Tobacco smoking changes during the first pre-vaccination phases of the COVID-19 pandemic: A systematic review and meta-analysis

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Summary

Background Globally, tobacco smoking remains the largest preventable cause of premature death. The COVID-19 pandemic has forced nations to take unprecedented measures, including 'lockdowns' that might impact tobacco smoking behaviour. We performed a systematic review and meta-analyses to assess smoking behaviour changes during the early pre-vaccination phases of the COVID-19 pandemic in 2020.

Methods We searched Medline/Embase/PsycINFO/BioRxiv/MedRxiv/SSRN databases (January−November 2020) for published and pre-print articles that reported specific smoking behaviour changes or intentions after the onset of the COVID-19 pandemic. We used random-effects models to pool prevalence ratios comparing the prevalence of smoking during and before the pandemic, and the prevalence of smoking behaviour changes during the pandemic. The PROSPERO registration number for this systematic review was CRD42020206383.

Findings 31 studies were included in meta-analyses, with smoking data for 269,164 participants across 24 countries. The proportion of people smoking during the pandemic was lower than that before, with a pooled prevalence ratio of 0·87 (95%CI:0·79−0·97). Among people who smoke, 21% (95%CI:14−30%) smoked less, 27% (95%CI:22−32%) smoked more, 50% (95%CI:41%-58%) had unchanged smoking and 4% (95%CI:1−9%) reported quitting smoking. Among people who did not smoke, 2% (95%CI:1−3%) started smoking during the pandemic. Heterogeneity was high in all meta-analyses and so the pooled estimates should be interpreted with caution (I^2>91% and p-heterogeneity<0·001). Almost all studies were at high risk of bias due to use of non-representative samples, non-response bias, and utilisation of non-validated questions.

Interpretation Smoking behaviour changes during the first phases of the COVID-19 pandemic in 2020 were highly mixed. Meta-analyses indicated that there was a relative reduction in overall smoking prevalence during the pandemic, while similar proportions of people who smoke smoked more or smoked less, although heterogeneity was high. Implementation of evidence-based tobacco control policies and programs, including tobacco cessation services, have an important role in ensuring that the COVID-19 pandemic does not exacerbate the smoking pandemic and associated adverse health outcomes.

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Introduction

Coronavirus disease 2019 (COVID-19) has caused substantial morbidity and mortality globally, with over 430 million people infected, resulting in over

Research in context

Evidence before this study

Emerging evidence indicates that the COVID-19 pandemic has impacted many aspects of everyday life, including lifestyle behaviours. We searched the Medline, Embase, and PsycInfo databases, the BioRxiv and MedRxiv pre-print servers, and the SSRN website using search terms relating to COVID-19 and tobacco smoking, with no language restrictions, for published studies and preprints up to 5 November 2020 that assessed the relationship between the first pre-vaccination phases of the COVID-19 pandemic and smoking prevalence or smoking behaviour changes. No existing systematic reviews with meta-analyses were identified, which was further confirmed in June 2021 by searches of two key databases, UNCOVER and the US Veterans' Affairs COVID-19 Evidence Review, that aggregate evidence reviews for COVID-19.

Added value of this study

To our knowledge, this is the most comprehensive systematic review on the COVID-19 pandemic and smoking to date, including over 269,000 participants from 24 countries covering multiple regions of the world. The meta-analyses provided pooled estimates describing smoking prevalence and diverse smoking behaviour changes, including increased, decreased and stable tobacco consumption, cessation and initiation, as well as varied intended and attempted efforts to quit smoking during the pandemic, relative to pre-pandemic times. In addition, we performed a detailed assessment of risk of bias, adapting existing tools for the specific study question, and have highlighted the present status of the research and evidence gaps for future research in the area of smoking behavioural changes during the COVID-19 pandemic.

Implications of all the available evidence

In addition to the direct population health impact of COVID-19, the pandemic is likely to affect the future burden of other diseases, due in part to the concomitant changes in risk factors such as the consumption of tobacco products. This review focused on tobacco smoking, and provides important evidence to guide policy to ensure that tobacco control strategies are implemented and maintained, and that individuals are encouraged and supported to avoid consumption of tobacco products into the future. The methods used in this review, including tools assessing the risk of bias can be extended to other studies, in particular those assessing other forms of behavioural change during the pandemic.

5·9 million deaths as of 1 March 2022, including over 67 million cases and 1·6 million deaths in the pre-vaccination phases of the pandemic prior to 7 December 2020.[1] Reducing the spread of the disease has been a major priority for governments worldwide, which have relied on the introduction of various containment measures, including testing and tracing programmes, mandatory isolation and quarantine, travel restrictions, social/physical distancing, and stay-at-home orders, especially in the early pre-vaccination phases of the pandemic. Since WHO declared COVID-19 a pandemic on 11 March 2020,[2] evidence has emerged of its profound impact on individuals and communities, affecting physical and mental health[3] and increasing financial distress. These effects may translate into lifestyle changes, including transitions to either more or less healthy behaviours, which in the longer-term may affect individuals' disease risk and the consequent population-wide disease burden.

Tobacco is a major cause of disease burden worldwide, accounting for 15·4% of all deaths (8·71 million) in 2019,[4] largely due to smoking-related non-communicable diseases. Early online surveys[5,6] reported diverging evidence on changes in smoking behaviours during the pandemic. This may reflect a complex interaction between individual, societal, and structural factors.[7–9] Smoking may have increased for some people as a coping mechanism for psychological distress, including anxiety and/or depression, and due to other structural factors such as increased opportunity to smoke; however, smoking may have decreased for others due to reduced access to retailers, limited social interactions, concerns about health and/or contracting COVID-19, or financial limitations. Smoking and many of the chronic diseases it causes (e.g., severe asthma, chronic obstructive pulmonary disease, cardiovascular disease) have also been proposed as risk factors for more severe COVID-19 infection outcomes (e.g., intensive care admission or mortality),[10–12] reports of which may have led to increased attempts to quit smoking during the pandemic.

Given the long-term impact of smoking behaviour on the future burden of disease, knowledge of smoking behaviour changes during the COVID-19 pandemic is important to inform recovery and preventive health efforts. Therefore, we aimed to systematically review the literature to evaluate the impact of the first pre-vaccination phases of the COVID-19 pandemic in 2020 (i.e., before the mass roll-out of vaccines in some, mostly high-income countries, and the emergence of the delta strain) on tobacco smoking behaviours, covering many aspects of tobacco smoking including prevalence, intensity, uptake or cessation. We synthesised the evidence using meta-analyses, conducted an in-depth risk of bias assessment, and identified evidence gaps requiring future research efforts.

Methods

This systematic review is reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) checklist.

Search strategy and selection criteria

We searched Medline (including MEDLINE Epub Ahead of Print, I-Process & Other Non-Indexed Citations), Embase, and PsycInfo databases on the OVID platform by combining database-specific subject headings and text terms for studies in humans on COVID-19 and tobacco smoking (CC). There were no language restrictions, and searches were undertaken to 5 November 2020. We also screened all COVID-19 related records on the BioRxiv and MedRxiv pre-print servers (https://connect.biorxiv.org/relate/content/181), and the SSRN website (https://www.ssrn.com/index.cfm/en/coronavirus/) to 5 November 2020. Supplementary Table 1 shows the detailed search strategies. We checked reference lists of relevant systematic reviews and all articles included in full-text screening for additional studies.

We included cross-sectional studies, cohort studies, and uncontrolled "before-and-during" studies that reported changes in tobacco smoking behaviours among the general population, smokers, non-smokers or ex-smokers, after the onset of the COVID-19 pandemic. We specifically sought studies that reported the tobacco smoking prevalence before and during the COVID-19 pandemic, and/or tobacco smoking increases, decreases, initiation, cessation, intentions or attempts to quit during the pandemic or related restrictions. The definitions of each smoking behaviour change were as reported in the included studies. For the analyses of changes in smoking intensity, where possible, only participants who smoked both before and during the pandemic were included. Many primary studies did not describe clearly whether specific estimates for increases or decreases in smoking intensity included participants who started or quit smoking during the pandemic, respectively, or it was clear that those who started or quit smoking were included. Included studies are labelled with the following categories in Tables 1a and 1b: quitting/initiation not included, quitting/initiation included, or unclear whether quitting/initiation is included. We included non-peer-reviewed pre-print publications, and letters, editorials, comments and published peer-reviewed articles. Conference abstracts, qualitative studies and studies restricted to populations with specific health conditions, occupations or employment status were excluded.

Titles and abstracts of identified articles were screened by one reviewer (SH). The full text of each potentially relevant article was independently assessed for inclusion by two reviewers (chosen from PS, CJC, CC, IS, AM) using pre-specified selection criteria. Disagreements were resolved by third-reviewer adjudication (SH).

Data extraction

Study characteristics and results of eligible studies were independently extracted by pairs of reviewers (chosen from PS, CJC, PV, EL, SE, JS, IS, AM, SH) with disagreements resolved by a third reviewer. We extracted information on study characteristics (publication type, study design, population source, sampling methods, survey modality, period, and country), severity and dates of COVID-19 restrictions,[13] participants' information (number, age, sex, and smoking status), tobacco smoking prevalence, intensity (mean or category frequencies) and changes (smoking prevalence, increases, decreases, intensity, initiations, cessations, intentions and attempts to quit) before and during the COVID-19 pandemic. Information from the study protocol and study website were also extracted, where available.

