Public Health 198 (2021) 273–279

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Association between overcrowded households, multigenerational households, and COVID-19: a cohort study

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ARTICLE INFO

Article history:
Received 6 April 2021
Received in revised form
11 July 2021
Accepted 24 July 2021
Available online 3 August 2021

Keywords:
COVID-19
Housing
Spatial analysis
Bayesian

ABSTRACT

Objectives: The role of overcrowded and multigenerational households as a risk factor for COVID-19 remains unmeasured. The objective of this study is to examine and quantify the association between overcrowded and multigenerational households and COVID-19 in New York City (NYC).
Study design: Cohort study.
Methods: We conducted a Bayesian ecological time series analysis at the ZIP Code Tabulation Area (ZCTA) level in NYC to assess whether ZCTAs with higher proportions of overcrowded (defined as the proportion of the estimated number of housing units with more than one occupant per room) and multigenerational households (defined as the estimated percentage of residences occupied by a grandparent and a grandchild less than 18 years of age) were independently associated with higher suspected COVID-19 case rates (from NYC Department of Health Syndromic Surveillance data for March 1 to 30, 2020). Our main measure was an adjusted incidence rate ratio (IRR) of suspected COVID-19 cases per 10,000 population. Our final model controlled for ZCTA-level sociodemographic factors (median income, poverty status, White race, essential workers), the prevalence of clinical conditions related to COVID-19 severity (obesity, hypertension, coronary heart disease, diabetes, asthma, smoking status, and chronic obstructive pulmonary disease), and spatial clustering.
Results: 39,923 suspected COVID-19 cases were presented to emergency departments across 173 ZCTAs in NYC. Adjusted COVID-19 case rates increased by 67% (IRR 1.67, 95% CI = 1.12, 2.52) in ZCTAs in quartile four (versus one) for percent overcrowdedness and increased by 77% (IRR 1.77, 95% CI = 1.11, 2.79) in quartile four (versus one) for percent living in multigenerational housing. Interaction between both exposures was not significant ($\beta_{interaction} = 0.99$, 95% CI: 0.99–1.00).
Conclusions: Overcrowdedness and multigenerational housing are independent risk factors for suspected COVID-19. In the early phase of the surge in COVID cases, social distancing measures that increase house-bound populations may inadvertently but temporarily increase SARS-CoV-2 transmission risk and COVID-19 disease in these populations.

Introduction

The COVID-19 pandemic has exposed striking health-related disparities in minority populations in the United States. Studies have highlighted disparities in COVID-19 testing, morbidity, and mortality between non-Hispanic Whites, non-Hispanic Blacks, and Hispanic Americans in both health care[1,2] and community settings.[3–6] Existing well-described disparities in health status, access to healthcare, and other social determinants may account for these differences. Furthermore, a growing body of evidence suggests that socio-economic factors (such as 'essential worker' status) may play a major role in the risk of acquiring SARS-CoV-2 infection and differential morbidity and mortality from COVID-19.[1,3,4] To date, however, the role of overcrowding and household composition on the transmission of SARS-CoV2 and diagnosis of COVID-19 remains poorly understood.

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https://doi.org/10.1016/j.puhe.2021.07.039
0033-3506/

The evolving science informing the transmission dynamics of SARS-CoV2 suggests that both proximities to infected patients[7,8] and concentration of inoculum[9] may play an important role in both acquisition of infection and subsequent severity of illness.[10,11] In particular, individuals residing in overcrowded and multigenerational households may be at increased risk of developing more severe forms of COVID-19,[12] since these settings reduce personal space and increase the risk of multiple exposures to a high inoculum of SARS-CoV-2 infection.[11,13]

In this study, we investigated whether ZIP code tabulation areas (ZCTA) with a higher percentage of overcrowded or multigenerational households represented independent risk factors for severe COVID-19 after accounting for other area-level socio-economic, clinical, and spatiotemporal factors. We defined severe COVID-19 as patients presenting to the emergency department with suspected COVID-19-like symptoms.

Methods

Study setting

We conducted a retrospective ZCTA-level time series analysis of daily suspected emergency department-presenting COVID-19 cases per 10,000 total population in each ZCTA in NYC in March 2020. Beginning in late February 2020, NYC became the global epicenter of the COVID-19 pandemic, with a first wave that crested in early April 2020. We chose to limit our analysis to March 2020 because we hypothesized that the role of multigenerational households and household overcrowdedness would be greatest at the start of the first wave of the COVID-19 pandemic in NYC both before and after the imposition of social distancing measures.

Variables and data sources

The dependent variable was the daily count by ZCTA of suspected COVID-19 cases presenting to one of the 53 hospital emergency departments in NYC. These data were obtained from the NYC Department of Health and Mental Hygiene (NYC DOHMH) Syndromic Surveillance system, which contains suspected COVID-19 cases for 173 ZCTAs. Suspected COVID-19 cases were defined as cases of pneumonia and influenza-like illness that appeared after the 2019–20 influenza season had ended (based on laboratory analysis, in February 2020).[14] This study used surveillance-based suspected cases rather than test-positive COVID-19 cases for two reasons: first, there was potentially vast undertesting for COVID-19 early in the pandemic in New York City, and second, daily test-positive COVID-19 case counts by residential ZCTA were not available. All data were obtained up to March 30, 2020.

The two exposure variables included jointly in the model were: (1) the percentage of overcrowded housing by ZCTA, defined as the estimated number of housing units with more than one occupant per room, divided by the number of occupied housing units; and (2) the percentage of multigenerational housing by ZCTA, defined as the estimated percentage of residences occupied by a grandparent and a grandchild less than 18 years of age. Both were obtained from the American Community Survey 5-year 2018 estimates. Both exposures were segmented into quartiles, with the first quartile (representing the least overcrowded or lowest proportion of multigenerational households) as reference.

Several socio-economic factors have been reported to be associated with a greater risk of COVID-19 infection and severity. These include factors related to lower socio-economic status such as lower median income,[1] minority status,[2] lack of health insurance,[5] population density,[15,16] and an individual's role as an essential worker.[17] To account for these associations in ecological analysis, we controlled for ZCTA-level estimates of the total population, percentage of patients living below the federal poverty line (FPL), median income, population density (calculated as ZCTA population divided by ZCTA area in square miles), percentage of White residents, and percentage of essential workers by ZCTA. The percentage of essential workers by ZCTA was calculated by replicating a method employed by the NYC Office of the Comptroller.[17] The proportion of essential workers in each ZCTA was identified from service-oriented non-public roles using Census Industrial Classification Codes in the following categories: (1) public transit workers; (2) grocery, convenience, and drug store workers; (3) trucking, warehouse, and postal service workers; (4) healthcare workers; (5) childcare, homeless, food and family service workers; and 6) building cleaning service workers.

The model also controlled for clinical factors identified by the U.S. Centers for Disease Control and Prevention (CDC) that increase the risk for developing more severe COVID-19 illness.[18] ZCTA-level data on COVID-19 disease clinical risk factors were obtained and derived from the CDC 500 Cities dataset 2016–2017. These included the percentage of obese adults (defined as body mass index [BMI] $\geq$ 30 kg/m^2), percentage of adults who smoke, and percentage of adults with coronary heart disease, hypertension, diabetes, asthma, or chronic obstructive pulmonary disease (COPD).

In order to undertake descriptive and inferential spatial analyses, spatial shapefiles of NYC's ZCTAs were downloaded and derived from the New York City Department of City Planning.[4]

Statistical analysis

Visual depictions of the suspected severe COVID-19 cases by ZCTA, percent of overcrowded households, and percent of multigenerational households were created using QGIS software. We used Moran's I[19] to formally assess spatial clustering of suspected severe COVID-19 cases, for which the null hypothesis is that suspected COVID-19 cases were randomly dispersed across the city.

To evaluate the average effect of household overcrowdedness and multigenerational households on suspected COVID-19 cases within each ZCTA, we first used a generalized linear model specifying a Poisson distribution for the dependent variable (using quasi-likelihood estimation to account for overdispersion) and robust standard errors. The model included daily time fixed effects, and suspected case counts by ZCTA were interpolated to account for the end-of-week variation in cases. All models used the population of individuals residing in each ZCTA as the population offset, with results interpreted as incidence rate ratios (IRR). To assess the robustness of the percent overcrowdedness and percent multigenerational households within each ZCTA as independent risk factors, we added the aforementioned control variables, which reflected reported ZCTA-level socio-economic associations with COVID-19 exposure and clinical risk of COVID-19 severity, to a baseline model that consisted of an intercept term, the two exposure variables, and time in days. Variance inflation factors (VIF) were used to assess for multicollinearity, and covariates with VIF > 10 were dropped sequentially. Furthermore, statistically, non-significant models were also dropped. The variables dropped from the final, adjusted analysis were population density, the prevalence of chronic obstructive pulmonary disease, diabetes, and hypertension at the ZCTA-level.

