Check for updates

RESEARCH ARTICLE

The changing contributory role to infections of work, public transport, shopping, hospitality and leisure activities throughout the SARS-CoV-2 pandemic in England and Wales [version 1; peer review: 1 approved, 3 approved with reservations]

Susan Hoskins[1], Sarah Beale[1,2], Vincent G Nguyen[1,2], Thomas Byrne[1], Alexei Yavlinsky[1], Jana Kovar[2], Erica Wing Lam Fong[1], Cyril Geismar[1,3], Annalan M. D. Navaratnam[1,2], Martie van Tongeren[4], Anne M. Johnson[5], Robert W. Aldridge[1], Andrew Hayward[2]

[1]Institute of Health Informatics, University College London, London, England, NW1 2DA, UK
[2]Institute of Epidemiology and Health Care, University College London, London, WC1E 6BT, UK
[3]Department of Infectious Disease Epidemiology, Imperial College London, London, W2 1NY, UK
[4]Centre for Occupational and Environmental Health, The University of Manchester, Manchester, England, UK
[5]Institute for Global Health, University College London, London, England, WC1E 6BT, UK

v1 **First published:** 03 Nov 2023, **3**:58
https://doi.org/10.3310/nihropenres.13443.1
Latest published: 03 Nov 2023, **3**:58
https://doi.org/10.3310/nihropenres.13443.1

Abstract

Background

Understanding how non-household activities contributed to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections under different levels of national health restrictions is vital.

Methods

Among adult Virus Watch participants in England and Wales, we used multivariable logistic regressions and adjusted-weighted population attributable fractions (aPAF) assessing the contribution of work, public transport, shopping, and hospitality and leisure activities to infections.

Results

Under restrictions, among 17,256 participants (502 infections), work

Open Peer Review

Approval Status ? ✓ ? ?

	1	2	3	4
version 1 03 Nov 2023	? view	✓ view	? view	? view

1. **Mario Coccia**, National Research Council of Italy, Torino, Italy
2. **Tsz Ho Kwan**, The Chinese University of Hong Kong, Hong Kong, Hong Kong
The Chinese University of Hong Kong, Hong Kong, Hong Kong
3. **Larese Filon Francesca**, Universita degli Studi di Trieste, Trieste, Italy
4. **Benjamin Wachtler**, Robert Koch

[adjusted odds ratio (aOR) 2.01 (1.65–2.44), (aPAF) 30% (22–38%)] and transport [(aOR 1.15 (0.94–1.40), aPAF 5% (-3–12%)], were risk factors for SARS-CoV-2 but shopping, hospitality and leisure were not. Following the lifting of restrictions, among 11,413 participants (493 infections), work [(aOR 1.35 (1.11–1.64), aPAF 17% (6–26%)] and transport [(aOR 1.27 (1.04–1.57), aPAF 12% (2–22%)] contributed most, with indoor hospitality [(aOR 1.21 (0.98–1.48), aPAF 7% (-1–15%)] and leisure [(aOR 1.24 (1.02–1.51), aPAF 10% (1–18%)] increasing. During the Omicron variant, with individuals more socially engaged, among 11,964 participants (2335 infections), work [(aOR 1.28 (1.16–1.41), aPAF (11% (7–15%)] and transport [(aOR 1.16 (1.04–1.28), aPAF 6% (2–9%)] remained important but indoor hospitality [(aOR 1.43 (1.26–1.62), aPAF 20% (13–26%)] and leisure [(aOR 1.35 (1.22–1.48), aPAF 10% (7–14%)] dominated.

Conclusions

Work and public transport were important to transmissions throughout the pandemic with hospitality and leisure's contribution increasing as restrictions were lifted, highlighting the importance of restricting leisure and hospitality alongside advising working from home, when facing a highly infectious and virulent respiratory infection.

Plain Language summary

Establishing which activities and venues that were restricted in England and Wales during lockdowns were the most likely to lead to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections will help us understand how useful the restrictions were and will help us to develop proportional responses to future public health threats. We found that during periods of intense restrictions (October 2020–May 2021) many people became infected with SARS-CoV-2 if they left home to go to work or used public transport. During the period after most public health restrictions were lifted (September–mid-December 2021), while many people continued to become infected at work or if they used public transport, indoor hospitality and indoor leisure venues became increasingly important as places where people became infected. During the Omicron wave of the pandemic (December 2021–April 2022), by which point there were very few restrictions on people's activities and many people were visiting hospitality and leisure venues with increasing frequency, people continued to become infected at work and on public transport, but hospitality and leisure venues were nearly as important places where people became infected. As essential activities led to most cases during periods of tight restrictions and leisure and hospitality activities became increasingly important under periods when rules were more relaxed, it is important to recognise how vital it was to encourage people to work from home, reduce public transport use and restrict visits to leisure and hospitality settings when the country was faced with a fast-spreading virus which killed many people.

Institute, Berlin, Germany

Any reports and responses or comments on the article can be found at the end of the article.

Outdoor use of leisure and hospitality venues appeared to be safer than indoor use.

Keywords
SARS-CoV-2, social-activities, work, transport, hospitality, leisure

Corresponding author: Sarah Beale (sarah.beale.19@ucl.ac.uk)

Author roles: Hoskins S: Conceptualization, Formal Analysis, Methodology, Writing – Original Draft Preparation, Writing – Review & Editing; **Beale S**: Data Curation, Formal Analysis, Methodology, Writing – Review & Editing; **Nguyen VG**: Data Curation, Formal Analysis, Software, Writing – Review & Editing; **Byrne T**: Methodology, Writing – Review & Editing; **Yavlinsky A**: Methodology, Writing – Review & Editing; **Kovar J**: Project Administration, Resources, Writing – Review & Editing; **Fong EWL**: Methodology, Writing – Review & Editing; **Geismar C**: Conceptualization, Writing – Review & Editing; **Navaratnam AMD**: Conceptualization, Data Curation, Writing – Review & Editing; **van Tongeren M**: Conceptualization, Writing – Review & Editing; **Johnson AM**: Conceptualization, Writing – Review & Editing; **Aldridge RW**: Conceptualization, Formal Analysis, Funding Acquisition, Investigation, Methodology, Supervision, Writing – Review & Editing; **Hayward A**: Conceptualization, Formal Analysis, Funding Acquisition, Investigation, Methodology, Supervision, Validation, Writing – Review & Editing

Competing interests: ACH serves on the UK New and Emerging Respiratory Virus Threats Advisory Group. AMJ and ACH are members of the COVID-19 transmission sub-group of the Scientific Advisory Group for Emergencies (SAGE). AMJ is Chair of the UK Strategic Coordination of Health of the Public Research board and is a member of COVID National Core studies oversight group.

Grant information: This work was commissioned by NIHR and funded by NIHR CRN as part of the NIHR infrastructure. This work was also supported by funding from the PROTECT COVID-19 National Core Study on transmission and environment, managed by the Health and Safety Executive on behalf of HM Government. The Virus Watch study is supported by the MRC Grant Ref: MC_PC 19070 awarded to UCL on 30 March 2020 and MRC Grant Ref: MR/V028375/1 awarded on 17 August 2020. The study also received $15,000 of Facebook advertising credit to support a pilot social media recruitment campaign on 18th August 2020. This study was also supported by the Wellcome Trust through a Wellcome Clinical Research Career Development Fellowship to RA [206602]. SB and TB are supported by an MRC doctoral studentship (MR/N013867/1). The funders had no role in study design, data collection, analysis and interpretation, in the writing of this report, or in the decision to submit the paper for publication.
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

How to cite this article: Hoskins S, Beale S, Nguyen VG *et al.* **The changing contributory role to infections of work, public transport, shopping, hospitality and leisure activities throughout the SARS-CoV-2 pandemic in England and Wales [version 1; peer review: 1 approved, 3 approved with reservations]** NIHR Open Research 2023, **3**:58 https://doi.org/10.3310/nihropenres.13443.1

First published: 03 Nov 2023, **3**:58 https://doi.org/10.3310/nihropenres.13443.1

Introduction

Prior to the availability of effective vaccines, repeated 'lockdowns' were a critical element of the coronavirus disease 2019 (COVID-19) pandemic response in the UK to reduce transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and resulting hospitalisation and mortality[1,2]. Lockdowns compelled the public to stay at home with advice to work from home where possible and minimise public transport use, and a range of retail, hospitality and leisure venues were closed, restricting non-essential activities and social mixing[1,2]. After the national vaccination programme began in England and Wales and public access to free testing increased, restrictions were gradually relaxed by increasing the range of public venues that could be visited and reducing restrictions on the number of people outside the home who could be visited[1–3]. The majority of activity and social mixing restrictions were removed in July 2021 (in England) and August 2021 (in Wales)[2,4]. While evidence suggests that restriction measures substantially reduced SARS-CoV-2 transmission and associated outcomes, these measures have far-reaching financial, social, and health-related impacts[5–7]. Understanding the transmission risk associated with different activities and venues affected by restriction measures is crucial to develop an understanding of the effectiveness of these measures and to develop proportional responses to future public health threats.

Several studies from varying regions and phases of the pandemic have aimed to investigate SARS-CoV-2 infection risk associated with different activities. Identified risk factors during the first wave of the pandemic include having an increased number of non-household contacts, air travel, employment, shopping, frequency of attending events of at least 10 people, participating in more than one non-essential activity per day, attending various indoor settings including restaurant visits, places of worship, gyms or salons[8–10]. However, first-wave data were limited as global testing capacity was low and infections data were likely incomplete. During periods when restrictions were lifted and public venues starting to reopen, data are conflicting. Public transport use has been associated with increased odds of infection, as has shopping at convenience stores and visiting a place of worship[11,12]. The drinking of alcohol in restaurants or bars and attending events with singing, or attending bars, parties of private ceremonies have been associated with greater odds of infection[12,13]. Visiting indoor leisure venues including fitness centres has also been found to increase infection risk, while working remotely has been found to reduce infection odds[13,14]. However, conflicting data from that period suggest that there is no relationship with infection for a range of essential and non-essential activities or public transport use, shopping, or leisure activities[12,14]. For a period, some months after the removal of most national restrictions, drinking in bars and restaurants and visiting fitness centres has been found to be associated with odds of infection[15].

Differences in which activities are associated with increased odds of infection may reflect different rates of infection and the implementation of other non-pharmaceutical interventions across regions, as well as differences in study design and collection of activity data. The impact of activities on SARS-CoV-2 transmission is likely to be differential depending on levels of national public health restrictions, as well as features of the dominant variant at the time of investigation and rates of infection and contact in the population. Comparison of the relative contribution of activities to transmission across different pandemic periods with comprehensive adjustment for potential confounding is lacking, particularly for later phases of the pandemic following the emergence of the highly infectious Omicron variant. This is warranted to inform responses to future public health emergencies.

To address this research gap, we used data from the Virus Watch Community Cohort Study in England and Wales, a study which collects individual level data both on infections and activities across time, to investigate how work, public transport, shopping, and hospitality and leisure activities contributed to SARS-CoV-2 infections during periods with different levels of national public health restrictions.

Methods

The current study was embedded within the Virus Watch community cohort study, which has been active since June 2020 and involves households across England and Wales completing a detailed baseline survey related to demographic and clinical characteristics, then subsequent weekly surveys about acute illnesses, COVID-19 vaccination, and SARS-CoV-2 testing (PCR or lateral flow) and monthly surveys about sociodemographic and behavioural topics (*e.g.,* activity patterns). Linkage was also performed to national records of SARS-CoV-2 testing and vaccination. The Virus Watch cohort methodology has been described in detail elsewhere[16].

Within this cohort, we examined the contributory role of non-household activities to SARS-CoV-2 infections during three periods of differing levels of public health restrictions in England and Wales: a period under intense restrictions and during the second wave of the UK pandemic (October 2020–May 2021); a period immediately following the lifting of national public health restrictions on 19th July 2021 during the third wave of the UK pandemic dominated by the Delta variant (September–mid-December 2021); and a period characterised by no restrictions for the majority of the time (with the exception of a return to mask guidance and self-testing prior to visiting vulnerable friends in the festive period), a level of social activity engagement closer to pre-pandemic levels, and dominated by the highly transmissible Omicron variant (December 2021–April 2022).

Patient and Public Involvement

Patients and/or the public were not involved in the development or dissemination of the current study. Due to Virus Watch being an urgent public health study during the COVID-19 pandemic, patients and/or the public were not involved in its initial design. An advisory group comprising members of the public, community leaders, charities and policy organisations provided feedback into the recruitment of ethnic minority participants and health equity focused analyses within Virus Watch but were not directly involved in the design or dissemination of this study.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Hampstead NHS Health Research Authority Ethics Committee, with the ethics approval number - 20/HRA/2320. Informed written consent was obtained from all individual participants included in the study.

Study participants

For each period, within the Virus Watch community study we identified a cohort of adult participant aged 18 years and above who completed monthly activity surveys. Infections were included if testing PCR or lateral flow positive during the relevant period, unless there was evidence of recent infection in the previous three months, as a positive test may have signalled ongoing infection acquired prior to the study period.