Risk of bias assessment

For each study, risk of bias assessment was performed by pairs of independent reviewers (chosen from PS, CJC, EL, PV, DO'C, IS). Differences were first discussed as a team, and if consensus was not reached, the item was independently assessed by a third reviewer (DO'C). We used two separate risk of bias assessment tools that were modified for our review. Cross-sectional studies were assessed using a risk of bias tool based on one for prevalence studies.[14] Cohort studies and uncontrolled before-and-during studies were assessed using an adaptation of the ROBINS-I tool.[15] In summary, the modified cross-sectional study tool and modified before-and-after study tool assessed biases using nine domains and four domains, respectively (with full details shown in Supplementary Tables 3, 4), and a summary provided in the Additional Methods (Supplementary material p.2). Overall risk of bias for each study was assigned as the highest risk of bias rating in any domain for that study.

Data synthesis and meta-analysis

We extracted frequencies, prevalences, odds ratios, prevalence ratios, absolute differences in proportions, and mean differences as applicable to each outcome and study design. We calculated the effects based on reported data where possible (see Supplementary material p.2). For the outcomes "smoking more", "smoking less", "smoking initiation" and "smoking cessation" during the COVID-19 pandemic, the prevalence of the outcome was the measure of effect. For the outcome "smoking quantity", our preferred measure of effect was the mean difference in smoking quantity before and during the pandemic but as none of the three studies that reported this outcome provided sufficient information to calculate the standard error of the change, meta-analysis was not performed.

A. Cross-sectional studies (164,184 participants in 27 studies).

Country / Authors	Population source*	Sampling method	Surveymode	Survey period (2020)	Participants	Sample characteristics: N, age, sex	Tobacco smoking prevalence		Outcome reported†
							Reported by study	WHO estimate[68]	
Bangladesh									
Ahmed[‡,29]	Social media for online survey; NR for face-to-face survey	Convenience	Online and face-to-face	27 Jun - 20 Jul	S + NS	1222, Mean: 30·8 (SD: 12·1), M: 61·4%, F: 38·1%	25·6% (313/1222)	23·5% M: 46·6% F: 1·0% (2018)	*Smoking changes* **All participants** Smoking more: 1·6% (20/1222) (increased or initiated) Smoking less: 12·4% (152/1222) (reduced or quit) **Smokers** Smoking more: 6·4% (20/313) (increased or initiated) Smoking less: 48·6% (152/313) (reduced or quit)
Belgium									
Vanderbruggen[53]	Social media; university communications; website	Convenience	Online	9–29 Apr	S + NS	3632, Mean: 42·1 (SD: 14·6), M: 29·8%, F: 70·0%, Gender-neutral: 0·2%	15·4% (558/3632)	19·4% M: 24·5% F: 14·6% (2018)	*Smoking prevalence* Before pandemic: 15·4% (558/3632) During pandemic: 15·3% (556/3632) *Smoking changes* **All participants** Smoking more: 6·3% (229/3632) (increased only — no initiation) Smoking less: 2·5% (reduced or quit) **Smokers** Smoking more: 43·9% (229/522) (increased only — no initiation) Stopped smoking: 6·5% (36/558) **Non-smokers** Started smoking: 1·1% (34/3074)

Table 1a (Continued)

Brazil									
Brazil									
Malta[43]	Contacts of authors	Convenience; snowballing	Online	24 Apr - 24 May	S + NS	45,161, 18–29: 24·7%, 30–49: 39·1%, 50+: 36·2%, M: 46·4%, F: 53·6%	12·0%	12·6% M: 15·9% F: 9·6% (2019)	*Smoking changes* **All participants** Smoking less: 1·5% (reduced only – no quitting) **Smokers** Smoking more: 34·0% (unclear if includes initiation) Smoking less: 12·1% (reduced only – no quitting)
China									
Ren[47]	Mobile phone users	Convenience; s nowballing	Online	14 Feb - 29 Mar	S + NS	1172, Median: 22·0 (Q1-Q3: 21·0–37·0), M: 30·7%, F: 69·3%	7·1% (83/1172)	26·6% M: 50·5% F: 2·1% (2018)	*Smoking changes* **Smokers** Smoking more: 30·1% (25/83) (unclear if includes initiation)
Sun[51]	Social media; website	Convenience	Online	24–31 Mar	S + NS	6416, Mean: 28·2 (SD: 9·2), M: 47%, F: 53%	12·8% (822/6416)		*Smoking prevalence* Before pandemic: 12·8% (822/6416) During pandemic: 13·6% (873/6416) *Smoking changes* **All participants** Smoking more: 1·7% (108/6416) (increased only – no initiation) **Smokers** Smoking more: 21·6% (108/605) (increased only – no initiation) Stopped smoking: 10·1% (83/822) **Non-smokers** Started smoking: 2·4% (134/5594)

Table 1a *(Continued)*

		China							
Yan[54]	Social media	Convenience	Online	25 Apr - 11 May	S + NS	9016, 18–29: 48·9%, 30–39: 33·4%, 40+: 17·7%, M: 42·6%, F: 57·4%	13·8% (1248/9016)		*Smoking changes* **All participants** Smoking less: 3·1% (278/9016) (unclear if includes quitting) **Smokers** Smoking more: 49·2% (614/1248) (unclear if includes initiation) Smoking less: 22·3% (278/1248) (unclear if includes quitting)
France									
Constant[35]	Online panel	Representative	Online	8–20 Apr	S + NS	4005, 18–39: 37·2%, 40–59: 37·1%, 60+: 25·8%, M: 48·8%, F: 51·2%	26·5% (1062/4005)	30·4% M: 34·6% F: 26·5% (2019)	*Smoking changes* **All participants** Smoking less: 4·4% (177/4005) (unclear if includes quitting) **Smokers** Smoking more: 21·8% (231/1062) (unclear if includes initiation) Smoking less: 16·7% (177/1062) (unclear if includes quitting)
Rolland[49]	Social media; national media	Convenience	Online	25–30 Mar	S + NS	11,391, 16–29: 29·9%, 30–49: 46·7%, 50+: 23·4% (unweighted percentages), M: 22·4%, F: 77·1%, Other: 0·5% (unweighted percentages)	24·5% (2792/11,399; weighted percentage)		*Smoking changes* **All participants** Smoking less: 5·2% (589/11,399; weighted percentage) (reduced or quit) **Smokers** Smoking more: 35·6% (995/2792; weighted percentage) (unclear if includes initiation) Smoking less: 21·1% (589/2792; weighted percentage) (reduced or quit)

Germany									
Georgiadou[38]	Social media; website; print media; radio	Convenience	Online	8–18 Apr	S + NS	2150, 18–24: 29%, 25–44: 42%, 45+: 29%, M: 34%, F: 66%	27·3% (582/2130)	23·4% M: 26·4% F: 20·2% (2018)	*Smoking prevalence* Before pandemic: 27·3% (582/2130) During pandemic: 24·7% (523/2115) *Smoking changes* **All participants** Smoking more: 11·9% (251/2115) (increased only – no initiation) Smoking less: 2·5% (53/2115) (reduced only – no quitting) **Smokers** Smoking more: 50·0% (251/502) (increased only – no initiation) Smoking less: 10·6% (53/502) (reduced only – no quitting) Stopped smoking: 11·5% (65/567) **Non-smokers** Started smoking: 1·4% (21/1548)
Ghana									
Asiamah[30]	Social media	Convenience; snowballing	Online	4–16 Apr	S + NS	621, 18–24: 18%, 25–44: 57%, 45+: 25%, M: 65·4%, F: 34·6%	27·9% (173/621)	NR M: 3·5% F: 0·2% (2017–2018)	*Smoking prevalence* Before pandemic: 27·9% (173/621) During pandemic: 27·9% (173/621) *Smoking changes* **All participants** Smoking less: 0·0% (0/621) (reduced only – no quitting) **Smokers** Smoking more: 0·0% (0/173) (unclear if includes initiation) Smoking less: 0·0% (0/173) (reduced only – no quitting) Stopped smoking: 0·0% (0/173)