Upon finding that there was significant spatial autocorrelation in our dependent variable (Moran's I: 0.456, $P = 0.001$), we then fit a Bayesian version of our quasi-Poisson model using the integrated nested Laplace approximation (INLA) method, a computationally efficient way of fitting models to data exhibiting spatial or temporal structure. This method, described by Blangiardo et al.,[20] models the variation in the dependent variable using a spatially structured

random effects term that accounts for local geographic influences indicated by the Moran's I. This random effects term follows a conditional autoregressive model, meaning that the random variation in a ZCTA's suspected COVID-19 case counts is modeled as the mean of the random effect terms for the adjacent ZCTAs. The temporal structure is accounted for in the model by both fixed and random effects. The temporal random effect is modeled by a random walk, which assumes that a ZCTA's suspected case count at time t in days is equal to the case count at time t-1 plus some amount of random noise that is normally distributed with mean 0.

The final, fully adjusted model used the INLA method and treated the number of suspected COVID-19 cases in each ZCTA as a Poisson-distributed variable. The model consisted of a population offset; the two exposure variables (percent of overcrowdedness by ZCTA, and percent of multigenerational households by ZCTA); ZCTA-level prevalence (defined as a percentage) of coronary heart disease, obesity (defined as BMI $\geq$ 30 kg/m^2), and smoking; percent white; percent below the FPL; the proportion of essential workers; and median income (defined in 2018 dollars). Coefficient results in the INLA model are presented with 95% Bayesian credible intervals. We assessed whether there was effect modification between the two exposures using an interaction term in the final fully adjusted model; the interaction term was not significant ($\beta_{interaction} = 0.99$, 95% credible interval: 0.99–1.00). Model outputs for all preceding models can be found in the Supplement.

The study protocol was approved by the [withheld for review] Institutional Review Board. All analyses were conducted in GeoDa version 1.16, QGIS version 3.16.2, and R version 4.0.3. Code to reproduce the analyses is available at: https://github.com/sara-venkatraman/NYC-Housing-COVID19.

Results

Descriptive statistics

There were 39,923 suspected severe COVID-19 cases across 173 ZCTAs in NYC between March 1 and March 30, 2020. Fig. 1 shows the proportion of overcrowded and multigenerational households in ZCTAs in NYC. The median proportion of overcrowded households by ZCTA was 5.06% (interquartile range [IQR] 4.68%), and the median proportion of multigenerational households by ZCTA was 6.88% (IQR 5.96%). Three of the top five ZCTAs in terms of cumulative suspected COVID-19 cases (11,368, 11,373, and 11,208 – all found in the borough of Queens) were also in the top five ZCTAs in terms of percentage of overcrowdedness. The five ZCTAs with the highest proportion of multigenerational households were 11,411, 11,412, 11,419, 11,413, and 11,429 – also found in Queens (see Fig. 1).

Table 1 reports how, at a ZCTA-level, the prevalence of COVID-19 clinical risk factors and associated socio-economic factors vary across quartiles of multigenerational households and overcrowded households. Compared to the first quartile, suspected severe COVID-19 cases rose almost four-fold in the fourth quartile of ZCTAs with multigenerational households and almost six-fold for overcrowded households. As the proportion of overcrowded households and multigenerational households rose by ZCTA in quartiles, there was a consistent increase in the prevalence of diabetes and smoking, as well as the proportion of residents living below the FPL, while there was a consistent decline in the proportion of White residents and median income.

Results from the multivariable models

Table 2 reports the results of the unadjusted and fully adjusted analysis. Controlling for both COVID-19 clinical risk factors and socio-economic characteristics, which may increase the risk of COVID-19 exposure, ZCTAs in the fourth quartile of percent overcrowdedness had a 67% increased risk of suspected severe COVID-19 cases compared to the first quartile (IRR 1.67, 95% CI = 1.12–2.52). Similarly, ZCTAs found in the fourth quartile of percent multigenerational households had a 77% increased risk of suspected severe COVID-19 cases compared to the first quartile (IRR 1.77, 95% CI = 1.11–2.79). Across both exposures, the case risk increased for each quartile, as noted in Fig. 2A and B, which compare the observed suspected severe COVID-19 case rates with modeled rates.

Discussion

In this ecological analysis of COVID-19 in NYC in March 2020, we found that ZCTAs with higher proportions of overcrowded and multigenerational households were associated with increased rates of suspected severe COVID-19 cases, after accounting for both socio-economic factors, which may increase the risk of infection with SARS-CoV-2 and clinical factors that may lead to more severe COVID-19 disease.

While several studies describe the role overcrowdedness may play as a risk factor for contracting COVID-19, this study is the first to establish the independent relationship between overcrowded households, multigenerational households, and suspected severe COVID-19 disease while adjusting for area-level socio-economic and clinical characteristics. In a national dataset of county-level data, Ahmad et al. found that counties with higher proportions of poorer housing conditions (including overcrowding, high housing cost, or incomplete kitchen or plumbing facilities) had up to 50% higher risk of COVID-19 incidence in adjusted analyses.[12] In NYC specifically, Emeruwa et al. found overcrowded housing to be an independent risk factor in a cohort of obstetric patients admitted for care during the COVID-19 surge.[12] On the other hand, the role of multigenerational housing in the propagation of COVID-19 in the general population has been unclear. Anecdotal data exists,[21–23] and the role of multigenerational housing has been suggested in the media as a potential accelerant in the spread of COVID-19, placing the elderly at risk.[24] However, no study to date has quantitatively examined this potential risk factor. Since our analysis modeled both the proportions of overcrowdedness and multigenerational households simultaneously, our findings suggest that multigenerational households are independently associated with higher rates of suspected COVID-19 infection and that this risk is independent of and roughly equivalent to that of overcrowding alone.

The results have notable scientific and clinical implications. First, by demonstrating a relationship between COVID-19 case rates and area-level measures of overcrowded and multigenerational housing, these findings may partly illustrate socioecological mechanisms that link observed inequities in COVID-19 related outcomes with the known biology of infectivity. Stark COVID-19-related racial/ethnic differences in mortality and morbidity exist, and data suggest that prehospitalization factors contribute to these differences.[1,25] Although not addressed in our analysis, racial/ethnic differences in residential crowdedness and multigenerational households may play a role in COVID-19-related disparities in addition to that of essential workers. Since racial/ethnic and socio-economic differences in multigenerational households exist, the association between multigenerational households and suspected COVID-19 case rates in our analysis may help to explain related disparities in COVID illness burden seen both in NYC and across the United States.[26]

Second, these results support recent developments in our understanding of the transmission dynamics of COVID-19. Our primary outcome, suspected severe COVID-19 cases defined as influenza-like illness or pneumonia, was captured at emergency departments throughout NYC. Although the health-seeking

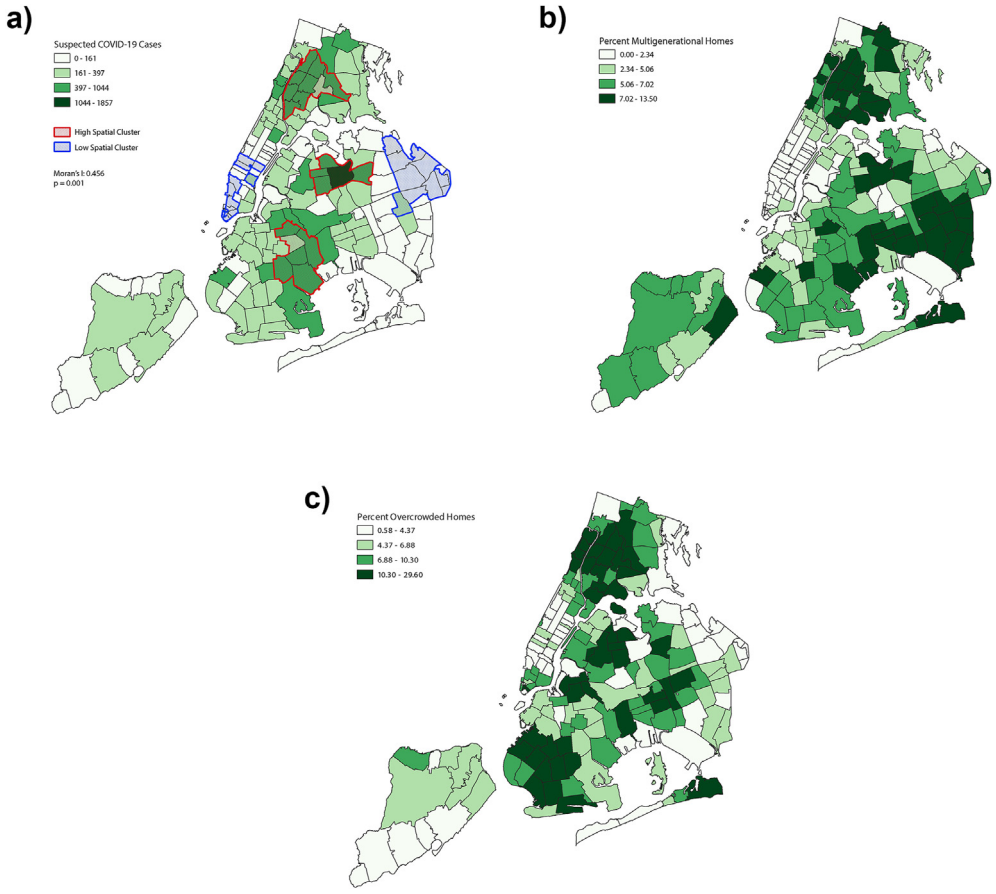

Fig. 1. Distribution of New York City ZIP code tabulation area (ZCTA) by (a) suspected COVID-19 cases during March 1–30 2020; and (b) overcrowded housing[a] and (c) multigenerational housing[b] in 2018. [a] Proportion of overcrowdedness defined as an estimated number of housing units with more than one occupant per room, divided by the number of occupied housing units in each ZCTA, expressed as a percentage from 2018 American Community Survey 5-year estimates. [b] Proportion of multigenerational housing defined as estimated percentage of residences occupied by grandparents and a grandchild less than 18 years of age in each ZCTA from the 2018 American Community Survey 5-year estimates.

behavior of patients may have varied throughout the pandemic, patients presenting to the emergency department during the initial phases of the outbreak in NYC were likely to have had more severe symptomatic COVID-19 infections, which has been shown to be correlated to the concentration of inoculum received.[10,11] These results add credence to the biologically plausible hypothesis of an association between transmission proximity, the density of inoculum, and COVID-19 severity.