For the period under intense restrictions, we identified adult participants answering two monthly activity surveys during the periods 1/12/2020–10/12/2020 and 17/02/2021–28/02/2021. Virus Watch activity surveys commenced in November 2020, so activity data were not available for earlier in the pandemic wave and we did not include responses from the early January 2021 activity survey as activities during the Christmas holiday period (measured in this survey) were not considered representative for the broader period under consideration. Infections were included if testing PCR or lateral flow positive between 01/10/2020 and 01/05/2021 unless there was evidence of recent infection in the previous three months.

For the period following the lifting of national public health restrictions, we identified adults who completed the three activity surveys during the periods 22/09/2021–29/09/2021, 19/10/2021–26/10/2021 and 16/11/2021–23/11/2021. We did not include responses from the August survey as many participants were on holiday and survey completion rates were low. Infections were included if testing PCR or lateral flow positive between 01/09/2021 and 16/12/2021 unless there was evidence of recent infection in the previous three months.

For the final period, characterised by the wide-spread circulation of the Omicron variant, we identified adult participants answering activity surveys during the periods 05/01/2022–12/01/2022, 15/02/2022–22/02/2022, and 23/03/2022–30/03/2022. Infections were included if testing PCR or lateral flow positive between 11/12/2021 and 30/03/2022 unless there was evidence of recent infection in the previous three months.

Some data from periods of intense restrictions and following the lifting of national public health restrictions have been used elsewhere, but the present investigation included more identified cases and further adjustment for potential confounding as well as further data from the Omicron wave of infections[17,18].

Outcome variable

Participants were considered to have had a SARS-CoV-2 infection if they had a positive PCR or lateral flow test identified through self-report or linkage to national records of SARS-CoV-2 testing (Public Health England's Second Generation Surveillance System (SGSS) including infections identified through hospitalisations and community testing). The linkage was performed by NHS Digital. Self-reported and linked tests were matched and, while there was a high degree of overlap, linkage was used as a preferred source due to accuracy.

Exposure variables

In the Virus Watch monthly surveys, participants reported the number of days that they engaged in a range of activities in week preceding each survey and their estimated number of close contacts. Using these surveys, we examined the frequency of the following activities: attending work or education outside the home, using public or shared transport, visiting retail settings, and visiting indoor and outdoor hospitality or leisure settings.

For each period, we averaged the frequency of each activity and the number of close contacts across all relevant surveys to give an estimated overall frequency of the activity during each period. We created the following composite variables: public transport activities (combining use of taxi, bus, over and underground rail and air travel), retail activities (combining use of essential and non-essential shops) and indoor hospitality (eating in an indoor restaurant, cafe or canteen; going to an indoor bar, pub or club; and going to an indoor party), outdoor hospitality (eating in an outdoor restaurant, cafe or canteen; going to an outdoor bar, pub or club; and going to an outdoor party), indoor leisure (attending a gym, the theatre, the cinema, a concert or sports event), outdoor leisure (outdoor team sport), and non-social activities (visiting barber, hairdresser, beautician or nail salon). For the period under national restrictions, when visits to hospitality and leisure venues was largely curtailed through closures, we created a composite variable for 'any other non-work non-public transport non-retail activity' to include visiting a canteen/café or restaurant, a bar, pub, club or disco, an indoor gym or outdoor team sport, attending a party, visiting a sports event, concert, cinema, or theatre, a hairdresser, barber or nail salon or a place of worship. As the Virus Watch surveys were adapted throughout the pandemic waves, the earlier surveys during times of lockdown restrictions gathered information on indoor and outdoor activities as combined groups whereas the latter surveys disaggregated the activities. Retail was categorised at levels that were appropriate for each time period.

We conducted univariate analyses to compare the proportion of infected participants based on their weekly frequency of going to work, the composite measures, and each exposure individually. We also conducted multivariate logistic regression using the following adjustment set, which was identified using a directed acyclic graph (DAG), to estimate the direct effect of each non-household activity exposure: mutual adjustment for each activity, sex, region, living arrangements (alone or with children), residence in a deprived area (utilizing a combination of rural, urban, conurbation area of residence, and deprivation status), and vaccine status. Age was not included in the adjustment set indicated by the DAG due to its effect operating through included variables; however, we performed a sensitivity analysis including age due as it widely regarded as a confounder for behavioural activities.

The timing of the UK vaccine policies influenced how we categorised vaccine status. As few participants had access to vaccines prior to our restriction period cohort, vaccine status was determined if a participant received any vaccine during the cohort period. During the second period, following the lifting of restrictions, only 1% of the cohort received a vaccine, as the vast majority had been vaccinated by July 2021 and the booster programme largely drive by the arrival of the Omicron variant had not started. For this period, therefore, we categorised vaccine status based on having none or at least one vaccine at the start of the wave. For the final period, we again categorised vaccine status based on being vaccinated or not during the study period.

We used inverse probability weighting to account for the older age structure of Virus Watch monthly respondents and calculated age-weighted, adjusted multivariate population attributable fractions (aPAF) to estimate the impact of each exposure on non-household transmission in the cohort. Weights were derived from estimates of the age structure of the UK population[19]. Missing data were sparse, and all observations were included in the univariate analyses, while complete case analysis performed for the multivariate adjusted models and resulting PAFs. Analyses were conducted in STATA version 16.

Results

Cohort characteristics

During the period under restrictions, among 17,256 participants, 502 cases were identified (Table 1). During the period immediately following the lifting of public health restrictions, among 11,413 participants 493 cases were identified. During the highly infectious Omicron wave as individuals engaged more frequently in social activities, among 11,964 participants, we identified 2335 infections. The participants in the cohorts who answered the Virus Watch activity surveys across the waves were similar in terms of demographics. Participants were in majority female (around 57%), and lived with another person (around 75%), few lived with children, though the proportion living with children was double during the earliest period under restrictions (12%) that of the later periods (6%). Just under half of participants (46%) lived in an urban area and most participants (around 58%) lived in postcodes classified as low deprivation according to the UK Office for National Statistics. The participants answering the surveys during the earliest wave were slightly younger (55% of working age) than those answering during the period immediately following the lifting of restrictions (48% working age) or during the Omicron wave (46% of working age). The cohorts were largely vaccinated.

Participant behaviour

During the period under restrictions, under one-third (29%) of participants left home for work or education, with this proportion increasing to around 35% during both the period following the lifting of restrictions and during the Omicron period (Table 2). During the period under national restrictions, a similar proportion (28%) of participants to those leaving home for work used any form of public transport, however this proportion increased to nearly half of the cohort (48%) during the period after the lifting of restrictions and remained at 42% of the cohort during the Omicron wave. During the period under restrictions, 43% of participants did three or more non-household activities a week (Table 2), although the proportions engaging in any single non-work non-transport non-retail activity was never more than 4% (Table 3). Once restrictions were lifted, nearly half of participants were visiting indoor (43%) or outdoor (41%) hospitality or indoor leisure (41%) venues and more than one-third (35%) undertook non-social activities including visiting a hairdresser, beautician or nail salon. After the restrictions had been lifted for some months, during the Omicron wave, the proportion of participants visiting indoor hospitality venues was nearly double (77%) that of the period immediately following the lifting of restrictions, while the proportion visiting hospitality venues outdoors (30%) dropped slightly. The proportion of participants visiting indoor leisure venues (39%), outdoor leisure (7%) and non-social activities (35%) stayed the same during the Omicron period as the period immediately following the lifting of restrictions.

Activities associated with infection over time

During the period under intense restrictions, after multivariate adjustments, there was strong evidence that leaving home to go to work or education [adjusted odds ratio (aOR) 2.01 (1.65–2.44)] carried the greatest infection risk, with some evidence that using public transport (aOR 1.15 (0.94–1.40) also carried a risk (Table 4, Figure 1). During this period when indoor social activities were largely curtailed, hospitality and leisure were not important risk factors for infection. During the period immediately following the lifting of public health restrictions, the risk associated with leaving home to go to work or education (aOR 1.35 (1.11–1.64) reduced in magnitude but remained the activity with the greatest infection risk while the risk associated with using public transport increased in magnitude and significance (aOR 1.27 (1.04–1.57). During this period after the removal of restrictions, indoor hospitality (aOR 1.21 (0.98–1.48)) and indoor leisure venues (aOR 1.24 (1.02–1.51)) became increasingly important risk factors. During the Omicron wave, leaving home for work (aOR 1.28 (1.16–1.41) and public transport (aOR 1.16 (1.04–1.28) were associated with a slightly lower, but significant infection risk than in the previous period while the risk of infection among participants using indoor hospitality (aOR 1.43 (1.26–1.62) and leisure venues (aOR 1.35 (1.22–1.48) increased.

Relative contribution of activities to overall infection over time

During the period under intense restrictions, leaving home for work or education [population attributable fraction (PAF) 30%

Table 1. **Characteristics of participants during three periods of the SARS-CoV-2 pandemic in England and Wales.**

		Restriction period			Post lifting of national restrictions			Omicron wave		
Characteristic	**Category**	**N=17,256 (% in category)**	**Number of infections n= 502 (% within category)**	**Unadjusted Odds ratio, 95% confidence interval, p-value**	**N=11,413 (% in category)**	**Number of infections n= 493 (% within category)**	**Unadjusted Odds ratio, 95% confidence interval, p-value**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted Odds Ratio, 95% confidence interval, p-value**
Sex	Male	7555 (44%)	191 (2.53%)	1.00	4857 (43%)	209 (4.3%)	1.00	5085(43%)	995 (19.57%)	1.00
	Female	9519 (56%)	307 (3.23%)	1.28 (1.06 – 1.54)	6470 (57%)	278 (4.3%)	0.99 (0.83 – 1.19)	6857 (57%)	1334 (19.45%)	0.99 (0.91 – 1.09)
	Missing	182		P=0.0069	86		P=0.9869	22		P=0.8778
Age	18 – 34	1322 (8%)	66 (4.99%)	1.00	467 (4%)	35 (7.5%)	1.22 (0.82 – 1.84)	389 (3.25%)	119 (30.59%)	1.00
	35 – 49	2332 (14%)	111 (4.76%)	0.95 (0.69 – 1.29)	1019 (9%)	92 (9.0%)	0.68 (0.47 – 0.99)	1013 (8.47%)	272 (26.85%)	0.83 (0.64 – 1.08)
	50 – 64	5812 (34%)	178 (3.06%)	0.60 (0.45 – 0.80)	3884 (34%)	204 (5.3%)	0.34 (0.23 – 0.49)	4075 (34.06%)	825 (20.25%)	0.58 (0.46 – 0.72)
	65 – 79	7296 (42%)	141 (1.93%)	0.38 (0.28 – 0.51)	5683 (49%)	153 (2.7%)	0.32 (0.15 – 0.67)	6127 (51.21%)	1,080 (17.63%)	0.49 (0.39 – 0.61)
	80 plus	494 (3%)	6 (1.21%)	0.23 (0.10 – 0.54)	359 (3%)	9 (2.5%)	1.00	360 (3.01%)	39 (10.83%)	0.28 (0.19 – 0.41)
				P<0.0001			P<0.0001			P<0.0001
Vaccination status	No	1,298 (8%)	64 (4.93%)	1.00	687 (6%)	29 (4.3%)	1.00	9,891 (83%)	1,968 (19.90%)	1.00
	Yes	15,958 (92%)	438 (2.74%)	0.54 (0.42 – 0.71)	10,726 (94%)	464 (4.2%)	1.03 (0.69 – 1.51)	2,073 (17%)	367 (17.70%)	0.87 (0.77 – 0.98)
		*during wave		P<0.0001	*by start of period		P=0.8955	*during wave		P=0.0207
Region	East Midlands	1652 (10%)	49 (2.97%)	1.00	1065 (9%)	35 (3.3%)	1.00	1142 (10%)	215 (18.83%)	1.00
	East of England	3598 (21%)	113 (3.14%)	1.06 (0.75 – 1.49)	2551 (23%)	92 (3.6%)	1.10 (0.74 – 1.64)	2443 (21%)	492 (20.14%)	1.09 (0.91 – 1.29)
	London	1935 (11%)	91 (4.70%)	1.61 (1.13 – 2.29)	1202 (11%)	57 (4.7%)	1.47 (0.95 – 2.25)	1139 (10%)	245 (21.51%)	1.18 (0.96 – 1.45)
	North East	906 (5%)	29 (3.20%)	1.08 (0.68 – 1.72)	581 (5%)	35 (6.0%)	1.89 (1.17 – 3.05)	590 (5%)	125 (21.19%)	1.16 (0.91 – 1.48)
	North West	1967 (12%)	59 (3.00%)	1.01 (0.69 – 1.49_	1192 (11%)	62 (5.2%)	1.61 (1.06 – 2.46)	1244 (11%)	248 (19.94%)	1.07 (0.88 – 1.32)
	South East	3109 (18%)	58 (1.87%)	0.62 (0.42 – 0.91)	2210 (19%)	102 (4.6%)	1.42 (0.96 – 2.11)	2407 (20%)	480 (19.94%)	1.07 (0.89 – 1.28)
	South West	1445 (8%)	33 (2.28%)	0.76 (0.49 – 1.19)	924 (8%)	33 (3.6%)	1.09 (0.67 – 1.77)	1079 (9%)	204 (18.91%)	1.01 (0.81 – 1.24)
	Wales	432 (3%)	8 (1.85%)	0.62 (0.29 – 1.31)	266 (2%)	18 (6.8%)	2.14 (1.19 – 3.83)	361 (3%)	52 (14.40%)	0.73 (0.52 – 1.01)
	W. Midlands	1030 (6%)	24 (2.33%)	0.78 (0.48 – 1.28)	626 (6%)	33 (5.3%)	1.64 (1.01 – 2.66)	684 (6%)	126 (18.42%)	0.97 (0.76 – 1.24)
	Yorkshire & The Humber	957 (6%)	36 (3.76%)	1.28 (0.83 – 1.98)	615 (5%)	15 (2.4%)	0.74 (0.39 – 1.36)	714 (6%)	120 (16.81%)	0.87 (0.68 – 1.11)
				P<0.0001						P=0.0687
	Missing	225			181			161		
Lives alone	Lives alone	3570 (21%)	110 (3.08%)	1.00	2,869 (25%)	81 (2.8%)	1.00	3124 (26.11%)	518 (16.58%)	1.00
	Lives with someone	13,667 (79%)	392 (2.87%)	0.93 (0.75 – 1.15)	8,544 (75%)	412 (4.8%)	1.74 (1.37 – 2.22)	8840 (73.89%)	1817 (20.55%)	1.30 (1.17 -1.45)
	Missing	19		P=0.5032			P<0.0001			P<0.0001

