525/3544 (14.9%) | 16.0% (13.4–17.7) | 1.26 (1.00–1.58) |
| Quartile 3              | 237/1670 (14.2%) | 134 (10.9–16.2) | 137 (11.0–17.1) | 165/888 (18.7%) | 130 (10.4–1.74) | 1.19 (0.86–1.62) | 525/3544 (14.9%) | 16.0% (13.4–17.7) | 1.26 (1.00–1.58) |
| Quartile 4 (highest)    | 174/1717 (10.1%) | 86 (7.2–9.9) | 100 (ref) | 136/744 (18.2%) | 100 (ref) | 100 (ref) | 310/1961 (15.8%) | 13.4% (11.8–15.0) | 100 (ref) |

| Socioeconomic status§  | Participants with physical activity before disease diagnosis (n=6641) | Participants with physical inactivity before disease diagnosis (n=1466) | All participants (N=8107) |
|------------------------|-------------------------------------------------|------------------------------------------------|--------------------------|
| Low (0)                | 188/720 (26.1%) | 359 (258–451) | 431 (302–614) | 244/747 (32.0%) | 70.8 % (60–81.1) | 141 (105–199) | 432/1067 (40.5%) | 35.5% (32.4–38.7) | 382 (295–488) |
| Lower-middle (1–2)     | 511/2734 (18.7%) | 262 (154–350) | 291 (211–402) | 423/712 (59.4%) | 61.4% (50.4–72.3) | 1.22 (0.92–1.69) | 934/3446 (27.1%) | 24.8% (23.3–26.4) | 2.67 (2.09–3.39) |
| Upper-middle (3–4)     | 301/2548 (11.8%) | 157 (9.9–212) | 161 (116–223) | 196/381 (51.3%) | 53.8% (41.6–65.9) | 1.07 (0.79–1.49) | 497/2909 (17.1%) | 14.6% (13.3–16.0) | 1.58 (1.22–2.00) |
| High (5)               | 47/639 (7.4%)  | 58 (4.7–8.4) | 100 (ref) | 23/46 (50.0%) | 100 (ref) | 100 (ref) | 70/685 (10.2%) | 9.4% (7.2–11.5) | 100 (ref) |

Data are n/N (%), unless otherwise indicated. NCD=non-communicable disease. OR=odds ratio. PR=prevalence ratio. *Observed prevalence of participants who initiated physical inactivity after disease diagnosis; OR>1 indicates increased odds of initiating physical inactivity. †Observed prevalence of participants who continued physical inactivity after disease diagnosis; OR>1 indicates higher odds of continuing physical inactivity. ‡Observed prevalence of participants who continued or initiated physical inactivity after disease diagnosis; OR>1 indicates higher odds of continuing or initiating physical inactivity. Results should only be interpreted for initiating or continuing physical inactivity as an aggregated outcome and should not be interpreted for initiating or continuing physical activity in a disaggregated way. §Socioeconomic status was constructed as the summed score (ranging 0–5) of education level (0, 1, or 2) and total household wealth quartiles (0, 1, 2, or 3), and categorised into four groups of low (0), lower-middle (1–2), upper-middle (3–4) and high SES (5). Models were adjusted for age at disease diagnosis, sex, and country. Simulation method was used to estimate 95% CIs of PRs, for participants with physical inactivity before disease diagnosis, Germany was removed from the model during simulation process because having no observations in that country might cause unstable estimated coefficients.
### Education

|                      | Non-smokers before disease diagnosis (n=6627) | Smokers before disease diagnosis (n=1480) | All participants (n=8107) |
|----------------------|-----------------------------------------------|----------------------------------------|--------------------------|
|                      | Observed prevalence* | Predicted prevalence (95% CI) | PR (95% CI) | OR (95% CI) | Observed prevalence† | Predicted prevalence (95% CI) | PR (95% CI) | OR (95% CI) | Observed prevalence‡ | Predicted prevalence (95% CI) | PR (95% CI) | OR (95% CI) |
| Education            |                               |                                       |                     |              |                               |                                       |                     |              |                               |                                       |                     |              |
| Primary              | 49/2237 (2.2%)               | 1.1% (0-24.5)                        | 1.08 (0.65-1.74)    | 1.06 (0.61-1.85) | 396/566 (70.0%)               | 73.1% (67.2-75.4)                        | 1.05 (0.93-1.12) | 1.17 (0.78-1.77) | 445/7803 (55.9%)              | 141% (127-155)                        | 1.68 (1.36-2.05) | 1.74 (1.01-1.53) |
| Secondary            | 59/301 (1.9%)                | 1.1% (0-14.0)                        | 1.09 (0.69-1.70)    | 1.09 (0.66-1.79) | 504/739 (68.2%)               | 68.8% (65.3-72.3)                        | 1.02 (0.90-1.15) | 1.04 (0.71-1.51) | 563/840 (14.7%)              | 12.0% (10.9-13.1)                       | 1.42 (1.18-1.71) | 1.32 (1.08-1.62) |
| Tertiary             | 24/1289 (1.9%)               | 1.0% (0-13.7)                        | 1.00 (ref)          | 1.00 (ref)     | 118/175 (67.4%)               | 68.0% (60.5-75.4)                        | 1.00 (ref)          | 1.00 (ref)     | 142/1464 (9.7%)               | 8.5% (7.0-9.9)                          | 1.00 (ref)          | 1.00 (ref) |