Hong Kong									
Luk[42]	Landline phone users; panel of mobile phone users	Random (landline phone users); convenience (panel of mobile phone users)	Telephone	9–23 Apr	S + NS	1501, 18–29: 15·0%, 30–59: 52·0%, 60+: 33·0% (unweighted percentages), M: 44·8%, F: 55·2% (unweighted percentages)	18·0% (weighted percentage)	26·6% M: 50·5% F: 2·1% (2018)	*Smoking changes* **All participants** Smoking less: 3·4% (weighted percentage) (unclear if includes quitting) **Smokers** Smoking more: 15·6% (weighted percentage) (unclear if includes initiation) Smoking less: 19·1% (weighted percentage) (unclear if includes quitting)
India									
Chopra[34]	Social media; email	Convenience; snowballing	Online and telephone	15–30 Aug	S + NS	995, Mean: 33·3 (SD: 14·5), M: 58·6%, F: 41·4%	5·6% (56/995)	10·7% M: 19·0% F: 2·0% (2016–2017)	*Smoking prevalence* Before pandemic: 5·6% (56/995) During pandemic: 4·7% (47/995)
Italy									
Cancello[31]	Social media	Convenience	Online	15 Apr - 4 May	S + NS	490, ≤30: 14·5%, 31–60: 65·1%, >60: 20·4%, M: 16·3%, F: 83·7%	21·4% (105/490)	19·0% M: 23·3% F: 15·0% (2018)[4]	*Smoking changes* **Smokers** Smoking more: 38% (40/105) (increased only – no initiation)
Di Renzo[36]	Social media; website; email	Convenience	Online	5–24 Apr	S + NS	3533, 12–17: 5·1%, 18–30: 29·7%, 31–50: 42·2%, 50+: 23·0, M: 23·9%, F: 76·1%	25·1% (887/3533)		*Smoking prevalence* Before pandemic: 25·1% (887/3533) During pandemic: 21·8% (771/3533)
Odone[45]	Online panel	Representative	Online	27 Apr - 3 May	S + NS	6003, 18–74: Age breakdown NR, NR	23·3%		*Smoking prevalence* Before pandemic: 23·3% During pandemic: 21·9%

Netherlands									
Bommelé[7]	Online panel	Representative	Online	11–18 May	S	957, Mean: 45·9 (SD: 16·4), M: 56·1%, F: 43·9%	NA	21·7% M: 25·4% F: 18·1% (2019)	*Smoking changes* **Smokers** Smoking more: 18·9% (unclear if includes initiation) Smoking less: 14·1% (reduced only – no quitting) Increased motivation/desire to quit: 16·1% Decreased motivation/desire to quit: 12·1%
Poland									
Chodkiewicz[33]	Social media	Convenience; snowballing	Online	10–29 April	S + NS	443, Mean: 31·9 (SD: 11·3), M: 21·4%, F: 78·6%	25·5% (113/443)	22·4% M: 25·8% F: 19·2% (2019)	*Smoking changes* **All participants** Smoking less: 5·0% (22/443) (unclear if includes quitting) **Smokers** Smoking more: 23·0% (26/113) (unclear if includes initiation) Smoking less: 19·5% (22/113) (unclear if includes quitting)
Sidor[50]	Social media	Convenience	Online	17 Apr - 1 May	S + NS	1097, 18–25: 53·6%, 26–45: 41·4%, 46+: 4·9%, M: 4·9%, F: 95·1%	14·1% (155/1097)[§]		*Smoking changes* **Smokers**[§] Smoking more: 45·2% (70/155) (unclear if includes initiating)
Spain									
Lopez-Bueno[41]	Social media	Convenience	Online	22 Mar - 5 Apr	S + NS	2741, Mean: 34·2 (SD: 13·0), M: 48·2%, F: 52·8%	13·9% (382/2741)	24·4% M: 28·2% F: 20·8% (2016–2017)[4]	*Smoking prevalence* Before pandemic: 13·9% (382/2741) During pandemic: 8·8% (241/2741)

United Kingdom									
Jackson[a39]	Media consumers, digital users, and vulnerable groups	Convenience	NR	21 Mar - 20 Apr	S + NS	53,221 (unweighted) 18—29: 10·4%, 30—49: 40·8%, 50+: 48·8% (unweighted percentages), M: 26·4%, F: 73·6% (unweighted percentages)	15·2% (8057/53,002; weighted percentage)	14·1% M: 15·9% F: 12·5% (2019)	*Smoking changes* **All participants** Smoking less: 2·0% (weighted percentage) (reduced only − no quitting) **Smokers** Smoking more: 42·2% (weighted percentage) (unclear if includes initiation) Smoking less: 13·4% (weighted percentage) (reduced only − no quitting)
Taylor[i,52]	Ongoing study (Lothian Birth Cohort 1936)	Unclear	Online	27 May - 8 Jun	S + NS	190, Mean: 84 (SD: 0·3), M: 52·7%, F: 47·3%	1·1% (2/189)		*Smoking prevalence* Before pandemic: 1·1% (2/189) During pandemic: 1·1% (2/189) *Smoking changes* **All participants** Smoking less: 0·0% (0/189) (reduced only − no quitting) **Smokers** Smoking more: 50·0% (1/2) (unclear if includes initiation) Smoking less: 0·0% (0/2) (reduced only − no quitting) Stopped smoking: 0·0% (0/2)
United States									
Chertok[32]	Social media; email	Convenience	Online	7—20 Apr (exact end date unclear)	S + NS	810, Mean: 33·5 (SD: 14·6), M: 27·5%, F: 72·5%	22·1% (179/810)	20·8% M: 24·9% F: 17·1% (2019)	*Smoking changes* **All participants** Smoking less: 8·5% (69/810) (reduced or quit) **Smokers** Smoking more: 18·3% (33/180) (unclear if includes initiation)

Table 1a *(Continued)*

United States								
								Smoking less: 38·3% (69/180) (reduced or quit) Increased motivation/desire to quit: 51·7% (93/180) Decreased motivation/desire to quit: 12·2% (22/180) Attempted to quit: 36·7% (66/180)
Emerson[37]	Social media, email	Convenience; snowballing	Online	30 Mar - 12 Apr	S + NS	833, 60—70: 62·8%, 71+: 37·2%, M: 19·5%, F: 80·5%	NR	*Smoking changes* **All participants** Smoking more: 1·3% (unclear if includes initiation) Smoking less: 1·1% (unclear if includes quitting)
Knell[40]	Social media	Convenience	Online	15 Apr - 5 May	S + NS	1809, 18—34: 31·5%, 35—49: 39·8%, 50+: 28·7%, M: 32·6, F: 67·4%	9·8% (177/1809)	*Smoking changes* **All participants** Smoking less: 1·9% (34/1809) (unclear if includes quitting) **Smokers** Smoking more: 30·5% (54/177) (unclear if includes initiation) Smoking less: 19·2% (34/177) (unclear if includes quitting)
Rogers[48]	Crowdsourcing website	Convenience	Online	Apr - May	S + NS	160, Mean: 37·9 (SD: 11·2), M: 56·5%, F: 43·5%	21·9% (35/160)	*Smoking changes* **Non-smokers** Started smoking: 8·8% (11/125)
Zimbabwe								
Matsungo[44]	Social media, email	Convenience	Online	11—25 May	S + NS	507, 18—30: 26·0%, 31—40: 48·1%, 50+: 10·5%, M: 37·0%, F: 63·0%	14·4% (Percentage estimated by review team from Fig. 3; n participants in Fig. 3= 421)	NR M: 17·7% F: 0·5% (2015)	*Smoking changes* **All participants** Smoking less: 4·9% (percentage estimated by review team from Fig. 3) (unclear if includes quitting) **Smokers**

Table 1a (Continued)

Zimbabwe									
									Smoking more: 45·9% (unclear if includes initiation) Smoking less: 30·6% (percentage estimated by review team from Fig. 3) (unclear if includes quitting)
9 European countries: Bosnia and Herzegovina, Croatia, Greece, Italy, Kosovo, Serbia, Slovakia, Slovenia, Spain									
Pisot[46]	Website; email	Convenience; snowballing	Online	**Bosnia and Herzegovina, Croatia, Serbia, Slovakia, Slovenia, Italy & Spain:** 15 Apr - 28 May **Kosovo:** 24 Apr - 3 May **Greece:** 28 Apr - 3 May	S + NS	4108, Mean: 32·0 (SD: 13·2), M: 37·2%, F: 62·8%	35·9% (1476/4108)	**Bosnia and Herzegovina:** NR **Croatia:** 35·0% (M: 40·0%; F: 31·0%) (2017) **Greece:** 27·1% (M: 24·6%; F: 29·6%) (2017) **Italy:** NA **Kosovo:** NR **Serbia:** NR **Slovakia:** 26·0% (M: 34·0%; F: 19·0%) (2017) **Slovenia:** 24·3% (M: 27·5%; F: 21·2%) (2014)[4] **Spain:** 24·4% (M: 28·2%; F: 20·8%) (2016–2017)[4]	*Smoking changes* **All participants** Smoking less: 14·1% (579/4108) (unclear if includes quitting) **Smokers** Smoking more: 22·2% (328/1476) (unclear if includes initiation) Smoking less: 39·2% (579/1476) (unclear if includes quitting)

***Table 1a*: Description of studies included in the meta-analyses.**

* Social media includes websites and digital applications used for social networking, such as Facebook, WhatsApp and Twitter.

† If only percentage shown, exact numbers NR by study.

‡ Pre-print.

§ Addicted to smoking, so unclear if 155 is the total number of smokers or if there are more (e.g., occasional smokers).**S**: Smokers, **NS**: Non-smokers; **M**: Male, **F**: Female; **SD**: Standard deviation; **Q1-Q3**: Quartile 1 to quartile 3; **NR**: Not reported, **NA**: Not applicable.