		Restriction period			Post lifting of national restrictions			Omicron wave		
Characteristic	**Category**	**N=17,256 (% in category)**	**Number of infections n= 502 (% within category)**	**Unadjusted Odds ratio, 95% confidence interval, p-value**	**N=11,413 (% in category)**	**Number of infections n= 493 (% within category)**	**Unadjusted Odds ratio, 95% confidence interval, p-value**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted Odds Ratio, 95% confidence interval, p-value**
Lives with children	No	15,167 (88%)	405 (2.67%)	1.00	10,679 (94%)	404 (3.8%)	1.00	11,267 (94%)	2128 (18.89%)	1.00
	Yes	2070 (12%)	97 (4.69%)	1.79 (1.43 – 2.25)	734 (6%)	89 (12.1%)	3.51 (2.57 – 4.47)	697 (6%)	207 (29.70%)	1.81 (1.53 – 2.15)
	Missing	19		P<0.0001			P<0.0001			P<0.0001
Residential area	Any rural	4533 (27%)	105 (2.32%)	1.00	2886 (26%)	106 (3.7%)	1.00	3153 (27%)	549 (17.41%)	1.00
	Any urban	7887 (46%)	205 (2.60%)	1.13 (0.89 – 1.43)	5209 (46%)	216 (4.2%)	1.13 (0.89 – 1.43)	5570 (47%)	1094 (19.64%)	1.16 (1.04 – 1.29)
	Any conurbation	4591 (27%)	190 (4.14%)	1.82 (1.43 – 2.32)	3137 (28%)	160 (5.1%)	1.41 (1.09 – 1.81)	3080 (26%)	664 (21.56%)	1.30 (1.15 – 1.48)
	missing	245		P<0.0001	181		P=0.0201	161		P=0.0002
Deprivation score (IMD quintile) 1= most deprived	1	1333 (8%)	61 (4.58%)	2.04 (1.49 – 2.80)	852 (8%)	44 (5.2%)	1.36 (0.96 – 1.92)	825 (7%)	184 (22.30%)	1.19 (0.99 – 1.42)
	2	2535 (15%)	99 (3.91%)	1.73 (1.32 – 2.27)	1589 (14%)	69 (4.3%)	1.13 (0.84 – 1.52)	1613 (14%)	317 (19.65%)	1.01 (0.87 – 1.17)
	3	3479 (20%)	114 (3.28%)	1.44 (1.11 – 1.87)	2,290 (20%)	94 (4.1%)	1.07 (0.81 – 1.39)	2366 (20%)	481 (20.33%)	1.06 (0.93 – 1.19)
	4	4538 (27%)	108 (2.38%)	1.04 (0.79 – 1.35)	3,032 (27%)	141 (4.7%)	1.21 (0.95 – 1.55)	3090 (26%)	564 (18.25%)	0.92 (0.82 – 1.04)
	5	5146 (30%)	118 (2.29%)	1.00	3,469 (31%)	134 (3.9%)	1.00	3909 (33%)	761 (19.47%)	1.00
	Missing			P<0.0001	181		P=0.3764	161		P=0.0865

Table 2. Unadjusted infection odds associated with activities during three periods of the SARS-CoV-2 pandemic.

		Restriction period			Post lifting of national restrictions			Omicron wave		
Activity	**Weekly frequency**	**Number (%) in cohort (17,258)**	**Number (%) of cases (n=502)**	**Odds Ratio (95% CI), p**	**N=11,413 (% in category)**	**Number of infections n= 493 (% within category)**	**Unadjusted odds ratio (95% CI), p**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted odds ratio (95% CI), p**
Leaving home for work or education	No Yes	12,228 (71%) 5028 (29%)	266 (2.18%) 236 (4.69%)	1.00 2.21 (1.85 – 2.65) p<0.0001	7294 (64%) 4119 (36%)	259 (3.6%) 234 (5.7%)	1.00 1.64 (1.37 – 1.96) p<0.0001	7756 (64.83%) 4208 (35.17%)	1373 (17.70%) 962 (22.86%)	1.00 1.38 (1.26 – 1.51) P<0.0001
Weekly frequency of using public or shared transport	None Any	12,469 (72%) 4787 (28%)	326 (2.61%) 176 (3.68%)	1.00 1.42 (1.18 – 1.71) P=0.0003	5902 (52%) 5511 (48%)	219 (3.7%) 274 (4.9%)	1.00 1.36 (1.13 – 1.62) P=0.0009	6,868 (57.41%) 5,096 (42.59%)	1212 (17.65%) 1123 (22.04%)	1.00 1.32 (1.20 – 1.44) P<0.0001
Weekly frequency of any retail		7462 (43%) 9794 (57%) *>0–1 >1	203 (2.72%) 299 (3.05%)	1.00 1.13 (0.94 – 1.35) P=0.1967	482 (4%) 2022 (18%) 5745 (50%) 3164 (28%) *0 >0 – 1 >1 – 3 > 3	14 (2.9%) 110 (5.4%) 262 (4.6%) 107 (3.4%)	0.85 (0.49 – 1.50) 1.64 (1.25 – 2.16) 1.37 (1.09 – 1.72) 1.00 P=0.0010	6029 (50.39%) 5935 (49.61%) 0 - 2 >2	1219 (20.22%) 1116 (18.80%)	1.09 (0.99 – 1.19) 1.00 P=0.0508
Weekly frequency of other non-household activities	0—3 More than 3	9769 (57%) 7487 (43%)	266 (2.72%) 236 (3.15%)	1.00 1.16 (0.97 – 1.39) P=0.0973	-	-	-	-	-	-
Indoor hospitality	None Any	-	-	-	6531 (57%) 4882 (43%)	258 (3.9%) 235 (4.8%)	1.00 1.23 (1.03 – 1.47) P=0.0254	2,772 (23.17%) 9192 (76.83%)	398 (14.36%) 1937 (21.07%)	1.00 1.59 (1.42 – 1.79) P<0.0001
Outdoor hospitality	None Any	-	-	-	6777 (59%) 4636 (41%)	276 (4.1%) 217 (4.7%)	1.00 1.16 (0.96 – 1.39) P=0.1179	8383 (70.07%) 3581 (29.93%)	1578 (18.82%) 757 (21.14%)	1.00 1.16 (1.05 – 1.27) P=0.0036
Indoor leisure	None Any	-	-	-	6713 (59%) 4700 (41%)	258 (3.8%) 235 (5%)	1.00 1.32 (1.01 – 1.58) P=0.0029	7252 (60.62%) 4712 (39.38%)	1231 (16.97%) 1104 (23.43%)	1.00 1.49 (1.37 – 1.64) P<0.0001
Outdoor leisure	None Any	-	-	-	10,570 (93%) 843 (7%)	449 (4.3%) 44 (5.2%)	1.00 1.24 (0.90 – 1.71) p=0.1943	11,092 (92.71%) 872 (7.29%)	2138 (19.28%) 197 (22.59%)	1.00 1.22 (1.04 – 1.44) P=0.0193
Non-social activity	None Any	-	-	-	7469 (65%) 3944 (35%)	351 (4.7%) 142 (3.6%)	1.00 0.76 (0.62 – 0.92) P=0.0053	7832 (65.46%) 4132 (34.54%)	1515 (19.34%) 820 (19.85%)	1.00 1.03 (0.94 – 1.14) P=0.5110

Table 3. Activity infection odds, unadjusted and adjusted (sex, region, vaccine status, living: alone; with children; in deprived area).

		Restriction period				Period after restriction				Omicron			
Activity	**Frequency**	**Number (%) in cohort (N=17,256)**	**Covid infection (%) N=502**	**Unadjusted OR (95% CI), p**	**Adjusted OR (95% CI), p**	**N=11,413 (% in category)**	**Number of infections n=493(% within category)**	**Unadjusted OR (95% CI), p**	**Adjusted OR, (95% CI), p (n=11,231)**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted OR (95% CI), p**	**Adjusted OR, (95% CI), p**
Essential shopping	0 - 1 >1 -2 >2	2,718 (16%) 10,456 (61%) 4,082 (24%) *0, >0-2, >2	70 (2.6%) 299 (2.9%) 133 (3.3%)	1.00 1.11 (0.86 – 1.45) 1.27 (0.95 – 1.45) P=0.2344	1.00 1.07 (0.82 – 1.39) 1.18 (0.88 – 1.59) P=0.5010	3,756 (33%) 3,877 (34%) 3,780 (33%)	182 (5%) 180 (5%) 131 (3%)	1.00 0.96 (0.77 – 1.18) 0.71 (0.56 – 0.87) P=0.0052	1.00 1.02 (0.82 – 1.26) 0.72 (0.57 – 0.92) P=0.0072	3,841 (32%) 4,022 (34%) 4,101 (34%)	758 (19.7%) 842 (20.9%) 735 (17.9%)	1.00 1.08 (0.96 – 1.20) 0.89 (0.79 – 0.99) P=0.0025	1.00 1.09 (0.98 – 1.22) 0.89 (0.79 – 0.99) P=0.0013
Non-essential shopping	None Up to once More than once	13,523 (78%) 3,733 (22%) *None Any	398 (2.9%) 104 (2.8%)	1.00 0.95 (0.76 – 1.18) P=0.6112	1.00 1.00 (0.80 – 1.25) P=0.9816	4,073 (36%) 5,224 (46%) 2,116 (19%)	183 (4%) 222 (4%) 88 (4%)	1.00 0.94 (0.77 – 1.15) 0.92 (0.71 – 1.19) P=0.7832	1.00 0.93 (0.76 – 1.14) 0.89 (0.68 – 1.16) P=0.6399	4,573 (38%) 5,405 (45%) 1,986 (17%)	861 (18.8%) 1,088 (20.1%) 386 (19.4%)	1.00 1.09 (0.98 – 1.20) 1.04 (0.91 – 1.19) P=0.2613	1.00 1.07 (0.97 – 1.18) 1.02 (0.89 – 1.17) P=0.4135
Indoor pub, bar, club	None Up to once More than once	17,045 (99%) 211 (1%) *indoor and outdoor combined during restriction period	497 (2.9%) 5 (2.4%)	1.00 0.81 (0.33 – 1.97) P=0.6282	1.00 0.82 (0.33 – 2.04) P=0.6672	6,137 (54%) 3,373 (29%) 1,903 (17%)	243 (4%) 147 (4%) 103 (5%)	1.00 1.11(0.89 – 1.36) 1.39 (1.09 – 1.76) P=0.0288	1.00 1.14 (0.92 – 1.40) 1.45 (1.13 – 1.84) P=0.0138	6,709 (56%) 3,513 (29%) 1,742 (15%)	1,149 (17.13%) 799 (22.74%) 387 (22.22%)	1.00 1.42 (1.29 – 1.58) 1.38 (1.21 – 1.57) P<0.001	1.00 1.43 (1.29 – 1.58) 1.43 (1.26 – 1.63) P<0.0001
Outdoor pub, bar, club	None At least once	*indoor and outdoor combined during restriction period	-	-	-	9,088 (80%) 2,325 (20%)	387 (4%) 106 (5%)	1.00 1.07 (0.86 – 1.34) P=0.5271	1.00 1.09 (0.87 – 1.36) P=0.4653	10,287(86%) 1,677 (14%)	1,972 (19.17%) 363 (21.65%)	1.00 1.16 (1.03 – 1.32) P=0.0190	1.00 1.19 (1.05 – 1.35) P=0.0089
Indoor restaurant, café, canteen	None Up to once More than once	16,648 (96%) 608 (4%) *indoor and outdoor combined during restriction period; None/Any categories	489 (2.9%) 13 (2.1%)	1.00 0.72 (0.41 – 1.26) P=0.2280	1.00 0.71 (0.40 – 1.26) P=0.2240	3,325 (29%) 5,320 (47%) 2,768 (24%)	119 (4%) 263(5%) 111 (4%)	1.00 1.40 (1.12 – 1.75) 1.13 (0.86 – 1.47) P=0.0063	1.00 1.38 (1.11 – 1.73) 1.14 (0.87 – 1.49) P=0.0120	3,840 (32%) 5,578 (47%) 2,546 (21%)	626 (16.30%) 1,128 (20.22%) 581 (22.82%)	1.00 1.30 (1.17 – 1.45) 1.52 (1.24 – 1.72) P<0.0001	1.00 1.29 (1.16 – 1.44) 1.52 (1.34 – 1.73) P<0.0001
Outdoor restaurant, café, canteen	None At least once in 3 months	*indoor and outdoor combined during restriction period	-	-	-	8,147 (71%) 3,266 (29%)	342 (4%) 151 (5%)	1.00 1.11(0.91 – 1.35) P=0.3153	1.00 1.14 (0.94 – 1.39) P=0.1939	9,416 (79%) 2,548 (21%)	1,806 (19.18%) 529 (20.76%)	1.00 1.10 (0.99 – 1.23) P=0.0756	1.00 1.11 (0.99 – 1.23) P=0.0776
Indoor party	None At least once in 3 months	17,205 (99%) 51 (<1%) *indoor and outdoor combined during restriction period	501 (2.9%) 1 (1.9%)	1.00 0.66 (0.09 – 4.84) P=0.6684	1.00 0.56 (0.08 – 4.07) P=0.5254	9,967 (87%) 1,446 (13%)	408 (4%) 85 (6%)	1.00 1.46 (1.15 – 1.86) P=0.0028	1.00 1.38 (1.08 – 1.77) P=0.0124	10,871 (91%) 1,093 (9%)	2,062 (18.97%) 273 (24.98%)	1.00 1.42 (1.23 – 1.64) P<0.0001	1.00 1.39 (1.19 – 1.61) P<0.0001