Third, our model demonstrates that certain commonly reported individual clinical and sociodemographic risk factors for COVID-19 hospitalization (e.g., presence of coronary heart disease,[27] obesity,[18,28] and minority status[1]) were not significantly associated with suspected COVID-19 cases at the area level. While the full meaning of this finding is unclear, it suggests that area-level risks that represent proximity in space, such as multigenerational housing and overcrowded households, may play a more powerful role in the spread of COVID-19 compared to individual clinical and sociodemographic COVID-19 risk factors. However, this is speculative, and further investigation is warranted, ideally using hierarchical models of City-wide data containing both individual clinical and socio-economic risk factors together with area-level measures which account for proximity in space.

Fourth, the location of the largest effects of overcrowdedness and multigenerational households on suspected COVID-19 cases reflects the on-the-ground reality of NYC's initial COVID-19 wave.[29] Although the study's analysis was limited to the month of March, it became clearer as NYC's cases rose through that month into early April that the boroughs of Queens and Brooklyn were inundated by COVID-19 cases.[30] This reality corresponds to the spatial relationship between suspected severe COVID-19 cases and ZCTAs with higher proportions of multigenerational and overcrowded housing seen in our data.

Limitations

Our study has several limitations. First, our analysis employed only area-level measures, which prevents making more generalizable statements at an individual level. However, our results concur with other studies that have employed area-level measures in their analysis, adding weight to our findings.[2,3]

Second, our analysis relied on a city-wide surveillance system tracking emergency room visits to determine suspected COVID-19 cases, which may not track with actual COVID-19 cases. Therefore, our dataset was likely to exclude both asymptomatic COVID-19 patients and those who chose not to present to emergency rooms (e.g., present to primary care physicians or urgent care facilities), which may favor higher socio-economic groups with health insurance. Nevertheless, these data have been used in prior published reports to infer early COVID-19 case rates.[14]

Third, the surveillance data used may have included patients with non-COVID 19 respiratory illnesses such as influenza, which may have led to an overestimation of the effect of overcrowdedness and multigenerational housing on COVID-19. However, analysis of emergency room utilization[31] and anecdotal reports[32] suggest that non-COVID-19 related patient volumes declined dramatically prior

Table 1
ZIP code tabulation area (ZCTA)-level clinical and socio-economic characteristics by a proportion of multigenerational households and proportion of overcrowded households, in quartiles.

Quartile cut-offs	Proportion of Multigenerational Households[g], in quartiles				Proportion of Overcrowded Households[h], in quartiles			
	First	Second	Third	Fourth	First	Second	Third	Fourth
	0 to ⩽ 2.34%	2.34 to ⩽ 5.06%	5.06 to ⩽ 7.02%	7.02 to ⩽ 13.48%	0.58 to ⩽ 4.37%	4.37 to ⩽ 6.88%	6.88 to ⩽ 10.33%	10.3 to ⩽ 29.64%
Total suspected COVID-19 cases[a], March 1–30, 2020	4006	8170	12,021	15,726	3665	8139	9893	18,226
ZCTA-level COVID-19 clinical factors[d], %								
Prevalence of hypertension	21.44	27.64	29.43	31.34	24.41	28.75	29.22	28.98
Prevalence of diabetes	6.78	10.46	11.65	13.00	7.91	10.65	11.47	12.26
Prevalence of coronary heart disease	4.10	5.50	5.86	5.77	4.74	5.16	5.61	5.86
Prevalence of obesity[b]	16.44	23.35	26.03	29.51	18.89	25.60	25.03	26.99
Prevalence of chronic obstructive pulmonary disease	3.82	5.59	6.31	6.07	4.57	5.43	5.83	6.18
Prevalence of smoking[c]	10.99	15.75	17.73	18.29	12.37	15.68	16.76	18.27
ZCTA-level socio-economic characteristics[e]								
Proportion of White residents, %	71.93	51.28	42.84	21.07	71.17	43.36	36.90	33.83
Proportion below federal poverty line, %	11.03	18.88	21.45	25.36	10.06	16.60	21.17	27.12
Median income, USD 2018	104,795	63,886	55,564	50,816	100,086	72,101	58,120	46,150
Proportion of essential workers[f], %	22.54	25.99	27.48	27.89	24.82	27.42	26.85	26.17

[a] Suspected COVID-19 cases defined as influenza-like illness and pneumonia cases taken from the New York City Department of Health and Mental Hygiene Syndromic Surveillance.
[b] Obesity defined as body mass index ≥30 kg/m^2.
[c] Smoking defined as residents ≥18 years who are currently smoking.
[d] Derived from Centers of Disease Control 500 Cities Project.
[e] Derived from 2018 American Community Survey 5-year estimates.
[f] Essential worker roles defined using service-oriented, non-public Census Industrial Codes derived from methods described elsewhere.[18]
[g] Multigenerational households defined as the estimated number of residences occupied by grandparents and a grandchild less than 18 years of age.
[h] Over-crowded households defined as an estimated number of housing units with more than one occupant per room, divided by the number of occupied housing units, expressed as a percentage.

Table 2
Adjusted incidence rate ratios (IRR) of suspected COVID cases per 10,000 for quartiles of ZIP code tabulation area-level (ZCTA)[a].

	Unadjusted model		Fully adjusted model[e]	
	IRR	95% CI	IRR	95% CI[g]
Percent of overcrowded households, in quartiles[b] (ref: Quartile 1)				
Quartile 2	1.56	1.47–1.65	1.45	1.13–1.87
Quartile 3	1.75	1.66–1.85	1.41	1.08–1.86
Quartile 4	2.05	1.92–2.18	1.67	1.12–2.52
Percent of multigenerational households, in quartiles[c] (ref: Quartile 1)				
Quartile 2	1.19	1.12–1.26	1.48	1.05–2.07
Quartile 3	1.30	1.22–1.37	1.89	1.28–2.78
Quartile 4	1.59	1.49–1.69	1.77	1.11–2.79
COVID-19 clinical risk factors, by ZCTA				
Prevalence of coronary heart disease			0.92	0.82–1.03
Prevalence of obesity (BMI ≥ 30 kg/m^2)			0.97	0.94–0.99
Prevalence of smoking			1.08	0.99–1.17
Socio-economic characteristics, by ZCTA				
Percent white			0.99	0.99–1.00
Percent below Federal Poverty Level			0.97	0.95–0.99
Median income, USD 2018			0.99	0.99–0.99
Percent in defined essential worker role[d]			1.01	0.98–1.04
Time, in days	1.04	1.04–1.05	1.04	1.04–1.04
Spatiotemporal structure accounted for?	No		Yes	
Model family	Generalized linear model		INLA[f]	

[a] All covariates measured as percent at ZCTA-level; both models employ robust standard errors.
[b] Overcrowdedness defined as > 1 occupant per room in each household, derived from the 2018 American Community Survey 5-year estimates.
[c] Multigenerational households defined as the estimated number of residences occupied by a grandparent and a grandchild less than 18 years of age, derived from the 2018 American Community Survey 5-year estimates.
[d] Essential worker roles defined using service-oriented, non-public Census Industrial Codes derived from methods described elsewhere.[18]
[e] The fully adjusted model included percent of overcrowdedness and percent of multigenerational households simultaneously.
[f] INLA is integrated nested Laplace approximation method.
[g] 95% Bayesian credible intervals.

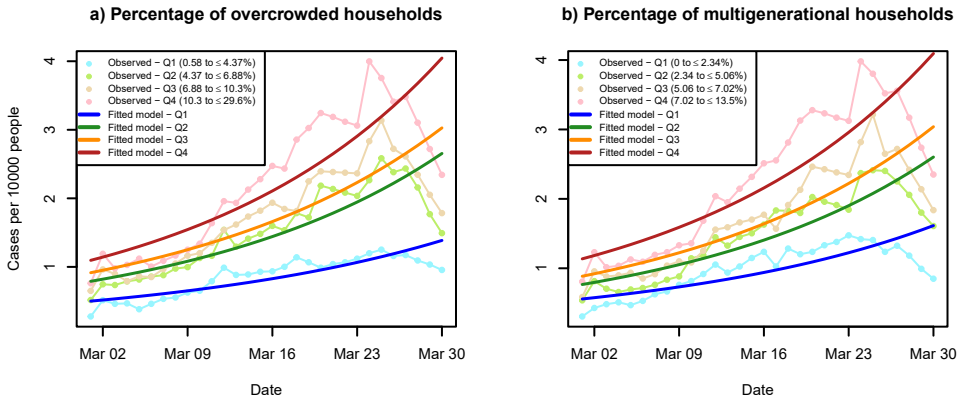

Fig. 2. Unadjusted and predicted trends[a] in suspected COVID-19 cases per 10,000 population during March 1–30 2020 by (a) percentage of multigenerational households, and (b) percentage of overcrowdedness, both in quartiles. [a] Predicted trends are taken from the fully adjusted model.

to the March 2020 NYC COVID-19 wave due to both biological and social factors.