Country / Authors	Population source	Sampling method	Participants	Before COVID-19 pandemic			During COVID-19 pandemic			Tobacco smoking prevalence		Outcomes reported*
				Sample characteristics: N, age, sex	Survey period	Surveymode	Sample characteristics: N, age, sex	Survey period (2020)	Surveymode	Reported by study	WHO estimate[68]	
Single cohort with longitudinal follow-up (same participants sampled before and during COVID-19 pandemic)												
Netherlands												
McIntyre[56]	Ongoing study (Lifelines prospective population cohort and the Lifelines NEXT birth cohort)	Unclear	S + NS	68,660, comprising two cohorts: Lifelines prospective population cohort 68,501, Mean: 54•3 (SD: 13•0), M: 39•2%, F: 60•8% Lifelines NEXT birth cohort 159, Mean: 33•0 (SD: 4•3), M: 36•5%, F: 63•5%	2006-last visit Lifelines prospective population cohort 2006-last visit Lifelines NEXT birth cohort 2016-last visit	NR	38,086[†] NR NR	18 May[†]	Online	Before pandemic: Lifelines prospective population cohort: Current smoker "at last visit": 14•0% Lifelines NEXT birth cohort: NR	21•7% M: 25•4% F: 18•1% (2019)	*Smoking prevalence* Before pandemic: Lifelines prospective population cohort: 14•0% (current smoker "at last visit")[‡] Lifelines NEXT birth cohort: NR During pandemic: Presumably, both cohorts combined: 7•8% ("Have you smoked in the last 7 days?")[‡]
Pakistan												
Siddiqi[58]	NR	Random sample	S	Wave 1 6014, 15−30: 20•1%, 31−50: 47•5%, 51+: 32•4%, M: 98•5%, F: 1•5%	Sep 2019 - Feb 2020	Face-to-face and tablet assisted interviews	Wave 2: 2062, Mean: 45•0 (SD: 14•5) NR	Wave 2 5 May - 4 Jun	Telephone	NA	13•7% M: 22•6% F: 4•7% (2017−2018)	*Smoking changes* **Smokers** Smoking more: 18•2% (323/1772) (increased only − no initiation) Smoking less: 68•3% (1210/1772) (reduced only − no

Table 1b *(Continued)*

Pakistan												
												quitting) Stopped smoking: 14•1% (290/2062)
United Kingdom												
Niedzwiedz[57]	Ongoing study (UK Household Longitudinal Study)	Representative	S + NS	9748 , 18–24: 6•4%, 25–44: 29•1%, 45+: 64•4% (weighted percentages), M: 44•3%, F: 55•7% (weighted percentages)	2017–2019	Mixed mode (face-to-face, telephone or online survey)	Same as before pandemic	24–30 Apr	Online	Before pandemic: 15•1% (weighted percentage)	14•1% M: 15•9% F: 12•5% (2019)	*Smoking prevalence* Before pandemic: 15•1% (weighted percentage) During pandemic: 12•1% (weighted percentage)
Multiple cross-sectional cohorts (different participants sampled before and during COVID-19 pandemic) United Kingdom												
Jackson[b55]	Ongoing study (Smoking and Alcohol Toolkit Studies)	Representative	S + NS	18,884, 16–24: 13•4%, 25–44: 32•6%, 45+: 54•0% (weighted percentages), M: 49•1%, F: 50•9% (weighted percentages)	Monthly, Apr 2019 - Feb 2020	Face to face and computer-assisted interviews	1674, 16–24: 10•9%, 25–44: 33•2%, 45+: 55•5% (weighted percentages), M: 49•1%, F: 50•9% (weighted percentages)	Apr	Telephone	Before pandemic: 15•9% (weighted percentage)	14•1% M: 15•9% F: 12•5% (2019)	*Smoking prevalence* Before pandemic: 15•9% (weighted percentage)[§] During pandemic: 17•0% (weighted percentage)[§]

***Table 1b*: Description of studies included in the meta-analyses. B. Before-and-during studies 104,980 participants in 4 studies (103,306 participants before pandemic and 51,552 participants during pandemic).**

* If only percentage shown, exact numbers NR by study.

† Personal communication with study authors.

‡ Estimates effectively unadjusted for potential confounding factors, as study had same participants before and during the pandemic, but with substantial loss to follow-up.

§ Estimates effectively unadjusted for potential confounding factors, as study had different participants before and during the pandemic.**S**: Smokers, **NS**: Non-smokers; **M**: Male, **F**: Female; **SD**: Standard deviation; **NR**: Not reported, **NA**: Not applicable.

We carried out separate quantitative syntheses for populations unselected for smoking status and for populations restricted to smokers or non-smokers for each outcome (smoking prevalence, smoking initiation, smoking cessation, smoking increase, smoking decrease, intention to quit and attempts to quit). We used the random-effects method to pool data. Heterogeneity among included studies was assessed visually and statistically, using the I-squared statistic (I^2) and Chi-squared test. For the meta-analyses of smoking increase and decrease, we performed a sensitivity analysis including only studies that reported both of these outcomes. We intended to perform subgroup meta-analyses to examine heterogeneity in effect estimates based on: age, sex, country, change in socio-economic circumstances (e.g., employment status), psychological and mental health factors (e.g., anxiety), and peer-review status. We could not conduct these subgroup analyses as there were no more than two studies reporting data on an outcome for the subgroups of interest. Meta-regression was used to assess the relationships between the included outcomes and (1) the severity of COVID-19 outbreaks in the study population and period (number of COVID-19 cases or deaths per capita between the start and end dates of the survey and also from the start date of the pandemic to the end date of the survey),[13] (2) the mean daily stringency index of the national response to the COVID-19 pandemic during the survey period,[13] and (3) the proportion of survey participants who were male, if reported for the study. Meta-regression was used when there were at least 10 studies for the outcome-predictor combination.

PROSPERO registration

The PROSPERO registration number for this systematic review was CRD42020206383 (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020206383).

Role of the funding source

No specific funding was received for this study. Funding sources had no role in study design, data collection, data analysis, data interpretation, writing of the report, or in the decision to submit the paper for publication. All authors had access to the data in this study and agreed to submit the article for publication.

Results

Summary of the studies included

Searches of published and pre-print literature identified 17,359 unique records, with an additional 158 records identified from citations (Figure 1). 213 articles that underwent full text screening were ineligible; most as they did not report an outcome of interest or were an excluded publication type or study design (Supplementary Table 2). 44 studies met the inclusion criteria of which 13 were excluded from the meta-analyses due to insufficient or inconsistent data (described in Supplementary Table 5),[16–28] with 31 studies remaining (27 cross-sectional[7,29–54] and 4 before-and-during,[55–58] described in Tables 1a and 1b, respectively).

Smoking data were collected from a total of 269,164 participants across 24 countries (including one study conducted across nine European countries). In most studies, the majority of participants were female (23/30 studies, where reported). The 27 cross-sectional studies included 164,184 participants surveyed between 14 February and 30 August 2020 (predominantly in April-May). Recruitment was via social media for over half of the studies. 25 of the studies that included both smokers and non-smokers reported smoking prevalence data. 17 studies reported outcomes for a subgroup of smokers, and eight studies reported outcomes for smokers only. The four before-and-during studies included 104,980 participants. Surveys for these studies were conducted from 2006 up to February 2020 before the pandemic, and from April to 4 June 2020 during the pandemic, with a minimum of two months to a maximum of 14 years between surveys. Three studies sampled participants from ongoing cohort studies and reported smoking prevalence: two studies re-surveyed the same participants, while the other study surveyed a different group at each time point. The fourth study assessed changes in smoking prevalence and behaviours amongst smokers across multiple waves during the COVID-19 pandemic, with follow-up of some participants previously surveyed.

Prevalence of smoking during compared to before the pandemic

12 studies (9 cross-sectional, 3 before-and-during) were included in the meta-analysis for changes in smoking prevalence during versus before the pandemic (Tables 1a, 1b and 2), the combined prevalence ratio being 0·87 (95%CI:0·79–0·97), indicating a relative reduction in the prevalence of smoking during the pandemic (Figure 2a) although the pooled estimate should be interpreted with caution due to the very high heterogeneity (I^2 = 99·3%, p < 0·001; see Discussion below). Meta-regression analyses showed no significant relationship between prevalence ratios and COVID-19 cases per capita, COVID-19 deaths per capita, mean daily stringency indexes or the proportions of survey participants who were male (p-values ranged from 0·215 to 0·766; Figure 2b shows meta-regression for stringency indexes).