**Total household wealth**

|                      |                               |                                       |                     |              |                               |                                       |                     |              |                               |                                       |                     |              |
|----------------------|                               |                                       |                     |              |                               |                                       |                     |              |                               |                                       |                     |              |
| Quartile 1 (lowest)  | 35/1577 (2.2%)                | 1.3% (0-16.7)                        | 1.53 (0.95-2.75)    | 1.64 (0.93-2.91) | 438/528 (75.3%)               | 75.1% (71.4-78.7)                        | 1.18 (1.05-1.33) | 1.70 (1.39-2.44) | 473/2159 (21.9%)              | 18.7% (16.9-20.9)                       | 2.34 (1.94-2.81) | 2.86 (2.35-3.49) |
| Quartile 2           | 45/1651 (2.7%)                | 1.5% (0-20.3)                        | 1.80 (1.30-3.25)    | 2.02 (1.17-3.46) | 256/378 (67.7%)               | 68.4% (63.6-73.2)                        | 1.07 (0.95-1.22) | 1.22 (0.85-1.79) | 301/2029 (14.8%)              | 13.0% (11.5-14.5)                       | 1.62 (1.34-1.97) | 1.79 (1.46-2.19) |
| Quartile 3           | 28/1671 (1.7%)                | 1.0% (0-12.9)                        | 1.24 (0.75-2.12)    | 1.27 (0.72-2.24) | 181/287 (63.1%)               | 64.1% (58.4-69.9)                        | 1.01 (0.88-1.15) | 1.01 (0.70-1.47) | 209/1958 (10.7%)              | 9.6% (8.3-10.9)                          | 1.20 (0.97-1.47) | 1.24 (1.00-1.54) |
| Quartile 4 (highest) | 24/1728 (1.4%)                | 0.8% (0-10.2)                        | 1.00 (ref)          | 1.00 (ref)     | 143/233 (61.4%)               | 62.8% (57.2-70.5)                        | 1.00 (ref)          | 1.00 (ref)     | 167/1961 (8.5%)               | 8.0% (6.8-9.3)                          | 1.00 (ref)          | 1.00 (ref) |

**Socioeconomic status**

|                      |                               |                                       |                     |              |                               |                                       |                     |              |                               |                                       |                     |              |
|----------------------|                               |                                       |                     |              |                               |                                       |                     |              |                               |                                       |                     |              |
| Low                  | 15/783 (1.9%)                 | 1.2% (0-35.2)                        | 1.09 (0.51-2.17)    | 1.05 (0.47-2.32) | 214/284 (75.4%)               | 76.6% (71.4-81.7)                        | 1.27 (1.03-1.59) | 2.08 (1.14-3.80) | 229/1067 (21.5%)              | 21.6% (18.9-24.2)                       | 3.71 (3.14-4.55) | 4.38 (3.16-6.11) |
| Lower-middle (1-2)   | 69/2723 (2.5%)                | 1.4% (0-18.6)                        | 1.27 (0-72.33)      | 1.29 (0-67.46) | 506/723 (70.0%)               | 70.4% (67.0-73.8)                        | 1.16 (0.96-1.46) | 1.51 (0.87-2.62) | 575/3446 (16.7%)              | 14.9% (13.7-16.2)                       | 2.56 (2.06-3.14) | 2.80 (2.06-3.81) |
| Upper-middle (3-4)   | 36/2590 (1.4%)                | 0.8% (0-10.9)                        | 0.84 (0-40.1-40)    | 0.74 (0-38.1-45) | 259/409 (63.3%)               | 64.0% (59.2-68.8)                        | 1.06 (0-86-133) | 1.13 (0-64-198) | 295/2909 (10.3%)              | 8.7% (7.6-9.7)                          | 1.49 (1.10-1.98) | 1.51 (1.10-2.07) |
| High                 | 12/621 (1.9%)                 | 1.1% (0-14.6)                        | 1.00 (ref)          | 1.00 (ref)     | 39/64 (60.9%)                 | 61.2% (48.7-73.6)                        | 1.00 (ref)          | 1.00 (ref)     | 51/685 (7.5%)                 | 5.9% (4.9-7.5)                          | 1.00 (ref)          | 1.00 (ref) |