		Restriction period				Period after restriction				Omicron			
Activity	**Frequency**	**Number (%) in cohort (N=17,256)**	**Covid infection (%) N=502**	**Unadjusted OR (95% CI), p**	**Adjusted OR (95% CI), p**	**N=11,413 (% in category)**	**Number of infections n=493(% within category)**	**Unadjusted OR (95% CI), p**	**Adjusted OR, (95% CI), p (n=11,231)**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted OR (95% CI), p**	**Adjusted OR, (95% CI), p**
Outdoor party	None At least once in 3 months	*indoor and outdoor combined during restriction period	-	-	-	10,959 (96%) 454 (4%)	474 (4%) 19 (4%)	1.00 0.97 (0.60 – 1.54) P=0.8850	1.00 0.91 (0.55 – 1.49) P=0.7110	11,745 (98%) 219 (2%)	2,286 (19.46%) 49 (22.37%)	1.00 1.19 (0.87 – 1.64) P=0.2898	1.00 1.19 (0.86 – 1.66) P=0.3025
Gym/indoor sport	None At least once in 3 months	16,954 (98%) 302 (2%)	491 (2.9%) 11 (3.6%)	1.00 1.27 (0.69 – 2.33) P=0.4610	1.00 1.20 (0.65 – 2.22) P=0.5657	8,894 (78%) 2,519 (22%)	361 (4%) 132 (5%)	1.00 1.31(1.07 – 1.60) P=0.0118	1.00 1.32 (1.07 – 1.63) P=0.0105	9,145 (76%) 2,819 (24%)	1,634 (17.87%) 701 (24.87%)	1.00 1.52 (1.38 – 1.68) P<0.0001	1.00 1.48 (1.33 – 1.64) P<0.0001
Team sport outdoors	None At least once	17,089 (99%) 167 (1%)	496 (2.9%) 6 (3.59%)	1.00 1.25 (0.55 – 2.83) P=0.6100	1.00 1.29 (0.56 – 2.96) P=0.5583	10,570 (93%) 843 (7%)	449 (4%) 44 (5%)	1.00 1.24 (0.90 – 1.71) P=0.1943	1.00 1.23 (0.89 – 1.71) P=0.2269	11,092 (93%) 872 (7%)	2,138 (19.28%) 197 (22.59%)	1.00 1.22 (1.04 – 1.44) P<0.0193	1.00 1.22 (1.03 – 1.44) P=0.0240
Theatre, cinema, concert, sports event	None At least	17,175 (99%) 81 (<1%)	498 (2.9%) 4 (4.9%)	1.00 1.74 (0.63 – 4.77) P=0.3207	1.00 1.74 (0.63 – 4.84) P=0.3229	8,250 (72%) 3,163 (28%)	336 (4%) 157 (5%)	1.00 1.23 (1.01 – 1.49) P=0.0387	1.00 1.23 (1.01 – 1.49) P=0.0464	9,095 (76%) 2,869 (24%)	1,679 (18.46%) 656 (22.87%)	1.00 1.31 (1.18 – 1.45) P<0.0001	1.00 1.28 (1.15 – 1.42) P<0.00001
Hairdresser, barber, beautician	None At least once in 3 months	16,797 (97%) 459 (3%)	494 (2.9%) 8 (1.7%)	1.00 0.59 (0.29 – 1.18) P=0.1046	1.00 0.59 (0.29 – 1.19) P=0.1123	7,469 (65%) 3,944 (35%)	351 (5%) 142 (4%)	1.00 0.76 (0.62 – 0.92) P=0.0053	1.00 0.76 (0.62 – 0.93) P=0.0078	7,832 (65%) 4,132 (35%)	1,515 (19.34%) 820 (19.85%)	1.00 1.03 (0.94 – 1.14) P=0.5110	1.00 1.04 (0.95 – 1.15) P=0.3931
Went to an outdoor market**	None Any	16,163 (94%) 1,093 (6%)	470 (2.9%) 32 (2.9%)	1.00 1.01 (0.70 – 1.45) P=0.9699	1.00 0.98 (0.68 – 1.42) P=0.9221	*not measured	-	-	-	*not measured	-	-	-
Went to a place of worship	None Any	16,688 (97%) 568 (3%)	486 (2.9%) 16 (2.8%)	1.00 0.97 (0.58 – 1.60) P=0.8937	1.00 0.96 (0.58 – 1.59) P=0.8655	*not measured	-	-	-	*not measured	-	-	-
Visited friends or family**	None Up to once More than once	*not measured	-	-	-	*not measured	-	-	-	3,339 (28%) 5,368 (45%) 3,257 (27%)	605 (18.12%) 1,109 (20.66%) 621 (19.07%)	1.00 1.18 (1.05 – 1.31) 1.06 (0.94 – 1.21) P=0.0108	1.00 1.18 (1.06 – 1.33) 1.08 (0.95 – 1.23) P=0.0099
Attended a wedding or funeral**	None Any	*not measured	-	-	-	*not measured	-	-	-	10,441 (87%) 1,523 (13%)	2.015 (19.30%) 320 (21.01%)	1.00 1.11 (0.97 – 1.27) P=0.1182	1.00 1.13 (0.98 – 1.29) P=0.0854

**not included in composites variables

Table 4. **Infection odds and PAFs (adjustments: sex, region, vaccine status, living: alone; with children; in deprived area).**

		Restriction period		Post lifting of national restrictions		Omicron wave	
Activity	**Weekly frequency**	**Adjusted odds ratio (95% CI), p**	**Population attributable fractions (weighted) (95% CI)**	**Adjusted odds ratio (95% CI), p, (n=11,232)**	**Population attributable fractions (weighted) (95% CI)**	**Adjusted odds ratio (95% CI), p, (n=11,784)**	**Population attributable fractions (weighted) (95% CI)**
Leaving home for work or education	No Yes	1.00 2.01 (1.65 – 2.44) P<0.0001	30.08 (21.-77 – 37.50)	1.00 1.35 (1.11 – 1.64) P=0.0029	16.51 (5.56 – 26.18)	1.00 1.28 (1.16 – 1.41) p<0.0001	10.92 (6.58 – 15.05)
Weekly frequency of using public or shared transport	None Any	1.00 1.15 (0.94 – 1.40) P=0.1814	4.77 (-2.50 – 11.52)	1.00 1.27 (1.04 – 1.57) P=0.0211	12.17 (1.59 – 21.61)	1.00 1.16 (1.04 – 1.28) P=0.0050	5.60 (1.65 – 9.40)
Weekly frequency of any retail	*	1.00 1.02 (0.84 – 1.24) P=0.8239	1.17 (-9.71 – 10.98)	1.05 (0.58 – 1.88) 1.83 (1.36 – 2.45) 1.51 (1.19 – 1.92) 1.00 P=0.0001	*not estimated	1.25 (1.13 – 1.37) 1.00 P<0.0001	*not estimated
Weekly frequency of other non-household activities	0—3 More than 3	1.00 0.95 (0.79 – 1.17) P=0.6776	*not plotted -1.96 (-11.64 – 6.89)	-	-		-
Indoor hospitality	None Any	-	-	1.00 1.21 (0.98 – 1.48) P=0.0710	7.26 (-0.90 – 14.77)	1.00 1.43 (1.26 – 1.62) P<0.0001	20.30 (13.14 – 26.37)
Outdoor hospitality	None Any	-	-	1.00 1.14 (0.94 – 1.39) P=0.1860	4.67 (-2.53 – 11.36)	1.00 1.08 (0.97 – 1.19) P=0.1578	1.68 (-0.69 – 3.99)
Indoor leisure	None Any	-	-	1.00 1.24 (1.02 – 1.51) P=0.0284	9.55 (0.71 – 17.60)	1.00 1.35 (1.22 – 1.48) P<0.0001	10.36 (6.91 – 13.68)
Outdoor leisure	None Any	-	-	1.00 1.14 (0.82 – 1.59) P=0.4521	1.14 (-1.96 – 4.16)	1.00 1.07 (0.90 – 1.27) P=0.4391	0.47 (-0.73 – 1.65)
Non-social activity	None Any	-	-	1.00 0.74 (0.59 – 0.90) P=0.0031	-8.69 (-14.42 - -3.25) *not plotted	1.00 0.99 (0.89 – 1.09) P=0.7919	-0.34 (-2.87 – 2.13) not plotted

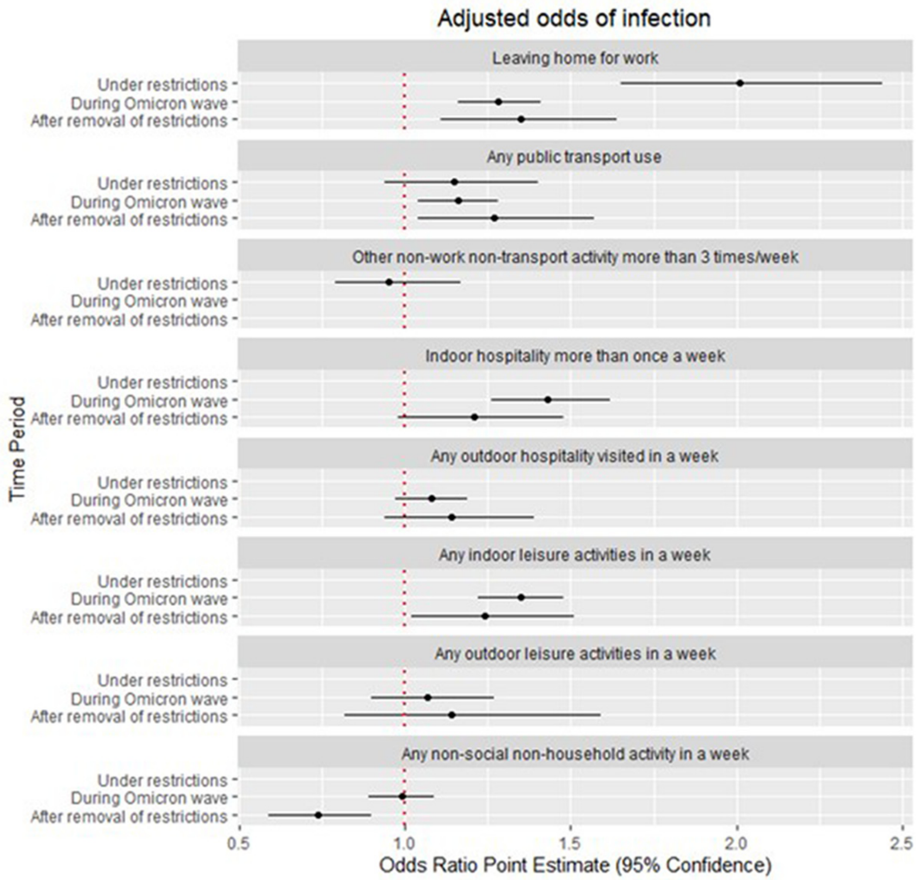

Figure 1. Adjusted odds of infection by activity throughout the waves. *Other non-work non-transport activities were disaggregated by Indoor and Outdoor activities for the periods After the removal of restrictions and During the Omicron wave.