Finally, case rates may not accurately reflect the remaining population base of ZCTAs in NYC because of pandemic-related flights.[33] Analysis of cell-phone data and mail forwarding requests comparing March 2 to May 1, 2020, has shown notable flight from particular neighborhoods throughout the borough of Manhattan and those that abut the East River in the boroughs of Brooklyn and Queens. This may have reduced the total population at risk in our analysis and led to the underestimation of the neighborhood-level effects observed in our analysis. However, the neighborhoods that are the focus of this study were distinct from those reported to have the majority of pandemic flights, likely limiting the impact of this population shift on our results.

Public health implications

COVID-19 lockdown policies globally have centered on some version of home quarantine and/or school closure, leading to increased household 'dwell time'. Though these policies have proved effective in the wider context, the implications of adherence to these measures for those living in close proximity to others, such as in overcrowded housing, have not been well explored.[34] Our ecological analysis of the beginning of NYC's spring COVID-19 wave suggests that lockdown-related school and non-essential business closures, which took place on March 13 and 23, 2020, were associated with adverse consequences for individuals living in areas characterized by high levels of household crowding and multigenerational households. Such public health measures may have amplified the household transmission of the SARS-CoV-2 virus and potentiated the severity of resulting COVID-19 cases. Since these housing characteristics follow racial/ethnic and socio-economic divides, for example, disproportionately affecting minority groups who serve as essential frontline workers, they may help explain resulting disparities in COVID-19 incidence. Future studies should seek to clarify this relationship to inform future public health interventions.

Author statements

Acknowledgments

This study received support from New York-Presbyterian Hospital (NYPH) and Weill Cornell Medical College (WCMC), including the Clinical and Translational Science Center (CTSC) (UL1 TR002384) and Joint Clinical Trials Office (JCTO).

Ethical approval

This work was reviewed by the Weill Cornell Institutional Review Board.

Funding

Dr. Ghosh is supported by National Center for Advancing Translational Sciences (NCATS) grant KL2-TR-002385 of the Clinical and Translational Science Center at Weill Cornell Medical College.

Dr. Ibrahim is supported in part by a K24 Mid-Career Development Award from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (K24AR055259).

Dr. Safford received salary support for investigator-initiated research from Amgen.

Competing interests

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.039.

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Public Health 198 (2021) 290–291

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Celebrating Public Health lives

Celebrating public health lives: Rudolf Virchow

Keywords:
Rudolf Virchow
Public health movement
History

On the occasion of the 200th birthday this year of the German pathologist and politician Rudolf Virchow, it seems appropriate to remember his pivotal role in promoting and improving public health in the 19th century. In his lifetime, Virchow received national and global recognition for his contributions to medical science, anthropology, and particularly public health and social medicine. However, in the context of the current development of ever more sophisticated molecular and imaging technologies, medicine premised on the biomedical model has gained ascendency, and the social determinants of health and disease are afforded less significance. In consequence, Virchow's name is recalled today, if at all, as a founding father of cellular biomedicine rather than for his role in social medicine and the public health movement.

Virchow's interest in public health was moulded by impressions he gained of the devastating conditions during a relapsing fever ('famine fever') epidemic in Upper Silesia. In 1848, as a young physician, Virchow was appointed to a commission tasked with investigating this typhus epidemic and submitting recommendations for its alleviation. In his uncompromising and scathing report, Virchow concluded that the epidemic was more a social than a medical problem because its effects were concentrated among poor peasants rendered vulnerable to disease by malnutrition and bad housing.[1] According to Virchow, the prevention of similar crises could be achieved only through the improvement of living conditions and the elimination of social inequality.[1] He developed a commitment to revolutionary social change and became a political activist, fighting on the barricades in Berlin during the German revolution of 1848.[2]

On the basis of his observations of the typhus epidemic in Upper Silesia and outbreaks of tuberculosis in Berlin as well as the living conditions of the population, Virchow developed a theory emphasising the major contribution of social circumstances in the dissemination of illness and the emergence of epidemics. He believed that inadequate social conditions rendered people more susceptible to other morbific causes, none of which would suffice in isolation to produce an epidemic.[3] Virchow linked disease, disability and premature death to the poor material conditions, such as nutrition, clothing and housing, of the working class. He supported this view by reference to the elevated morbidity and mortality rates observed in working-class areas of European cities. Virchow's studies on the social origins of illness led him to oppose the conservative medical establishment in espousing social reform and demanding political change as a solution to medical problems. He took the view that 'medicine is social science and politics nothing but medicine on a grand scale' and believed that the remit of medicine involved not merely the treatment of disease but also the improvement of the health of entire populations.[4] The attainment of this goal required the focus of medicine to be placed on its social as well as its biological underpinnings. Virchow therefore advocated for changes in the material conditions of the poor and called for a public health service with publicly owned and operated health care facilities as well as a corps of medical experts and physician reformers, acquainted with epidemiological principles and able to provide detailed studies of local conditions without undue deference to authority.[5]

Prevention was central to Virchow's concept of a public health service, and he contributed widely to the field of preventive medicine. For example, after his discovery of the pathophysiology of trichinosis, Virchow led a campaign to establish compulsory meat inspection in Germany. As an urban social reformer claiming that sanitation was an integral part of the state's responsibilities, Virchow successfully accomplished a sanitation reform and designed an underground sewage disposal system in Berlin, which set an example for similar policies in Germany and other countries. As a liberal politician and an elected member of the Prussian parliament for 40 years and of the German Reichstag for 13 years, Virchow became an outspoken and impassioned advocate for the public health movement and a continental European figurehead for the movement. By the end of the 19th century, Virchow was renowned worldwide. In 1873, as a young doctor, William Osler spent several months with Virchow in Berlin and was profoundly inspired by his views concerning not only pathology but also public health.[2]

Virchow's fundamental goals were the founding of the practice of medicine on the exact sciences and the improvement of health through social and political action. The paradigm of cellular biomedicine appears to be very successful in the prevention and treatment of acute (e.g. infectious) diseases, which constituted the major health problems in the 19th century and the first half of the 20th century. Virchow's best known work, among his more than 2000 publications, is his book 'Cellular Pathology', which is based on his findings of altered cell structure in inflammation, degeneration and tumour growth and presents the cell as the basic unit of physiological and pathological processes.[6] Virchow's descriptions of cellular pathophysiology, together with the germ

https://doi.org/10.1016/j.puhe.2021.07.024

theory of Robert Koch and Louis Pasteur, contributed enormously to the spectacular progress of medicine at that time.

However, as in Virchow's times, the critical role of socio-economic factors in the spread and health effects of infectious diseases can be seen in the current COVID-19 pandemic. Socio-economic inequalities in the risk of infection and the severity of the course of COVID-19 have been found, with socioeconomically less privileged individuals being affected more severely.[7] Lifestyle factors likely to be involved in the prevention of COVID-19, such as smoking, obesity and lack of physical exercise, are also known to be linked to social status.[8] Furthermore, present evidence shows that the reductionist biomedical approach appears to be less effective in chronic (non-communicable) diseases, which, since the 1960s, have become primary health problems and the principal cause of disability in high-income countries and increasingly also in low-resource regions.[9] Non-communicable diseases are characterised by complex pathogenetic host–environment interactions involving social conditions and self-management, with multiple approaches needed to control disease rather than a cure using 'magic bullets'.[10]

In addressing the issue of political action for better health, Virchow pronounced that improvements in social conditions can prolong human life more rapidly and successfully than improvements in medicine.[2] Although public health statistics were rudimentary in Virchow's time, his assertion was reaffirmed by mortality data from the United States in the 1970s. These data suggested that policies designed to improve the socio-economic conditions of disadvantaged people may decrease death rates more rapidly than progress in biomedical science.[11] Health disparities linked to socio-economic status have been found to have widened in several countries.[10] Although these trends could reflect unequal access to medical care, findings from the United Kingdom have shown that health disparities related to socio-economic status were not eliminated by universal access to the National Health Service.[10] The limited significance of access to health care has also been demonstrated by findings that job classification as a measure of socio-economic status in Britain and the level of formal education and non-completion of high school in the United States were better predictors for the development of various diseases than biological factors.[10]

Rudolf Virchow's main achievements include his characterisation of medicine as a social science as much as a biological science, his promotion of public health and his contributions to biomedicine. He can be remembered as a principal architect of the foundations of scientific medicine, whose decisive and seminal studies established the cell doctrine in pathology, which forms the scientific basis of today's prevailing biomedical model of disease. More importantly, Virchow should be remembered as a social reformer and public health activist, who described the large-scale social forces shaping human health and giving rise to disease. He was an early proponent of the idea of sociomedical causation and of a biopsychosocial model of health and disease, which can provide a more comprehensive framework for preventive medicine and public health practice today. Therefore, the expensive search for magic bullet cures needs to be complemented by sufficient funding for an extensive investigation of the social determinants of health and of their importance in public health policies.