OR=odds ratio. PR=prevalence ratio. *Observed prevalence of participants who initiated smoking after disease diagnosis; OR>1 indicates higher odds of initiating smoking. †Observed prevalence of participants who continued smoking after disease diagnosis; OR>1 indicates higher odds of continuing smoking. ‡Observed prevalence of participants who continued or initiated smoking after disease diagnosis; OR>1 indicates higher odds of continuing or initiating smoking. Results should only be interpreted for initiating or continuing smoking as an aggregated outcome and should not be interpreted for initiating smoking or continuing smoking in a disaggregated way. Socioeconomic status was constructed as the summed score (ranging 0-5) of education level (0, 1, or 2) and total household wealth quartiles (0, 1, 2, or 3), and categorised into four groups of low (0), lower-middle (1-2), upper-middle (3-4) and high S55 (5). Models were adjusted for age at disease diagnosis, sex, and country. Simulation method was used to estimate 95% CIs of PRs.

Table 4: Associations of socioeconomic indicators with continuing or initiating smoking before and after NCD diagnosis.
focused on a pooled population of middle-aged and older adults from different countries, examined four common lifestyle-related NCDs, and comprehensively assessed physical inactivity and current smoking behaviours, thus contributing to an overall picture of the secondary prevention of NCDs. Although heterogeneity in behaviour changes was present among individual studies, the overall high proportions of continuing physical inactivity, initiating physical inactivity, and continuing smoking observed in our study, highlight the urgency for strategies and measures to promote health behaviours, particularly in controlling the burden of major NCDs.

As for factors influencing behaviour changes, previous studies typically included SES as a set of covariates and their effects were rarely reported. Our study, by contrast, measured SES compositely by combining education and total household wealth and examined the associations of SES with continuing or initiating behaviours comprehensively. Our findings were in line with the existing evidence and showed that low SES was associated with continuing or initiating physical inactivity and continuing smoking after NCD diagnosis. The results for initiating smoking showed an inconsistent pattern but were not significant because of the small number of participants initiating smoking after NCD diagnosis, and thus warrant future studies with greater statistical power. By using large population-based samples from multiple countries and an extensive set of NCDs and conducting various sensitivity analyses, our
### A

|                          | n/N     | OR (95% CI) | Weight |
|--------------------------|---------|-------------|--------|
| **Low SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 94/275 (34%) | 4.45 (2.89–6.84) | 31.6%   |
| CHARLS                   | 30/57 (53%) | 1.99 (0.22–17.89) | 5.5%    |
| SHARE                    | 69/287 (24%) | 9.48 (3.66–26.78) | 16.5%   |
| KLoSA                    | 84/115 (73%) | 3.16 (1.36–7.36) | 20.6%   |
| ELSA                     | 139/371 (44%) | 7.60 (4.01–14.44) | 25.7%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=23%, p=0.27 |         |             |        |
| **Lower-middle SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 347/1216 (28%) | 3.32 (2.30–4.80) | 31.8%   |
| CHARLS                   | 45/116 (39%) | 1.33 (0.15–11.46) | 5.4%    |
| SHARE                    | 355/1000 (36%) | 5.82 (2.11–16.05) | 16.2%   |
| KLoSA                    | 352/241 (63%) | 2.26 (1.06–4.84) | 21.5%   |
| ELSA                     | 198/784 (25%) | 3.42 (1.84–6.36) | 25.1%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=0%, p=0.58 |         |             |        |
| **Upper-middle SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 229/1299 (18%) | 1.68 (1.16–2.45) | 32.0%   |
| CHARLS                   | 18/54 (33%) | 1.02 (0.11–9.17) | 5.3%    |
| SHARE                    | 59/670 (9%) | 3.42 (1.22–9.64) | 16.0%   |
| KLoSA                    | 90/181 (50%) | 1.41 (0.66–3.03) | 21.7%   |
| ELSA                     | 187/1000 (18%) | 1.56 (0.82–2.95) | 24.9%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=4%, p=0.53 |         |             |        |