(21.77–37.50)] was the greatest contributor to infections, with public transport use (PAF 5% (-3–12%) contributing somewhat (Table 4, Figure 2). Shopping contributed minimally during this period (PAF 1% (-9 to 11%) and other hospitality and leisure activities were not important. During the period immediately following the lifting of public health restrictions, leaving home for work (PAF 17% (6–26%) reduced in relative importance but continued to contribute significantly to infections. The relative contribution to infections of public transport use (PAF 12% (2–22%) became increasingly important as did the role of indoor hospitality (PAF 7% (-1–15%) and indoor leisure activities (PAF 10% (1–18%). During the Omicron wave, the relative role of leaving home for work (PAF (11% (7–15%) stayed the same as during the period immediately following the lifting of restrictions, but the role of public transport use (PAF 6% (2–9%) halved, through remained a significant contributor to overall infections. During this period of mostly no restrictions, the greatest contributor to infections was indoor hospitality (PAF 20% (13–26%), contributing nearly double the amount to infections than that contributed through leaving home for work. Indoor leisure use continued to contribute significantly (PAF 10% (7–14%), surpassing the role of public transport use during this period.

Given the (unexpected) inverse relationship between shopping frequency and infection (Table 3 and Table 4) during the period after the lifting of restrictions and during the Omicron wave, we did not calculate PAF for shopping.

When additionally controlling for age (Table 5), the relative contribution to infections of work was reduced under all three levels of national restrictions [in the period under restrictions (PAF 16% (17–34%), most notable during the period following the lifting of restrictions (PAF 3% (-10–15%)) and during the Omicron wave (PAF 6% (1–11%)].

When additionally adjusting for age (Table 5), the only activity to be affected with much importance was leaving home for work, whose infection odds and relative contributory role to overall infections was reduced across all periods. During the period under restrictions the odds of infection associated with leaving home for work or education reduced slightly (OR 1.79 [1.45 – 2.21]), but work remained the greatest contributor (PAF 26% [17 – 34%] to infections during this period. The adjustment for age had the greatest impact on the role of work during the period immediately following the lifting of restrictions, with the odds of infection associated with leaving

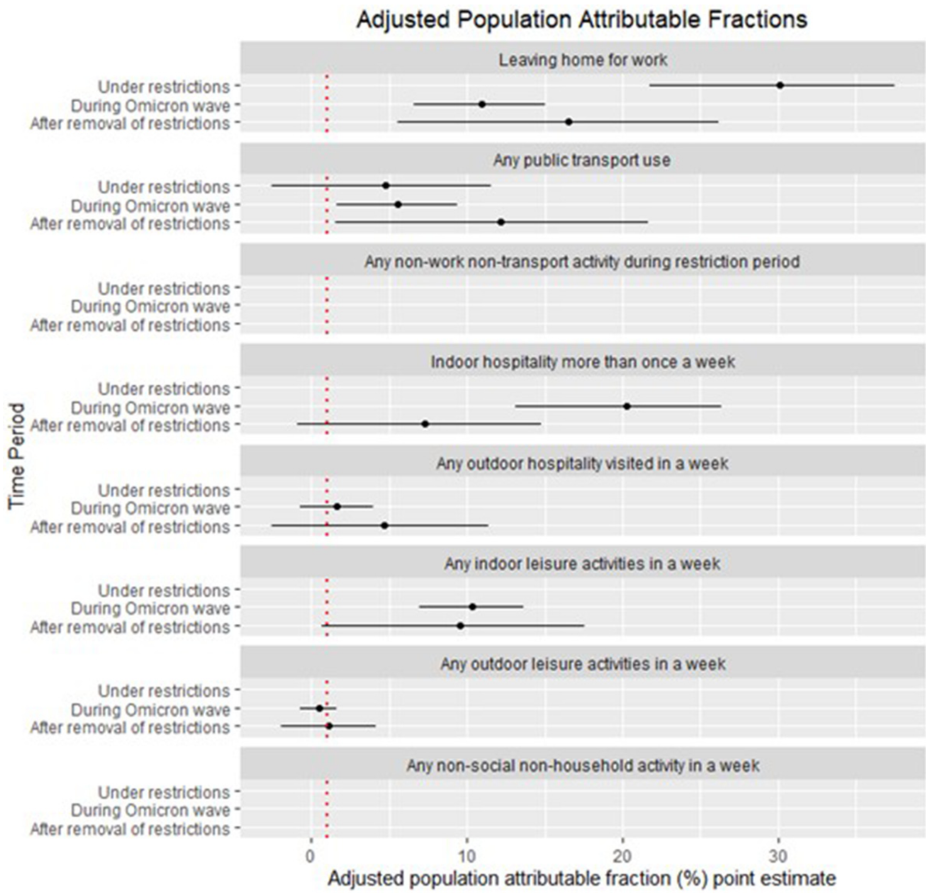

Figure 2. Adjusted Population Attributable Fractions (PAFs) by activity across the waves. **AFs below 0 are not plotted. Other non-work non-transport activities were disaggregated by Indoor and Outdoor activities for the periods After the removal of restrictions and During the Omicron wave.

home for work becoming non-significant ((OR 1.06 [0.85 – 1.30] and its contributory role reduced to 3% PAF (-10 to 15%). During the Omicron wave, the additional adjustment for age halved the odds associated with leaving home for work (OR 1.15 (1.03 – 1.28) and its contributory role to infections (PAF 6% (1 – 11%). For all other activities, the infection risk and the contributory role to overall infections were little affected when additionally adjusting for age.

Individual activities associated with infection over time

Throughout the pandemic, the magnitude of infection odds associated with individual transport methods (Table 6) increased as a greater proportion of participants used public transport. Notably, bus use carried an increased infection odds of between OR 1.22 (0.89–1.67) when 7% of participants used a bus in the restriction period and OR 1.27 (1.14–1.41) when one quarter of participants used a bus during the Omicron wave. Similarly, there was a consistent increased odds of infection with overground train or tram use throughout the pandemic, gaining in strength and significance over time, up to OR 1.45 (1.13–1.86) during the Omicron period. Infection odds associated with underground use oscillated from nearly double during the restriction phase (OR 1.87, 1.26–2.77) when only 3% of participants used an underground train, to OR 1.14 (0.87–1.51) in the period after the removal of restrictions, regaining strength and significance (OR 1.35, 1.16–1.56) during the Omicron wave. The risk associated with airplane use was high (OR 1.39, 1.20–1.62).

During the period under restrictions, individual activities (Table 3) were undertaken by around 1% of participants and no individual activity was associated with a significant increased infection odds. When venues were no longer under public health restrictions, visiting an indoor bar, club or pub carried a consistently higher odds of infection [OR 1.45 (1.13–1.84) after the lifting of restrictions and OR 1.43 (1.26–1.63) during the Omicron wave] than visiting its indoor equivalent [OR 1.09 (0.87–1.36) after the lifting of restrictions and OR 1.19 (1.05–1.35) during the Omicron wave]. A similar magnitude of elevated risk was associated with indoor restaurant use [OR 1.38 (1.11–1.73) after the lifting of restrictions and OR 1.52 (1.34–1.73) during the Omicron wave] but not with its outdoor equivalent [OR 1.14 (0.94–1.39) immediately after the lifting of restrictions and OR 1.11 (0.99–1.23) during the Omicron wave],

Table 5. Infection odds and PAFs (adjustments: age, sex, region, vaccine status, living: alone; with children; in deprived area).

		Restriction period		Post lifting of national restrictions		Omicron wave	
Activity	**Weekly frequency**	**Adjusted odds ratio additionally adjusted for age (95% CI), p, (n=16, 931)**	**Population attributable fractions when adjusting for age (weighted) (95% CI)**	**Adjusted odds ratio additionally adjusted for age (95% CI), p**	**Population attributable fractions when adjusting for age (weighted) (95% CI)**	**Adjusted odds ratio additionally adjusted for age (95% CI), p, (n=11,784)**	**Population attributable fractions when adjusting for age (weighted) (95% CI)**
Leaving home for work or education	No Yes	1.00 1.79 (1.45 – 2.21) P<0.0001	25.80 (16.64 – 33.95)	1.00 1.06 (0.85-1.30) P=0.6181	3.25 (-10.25 – 15.10)	1.00 1.15 (1.03 – 1.28) P=0.0119	6.17 (1.31 – 10.80)
Weekly frequency of using public or shared transport	None Any	1.00 1.15 (0.94 – 1.41) P=0.1699	4.88 (-2.36 – 11.60)	1.00 1.27 (1.03 – 1.56) P=0.0260	11.85 (1.18 – 21.37)	1.00 1.15 (1.04 – 1.27) P-0.0084	5.13 (1.27 – 8.85)
Weekly frequency of any retail		1.00 1.03 (0.85 – 1.25) P=0.7618	1.59 (-9.24 – 11.35)	0.99 (0.55 – 1.79) 1.79 (1.33 – 2.41) 1.49 (1.18 – 1.89) 1.00 P=0.0002	*not estimated	1.25 (1.13 – 1.37) 1.00 P<0.0001	* not estimated
Weekly frequency of other non-household activities	0—3 More than 3	1.00 0.95 (0.78 – 1.16) P=0.6375	not estimated due to lack of significance		-	-	-
Indoor hospitality	None Any	-	-	1.00 1.22 (0.99 – 1.49) P=0.0567	7.64 (-0.49 – 15.12)	1.00 1.44 (1.27 – 1.63) P<0.0001	19.59 (12.87 – 25.79%)
Outdoor hospitality	None Any	-	-	1.00 1.11 (0.91 – 1.35) P=0.3091	3.62 (-3.63 – 10.36)	1.00 1.07 (0.97 – 1.19) P=0.1876	1.50 (-0.77% - 3.72)
Indoor leisure	None Any	-	-	1.00 1.21 (0.99 – 1.47) P=0.0621	8.24 (-0.73 – 16.40)	1.00 1.33 (1.21 – 1.47) P<0.0001	9.66 (6.30 – 12.90)
Outdoor leisure	None Any	-	-	1.00 1.14 (0.82 – 1.59) P=0.4532	1.17 (-2.01 – 4.25)	1.00 1.07 (0.89 – 1.26) P<0.4861	0.41 (-0.75 – 1.54)
Non-social activity	None Any	-	-	1.00 0.74 (0.60 – 0.91) P=0.0042	-8.37 (-14.08 - -2.94) *not estimated	1.00 0.98 (0.89 – 1.08) P=0.9950	-0.01% (-2.42 – 2.35) *not estimated

Table 6. Transport infection odds, unadjusted and adjusted (sex, region, vaccine status, living: alone; with children; in deprived area).