Smoking more, less or unchanged among smokers during the pandemic. Twenty-two cross-sectional studies

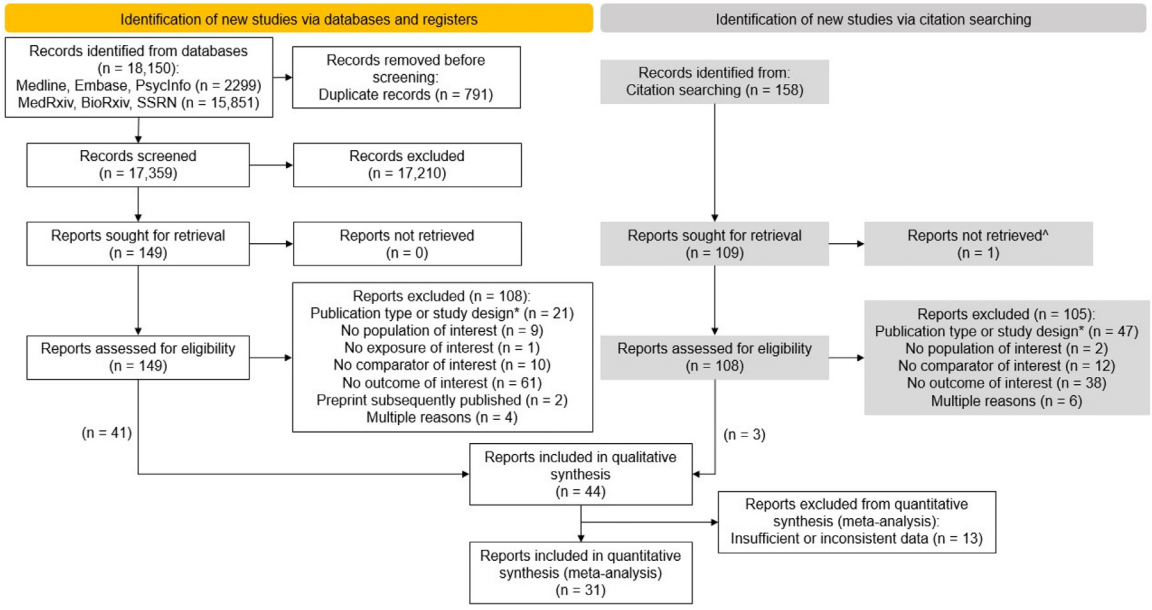


Figure 1. Flow diagram based on the PRISMA 2020 flow chart summarising the article screening process.

The characteristics and outcomes of all 44 included studies are described qualitatively. Studies included in the quantitative synthesis had sufficient data for pooling in a meta-analysis and are described in Tables 1a, 1b. Studies with insufficient or inconsistent data excluded from the quantitative synthesis are described in Supplementary Tables 5a and b. *Excluded publication type or study design, or letter or comment without relevant primary data. ^The full text of one study was unable to be retrieved for eligibility assessment (French, M., et al., 2020. PMID: 32853158).

were included in meta-analyses of smoking less ($n = 17$), smoking more ($n = 22$), or unchanged smoking ($n = 17$) among smokers (Tables 1a, 1b and 2). The pooled proportions were: 21% (95%CI:14–30%) for smoking less, 27% (95%CI:22–32%) for smoking more, and 50% (95%CI:41–58%) calculated to have unchanged smoking intensity during the COVID-19 pandemic. Heterogeneity was high in the three meta-analyses: all $I^2 > 98\%$, $p < 0{\cdot}001$ (Table 2 and Figure 3). The results for smoking more and smoking less among all survey respondents are described in the Additional Results (Supplementary material p.3) and shown in Table 2 and Supplementary Fig. 1. A sensitivity analysis including only studies that reported both smoking more and smoking less is shown in Supplementary Fig. 2.

Started smoking or quit smoking (including motivation and attempts to quit) during the pandemic. Six studies provided usable data on the proportion of smokers who quit during the COVID-19 pandemic (Tables 1a, 1b and 2): the pooled proportion was 4% (95%CI:1–9%) with high heterogeneity ($I^2 = 94{\cdot}8\%$, $p < 0{\cdot}001$) (Figure 4a). Additionally, four studies provided data on starting or restarting smoking during the pandemic among non-smokers, the pooled proportion being 2% (95%CI:1–3%) with high heterogeneity ($I^2 = 91{\cdot}7\%$, $p < 0{\cdot}001$) (Figure 4b). For smokers, two studies reported increased motivation or desire to quit smoking (pooled proportion 21%, 95%CI:18–23%, Figure 4c), two studies reported decreased motivation or desire to quit smoking (pooled proportion 12%, 95%CI:10–14%, Figure 4d), and only one study reported attempts to quit smoking (proportion 37%, 95%CI:33–40%, Table 2). Heterogeneity was not calculated for these estimates due to a small number of studies.

Risk of bias

All 27 cross-sectional studies included in meta-analyses had high risk of bias (Table 3a) with the major source of bias being that study populations were not representative of the target population, as 23 studies used convenience samples with online questionnaires distributed via social media, websites, and/or mailing lists, and four studies contacted online or mobile phone panels. Of the four before-and-during studies, one had overall moderate risk of bias, two had serious risk of bias, and one had critical risk of bias (Table 3b). The two major sources of bias were selection of participants into the study, mainly due to non-representative participants or low response rates, and in the measurement of the outcome with different methods and/or tools/questions used before and during the pandemic.

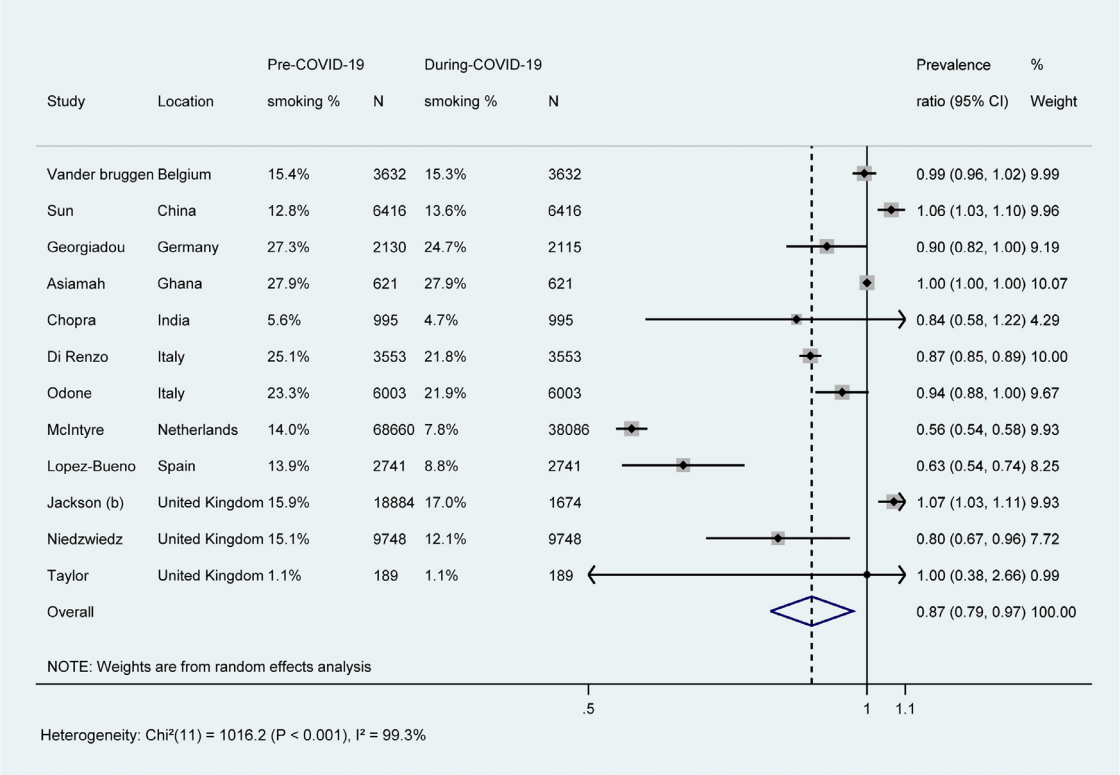
Figure #	Outcome	Participants	Number of participants	Number of studies	Pooled effect estimate (95%CI)	I^2 (*p*-heterogeneity)
2.a.	Smoking prevalence ratio (during vs before)	S + NS	125,246	12	0·87 (0·79–0·97)	99·3% (<0·001)
3	Prevalence among smokers (%)					
3.a.	Smoking less	S	22,335	17	21% (14–30%)	99·4% (<0·001)
3.b.	Smoking more	S	23,805	22	27% (22–32%)	98·5% (<0·001)
3.c.	Smoking unchanged	S	22,690	17*	50% (41–58%)	99·2% (<0·001)
4	Prevalence among non-smokers or smokers (%)					
4.a.	Stopped smoking	S	4184	6	4% (1–9%)	94·8% (<0·001)
4.b.	Started smoking	NS	10,341	4	2% (1–3%)	91·7% (<0·001)
4.c.	Increased motivation or desire to quit	S	1137	2	21% (18–23%)	Not calculable
4.d.	Decreased motivation or desire to quit	S	1137	2	12% (10–14%)	Not calculable
–	Attempted to quit	S	180	1	37% (33–40%)	Not calculable
Suppl. 1	Prevalence among all survey respondents (%)					
Suppl. 1.a.	Smoking less	S + NS	140,287	17	3% (2–5%)	99·1% (<0·001)
Suppl. 1.b.	Smoking more	S + NS	14,218	5	4% (1–8%)	99·0% (<0·001)

***Table 2*: Summary estimates of smoking prevalence and smoking behaviour changes, among 269,164 participants in 31 studies.**
* Only studies that reported the outcomes of both smoking more and smoking less. **S**: Smokers, **NS**: Non-smokers.