### B

|                          | n/N     | OR (95% CI) | Weight |
|--------------------------|---------|-------------|--------|
| **Low SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 56/275 (20%) | 4.10 (2.40–7.01) | 28.3%   |
| CHARLS                   | 10/57 (18%) | 2.16 (0.23–20.30) | 7.0%    |
| SHARE                    | 66/287 (24%) | 2.44 (1.35–4.40) | 27.8%   |
| KLoSA                    | 18/115 (16%) | 4.26 (1.38–13.17) | 17.4%   |
| ELSA                     | 79/371 (25%) | 13.92 (4.95–39.14) | 19.0%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=53%, p=0.07 |         |             |        |
| **Lower-middle SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 234/1216 (19%) | 3.51 (2.20–5.60) | 28.6%   |
| CHARLS                   | 9/116 (8%) | 0.47 (0.06–3.99) | 7.1%    |
| SHARE                    | 18/1000 (19%) | 1.67 (0.98–2.86) | 27.3%   |
| KLoSA                    | 34/241 (14%) | 1.77 (0.66–4.75) | 18.8%   |
| ELSA                     | 110/784 (14%) | 6.27 (2.26–17.36) | 18.2%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=60%, p=0.04 |         |             |        |
| **Upper-middle SES vs high SES in continuing or initiating physical inactivity** |         |             |        |
| HRS                      | 126/1299 (10%) | 1.84 (1.14–2.98) | 329.0%  |
| CHARLS                   | 6/54 (11%) | 0.78 (0.08–7.39) | 6.7%    |
| SHARE                    | 101/670 (15%) | 1.09 (0.63–1.91) | 27.6%   |
| KLoSA                    | 18/181 (10%) | 0.86 (0.31–2.44) | 18.4%   |
| ELSA                     | 43/685 (6%) | 2.44 (0.86–6.94) | 18.2%   |
| **Random effects model** |         |             |        |
| Heterogeneity: IA=4%, p=0.38 |         |             |        |

**Figure 2:** Forest plot of study-specific ORs of socioeconomic status on the aggregated continuation or initiation of unfavourable behaviours before and after NCD diagnosis.

Results should only be interpreted for continuing or initiating smoking or physical inactivity as aggregated outcomes. Particularly, in disaggregated analysis, we found no significant association between SES and initiating smoking among non-smokers before disease diagnosis. All estimates were adjusted for age and sex.

SHARE included 12 countries consisting of Austria, Belgium, Czechia, Denmark, Estonia, France, Germany, Italy, Slovenia, Spain, Sweden, and Switzerland.

NCD=non-communicable disease. OR=odds ratio. SES=socioeconomic status. CHARLS=China Health and Retirement Longitudinal Study. CRELES=Costa Rican Longevity and Healthy Aging Study. ELSA=English Longitudinal Study on Ageing. HRS=US Health and Retirement Study. SHARE=Survey of Health, Ageing and Retirement in Europe. KLoSA=Korean Longitudinal Study of Aging.
study has added evidence of the socioeconomic inequality in the secondary prevention of NCDs, especially in relation to behavioural risk factors. The link between higher SES and physical inactivity or continuing smoking might be associated with higher health literacy,39 access to professional health-care services, and social networks to provide emotional support among people with high SES.39

We also investigated the association of SES with the aggregated outcomes of continuing or initiating physical inactivity or smoking, based on WHO recommendations2,3 and previous studies.4 Overall, SES had a dose-response relationship with the aggregated outcomes with varied ORs across subgroups stratified by age, sex, and type of diseases. We observed smaller ORs of SES for aggregated changes in physical inactivity among participants with diabetes than among participants with other diseases, which might be due to exercise prescription for diabetes being more common and easier to follow in clinical practice.11 Nevertheless, participants with cardiovascular disease, cancer, or chronic lung disease might have exercise intolerance and need supervised physical activity training programmes with consideration of type, frequency, timing, duration, and intensity.12,13 This kind of professional supervision is technically complicated and fee based in some countries (eg, in China), thereby not easily accessible to all.

Low SES was associated with continuing or initiating physical inactivity and continuing smoking after NCD diagnosis. These findings provide valuable implications for secondary prevention including promotion of physical activity and smoking cessation. The strong dose-response relationship between SES and the aggregated outcomes after major NCD diagnosis observed in our study suggests that people with low SES should be prioritised in the secondary prevention of NCDs, and the societal-level interventions targeting SES should also be applied and emphasised in the secondary prevention of NCDs—even moderate efforts in reducing socioeconomic inequality in health behaviours might yield considerable gains. Our findings are in line with recommendations from the Commission on Social Determinants of Health.44

Additionally, our study provides policy imperatives for targeting social determinants of health for improving the uptake of population interventions targeting smoking and physical inactivity, which is closely aligned with Sustainable Development Goal 3. Future studies involving low-income and middle-income countries are warranted to validate and extend the evidence from the present study done in high-income and middle-high income countries.