		Period under restrictions				Post lifting of restrictions				Omicron wave			
Characteristic	**Frequency**	**Number in cohort (%) (N=17,256)**	**Number of infections (N=502) (% within category)**	**Unadjusted OR, 95% CI, p**	**Adjusted OR, 95% CI, p (n=16,931)**	**N=11,413(% in category)**	**Number of infections n= 493 (% within category)**	**Unadjusted OR**	**Adjusted OR, 95% CI, p (n=11,231)**	**N=11, 964 (% in category)**	**Number of infections n= 2,335 (% within category)**	**Unadjusted OR**	**Adjusted OR, 95% CI, p**
Shared car	None Any	13,705 (79%) 3,551 (21%) *shared car and taxi combined	375 (2.7%) 127 (3.6%)	1.00 1.32 (1.07 – 1.62) P=0.0096	1.00 1.26 (1.02 – 1.56) P=0.0314	4,634 (41%) 6,779 (59%)	211 (5%) 282 (4%)	1.00 0.91 (0.76 – 1.09) P=0.3112	1.00 0.99 (0.83 – 1.20) P=0.9642	5,040 (42%) 4,862 (41%) 2,062 (17%)	890 (17.7%) 1,004 (20.7%) 441 (21.4%)	1.00 1.21 (1.09 – 1.34) 1.27 (1.12 – 1.44) P=0.0001	1.00 1.22 (1.11 – 1.36) 1.34 (1.18– 1.53) P<0.0001
Taxi	None Any	*combined with shared car in restriction period	-	-	-	9,217 (81%) 2,196 (19%)	376 (4%) 117 (5%)	1.00 1.32 (1.07 – 1.64) P=0.0117	1.00 1.28 (1.03 – 1.59) P=0.0321	10,128 (85%) 1,836 (15%)	1,922 (18.9%) 413 (22.5%)	1.00 1.24 (1.09 – 1.39) P=0.0006	1.00 1.22 (1.08 – 1.38) P=0.0014
Bus	None Any	16,024 (93%) 1,232 (7%)	448 (2.8%) 54 (4.4%)	1.00 1.59 (1.19 – 2.13) P=0.0028	1.00 1.22 (0.89 – 1.67) P=0.2098	8,250 (72%) 3,163 (28%) * None Any	342 (4%) 151 (5%)	1.00 1.16 (0.95 – 1.41) P=0.1432	1.00 1.27 (1.03 – 1.56) P=0.0291	9,007 (75%) 2,957 (25%)	1,675 (18.6%) 660 (22.3%)	1.00 1.26 (1.14 – 1.39) P<0.001	1.00 1.27 (1.14 – 1.41) P<0.0001
Overground train	None Any	16,629 (96%) 627 (4%) *combined train or tram in restriction period	473 (2.8%) 29 (4.6%)	1.00 1.66 (1.13 – 2.43) P=0.0159	1.00 1.25 (0.83 – 1.86) P=0.2968	8,694 (76%) 2,719 (24%) *overground train and tram combined	344 (4%) 149 (5%)	1.00 1.41 (1.16 – 1.71) P=0.0009	1.00 1.41 (1.14 – 1.74) P=0.0017	9,737 (81%) 2,227 (19%)	1,824 (18.7%) 511 (22.9%)	1.00 1.29 (1.16 – 1.44) P<0.0001	1.00 1.27 (1.13 – 1.43) P=0.0001
Overround tram	None Any	*combined train or tram in restriction period	-	-	-	*combined with overground train	-		-	11,612 (97%) 352 (3%)	2,243 (19%) 92 (26.1%)	1.00 1.48 (1.16 – 1.88) P=0.0022	1.00 1.45 (1.13 – 1.86) P=0.0044
Underground train	None Any	16,735 (97%) 521 (3%)	466 (2.8) 36 (6.9%)	1.00 2.59 (1.82 – 3.68) P<0.0001	1.00 1.87 (1.26 – 2.77) P=0.0032	9,709 (85%) 1,704 (15%)	409 (4%) 84 (5%)	1.00 1.18 (0.93 – 1.49) P=0.1870	1.00 1.14 (0.87 – 1.51) P=0.3406	10,512 (88%) 1,452 (12%)	1,984 (18.9%) 351 (24.2%)	1.00 1.37 (1.20 – 1.56) P<0.0001	1.00 1.35 (1.16 – 1.56) P=0.0001
Airplane	None Any	17,114 (99%) 142 (1%)	497 (2.9%) 5 (3.5%)	1.00 1.22 (0.49 – 2.99) P=0.6729	1.00 1.14 (0.46 – 2.79) P=0.7864	10,338 (91%) 1,075 (9%)	443 (4%) 50 (5%)	1.00 1.09 (0.81 – 1.47) P=0.5783	1.00 1.04 (0.76 – 1.41) P=0.8259	10,924 (91%) 1,040 (9%)	2,073 (18.9%) 262 (25.2%)	1.00 1.44 (1.24 – 1.67) P<0.001	1.00 1.39 (1.20 – 1.62) P<0.0001

and with attending an indoor party [OR 1.38 (1.08–1.77) after the lifting of restrictions and OR 1.39 (1.19 – 1.61) during the Omicron wave] but not with attending a party outdoors [OR 0.91 (0.55–1.49) after the lifting of restrictions and OR 1.19 (0.86–1.66), during the Omicron wave). Indoor sport carried a significantly higher risk than outdoor sport during both periods and visiting a theatre or concert increased risk by around a quarter (OR 1.23 (1.01–1.49) after the lifting of restrictions and OR 1.28 (1.15–1.42) during the Omicron wave].

Discussion

We found that during periods of intense restrictions (October 2020–May 2021), work and public transport were important risk factors for SARS-CoV-2 acquisition and contributors to overall infections, but hospitality and leisure were not important. During the period when most public health restrictions were lifted (September–mid-December 2021) work, public transport, indoor hospitality and indoor leisure venues became important contributors to transmission. During the Omicron wave (December 2021–April 2022), characterised by no restrictions for the majority of the period and a return to activity levels closer to those of pre-pandemic, work and public transport were still significant risk factors but diminished in importance with indoor hospitality and leisure venues increasing in importance.

The sizeable contributory role to infections of leaving home for work during the period under restrictions relative to other activities demonstrates the effectiveness of the restriction measures. One of the few reasons individuals in the UK were allowed to leave home during the period under restrictions was for work that could not feasibly be done from home such as being an essential worker. Such roles included working in healthcare, as a carer or transport worker. These roles were demonstrated early in the pandemic to carry considerable increased transmission risk and our findings that the greatest contribution to infections during the restriction period was among individuals leaving home for work fits with this. We have previously found that front line occupations were most at risk during the early stages of the pandemic, but occupation became a less important driver of infection risk in later waves of the pandemic[20]. The lack of contribution to infections of hospitality and leisure venues during the restriction period compared to their important contribution after the removal of restrictions highlights the effectiveness of the closure of these venues when the country was faced with a respiratory virus of high pathogenicity. As increasing numbers of participants returned to visiting indoor venues during the period immediately after the removal of restrictions and some months later during the Omicron wave, the risk of infection increased. The larger contribution to infections of indoor hospitality during the Omicron period compared to the role of work during that period can be partly explained by the near double proportion of participants attending indoor hospitality venues (77%) *versus* the proportion leaving home for work (35%) and may also relate to the increased transmissibility of Omicron. As restrictions were lifted, how people became infected was largely based on the extent to which people used the new freedoms to use leisure and hospitality venues.

Indoor hospitality and leisure activities significantly increased risk of infection but this risk was diminished and not statistically significant for outdoor hospitality and leisure activities, (likely due to massively higher ventilation in outdoor settings). This suggests that measures to allow outdoor use of such venues may be a proportionate approach to balancing risk of infection whilst avoiding total closure of such venues. However, a relatively small proportion of participants visited outdoor hospitality or leisure venues compared to the proportion undertaking indoor hospitality and leisure activities limiting the power to accurately measure risk in outdoor settings.

We hypothesised that age is a very strong determinant of social interactions and particularly for whether or not people work, and that therefore controlling for age would reduce or remove many of the associations found. However, with the exception of leaving home for work, the effect of controlling for age was minimal. The notable reduction in risk related to leaving home for work when additionally adjusting for age suggests that an important part of the reduced risk of infection in older adults relates to reduced exposure to work in those over retirement age.

Odds of infection were paradoxically found to decrease with more frequent shopping, except in the period under restrictions. We hypothesize that shopping once a week may be associated with a longer ‘weekly shop’ in larger venues, consequently presenting greater risk than more frequent, shorter shops in smaller stores with a lower capacity.

Other work

Findings in this study update a previous investigation during the restriction period to include more identified cases and further adjustment for potential confounding; essential activities such as attending work and using transport remained important contributors to risk[17]. Findings broadly corroborate and extend results identified in other studies investigating the relationship between activities and SARS-CoV-2 infection but extend this by using consistent methodology through multiple periods of the pandemic, with comprehensive measurement of the range of settings where exposure can occur and adjustment for important confounders.

Findings regarding the period during which most restrictions were lifted are similar to other studies investigating periods with relatively relaxed restrictions. During periods following the relaxation of restrictions, public transport was identified as a risk factor in studies from previous pandemic phases in the USA and France, although non-pharmaceutical interventions were more stringent in these settings than in England and Wales during the period in this study[11,12]. Similar to our own results, indoor hospitality and leisure venues were also identified to contribute to infection risk during periods of relaxed restrictions in France and Denmark[12,13,15]. The persistent, though attenuated, relationship between attending work and transmission identified in the present study but not in previous literature may reflect differences in activity measurement, adjustment, and/or features of the pandemic including infection control within workplaces and prevalence of home working in different countries. Broadly, findings corroborate previous studies indicating that essential activities are the primary contributor to transmission during periods of stringent restrictions and that leisure and hospitality activities become increasingly important under periods of relaxed restrictions.

Strengths and limitations

Self-reported activity surveys may be affected by recall and social desirability bias, however previous studies have supported the validity of self-reported contact survey data to reflect infection dynamics[21]. To reduce participant burden and increase retention in the survey, we elected to use monthly surveys with detailed reporting of activities over a one week period prior to the survey, with much less detailed reporting in weekly surveys. This allowed comprehensive recording of a wide range of activities conducted in different settings and by averaging results from monthly surveys provided a measure of exposure over that period. The surveys asked about activities in the week before the survey to minimise recall bias. Measures of exposure behaviour in the incubation period prior to infection could theoretically be obtained from weekly behavioural surveys, and may facilitate stronger causal interpretation, but was complicated by isolation restrictions whereby contacts of known cases reduced exposure to non-household activities in the period before infection. Also, as stated above, the weekly surveys had considerably less detail. A strength of the study is that we sought to obtain good ascertainment of SARS-CoV-2 infections through both self-reported and linked data on test results from the national testing system, which allowed ascertainment of infections. However, these will depend on testing behaviours which may vary across groups potentially introducing biases.

Results may be affected by residual confounding - given challenges with adjustment for multiple complex sociodemographic and behavioural factors – and recall bias given that surveys required retrospective recall. These biases may provide an alternate explanation for the protective effect of personal care activities. Surveys were also limited in detail to reduce participant burden, and consequently could not capture detail of protective behaviours (e.g., face coverings and hand hygiene) or risk-relevant environmental features (e.g., ventilation) during public activities.

Our comparison across the waves is subject to survivorship bias. Participants who died or suffered severe illness due to COVID-19 early in the pandemic could not or would be unlikely to contribute to activity analyses during the latter waves. However, as the overall proportion of these severe cases is low, this is unlikely to have had an important impact on findings. Our study may have been subject to selection bias whereby individuals who elect to be part of a research study examining associations between their activities and infection may have had different frequency of exposure to activities or differing self-protection behaviours such as mask wearing or hand washing than the general population. We partially addressed this through weighting PAFs to the national age structure of the population (accounting for the the older age structure of the Virus Watch population) but could not address other systematic differences in exposures in the cohort compared to the general population. For example, if Virus Watch contained a lower proportion of public transport users than the general public, then the proportion of infections attributed to public transport use within the cohort would likely be an underestimate of the proportion attributable to this exposure across the wider English population.

Conclusion and recommendations

We found that essential activities are the primary contributor to transmission during periods of stringent restrictions and that leisure and hospitality activities become increasingly important under periods of relaxed restrictions. The change in risk factors across the three periods of the pandemic through differing levels of national restrictions and resulting behaviour in England and Wales highlights the value of encouraging people to work from home, reduce public transport use and restrict visits to leisure and hospitality settings when the country was faced with a highly infectious virulent respiratory infection. Outdoor use of leisure and hospitality venues appeared to be safer than indoor use.

As population immunity has increased and the severity of COVID-19 has decreased, most countries have now moved to a phase of "living with Covid" with little or no restrictions. Improving ventilation in workplaces, hospitality and leisure venues may provide ongoing protection against transmission of COVID-19 and a range of other respiratory infections with minimal societal disruption.

In the event of the emergence or re-emergence of a highly transmissible respiratory infection with appreciable mortality, these findings support the value of advice/restrictions to work from home where possible, workplace mitigations for those who cannot work from home and advice/restrictions to avoid indoor usage of hospitality and leisure venues as effective approaches to reduce transmission and associated mortality.

Data availability

As the Virus Watch dataset contains sensitive health data as well as other sensitive personal information, the raw data cannot be published publicly at the individual level. Individual record-level (excluding any data or variables originating from linkage via NHS Digital) are available on the Office for National Statistics Secure Research Service (SRS) [https://ons.metadata.works/]. The data are available under restricted access and can be obtained by submitting a request directly to the SRS by searching for 'Virus Watch' and following the subsequent instructions.

Acknowledgements

We acknowledge the following members of the Virus Watch Collaborative: Susan Michie, Pia Hardelid, Linda Wijlaars, Eleni Nastouli, Moira Spyer, Ben Killingley, Ingemar Cox, Vasileios Lampos, Rachel A McKendry, Tao Cheng, Yunzhe Liu, Jo Gibbs, Richard Gilson, Anne M Johnson, Alison Rodger.