Author statements

Ethical approval

None sought.

Funding

None declared.

Competing interests

None declared.

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14 July 2021
Available online 7 September 2021

Public Health 198 (2021) 164–170

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

COVID-19 incidence, hospitalizations and mortality trends in Croatia and school closures

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ARTICLE INFO

Article history:
Received 12 April 2021
Received in revised form
23 July 2021
Accepted 23 July 2021
Available online 3 August 2021

Keywords:
COVID-19
Return to school
Joinpoint regression

ABSTRACT

Objectives: COVID-19 pandemic affected majority of students worldwide because school closures were one of the first and frequently taken measures in tackling epidemic. This study analyzed trends in COVID-19 morbidity and mortality from the beginning of pandemic in Croatia, in relation to schools opening and closing.

Study design: Retrospective data review.

Methods: Data on COVID-19 positive patients in Croatia from week 9 of 2020 to week 10 of 2021 in Croatia were analyzed using joinpoint regression. Analysis also included hospitalizations and mortality trends for age groups 26 to 65 and 66+ from week 30 of 2020.

Results: Schools opened in fall after the summer holidays in week 37. Joinpoint regression analysis revealed a statistically significant increase in cumulative incidence rates of COVID-19 in all age groups until 50th week, except in the 19–25 age group which saw an increase until 49th week. During the period of increase, there were periods of moderate increases and rapid increases in incidence that were present between 39/41 week and 43/44 week in all age groups except in those 0–6 years [from 40th till 43rd week in age groups 7–14 and 15–18, average percentage change (APC) = 87.41, $P = 0.035$, and APC = 83.47, $P = 0.013$; from 39th till 43rd in 19–25, APC = 91.90, $P = 0.002$; from 40th till 44th in 26–65, APC = 74.79, $P < 0.001$; from 41st till 44th in 66+, APC = 81.95, $P = 0.004$]. Steeper increase in hospitalizations was seen in 40th week for age groups 26 to 65 (40th to 45th week APC = 34.67, $P < 0.001$) and 66+ (40th to 45th week APC = 38.76, $P < 0.001$). Steeper increase in mortality started in 41st week for both age groups 26 to 65 and 66+ (41st to 46th week APC = 59.59, $P < 0.001$ and 41st to 45th week APC = 70.28, $P < 0.001$). Schools were closed for winter holidays in week 51. A steep decrease occurred in week 50 for cases and in week 51 for mortality and hospitalizations. There was no significant increase in hospitalizations and mortality after schools were re-opened in week 03 of 2021 (primary schools) and week 07 (secondary schools).

Conclusion: COVID-19 morbidity and mortality trends in Croatia observed in fall 2020 in Croatia perhaps cannot completely exclude potential association of school opening in all age groups. However, in winter 2021 effect was completely lacking and numbers were independent of schools' dynamics. The observed inconsistent pattern indicates that there were no association of school openings and COVID-19 morbidity and mortality trends in Croatia and that other factors were leading to increasing and decreasing numbers. This emphasizes the need to consider the introduction of other effective and less harmful measures by stakeholders, or at least to use school closures as a last resort.

Introduction

On 11 March 2020, the World Health Organization (WHO) declared the coronavirus disease 2019 (COVID-19) outbreak, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)

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https://doi.org/10.1016/j.puhe.2021.07.030
0033-3506/

as a pandemic.[1] In light of this pandemic researchers and policy makers have been tasked to identify public safety measures to help prevent the healthcare system from getting overwhelmed and reduce the number of deaths while keeping in mind that COVID-19 spread and implementation of different measures, such as lockdowns, will affect people's day-to-day lives and could lead to disruption in daily activities.[2,3] Over the course of this pandemic, new data have been collected and analyzed, which policy makers have to take into account and weigh the balance of risks to children's health, well-being, learning, and development posed by disease transmission versus not going to school.[4] With limited information at the beginning of the pandemic many countries chose to approach with caution and make the call to close schools rather than encounter the detrimental effects of potentially overwhelming the health care system. By mid-April 2020, 192 countries had closed schools, affecting more than 90% of the world's student population.[5] However, as knowledge of the disease progresses, clinical evidence has shown that children mainly have asymptomatic or mild disease and they are also less likely to spread the virus.[6,7] Scientific evidence and perception is still not homogeneous in regards to openings and closures of schools, and while some studies revealed that school closures do not have an impact on the incidence of coronavirus infection[8] or that outbreaks are uncommon in educational settings,[9] and clustering are rare[10] other papers strongly criticized them.[11] However, systematic reviews and meta-analysis published in this area are suggesting that children are unlikely to be the main drivers of the pandemic. Opening up schools and kindergartens seems to be unlikely to impact COVID-19 mortality rates in older people[12] or if there is an effect, the potential harms of school closures are much higher.[13] Furthermore, published meta-analysis revealed that adolescents play a less pronounced role than adults in transmission of SARS-CoV-2 at a population level[14] while a decision analytical model estimated that school closures will lead to even more years of life lost through reduced educational achievements.[15]

Croatia reported its first case on the 25 February 2020.[16] As part of the response to COVID-19 containment measures, the Croatian government declared closure of schools throughout the country, starting on 16 March 2020.[17] As the situation improved over the following month, educational institutions reopened for younger children to be able to attend in-person classes, recommendations needed to be made before this. The Croatian Institute of Public Health (CIPH) issued guidelines and recommendations for schools so that with the ease of restrictions children and staff could come back to school with minimal risk.[18] This document was revised and updated throughout the course of the epidemic with the last version being published before all children (primary and secondary) were to return to school (24 August 2020). The document is similar to WHO recommendations[19] and included general measures (hand hygiene, mask use, distancing, etc.) as well as specifically detailed measures for school settings. Specific measures were staggered arrival and departure times, limitations in mixing cohorts creating 'bubbles', physical distancing measures which were defined as required anywhere possible (1.5 m primary, 2 m secondary) and grades 1–4 primary were the only students omitted from mandatory masks. Schools were offered, by the Ministry of Education, three different types of models:[20] A. in-person learning; B. mixed form (primary grades 5–8 and secondary schools); C. remote learning (primary grades 5–8 and secondary schools). At that time, over 90% of schools in Croatia chose model A, which means that the majority of children attended school through in-person learning. Models B or C are applied when a student or teacher is positive for COVID-19 so the entire class stays home. In addition, model C was applied as per local decisions if the epidemiological situation requires this. This model (i.e. mostly model A with temporary use of models B or C as necessary) was in place for more than three months, and, facing the peak of the second wave at the beginning of December 2020, school closures were again introduced for secondary and some primary schools (upper grades) on December 14th, one week before official school holidays in Croatia, i.e. mid-December. The same week (December 14th) was the first week when the epidemiological situation improved substantially. The improvement continued in the following weeks and in mid-January 2021 primary schools resumed normally, while secondary schools were online until the beginning of or mid-February, depending on the situation in each county.

School closures are still one of the measures frequently suggested and considered in Croatia and other countries despite its detrimental effects to education and health. Therefore, evidence regarding the potential impact of school closure policies in Croatia could additionally add to the scientific evidence and support decisions regarding school policy. The aim of this study was to analyze trends and potential change in COVID-19 incidence, hospitalization, and mortality trends in Croatia that could be associated with school closures and re-openings during the pandemic.

Methods

For the purpose of this study data were collected, combined, and analyzed using several different data sources. Data from clinical laboratories and primary health care providers were collected using the Central Health Information System of the Republic of Croatia (CEZIH). The Croatian Institute of Public Health regularly collects data through the Croatian Health Insurance Fund (CHIF), which operates the central segment of the CEZIH system[21] and uses it for the purposes of scientific and expert analysis. Data regarding deceased COVID-19 patients were collected directly via hospital reports which communicate patients who died with or due to COVID-19. COVID-19 test results were obtained from clinical laboratories and included results of all individuals whose nasopharyngeal swab samples were tested for SARS-CoV-2 (PCR) from the 25th of February 2020 (week 09 of 2020) to 14th of March 2021 (week 10 of 2021). Age specific rates were calculated using the estimation of Croatian population at the end of 2019 according to the Croatian Bureau of Statistics.

COVID-19 incidences were analyzed from week 09 of 2020, in all age groups (0–66+ years). Hospitalization and mortality rates were analyzed from week 30 of 2020 and only in adults (26–66+ years). This was due to low hospitalization and mortality rates in younger age groups and during the first COVID-19 epidemics wave.

The joinpoint regression model defining joinpoints by performing several permutation tests and using Monte Carlo methods with Bonferroni correction was used to analyze changes in COVID-19 incidence, hospitalization, and mortality rates.[22] Analysis was carried out using Joinpoint Statistical Software for analysis of continuous linear trends with change points, i.e. joinpoints, version 4.6.0.0. Given the number of time periods, considered maximum number of joinpoint was set at 5. Logarithmic transformation was applied, with statistical significance for average percent changes (APC) set at 0.5 level.