We also examined the separate and composite effects of education and total household wealth. We found that using a composite measure showed stronger associations in terms of ORs than did using individual components when predicting the continuation or initiation of unfavourable behaviours. Additionally, the gradient change of ORs on continuing or initiating unfavourable behaviours before and after disease diagnosis among the different combinations of education and total household wealth to some extent justified the use of summed score of SES. However, the diagonal ORs (which had the same summed SES score) were not always similar, suggesting that education and total household wealth were not completely exchangeable. As many studies have established the importance of SES in health and called for integration of SES into traditional risk prediction models,15,16 the present study might advance our understanding of how composite SES performs in models, thereby informing strategies for combining different SES indicators in future research.

The use of large population-based samples from 17 countries and inclusion of all the major NCDs emphasised by the WHO Global Action plan supports the generalisability of our results of behaviour changes and of the gradient associations of SES therewith. Additionally, we not only used different ways of measuring SES (education and total household wealth separately, exhaustive combinations and summed score of the two), but also included various subgroups and sensitivity analyses to explore variations in the ORs of SES on continuing or initiating unfavourable behaviours and to ensure the robustness of the results. However, this study also has some limitations. First, this study used self-reported data, which can be a major source of bias. Second, although 217 370 participants were recruited at baseline, only 8107 with three consecutive surveys and who were newly diagnosed with at least one of four major NCDs were included in the final analysis. The study was also limited by the small sample size (eg, only 132 non-smokers initiated smoking after diagnosis). Third, although education and wealth are two important components of SES and were often used in constructing SES, other indicators, such as occupational status, should also be considered in future studies. Fourth, heavy alcohol consumption and unhealthy diet (eg, low in fruits and high in salt) are also socially patterned and were included into the risk factors modules of the STEPwise Approach to NCD Risk Factor Surveillance.1 However, because of the unavailability of data on alcohol consumption level and diet type, we did not consider these measures as primary outcomes in the present study. Future studies focusing on alcohol use and diet are warranted. Fifth, our results were potentially biased because we excluded participants with missing data. We used two different multiple imputation methods to impute the missing data assuming missing at random. We acknowledge that missing at random cannot be verified given the data we have. Therefore, we reported results of the complete case analyses as our main results because the imputation might lead to bias as big as or bigger than the bias in the analyses of complete cases if the data were missing not at random.39 Further, comparing complete case analyses with two multiple
imputation methods added robustness to the findings of main analyses. Sixth, although we carefully examined and selected covariates using a directed acyclic graph, unknown confounders could still undermine the conclusions. Seventh, compared with the association between SES and the disaggregated behaviour outcomes, the association between SES and the aggregated outcomes (eg, continuing or initiating physical inactivity) is inflated because the aggregated outcome is conflated by people’s initial behaviour before NCD diagnosis, which is also associated with SES. Since the causal relationship between SES and initial behaviour before NCD diagnosis is unclear, there is potential confounding caused by the conflated outcome. Eighth, we did not consider NCD severity or treatment, which could affect behavioural changes. Ninth, because of a small number of studies included in our meta-analysis, the I² statistics should be interpreted with caution. Last, we only covered the 4-year period before and after the diagnosis of NCDs, which did not capture the long-term behaviour trends after NCD diagnosis. Future studies with repeated measures are needed.

In this multi-cohort study, low SES was associated with continuing or initiating physical inactivity, and continuing smoking. These findings support the need for urgent actions and reinforced efforts to address socioeconomic inequalities in achieving behaviour changes after NCD diagnosis, and provide valuable implications for targeted intervention. Policy makers and health professionals should prioritise socioeconomically disadvantaged groups when designing and implementing secondary prevention programmes on NCDs.

Contributors
XX contributed to the study conceptualisation and supervised the whole project. XX, XD, and DW made the analysis plan and did the statistical analyses. XX, XD, and DW accessed and verified the underlying data. All authors contributed to and approved the final manuscript. XX, the corresponding author, had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Data sharing
The original data for this study are available on the HRS, ELSA, SHARE, CRELES, KLoSA, and CHARLS websites.

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