Discussion

This is the first systematic review and meta-analyses of changes in smoking behaviours during the early phases of the COVID-19 pandemic. The prevalence of smoking during the COVID-19 pandemic was observed to be lower than pre-pandemic in most of the included studies, with the pooled prevalence ratio suggesting a 13% (95%CI:3–21%) relative decline in smoking prevalence (high heterogeneity: I^2 = 99·3%, p < 0·001). Among people who smoke, changes in amount smoked during the pandemic varied between studies, with 21% (95%CI:14–30%) of people who smoke reporting smoking less, 27% (95%CI:22–32%) smoking more, and 50% (95%CI:41%–58%) with unchanged smoking (high heterogeneity: all I^2 > 98%, p < 0·001). Further, 4% (95%CI:1–9%) of people who smoke reported quitting smoking, while 2% (95%CI:1–3%) of people who did not smoke started (high heterogeneity: both I^2 > 91%, p < 0·001). We note that the pooled estimate of 4% of smokers who reported quitting is based on different studies compared to the pooled estimate of an overall 13% relative decline in smoking prevalence, and are thus not directly comparable. Given the rapid response of these studies to the onset of the pandemic, most were cross-sectional with convenience samples recruited via social media and other online platforms and almost all were at high risk of bias. However, they offer an informative and indicative first look at the impact of the pandemic on consumption of the world's most lethal legal consumer product. Importantly, the included studies represent many different populations, offering an international snapshot of this issue.

The reduction in the proportion of participants who reported smoking during the pandemic is an encouraging result. Although all but two included studies were not representative, such observed decreases in smoking prevalence could be leveraged to inform tobacco control policies within individual settings to support continued decreases over time. Some public health measures implemented during the pandemic to control COVID-19 outbreaks also represent an opportunity to study interventions that may reduce exposure to non-communicable disease risk factors, including smoking. For example, during lockdown in South Africa the sale of all tobacco products was banned, and in one South African study 9% of people who smoked quit during the pandemic.[59] It is important to note that smoking prevalence in many of the countries in Europe and North America represented here had already been declining prior to the pandemic, albeit at different rates.[60] As nationally representative tobacco surveillance reports become available, the picture will become clearer for individual countries.



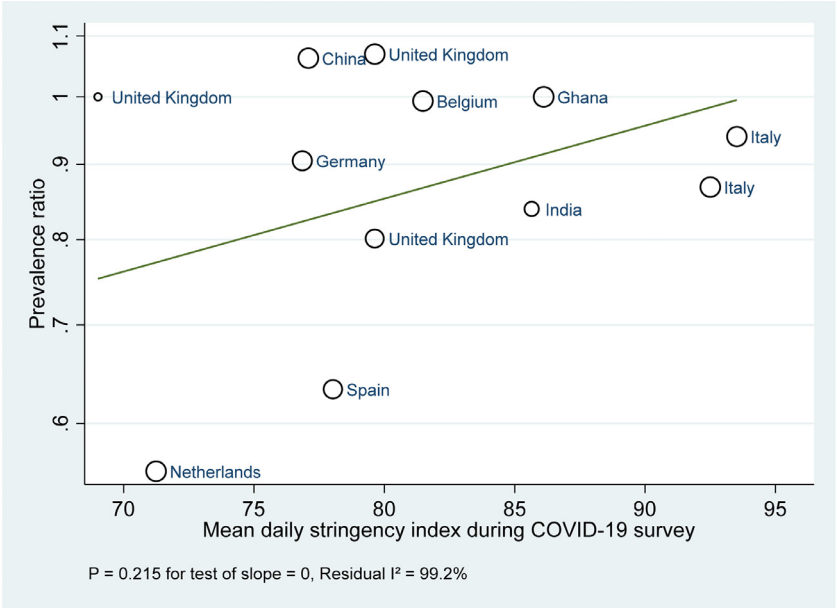


Figure 2. a. Meta-analysis of prevalence ratios for smoking prevalence during early COVID-19 pandemic (2020) compared to smoking prevalence before COVID-19 pandemic.

*Prevalence ratios less/more than one indicate a reduction/increase in smoking prevalence during the COVID-19 pandemic, respectively. Surveys are cross-sectional (n = 9) that asked participants about their smoking behaviour before (retrospectively) and during the pandemic, or longitudinal (n = 3, Jackson[b], McIntyre and Niedzwiedz) that asked participants about their smoking behaviour contemporaneously before and during the pandemic. **CI**: Confidence interval. Fig. 2b. Meta-regression of smoking prevalence ratios for smoking prevalence during COVID-19 pandemic compared to smoking prevalence before COVID-19 pandemic by mean daily stringency index during the study survey period.

The results with respect to changes in smoking intensity were diverse with similar proportions of people who smoke increasing their intake or reducing their intake, and approximately a half retaining previous levels of smoking intensity. Understanding the causes of smoking behaviour changes is important, as it assists in quantifying potential long-term impacts and identifying best intervention measures to support recovery and future prevention. The mixed response we report in this systematic review likely reflects a complex interplay between individual, societal, and systemic factors.[7–9] Individual factors include: (a) perceived risks of exposure to severe illness or death from COVID-19; (b) feelings of uncertainty, for example regarding one's own health, the health of loved ones, and economic insecurity; and (c) the psychological stress response to these factors, experienced in the context of one's physical and mental health, economic situation, and related vulnerabilities. Factors that influence COVID-19 risk such as health and public health systems, government responses to the pandemic (i.e. degree of strictness and of enforcement) and pre-existing health disparities and social inequities, as well as factors such as tobacco control policies before and during the pandemic, can all influence individuals' tobacco use behaviours. Tobacco product scarcity in certain countries at the start of the pandemic may also have influenced smoking behaviours, potentially positively due to reduced supply of tobacco or negatively due to increased smoking of tobacco after 'stocking up'.[61] Overall, the evidence for changes in tobacco smoking in response to the COVID-19 pandemic highlights the importance of public health campaigns for tobacco cessation and for enhancing resources for, and access to, tobacco cessation services.[7]

It is yet to be determined whether short-term changes in smoking patterns reported here translate into long-term, sustained changes. There is evidence that some lifestyle behaviours persist for some time after a pandemic. For example, individuals in China who were quarantined or worked in high-risk locations during the 2003 SARS epidemic were more likely to use alcohol as a coping mechanism, and this was significantly associated with increased alcohol abuse/dependence symptoms three years after the outbreak.[62] It is also possible that changes in smoking during the early phase of the pandemic may not be sustained or indicative of changes that occur in later phases as living with COVID-19 becomes a norm.[63] Further, the adverse impact of the COVID-19 pandemic on smoking is expected to be most pronounced for already disadvantaged groups, potentially leading to exacerbated health disparities. This potentially includes population subgroups with disproportionately higher rates of smoking including those with pre-existing medical, psychiatric, or substance use problems, or those with low socio-economic status, or who are marginalised for other reasons (e.g.[64–67]). There is also a need for studies focussed on youth, as any impact on them is likely to have the largest impact on long-term smoking rates. Given potential differences in COVID-19 outcomes by sex,[68] it may be important to consider smoking changes disaggregated by sex as well. These subgroups should be highlighted for future research.

Our review should be a driver for researchers to develop tools to support high quality harmonized data collection, including validated questions measuring changes in tobacco smoking during and after the pandemic, and for standardised platforms to collect these data. The reported results are also valuable for informing realistic ranges of values that can be used for modelling. Modelling studies can be a valuable tool enabling the prediction of the disease burden, outcomes, and resource utilisation for the whole population as well as for specific subgroups by sex, age, or socio-economic status, especially if the pandemic had a differential impact on population subgroups. Such evaluations are planned by the COVID-19 and Cancer Global Modelling Consortium (CCGMC; https://ccgmc.org/) which has a working group dedicated to assessing the impact of the pandemic on cancer risk. An important goal of the CCGMC is to inform best practices in cancer prevention in order to mitigate the long-term impact on future cancer burden. One important aspect of the CCGMC endeavours will be to assess the overall direct and indirect effects of the pandemic on cancer outcomes, considering changing exposure to risk factors (as here), pauses or reduced participation in cancer screening programmes, delays to detection of symptomatic cancer, the direct impact of COVID-19 infection on mortality in cancer patients, and the indirect effects of delays and disruptions to cancer treatment. These complex effects will play out in different timescales and to different degrees in different settings, and policy-makers will require clear information on best-practice response and prioritisation strategies. The CCGMC will continue to monitor changes in smoking and other risk factors in response to the COVID-19 pandemic.

Prevalence ratios less/more than one indicate a reduction/increase in smoking prevalence during COVID-19 pandemic, respectively. Surveys are cross-sectional (n = 9) that asked participants about their smoking behaviour before (retrospectively) and during lockdown, or longitudinal (n = 3, Jackson[b], McIntyre and Niedzwiedz) that asked participants about their smoking behaviour contemporaneously before and during lockdown.

Repeated countries are due to different studies being conducted in the same countries.