References

1. **Coronavirus: A history of English lockdown laws.** UK Government, House of Commons Library, published 22/12/2021, accessed 02/02/23.
   Reference Source
2. **Coronavirus timeline: Welsh and UK governments' response.** published 19/03/2020, updated 28/03/2022, accessed 02/02/23.
   Reference Source
3. **COVID-19 Response - Spring 2021 (Roadmap).** UK Government. accessed 02/02/23.
   Reference Source
4. **Prime Minister sets out plan to ease restrictions at step 4.** UK Government, accessed 02/02/23.
   Reference Source
5. Mendez-Brito A, El Bcheraoui C, Pozo-Martin F: **Systematic review of empirical studies comparing the effectiveness of non-pharmaceutical interventions against COVID-19.** *J Infect.* 2021; **83**(3): 281–293.
   PubMed Abstract | **Publisher Full Text** | **Free Full Text**
6. Chiesa V, Antony G, Wismar M, *et al.*: **COVID-19 pandemic: health impact of staying at home, social distancing and 'lockdown' measures-a systematic review of systematic reviews.** *J Public Health (Oxf).* 2021; **43**(3): e462–e481.
   PubMed Abstract | **Publisher Full Text** | **Free Full Text**
7. Palomino JC, Rodríguez JG, Sebastian R: **Wage inequality and poverty effects of lockdown and social distancing in Europe.** *Eur Econ Rev.* 2020; **129**: 103564.
   PubMed Abstract | **Publisher Full Text** | **Free Full Text**
8. Lin A, Vittinghoff E, Olgin J, *et al.*: **Predictors of incident SARS-CoV-2 infections in an international prospective cohort study.** *BMJ Open.* 2021; **11**(9): e052025.
   PubMed Abstract | **Publisher Full Text** | **Free Full Text**
9. Nash D, Rane MS, Chang M, *et al.*: **SARS-CoV-2 incidence and risk factors in a national, community-based prospective cohort of U.S. adults.** Version 2. *medRxiv.* Preprint. 2021.
   PubMed Abstract | **Publisher Full Text** | **Free Full Text**
10. Mehta SH, Clipman SJ, Wesolowski A, *et al.*: **Holiday gatherings, mobility and SARS-CoV-2 transmission: results from 10 US states following Thanksgiving.** *Sci Rep.* 2021; **11**(1): 17328.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
11. Clipman SJ, Wesolowski AP, Gibson DG, *et al.*: **Rapid Real-time Tracking of Nonpharmaceutical Interventions and Their Association With Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Positivity: The Coronavirus Disease 2019 (COVID-19) Pandemic Pulse Study.** *Clin Infect Dis.* 2021; **73**(7): e1822–e1829.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
12. Grant R, Charmet T, Schaeffer L, *et al.*: **Impact of SARS-CoV-2 Delta variant on incubation, transmission settings and vaccine effectiveness: Results from a nationwide case-control study in France.** *Lancet Reg Health Eur.* 2022; **13**: 100278.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
13. Munch P, Espenhain L, Hansen C, *et al.*: **Societal activities associated with SARS-CoV-2 infection: A case-control study in Denmark, November 2020.** *Epidemiol Infect.* 2022; **150**: E9.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
14. Leite A, Leão T, Soares P, *et al.*: **A Case-Control Study of Contextual Factors for SARS-CoV-2 Transmission.** *Front Public Health.* 2021; **9**: 772782.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
15. Munch PK, Espenhain L, Hansen CH, *et al.*: **Case-control study of activities associated with SARS-CoV-2 infection in an adult unvaccinated population and overview of societal COVID-19 epidemic counter measures in Denmark.** *PLoS One.* 2022; **17**(11): e0268849.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
16. Hayward A, Fragaszy E, Kovar J, *et al.*: **Risk factors, symptom reporting, healthcare-seeking behaviour and adherence to public health guidance: protocol for Virus Watch, a prospective community cohort study.** *BMJ Open.* 2021; **11**(6): e048042.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
17. Hoskins S, Beale S, Nguyen V, *et al.*: **Settings for non-household transmission of SARS-CoV-2 during the second lockdown in England and Wales - analysis of the Virus Watch household community cohort study [version 1; peer review: 2 approved].** *Wellcome Open Res.* 2022; **7**: 199.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
18. Hoskins S, Beale S, Nguyen V, *et al.*: **Relative contribution of essential and non-essential activities to SARS-CoV-2 transmission following the lifting of public health restrictions in England and Wales.** *Epidemiol Infect.* 2023; **151**: E3.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**
19. ONS: **Population estimates for the UK, England and Wales, Scotland and Northern Ireland: mid-2020.**
    Reference Source
20. Beale S, Hoskins S, Byrne T, *et al.*: **Differential Risk of SARS-CoV-2 Infection by Occupation: Evidence from the Virus Watch prospective cohort study in England and Wales.** *medRxiv.* 2021; **11**(6).
    Publisher Full Text
21. Tomori DV, Rübsamen N, Berger T, *et al.*: **Individual social contact data and population mobility data as early markers of SARS-CoV-2 transmission dynamics during the first wave in Germany—an analysis based on the COVIMOD study.** *BMC Med.* 2021; **19**(1): 271.
    PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Open Peer Review

Current Peer Review Status: ? ✔ ? ?

Version 1

Reviewer Report 15 September 2024

https://doi.org/10.3310/nihropenres.14581.r30945

? **Benjamin Wachtler**
Department of Epidemiology and Health Monitoring, Robert Koch Institute, Berlin, Germany

Overall:
Thank you for giving me the opportunity to read and comment on this interesting research paper. The present study used data from the Virus Watch Community Cohort Study in England and Wales and aimed to investigate how work, public transport, shopping and hospitality and leisure activities contributed to SARS-CoV-2 infection risk during different periods with different public health restrictions. It thereby aims to assess the effectiveness of different public health interventions across different periods of the pandemic. Odds Ratios (OR) from multivariate logistic regression models and adjusted populations attributable fractions (aPAF) were estimated. Overall, the manuscript is well written and uses appropriate methods. I appreciate that the study aims to investigate the time varying effects of different activities by using high quality data and think that the research question is interesting and the results are still timely and needed for further debates around pandemic preparedness. However, I have some questions and comments that I would ask the authors to address to further improve their study and to reduce ambiguities.

1. It remains unclear what epidemiological design was used here. The authors used data from the Virus Watch Study for three different time periods. It remains unclear if the individuals may occur in several of these periods or only in one time period. Please indicate how many of the participant of each time period were the same or if these were different individuals. A explaining figure might help here. Please give at least short information about the sampling strategy, drop-outs and systematic non-response and how this might have affected the results and how these issues were handled.
2. If these three samples were independent samples, they should be described separately like it is done in table 1. Are there individual level information about socioeconomic position (SEP) available? Further information about the sociodemographic composition of the sample are desirable as we know, that SEP is a strong and time dependent predictor of SARS-CoV-2 infection. This is not mentioned in the manuscript but should be at least discussed. In addition, we know that the infection risk of different occupations changed between different periods of the pandemic, e.g. health care worker had a very high infection risk at the beginning of the pandemic that later was reduced by the introduction of sufficient personal protection equipment and vaccinations and during later phases of the pandemic

e.g. construction worker had a higher infection risk. Please indicate how changing distributions of occupations between the samples might have infected your results.
3. To calculate PAFs is an interesting approach here but the underlying strong assumption of causality should be further discussed in this context. I have some doubts that causality can be assumed here. Please describe in more detail the approach that was used to calculate PAF.
4. I was wondering why you decided to calculate OR instead of using all available information of your data and calculate incidence rate ratios? Wouldn't this be the 'gold standard' for assessing relative risks? Please explain your rationale and the potential limitations of this approach in more detail.
5. Please provide the reader with the DAG that was used to identify the adjustment set of the analyses (e.g. as supplementary material). The role of age in your analyses still remains unclear and I believe you should stratify the analyses by age to further explore the role of age in your study. In this context, please give the reader more background about the role of participants' SEP. What was the rationale to include area level deprivation as a confounding variable? You are arguing that age is reflected by its affects on social behaviour. The same holds true for the SEP. We know that compliance with public health interventions is associated with SEP as well as infection risk and the possibility to reduce work-related and non-work-related physical contacts. I am missing a discussion of these questions in this paper.
6. Table 3 and table 4: I was wondering how the estimates given here were derived? Are all these estimates from one model? How do you rule out table II fallacy here? (Westreich D, Greenland S, 2013 [Ref-1])

In detail:
Title: The title appears to be very long. Is there the possibility to formulate a more concise title?
Fig 1 and Fig. 2 Both figures should include information about the adjustment sets used for the calculation in order to be interpretable without referring to the main text
Discussion:
The discussion about the reduced importance of occupation as driver of infection risk in later waves of the pandemic should be discussed in more detail here. What may have driven this reduction in importance and what does this mean for public health interventions and pandemic preparedness?

References
1. Westreich D, Greenland S: The table 2 fallacy: presenting and interpreting confounder and modifier coefficients.*Am J Epidemiol*. 2013; **177** (4): 292-8 PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Social Epidemiology, Health Inequalities in COVID-19, Public Health

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 15 September 2024

https://doi.org/10.3310/nihropenres.14581.r31022

?

Larese Filon Francesca
Department of Medical Sciences, Universita degli Studi di Trieste, Trieste, Friuli-Venezia Giulia, Italy

The paper analyses factors associated to COVID-19 in a cohort of population during 2020-2021-2022. The paper is valuable; methods and statistical analysis are strong and well done. It deserve indexing. I suggest some improvements-

1. Please specify in the tables the 3 periods considered to increase readability
2. M&M please explain better the periods used for analysis: it is not clear to the reader
3. Effect of vaccination: would be interesting to discuss why the paper fails to find a protective effect for vaccination in the second period considered
4. I suggest to specify the number of doses of vaccine done in table 1 and to specify how many doses were considered as “vaccinates status yes” in the adjustment.
5. Did you consider the time of vaccination in relation to infections? I suggest to specify that in M&M section

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology of COVID-19 in workers

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 08 January 2024

https://doi.org/10.3310/nihropenres.14581.r30771

Tsz Ho Kwan
[1] Stanley Ho Centre for Emerging Infectious Diseases, The Chinese University of Hong Kong, Hong Kong, Hong Kong
[2] Jockey Club School of Public Health and Primary Care, The Chinese University of Hong Kong, Hong Kong, Hong Kong

This study used the data collected from monthly household surveys in England and Wales to quantify the role of various activities in SARS-CoV-2 infection. The authors estimated and compared the activities' contributions to transmission across the three periods. The paper was well written, the methods were well constructed, and the discussion was supported by the results. This paper reflected the necessity of the stringent policies in place and the effects of lifting such restrictions. While the results were within expectations, it highlighted the importance of using household surveys to collect and evaluate the transmission risk of respiratory pathogens.

There are some minor queries:
- It was noted that the periods of data inclusion were of different lengths. Would this affect the results?
- The periods of infection data were inconsistent as well. For the first period, there was a two-month period after the survey; the period became less than a month for the second period; and it

was 0 day for the third period (30 March 2022). How would this affect the fair comparison and the results?
- Would the authors confirm if the starting date of the infection data collection period 2 months earlier than the first period's survey period? It was noted that the recall period of the monthly survey was one month.
- Interpreting insignificant results should be cautioned (page 13 on the PAFs, and page 14 on bus use).
- It was noted age modified the importance of various types of activities, a stratified analysis may be useful to determine the effect across age groups. I might have missed the results but there was a discussion on this (page 17 second column second paragraph).

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: infectious diseases epidemiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 08 January 2024

https://doi.org/10.3310/nihropenres.14581.r30943

?

Mario Coccia
IRCRES-CNR, Turin Research Area of the National Research Council, National Research Council of

Italy, Torino, Italy

The changing contributory role to infections of work, public transport, shopping, hospitality and leisure activities throughout the SARS-CoV-2 pandemic in England and Wales

The topics of this paper are interesting, though well known. The structure and content must be revised, and results have to be better explained by authors before to be reconsidered for publication.

Title has to be shorter, but to indicate the period such as 2020-2021, etc.

Abstract has to clarify the goal and health and social policy implications to face next health emergencies.

Introduction has to better clarify the research questions of this study and provide more theoretical background. Authors have to better describe the different sources of transmission dynamics of COVID-19 (e.g., climate, air pollution, density, mobility, trade, etc.) and risk factors in society, which can accelerate diffusion of this novel coronavirus in environment, and after that they can focus on the topics of this study to provide a correct analysis for fruitful analysis and discussion (See suggested readings that must be all read and used in the text).

Methods of this study has to be better systematize. The section of Materials and methods must be re-structured with following three sections to be clear:

- Sample and data
- Measures of variables. They have to be well clarified how they are normalized.
- Models and Data analysis procedure.

Authors have to avoid a lot of subheadings that create fragmentation and confusion. If necessary, can use bullet points (same comments for section of results and all sections).

Results.
The paper has a lot of long and full tables that are difficult to digest, some of them can be put in appendix and inserting in the text the most important ones to improve the readability…

An aspect that is not clear is if these people infected are or not vaccinated. Only infections is a partial analysis, fatality rates also matters, for a complementary and robust analysis.

Results seem to be relevant but representation with figure 1 and 2 do not show the really effective differences under and after the removal of restrictions. Moreover, the level of infections alone is not sufficient, it should be associated with fatality rates considering an appropriate time lag from infection. We know that Omicron has a high rate of infections but mortality is lower than Delfa variants. Results have to be better clarified.

A main aspect to clarify is that transmission dynamics is associated with density of people, mainly in urban contexts. Wales and England have different density and different cities of large size. It is not clear how data are normalized for comparative analyses and if they refer to urban or rural contexts. These differences should be clarified for better implications.
All tables and figures have to indicate the period under study.

Discussion.
First, authors have to synthesize the main results in a simple table to be clear for readers and then show what this study adds compared to other studies. Now reading the long description, reader loses and does not catch the difference of infections with and without restriction.