Ethical approval for this research was granted by CIPH Ethical Committee.

For the purpose of clarity, we present a table with dates and weeks of schools' closures and openings and other major measures.

The table of schools closing and opening and other major measures the timeline and study period is available as supplementary material.

Results

During the study period (25 February 2020 to 14 March 2021—week 09 of 2020 through to end of week 10 2021), there were 251,194 new positive cases of COVID-19, 1,431,342 persons were tested, 28,004 hospitalized, and 5677 persons died. Total crude incidence rates are presented in Fig. 1. The incidences ranged from 0.00 to 6.17/1000.

Age specific incidence rates of COVID-19

Age specific incidence rates from the beginning to the end of investigated period varied from 0.00 to 0.53/1000 in 0–6 age group, 0.00 to 0.93/1000 in age group 7–14 years, 0.01 to 1.5/1000 in age group 15–18 years, 0.02 to 1.01/1000 in age group 19–25 years, 0.00 to 1.32/1000 in age group 26–65 years, and 0.00 to 0.81/1000 in 66+ years age group revealing the up to 81-fold increase in rates during the investigated period.

Joinpoint regression analysis revealed a statistically significant increase in cumulative incidence rates in all age groups until 50th week, except in the 19–25 age group which saw an increase until 49th week. However, during the period of increase, there were periods of moderate increases and rapid increases in incidence that were present between 39/41 week and 43/44 week in all age groups except in those 0–6 years. In 49th week, a decrease was observed in the 19–25 age group that was followed by a decrease of rates in all other age groups in 50th week. While a decrease was present in the majority of age groups in 2nd week of 2021, in age group 7–14 an increase was noted and followed with significant incidence increases in 15–18 and 26–65 age groups in 6th week of 2021. Significant average percent changes per week (APC) according to age groups are presented in Fig. 2.

Mortality trends of COVID-19

Because of low numbers of deceased persons before the beginning of second wave, mortality trends were analyzed from 30th week of 2020 and only for age groups 26–65 and 66+.

Mortality 66+ increased significantly from weeks 30–51. Schools were opened after the summer break in week 37. During week 42, a steep increase in mortality of 66+ began and does not slow down until week 45. In week 45 it slows down, but the increase was still notable and lasted till week 51. During week 51, a steep decrease began. The same week, week 51, schools were closed due to winter holidays. Primary schools were re-opened for face-to-face classes in week 03 and secondary schools in week 07; there was no significant increase in mortality.

Mortality 26 to 65 increased significantly from weeks 30–46. Schools were opened after the summer break during week 37. A more noticeable increase occurred in week 46. Decrease began in week 51. Schools were closed the same week because of winter holidays. There was no significant increase after schools re-opening (primary schools week 03, secondary schools week 07).

In more detail, age-specific mortality rates from the beginning to the end of the investigated period varied from 0.00 to 0.01/1000 in 26–65 age group and 0.02 to 0.09/1000 in age group 66+. In age group 26–65 years between 30th and 41st week there was a statistically insignificant APC of 5.56 ($P = 0.351$) after which a significant increase was observed until the beginning of the 51st week (41st to 46th week APC = 59.59, $P < 0.001$ and 46th to 51st week APC = 13.31, $P = 0.034$). In the age group 66+ years, there was significant increase until 51st week (30th to 41st APC = 10.24, $P = 0.007$ then 41st to 45th week APC = 70.28, $P < 0.001$ and 45th to 51st week APC = 15.05, $P < 0.001$). After 51st week significant decrease in 26–65 and 66+ years age group was present (APC = −16.52, $P < 0.001$ and APC = −16.50, $P < 0.001$ respectively). Results are presented in Fig. 3A.

Hospitalization trends of COVID-19

Hospitalization trends were analyzed from 30th week of 2020 and only for age groups 26–65 and 66+ and are shown in Fig. 3.

Hospitalizations for 66+ increased significantly from week 30. In week 37, schools were opened after the summer break. Steeper increase is noticeable from week 40 to week 45. Further but slower increase is noticeable till week 51. In week 51, a steep decrease is noticeable. Schools were closed same week due to winter holidays, week 51. There was no significant increase following primary and secondary schools reopening in weeks 3 and 7, respectively.

Hospitalizations for 26 to 65 increase significantly from week 30. In week 37, schools were opened after the summer break. In week 40, a more noticeable increase is noted. Decrease starts in

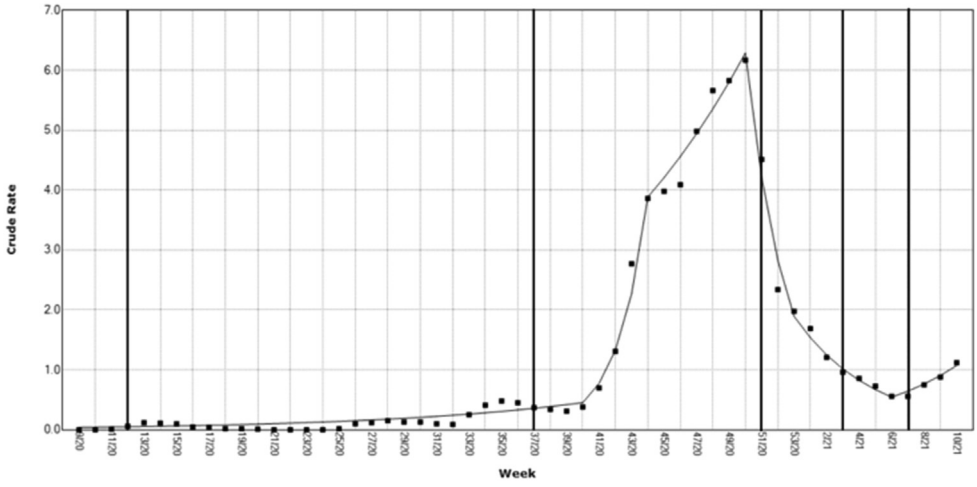
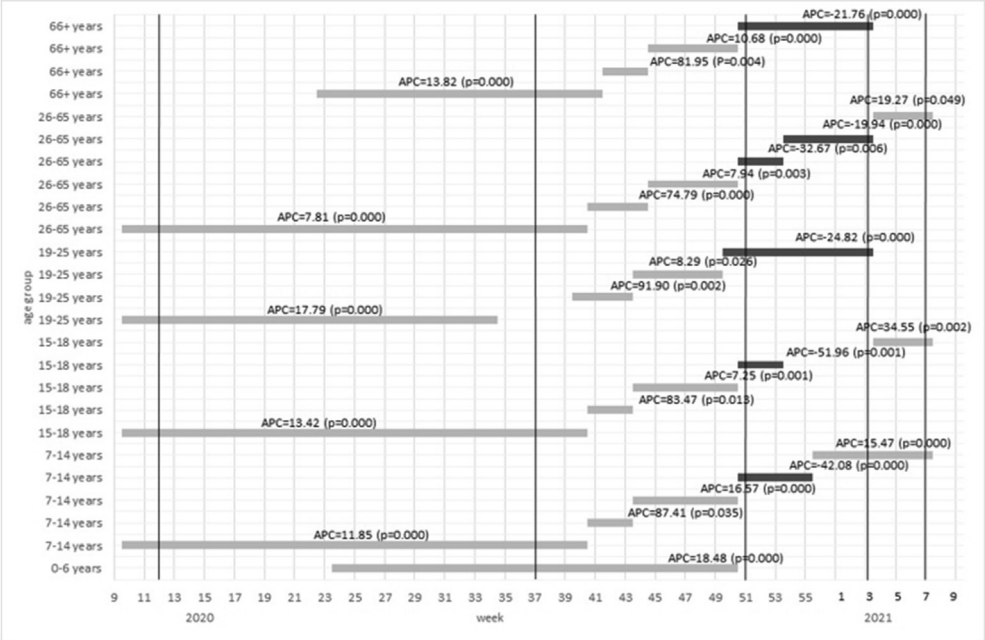


Fig. 1. Weekly COVID-19 incidences during study period.



Legend: APC= average percentage change; horizontal dark lines= decrease in APC; horizontal light lines= increase in APC; vertical lines=marks of school closings/openings, lefmost line is school closing

Fig. 2. Significant average percent changes of COVID-19 incidences per week (APC) according to age groups.

week 51. Schools were closed that same week, week 51. There was no significant increase after primary and secondary schools reopening on weeks 3 and 7, respectively.

In more detail, age-specific hospitalization rates from the beginning to the end of investigated period varied from 0.02 to 0.08/1000 in 26–65 age group and 0.04 to 0.24/1000 in age group 66+. In age group 26–65 years between 30th and 45th week, there was statistically significant APC increase (30th to 40th week APC = 13.06, $P < 0.001$ and 40th to 45th week APC = 34.67, $P < 0.001$). Significant decrease starts at week 50 and lasts till week 6/2021 (APC = −16.58, $P < 0.001$). In age group 66+ years between 30th and 45th week, there was statistically significant APC increase (30th − 40th week APC = 16.68, $P < 0.001$ and 40th to 45th week APC = 38.76, $P < 0.001$). Significant decrease starts at week 50 and lasts till week 8/2021 (50th − 53rd week APC = −15.30, $P < 0.001$). Results are presented in Fig. 3B.