The OxCGRT Stringency Index is a measure of variation in governments' responses to COVID-19 and is an additive score of nine indicators (such as school closures, travel bans, etc.) rescaled to vary from 0 to 100.[10]

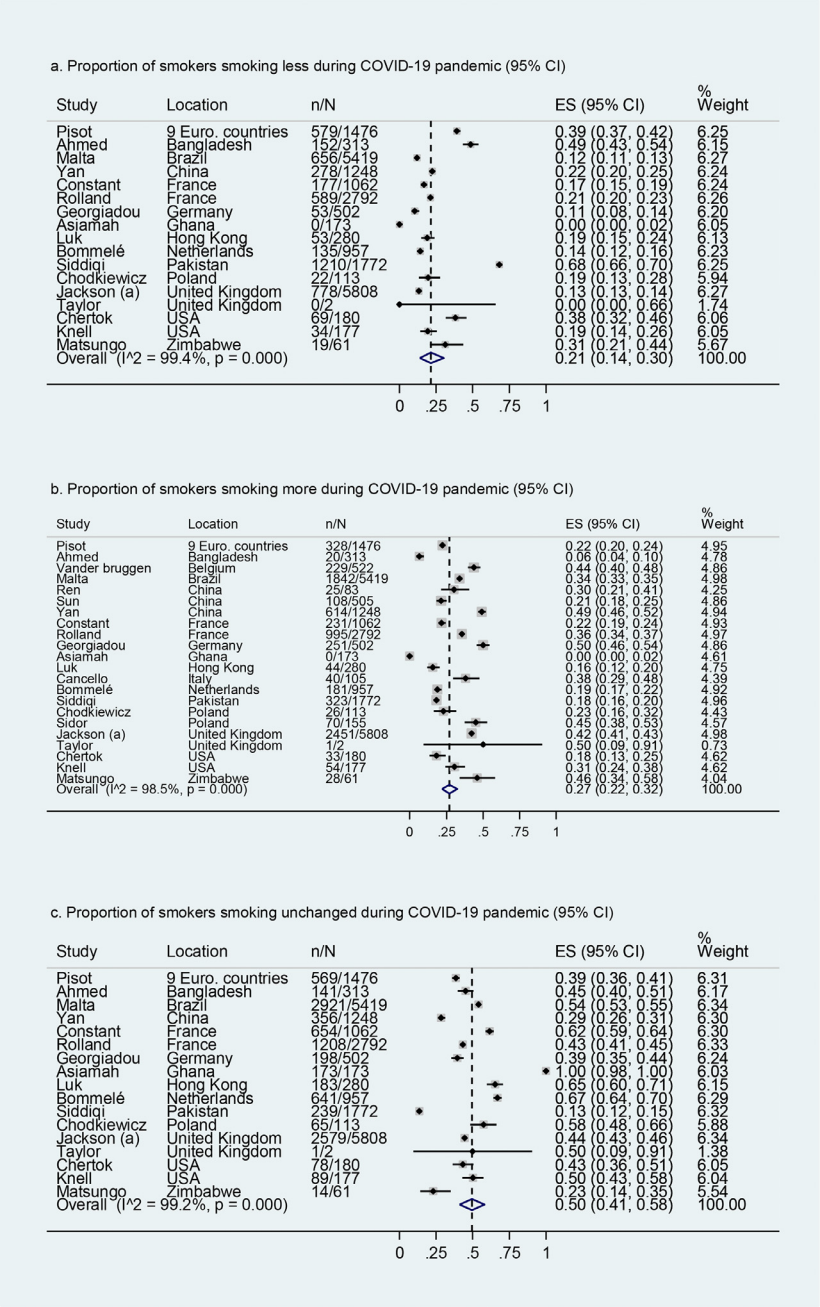


Figure 3. Meta-analysis of proportion (effect estimates, ES) of smokers who reported: (a) smoking less, (b) smoking more and (c) smoking unchanged during the COVID-19 pandemic.

*A sensitivity analysis including only studies that reported both smoking more and smoking less is presented in Supplementary Fig. 2. †Proportions for unchanged smoking were calculated only for those studies that reported both more and less smoking as 1-ES(more)-ES(less). **CI**: Confidence interval.

The included studies in this review have limitations. The majority were carried out using convenience samples, and 20 of 31 studies used surveys distributed via social media. The reported estimates are therefore unlikely to be representative, and overall smoking prevalence estimates from different surveys in the same country varied considerably. Almost all studies had a high risk of bias, often due to the use of unvalidated survey questions that place limitations on the interpretability and comparability of the resulting estimates. Many

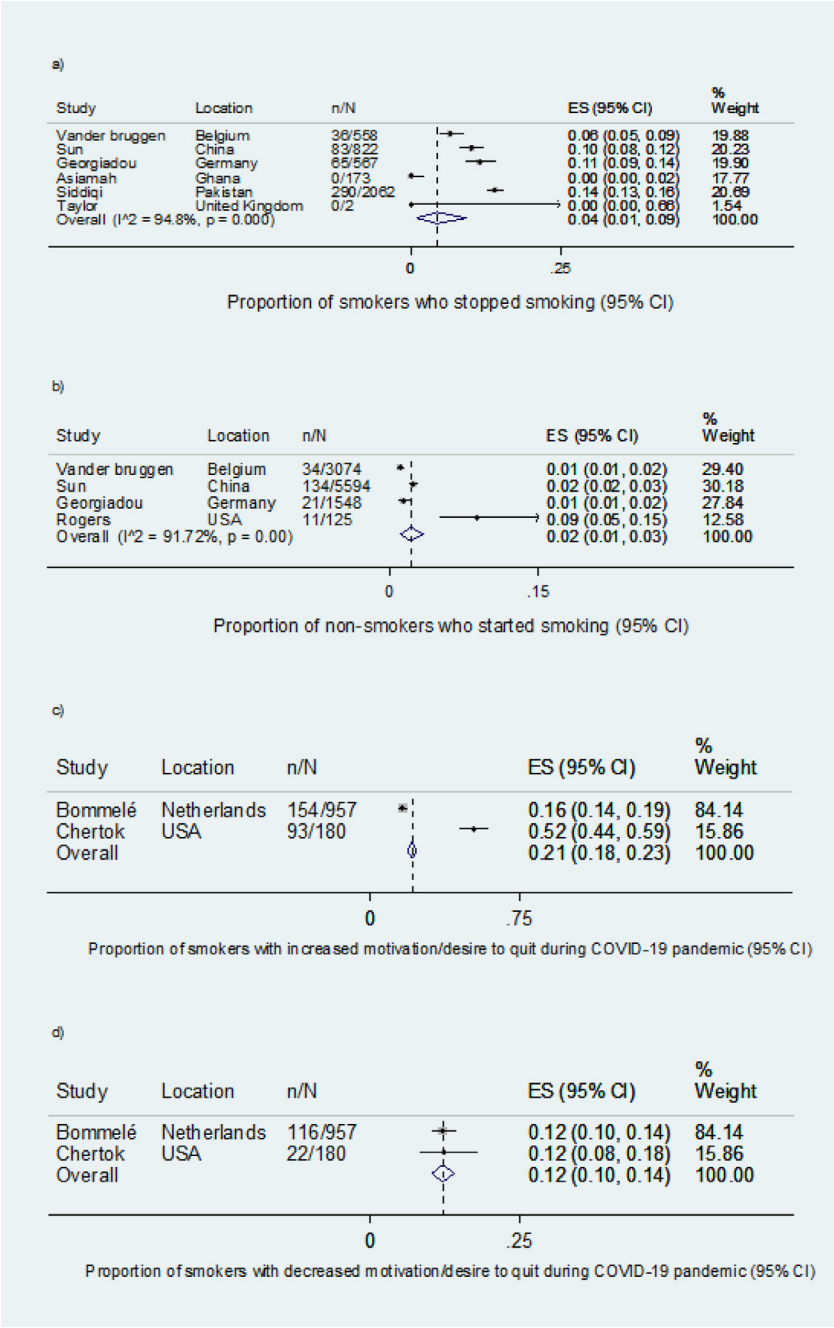


Figure 4. Meta-analysis of smoking behaviour changes for (a) proportion (effect estimates, ES) of smokers who stopped smoking, (b) proportion of non-smokers who started smoking, (c) proportion of smokers who had an increased motivation or desire to quit, (d) proportion of smokers who had a decreased motivation or desire to quit during the COVID-19 pandemic.

For plot (a) surveys are cross-sectional ($n = 4$) that asked participants about their smoking behaviour before (retrospectively) and during COVID-19 pandemic, or longitudinal ($n = 2$, Jackson and Siddiqi) that asked participants about their smoking behaviour contemporaneously before and during COVID-19 pandemic. For plot (b) surveys are cross-sectional that asked participants about their smoking behaviour before (retrospectively) and during lockdown. *For plots (c) and (d) heterogeneity estimates were not calculable as there were only 2 studies. **CI**: Confidence interval.