To reiterate remove sub-headings that create a lot of fragmentation. Results have to be better explained also considering density of cities under study, level of pollution, duration of restrictions, etc. Now many factors of transmission dynamics are not discussed and reduce the value of this contribution for policy implications.

Conclusion has not to be a summary, but authors have to focus on manifold limitations of this study (moving here previous section) and provide suggestions of health, crisis management and social policy, as well as how nations can prevent and manage next pandemics, with good governance, with timely nonpharmaceutical measures of control and vaccination plans.

Overall, then, the paper is interesting, but many results well known. Theoretical framework is weak, and some results create confusion… structure of the paper has to be improved; study design, discussion and presentation of results have to be clarified using suggested comments.

To be clear, I strongly suggest improving the paper, by using all comments (suggested papers included to read and use all) that I will in-depth verify, and maybe it can be considered.

Suggested readings of relevant papers that have to be read and all inserted in the text and references.

Benati I.,Coccia M. 2022. Effective Contact Tracing System Minimizes COVID-19 Related Infections and Deaths: Policy Lessons to Reduce the Impact of Future Pandemic Diseases. Journal of Public Administration and Governance, vol. 12, n. 3, pp. 19-33. DOI: https://doi.org/10.5296/jpag.v12i3.19834

Ball P (2021) What the COVID-19 pandemic reveals about science, policy and society. Interface Focus 11:20210022. https:// doi. org/10. 1098/ rsfs. 2021. 0022

Coccia M. 2023. Sources, diffusion and prediction in COVID-19 pandemic: lessons learned to face next health emergency[J]. AIMS Public Health, 2023, 10(1): 145-168. doi: 10.3934/publichealth.2023012

Anttiroiko A-V (2021) Successful government responses to the pandemic: contextualizing national and urban responses to the COVID-19 outbreak in east and west. Int J E-Plan Res (IJEPR),IGI Global 10(2):1–17

Coccia M. 2022. Preparedness of countries to face COVID-19 pandemic crisis: Strategic positioning and underlying structural factors to support strategies of prevention of pandemic threats, Environmental Research, Volume 203, n. 111678, https://doi.org/10.1016/j.envres.2021.111678.

Núñez-Delgado A., Bontempi E., Coccia M., Kumar M., Farkas K., Domingo, J. L. 2021. SARS-CoV-2 and other pathogenic microorganisms in the environment, Environmental Research, Volume 201, n. 111606, https://doi.org/10.1016/j.envres.2021.111606.

Allen DW (2022) COVID-19 lockdown cost/benefits: a critical assessment of the literature. Int J Econ Bus 29(1):1–32. https:// doi. org/10. 1080/ 13571 516. 2021. 19760 51

Coccia M. 2021. The impact of first and second wave of the COVID-19 pandemic: comparative analysis to support control measures to cope with negative effects of future infectious diseases in society. Environmental Research, vol. 197, June, n. 111099, https://doi.org/10.1016/j.envres.2021.111099

Askitas, N., Tatsiramos, K., Verheyden, B. 2021. Estimating worldwide effects of non-pharmaceutical interventions on COVID-19 incidence and population mobility patterns using a multiple-event study (Open Access)(2021) Scientific Reports, 11 (1), art. no. 1972.

Coccia M. (2020). Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. The Science of the total environment, 729, 138474. https://doi.org/10.1016/j.scitotenv.2020.138474

Jamison JC, Bundy D, Jamison DT, Spitz J, Verguet S (2021) Comparing the impact on COVID-19 mortality of self-imposed behavior change and of government regulations across 13 countries. Health Serv Res 56(5):874–884. https:// doi. org/ 10. 1111/ 1475- 6773. 13688

Bontempi E., Coccia M., Vergalli S., Zanoletti A. 2021. Can commercial trade represent the main indicator of the COVID-19 diffusion due to human-to-human interactions? A comparative analysis between Italy, France, and Spain, Environmental Research, vol. 201, Article number 111529, https://doi.org/10.1016/j.envres.2021.111529

Khandia R, Singhal S, Alqahtani T, Kamal MA, El-Shall NA, Nainu F, Desingu PA, Dhama K (2022) Emergence of SARS-CoV-2 Omicron (B.1.1.529) variant, salient features, high global health concerns and strategies to counter it amid ongoing COVID-19 pandemic. Environ Res 209:112816. https:// doi. org/ 10. 1016/j.envres. 2022. 112816

Coccia M. 2022. COVID-19 pandemic over 2020 (with lockdowns) and 2021 (with vaccinations): similar effects for seasonality and environmental factors. Environmental Research, Volume 208, 15 May 2022, n. 112711. https://doi.org/10.1016/j.envres.2022.112711

Diao, Y., Kodera, S., Anzai, D., (...), Rashed, E.A., Hirata, A. 2021. Influence of population density, temperature, and absolute humidity on spread and decay durations of COVID-19: A comparative study of scenarios in China, England, Germany, and Japan, One Health, 12,100203

Coccia M. 2021. Pandemic Prevention: Lessons from COVID-19. Encyclopedia, vol. 1, n. 2, pp. 433-444. doi: 10.3390/encyclopedia1020036

Mahmoudi J, Xiong C (2022) How social distancing, mobility, and preventive policies affect COVID-19 outcomes: big data-driven evidence from the District of Columbia-Maryland-Virginia (DMV) megaregion. PLoS One 17(2):e0263820. https:// doi. org/ 10. 1371/journ al. pone. 02638 20

Coccia M. 2021. High health expenditures and low exposure of population to air pollution as critical factors that can reduce fatality rate in COVID-19 pandemic crisis: a global analysis.

Environmental Research, vol. 199, Article number 111339, https://doi.org/10.1016/j.envres.2021.111339

Qiu Z, Cao Z, Zou M, (...), Wang D, Du X (2022) The effectiveness of governmental nonpharmaceutical interventions against COVID-19 at controlling seasonal influenza transmission: an ecological study. BMC Infect Dis 22(1):331

Coccia M. 2023. Effects of strict containment policies on COVID-19 pandemic crisis: lessons to cope with next pandemic impacts. Environmental science and pollution research international, 30(1), 2020–2028. https://doi.org/10.1007/s11356-022-22024-w

Wieland T (2020) A phenomenological approach to assessing the effectiveness of COVID-19 related nonpharmaceutical interventions in Germany. Saf Sci 131:104924

Coccia M. 2022. COVID-19 Vaccination is not a Sufficient Public Policy to face Crisis Management of next Pandemic Threats. Public Organization Review, https://doi.org/10.1007/s11115-022-00661-6

Wood SN (2021) Inferring UK COVID-19 fatal infection trajectories from daily mortality data: were infections already in decline before the UK lockdowns? Biometrics. https://doi.org/10.1111/biom.13462.doi:10.1111/biom.13462

Coccia M. 2022. Improving preparedness for next pandemics: Max level of COVID-19 vaccinations without social impositions to design effective health policy and avoid flawed democracies. Environmental Research, vol. 213, n. 113566. https://doi.org/10.1016/j.envres.2022.113566

Zhu P, Tan X (2022) Evaluating the effectiveness of Hong Kong's border restriction policy in reducing COVID-19 infections. BMC Public Health 22(1):803

References

1. Benati I, Coccia M: Effective Contact Tracing System Minimizes COVID-19 Related Infections and Deaths: Policy Lessons to Reduce the Impact of Future Pandemic Diseases. *Journal of Public Administration and Governance*. 2022; **12** (3). Publisher Full Text
2. Ball P: What the COVID-19 pandemic reveals about science, policy and society.*Interface Focus*. 2021; **11** (6): 20210022 PubMed Abstract | Publisher Full Text
3. Coccia M: Sources, diffusion and prediction in COVID-19 pandemic: lessons learned to face next health emergency.*AIMS Public Health*. 2023; **10** (1): 145-168 PubMed Abstract | Publisher Full Text
4. Anttiroiko A: Successful Government Responses to the Pandemic. *International Journal of E-Planning Research*. 2021; **10** (2): 1-17 Publisher Full Text
5. Coccia M: Preparedness of countries to face COVID-19 pandemic crisis: Strategic positioning and factors supporting effective strategies of prevention of pandemic threats.*Environ Res*. 2022; **203**: 111678 PubMed Abstract | Publisher Full Text
6. Núñez-Delgado A, Bontempi E, Coccia M, Kumar M, et al.: SARS-CoV-2 and other pathogenic microorganisms in the environment. *Environmental Research*. 2021; **201**. Publisher Full Text
7. Allen D: Covid-19 Lockdown Cost/Benefits: A Critical Assessment of the Literature. *International Journal of the Economics of Business*. 2022; **29** (1): 1-32 Publisher Full Text
8. Coccia M: The impact of first and second wave of the COVID-19 pandemic in society: comparative analysis to support control measures to cope with negative effects of future infectious diseases.*Environ Res*. 2021; **197**: 111099 PubMed Abstract | Publisher Full Text

9. Askitas N, Tatsiramos K, Verheyden B: Estimating worldwide effects of non-pharmaceutical interventions on COVID-19 incidence and population mobility patterns using a multiple-event study.*Sci Rep*. 2021; **11** (1): 1972 PubMed Abstract | Publisher Full Text
10. Coccia M: Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID.*Sci Total Environ*. 2020; **729**: 138474 PubMed Abstract | Publisher Full Text
11. Jamison JC, Bundy D, Jamison DT, Spitz J, et al.: Comparing the impact on COVID-19 mortality of self-imposed behavior change and of government regulations across 13 countries.*Health Serv Res*. 2021; **56** (5): 874-884 PubMed Abstract | Publisher Full Text
12. Bontempi E, Coccia M, Vergalli S, Zanoletti A: Can commercial trade represent the main indicator of the COVID-19 diffusion due to human-to-human interactions? A comparative analysis between Italy, France, and Spain.*Environ Res*. 2021; **201**: 111529 PubMed Abstract | Publisher Full Text
13. Khandia R, Singhal S, Alqahtani T, Kamal M, et al.: Emergence of SARS-CoV-2 Omicron (B.1.1.529) variant, salient features, high global health concerns and strategies to counter it amid ongoing COVID-19 pandemic. *Environmental Research*. 2022; **209**. Publisher Full Text
14. Coccia M: COVID-19 pandemic over 2020 (withlockdowns) and 2021 (with vaccinations): similar effects for seasonality and environmental factors.*Environ Res*. 2022; **208**: 112711 PubMed Abstract | Publisher Full Text
15. Diao Y, Kodera S, Anzai D, Gomez-Tames J, et al.: Influence of population density, temperature, and absolute humidity on spread and decay durations of COVID-19: A comparative study of scenarios in China, England, Germany, and Japan.*One Health*. 2021; **12**: 100203 PubMed Abstract | Publisher Full Text
16. Coccia M: Pandemic Prevention: Lessons from COVID-19. *Encyclopedia*. 2021; **1** (2): 433-444 Publisher Full Text
17. Hippmann AA, Schuback N, Moon KM, McCrow JP, et al.: Proteomic analysis of metabolic pathways supports chloroplast-mitochondria cross-talk in a Cu-limited diatom.*Plant Direct*. 2022; **6** (1): e376 PubMed Abstract | Publisher Full Text
18. Coccia M: High health expenditures and low exposure of population to air pollution as critical factors that can reduce fatality rate in COVID-19 pandemic crisis: a global analysis.*Environ Res*. 2021; **199**: 111339 PubMed Abstract | Publisher Full Text
19. Qiu Z, Cao Z, Zou M, Tang K, et al.: The effectiveness of governmental nonpharmaceutical interventions against COVID-19 at controlling seasonal influenza transmission: an ecological study.*BMC Infect Dis*. 2022; **22** (1): 331 PubMed Abstract | Publisher Full Text
20. Coccia M: Effects of strict containment policies on COVID-19 pandemic crisis: lessons to cope with next pandemic impacts.*Environ Sci Pollut Res Int*. 2023; **30** (1): 2020-2028 PubMed Abstract | Publisher Full Text
21. Wieland T: A phenomenological approach to assessing the effectiveness of COVID-19 related nonpharmaceutical interventions in Germany.*Saf Sci*. 2020; **131**: 104924 PubMed Abstract | Publisher Full Text
22. Coccia M: COVID-19 Vaccination is not a Sufficient Public Policy to face Crisis Management of next Pandemic Threats. *Public Organization Review*. 2023; **23** (4): 1353-1367 Publisher Full Text
23. Wood SN: Inferring UK COVID-19 fatal infection trajectories from daily mortality data: Were infections already in decline before the UK lockdowns?. *Biometrics*. 2022; **78** (3): 1127-1140 PubMed Abstract | Publisher Full Text
24. Coccia M: Improving preparedness for next pandemics: Max level of COVID-19 vaccinations without social impositions to design effective health policy and avoid flawed democracies.*Environ Res*. 2022; **213**: 113566 PubMed Abstract | Publisher Full Text

25. Zhu P, Tan X: Evaluating the effectiveness of Hong Kong's border restriction policy in reducing COVID-19 infections.*BMC Public Health*. 2022; **22** (1): 803 PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: COVID-19 pandemic crisis, crisis management, pandemic prevention, Infectious diseases, epidemiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.