Discussion

In Croatia, in week 37 of the year 2020 schools opened in fall for face-to-face classes following summer break. According to previously published estimations significant impact of school openings on reproduction number and epidemiological dynamics should already be seen after two weeks.[23] Trend change in 39th week was observed for age-specific 7-day cumulative incidence rates only in those 19–25 years while 7–14, 15–18, and 26–65 years had trend changes after 3 weeks and those 66+ after4 weeks. Hospitalization rates for age groups 26 to 65 and 66+ increased significantly 3 weeks after schools opening, and mortality rates increased more steeply 5 and 9 weeks after schools opening for groups 66+ and 26 to 65, respectively. Our study did not observe any significant change in the youngest age group, 0–6 years. Therefore, we can argue that the beginning of the school year did not influence this age group at all.

The decrease in cases rates began in week 50 and in mortality and hospitalization rates in week 51. The same week, week 51, schools were closed for winter holidays. This shows that the rates began to fall regardless of the schools closing because schools closing could have not caused effect within same week and for cases the decrease even began prior to schools closing. This decrease in all indicators was noted 3 weeks after the new epidemiological measures which included ban of public and private gatherings, masks mandatory outdoors if distance between two people is less than 1.5 m as well as indoors, limited number of people in shops and public transportation, closure of coffee shops, restaurants, sports activities, gyms, children's playrooms, and foreign language schools.

Re-opening in mid-January 2021 (primary schools) and mid-February 2021 (secondary schools) did not lead to a significant increase in any of the indicators.

Regarding the increase in all indicators following opening in week 37 because the effect was expected to occur earlier,[19] it is hard to speculate if the increase in rates could be associated with schools opening for the beginning of the year. It is also very hard to estimate the individual impact of school openings and closures as well as in other studies, which came to such conclusions and observed that the impact of other concurrent non-pharmaceutical interventions could not be excluded.[24] Measures embedded during the time period this study covers, besides general epidemiological measures and recommendations, included restrictions in bars and restaurants working hours and maximum capacity, mask use in all closed places, official institutions, and public transportation as well as restrictions of large gatherings and number of guests permitted at weddings and other private events. In addition, some studies imply there is seasonality in COVID-19 cases with increases being possible in fall and peaking in winter.[25] It is possible this is what happened in Croatia. Had the schools opening affected the epidemics

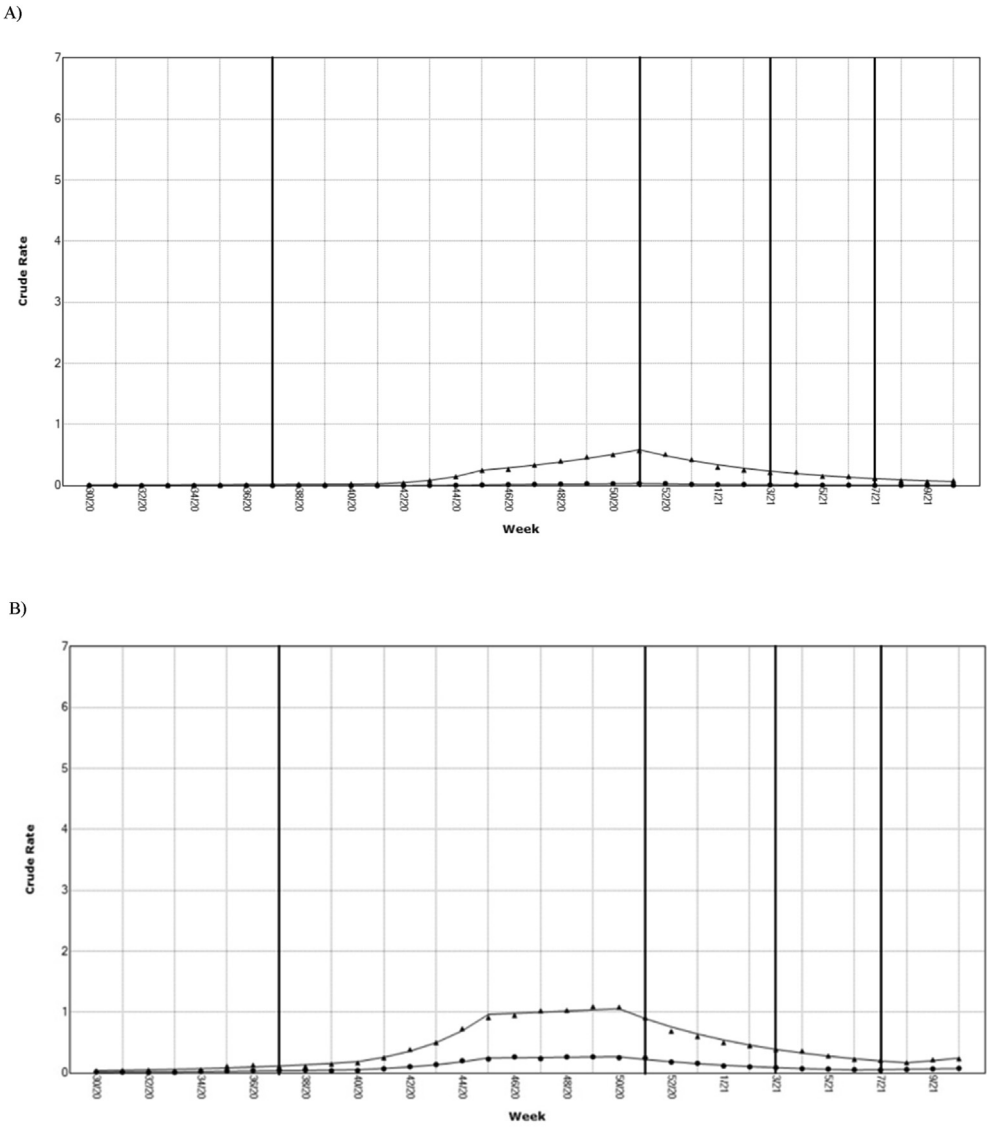


Fig. 3. Multiple joinpoint models of COVID-19 mortality (A) and hospitalization (B) rates by weeks for age groups 26 to 65 and 66+.

significantly, a rise in numbers would have happened in January and February as well. However, it has not.

Previously published systematic reviews revealed that even if there is an impact of school closures on tackling the epidemic, the impact is smaller than in case of other social distancing interventions,[13] while other meta-analysis concluded that children and adolescents play a less important role than adults in transmission of SARS-CoV-2 at a population level.[14] Furthermore, other published analysis showed that summer closures did not have significant effect on the SARS-CoV-2 transmission among children or older generations. Studies also did not find any evidence that the return to school increased infection rates among children or adults; they observed an increased rate during the last weeks of summer holidays.[26] A technical review, published by the European Centre for Disease Prevention and Control (ECDC), revealed that school settings do not play a substantial role in transmission and school closures should be used as a last resort because of the negative physical, mental health, and educational impacts on children, as well as the economic impact on society outweighing the benefits.[27]

Thus, taking into account our results, a previously published study[19] and the fact that during the 40th week seasonal changes occur, bringing colder and rainier conditions, it is hard to distinguish the impact of school openings from the other potential drivers of the sharp incidence increase in September and October 2020. However, even if that impact is not completely excluded, our study showed a completely different pattern in January and February 2021 when school began after winter holidays. After winter holidays, an increase in incidence started before or simultaneously with the return of students to primary and secondary schools in Croatia and did not show any changes in trend after two, three or four weeks. In one county, secondary schools began at even two weeks after the beginning of the incidence increase in the corresponding age group at the national level. The trends observed in January and February 2021 are in contradiction to previously

published results[19] and trends observed in Croatia after the summer holidays in 2020; thus, any causality between school opening and incidence increase seems to be unlikely.

Mortality trends were analyzed only in those above 26 years because of low mortality rates in younger people and children. Our study revealed an increase in mortality rates until 51st week, one week after the decrease in incidence began. This was expected, as well as the observed decrease in mortality until the end of analyzed period, because mortality rates follow the incidence rates with a delay of up to three weeks due to the natural course of the disease.[28]

Our study investigated national data during the period of one whole year and compared incidence and mortality rates in different age groups providing better insight into incidence and mortality patterns with special reference to the beginning of school following holidays and face-to-face learning. However, there are also some limitations to our study. Official surveillance was based on laboratory confirmed cases, and therefore a clinically diagnosed case without laboratory confirmation was not included in the analysis. Furthermore, testing policy and limitation of testing capacity may have influenced confirmation to a different extent in different age groups. We were also unable to distinguish the influence of schools opening from other non-pharmaceutical interventions present during the investigated period as well as influence of concomitant seasonal changes and their influence on observed incidence trends. There are also some restrictions regarding hospitalizations and mortality data. While COVID-19 incidence data were analyzed from week 09 of year 2020 and in all age groups, hospitalization and mortality rates were analyzed from week 30 of 2020 and in adults (26–66+ years) only. This was due to low hospitalization and mortality rates in these age groups and during the first COVID-19 epidemics wave. To maintain sufficiently large numbers for analysis, we excluded population under 26 and period before week 30 of year 2020. Therefore, presented hospitalization and mortality rates should not be seen as whole-population data and data that refer to the whole period of epidemics but only second-wave adult-population data. In addition, mortality data are preliminary data, gathered from hospitals and not from official mortality certificates with official confirmation about the person died due to COVID-19 infection. Same refers to hospitalizations data. This means that there is a possibility that patients who were hospitalized or died due to another reason, but just with COVID-19 positive test as an incidental finding, are included in the current analysis.