Study	1. **Was the** study population **a close representation of the target population in relation to relevant variables, e.g. age, sex?**	2. **Was the** sampling frame **a true or close representation of the target population?**	3. **Was some form of random selection used to** select the sample**, OR, was a census undertaken?**	4. **Was the likelihood of** non-response bias **minimal?**	5. **Were data collected directly from the subjects (as opposed to a proxy)?**	6. **Was an acceptable definition of change in smoking behaviour used in the study?***	7. **Were the survey questions that measured the parameter of interest (e.g. prevalence of smoking behaviour changes) shown to have reliability and validity?***	8. **Was the same mode of data collection used for all subjects?**	9. **Were the numerator(s) and denominator (s) for the parameter of interest appropriate?***	Overall risk of bias
Ahmed[29]	High	High	High	High	Low	High	High	High	Low	High
Asiamah[30]	High	High	High	High	Low	Moderate	High	Low	Low	High
Bommele[7]	High	High	High	High	Low	Moderate	Moderate	Low	Low	High
Cancello[31]	High	High	High	High	Low	Moderate	High	Low	Low	High
Chertok[32]	High	High	High	High	Low	Moderate	High	Low	Low	High
Chodkiewicz[33]	High	High	High	High	Low	Moderate	High	Low	High	High
Chopra[34]	High	High	High	High	Low	Low	Moderate	High	High	High
Constant[35]	High	High	Low	Low	Low	Moderate	High	Low	Low	High
Di Renzo[36]	High	High	High	High	Low	Low	High	Low	Low	High
Emerson[37]	High	High	High	High	Low	Moderate	High	Low	Moderate	High
Georgiadou[38]	High	High	High	High	Low	High	High	Low	High	High
Jackson[a39]	High	High	High	High	Low	High	High	High	Moderate	High
Knell[40]	High	High	High	High	Low	Moderate	Moderate	Low	Low	High
Lopez-Bueno[41]	High	High	High	Low	Low	Low	High	Low	Low	High
Luk[42]	High	High	Low	High	Low	Moderate	Moderate	High	Low	High
Malta[43]	High	High	High	High	Low	Low	High	Low	Moderate	High
Matsungo[44]	High	High	High	High	Low	Moderate	High	Low	Moderate	High
Odone[45]	High	High	High	High	Low	Moderate	High	Low	Moderate	High
Pisot[46]	High	High	High	High	Low	Moderate	High	Low	Low	High
Ren[47]	High	High	High	High	Low	Moderate	High	Low	Low	High
Rogers[48]	High	High	High	High	Low	Moderate	High	Low	Low	High
Rolland[49]	High	High	High	High	Low	Moderate	High	Low	Low	High
Sidor[50]	High	High	High	High	Low	Moderate	High	Low	High	High
Sun[51]	High	High	High	High	Low	Moderate	High	Low	Mixed*	High
Taylor[52]	High	High	High	Low	Low	Moderate	High	Low	Low	High
Vanderbruggen[53]	High	High	High	High	Low	Low	High	Low	Low	High
Yan[54]	High	High	High	High	Low	Moderate	Moderate	Low	Low	High

***Table 3a*: Risk of bias for cross-sectional studies included in quantitative analyses.**

* Risk of bias assessed separately for each included study outcome.[†]Low risk of bias for some outcomes (smoking prevalence, quit smoking) and Moderate risk of bias for others (initiate smoking, relapse, increase smoking, change from occasional to regular smoking).

Study	1. Selection of participants into the study	2. Measurement of outcome	3. Confounding	4. Missing data	5. Selection of reported results	Overall risk of bias
Jackson[55]	Moderate	Moderate	Low	Low	Low	Moderate
McIntyre[56]	Critical	Critical	Serious	Serious	Low	Critical
Niedzwiedz[57]	Moderate	Serious	Low	Low	Low	Serious
Siddiqi[58]	Serious	Serious	Low	Low	Low	Serious

***Table 3b*: Risk of bias for before-and-during studies included in quantitative analyses.**

studies also reported estimates that either combined several qualitatively different groups (e.g., those who never smoked and those who reduced smoking), did not report results for all outcomes available, did not report standard errors, or did not use appropriate denominators or numerators. Further, the question wording used in each survey was highly variable from study to study, and interpretation was made difficult by the fact that many studies did not provide detail about the specific questions asked, nor adequate information describing how responses were analysed. We have used the definitions of each smoking behaviour change as reported in the included studies, where these were reported. Two studies provided estimates that were effectively unadjusted for potential confounding factors, with one study involving different participants before and during the pandemic,[55] and one study involving the same participants before and during the pandemic but with substantial loss to follow-up.[56] Finally, given the limited data on the differences in the timing and extent of COVID-19 outbreaks and measures taken to control the pandemic between countries and contexts, and on pre-pandemic trends in smoking prevalence, we also cannot infer any causal relationships between the pandemic and specific aspects of smoking behaviour changes. Some studies specifically asked whether a participant's smoking behaviour changed due to the pandemic or lockdown, however these studies were still considered at high risk of bias for the aforementioned reasons.

We note that caution must be taken in the interpretation of the meta-analyses due to the high statistical heterogeneity for each of the outcomes examined (I^2>91%, p<0·001), reflecting the differences in methods and high risk of bias for the included studies and the differences in the impact of the pandemic in different populations and around the world. Nonetheless, we believe that the meta-analyses presented here provide useful information consolidating evidence on the range of changes to date, and that the assessment of heterogeneity from the meta-analyses is in itself informative for the appraisal of the evidence base on this topic. Moreover, a recent study[69] systematically sampled 134 published meta-analyses of prevalence and found that the median I^2 was 96·9% (IQR: 90·5% to 98·7%), concluding that *"…in meta-analyses of prevalence, I^2 statistics may not be discriminative and should be interpreted with caution, avoiding arbitrary thresholds"*. This supports the reporting of meta-analyses to estimate the pooled prevalence even when heterogeneity is high, with the appropriate caveats regarding interpretation as highlighted above.

The approach and methods used for our review have notable strengths, including a rigorous risk of bias assessment using tools customised for this review. The full-text screening, data extraction, and risk of bias assessments were all carried out in duplicate. Moreover, we used representative estimates of smoking prevalence from the WHO to help contextualise and interpret estimates from the included studies.[70] The limitations of our review include that titles and abstracts were only screened by one reviewer; however, we checked the references of articles included in full-text screening to identify any additional relevant studies. Also we did not contact authors of the original studies for clarification. The pooled estimates derived from meta-analyses are prone to the biases found in the original studies, including differences in the definitions of smoking behaviours between studies. Our review did not include grey literature such as national and jurisdictional surveys carried out by governments and other organisations, which may provide more representative data; a dedicated search of such surveys is planned by the CCGMC.

To conclude, there was considerable variation in smoking behaviour changes during the early pre-vaccination phases of the COVID-19 pandemic in 2020. Our meta-analyses indicate a relative reduction in overall smoking prevalence during the pandemic, while similar proportions of people who smoke smoked more or smoked less, although statistical heterogeneity was high and the pooled estimates should be interpreted with caution. The implementation of tobacco control measures and the delivery of tobacco cessation services, by adhering to policies and procedures such as those set out by the Framework Convention on Tobacco Control,[71] have an important role in ensuring that the COVID-19 pandemic does not exacerbate the smoking pandemic and its associated adverse health outcomes.

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Data sharing statement

All the original data of this study were available upon reasonable request to the corresponding author (KC).

Authors' contributions

CC performed the literature search. SH screened titles and abstracts. PS, CJC, CC, IS, AM and SH assessed full text articles for inclusion. PS, CJC, PV, EL, SE, JS, IS, AM and SH performed data extraction and verified the underlying data. PS, CJC, EL, PV, DO'C and IS performed the risk of bias assessment. SE performed statistical analysis and created the figures. All authors contributed to the conceptualisation of the study, to interpreting the data, and to writing and reviewing the manuscript. All authors confirm that they had full access to all the data in the study and accept responsibility for the decision to submit for publication.

Declaration of interests

KC is co-PI of an investigator-initiated trial of cervical screening, *Compass*, run by the VCS Foundation, which is a government-funded not-for-profit charity; the VCS Foundation has received equipment and a funding contribution from Roche Molecular Diagnostics. She is also co-PI on a major investigator-initiated implementation program *Elimination of Cervical Cancer in the Western Pacific (ECCWP)* which will receive support from the Minderoo Foundation, the Frazer Family Foundation and equipment donations from Cepheid Inc. Neither KC nor her institution on her behalf receives direct funding from industry for any project. KC's research is supported via a National Health and Research Council Australia Leadership Fellowship (NHMRC; APP1194679). KC chairs and participates in a number of advisory committees to government and not-for-profit agencies; no committee participation for commercial companies. MC is an investigator on an investigator-initiated trial of cytology and primary HPV screening in Australia ('Compass') (ACTRN12613001207707 and NCT02328872), which is conducted and funded by the VCS Foundation a government-funded not-for-profit charity. The VCS Foundation has received equipment and a funding contribution for the Compass trial from Roche Molecular Systems. However neither MC nor his institution on his behalf (The Daffodil Centre, a joint venture between Cancer Council NSW and The University of Sydney) receive direct or indirect funding from industry for Compass Australia or any other project. MW's institution (The Daffodil Centre) received competitive grant and contract funding from the Australian Government for various projects outside the submitted work on which she is a named investigator, and received an honorarium from scientific meeting organisers for a presentation outside the submitted work. Where authors are identified as personnel of the International Agency for Research on Cancer or World Health Organization, the authors alone are responsible for the views expressed in this article and they do not necessarily represent the decisions, policy or views of the International Agency for Research on Cancer or World Health Organization. The opinions expressed in this article are the authors own and do not reflect the view of the National Institutes of Health, the Department of Health and Human Services, or the United States Government.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.eclinm.2022.101375.

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