There is no obvious pattern when it comes to increase in cases and school openings. Thus, in conclusion, schools opening and an aggravation of the epidemic in Croatia are very unlikely to have a causal relationship, and these results need to be the basis for further school policy and national health policy decision-making during the pandemic. When reconsidering school closures, stakeholders need to take into account results of published scientific literature including those that revealed that there is more than 98% probability that primary schools opening is associated with lower total years of life lost than school closure[13] due to reduced educational achievements. Schools closures are associated with interrupted and deprived learning, confusion, and stress for teachers and parents unprepared for distance learning, gaps in childcare due to absent working parents and closed schools, social isolation, and so on, and the effect is most pronounced in already marginalized and vulnerable groups of students.[29] Closures are also associated with increases in child obesity,[30] inactivity of children and mental health of both parents and children,[31] negative impacts on parents working hours and lower income, negative impact on healthcare workforce that could lead to excess in deaths,[32] and many other negative consequences.[25] There are measures that can be implemented with greater effect and less harm.[9] Therefore, school closures need to be reconsidered very carefully, each time handled carefully as an enormous health and social threat, without an impulsive reaction due to the worsening of COVID-19 numbers.

Author statements

Ethical approval

Ethical approval for this research was granted by CIPH Ethical Committee.

Funding

None declared.

Competing interests

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.030.

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Public Health 198 (2021) 260–262

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Short Communication

Do members of the public think they should use lateral flow tests (LFT) or polymerase chain reaction (PCR) tests when they have COVID-19-like symptoms? The COVID-19 Rapid Survey of Adherence to Interventions and Responses study

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ARTICLE INFO

Article history:
Received 9 July 2021
Accepted 20 July 2021
Available online 28 July 2021

Keywords:
Antigen testing
Lateral flow devices
Testing
Behaviour
Knowledge
COVID-19

ABSTRACT

Objectives: This study aimed to investigate public use of lateral flow tests (LFT) and polymerase chain reaction (PCR) tests when experiencing key COVID-19 symptoms.
Study design: In this study, data from two waves of a cross-sectional nationally representative online survey (data collected 1 and 2 June, and 14 and 15 June 2021; $n = 3665$ adults aged $\geq$18 years living in England or Scotland) were used.
Methods: We report data investigating which type of test, if any, the public think Government guidance asks people to use if they have COVID-19 symptoms. In people with key COVID-19 symptoms (high temperature / fever; new, continuous cough; loss of sense of smell; loss of taste), we also describe the uptake of testing, if any.
Results: Ten percent of respondents thought Government guidance stated that they should take an LFT if symptomatic, whereas 18% of people thought that they should take a PCR test; 60% of people thought they should take both types of test (12% did not select either option). In people who were symptomatic, 32% reported taking a test to confirm whether they had COVID-19. Of these, 53% reported taking a PCR test and 44% reported taking an LFT.
Conclusions: Despite Government guidance stating that anyone with key COVID-19 symptoms should complete a PCR test, a significant percentage of the population use LFT tests when symptomatic. Communications should emphasise the superiority of, and need for, PCR tests in people with symptoms.

Since 18 May 2020, guidance in the United Kingdom has been that people with a new onset cough, high temperature, or loss of taste or smell should receive a polymerase chain reaction (PCR) test for COVID-19.[1] In addition, since 9 April 2021, everyone in the United Kingdom has been able to access free, rapid lateral flow tests (LFTs) for COVID-19 for use when asymptomatic.[2] In England and Scotland, it is recommended that all adults should use an LFT twice a week, with any positive LFT results requiring a follow-up PCR test to confirm infection. Although the results of all LFTs conducted at home should be reported on a Government website, in practice, it is believed that most LFTs go unreported.[3] How LFTs should be incorporated into efforts to combat the pandemic has been a source of controversy, with arguments played out across academic journals and the national media.[4,5] Often missing from this debate are any data on how tests are used in practice. Many members of the public are uncertain as to the difference between PCR tests and LFTs

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https://doi.org/10.1016/j.puhe.2021.07.023

and, despite warnings from the Government and NHS that people should '… not use a rapid lateral flow test if you have COVID-19 symptoms. Get a PCR test and self-isolate',[6] it is clear that some people do indeed use LFTs to check their symptoms.

To assess current public usage of tests, we analysed data from the CORSAIR study (COVID-19 Rapid Survey of Adherence to Interventions and Responses study). This is a series of nationally representative (UK) cross-sectional surveys, conducted by BMG data on behalf of the Department of Health and Social Care.[7] This work was conducted as part of service evaluation of the marketing and communications run by the Department of Health and Social Care and, following advice from King's College London Research Ethics Subcommittee, was exempt from ethical approval. For this study, we used a sample of 3665 adults aged ≥18 years living in England or Scotland from two survey waves, collected 1 and 2 June, and 14 and 15 June 2021.

Participants were asked what they thought Government advice was if they had symptoms of COVID-19 (true/false statements). Only 17.8% of people selected that they should take a PCR test, 10.0% thought they should take an LFT, and 60.0% thought they should take both types of test (Table 1). Twelve percent of people did not select either option.

Among people who reported that they had developed a new, continuous cough, high temperature / fever, or loss of sense of smell or taste in the last 10 days ($n = 185$), 31.9% (95% confidence interval [CI] 25.1%–38.7%, $n = 59$) reported taking a test to confirm whether they had COVID-19. Of those, 52.5% (95% CI 39.4%–65.7 %, $n = 31/59$) reported taking a PCR test, and 44.1% (95% CI 31.0%–57.1%, $n = 26/59$) reported taking an LFT. Two people did not know what type of test they took. We did not include a 'both' option for this item.

Our findings suggest that intended and actual testing behaviours in the public are out of step with Government recommendations. Our previous work has suggested that only 20% of people with COVID-19-like symptoms requested a test for COVID-19 in the United Kingdom,[7] although among those who have reason to believe they have been exposed to infection, this percentage is likely to be higher.[8] The easy accessibility of LFTs, 30 min turnaround time, and lack of compulsion to formally register the test with the Government (and hence self-isolate if the result is positive) probably make LFTs a more attractive option than PCR for some people. What the net effect of this is on rates of transmission is unclear. If LFTs are used instead of PCR by symptomatic people who would otherwise have requested a PCR test, their lower sensitivity reduces the chances of an accurate diagnosis.[4] On the other hand, if LFTs are used by people who would not otherwise have sought a test, and a positive result leads to a reduction in behaviours associated with transmission, then this would be a beneficial outcome. The use of an LFT among symptomatic people who have already requested a PCR test is unclear. At present, adherence to self-isolation among people who seek a PCR test tends to be weakest in the period between symptom onset and receiving a test result.[9] If a positive LFT result during this period encourages more people to self-isolate, this may reduce transmission. Conversely, a false-negative result at this point may reduce adherence in some, offsetting this impact, although the findings from elsewhere suggest reduced adherence as a result of false reassurance is relatively uncommon.[10]

Modelling is required to quantify the impact of testing behaviours. Until then, good communication with the public emphasising the superiority of PCR tests when symptomatic remains important.

Author statements

Ethical approval

This work was conducted as part of service evaluation of the marketing and communications run by the Department of Health and Social Care and, following advice from King's College London Research Ethics Subcommittee, was exempt from ethical approval.

Funding

This work was funded by the National Institute for Health Research (NIHR) Health Services and Delivery Research programme. Surveys were commissioned and funded by the Department of Health and Social Care (DHSC), with the authors providing advice on the question design and selection. L.S., R.A., and G.J.R. are supported by the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response, a partnership between Public Health England, King's College London, and the University of East Anglia. R.A. is also supported by the NIHR HPRU in Behavioural Science and Evaluation, a partnership between Public Health England and the University of Bristol. HWWP receives funding from Public Health England and NHS England. NTF is partly funded by a grant from the UK Ministry of Defence. The views expressed are those of the authors and not necessarily those of the NIHR, Public Health England, the Department of Health and Social Care or the Ministry of Defence.

Role of the funding source

NIHR and DHSC had no role in analysis, decision to publish, or preparation of the article. Preliminary results were made available to DHSC and the UK's Scientific Advisory Group for Emergencies.

Competing of interests

All authors had financial support from NIHR for the submitted work. R.A. is an employee of Public Health England; HWWP receives additional salary support from Public Health England and NHS England; NTF is a participant of an independent group advising NHS Digital on the release of patient data. All authors are participants of the UK's Scientific Advisory Group for Emergencies or its subgroups. There are no other financial relationships with any organisations that might have an interest in the submitted work in

Table 1
Understanding of Government guidance on testing if you have symptoms of COVID-19.

The Government has issued advice on how people should help prevent the spread of coronavirus if they have symptoms. If you have symptoms of coronavirus, you: (total $n = 3665$)	Selected 'true', % (95% CI)	N
Should take a rapid 'lateral flow' coronavirus test (results within 30 min)	10.0 (9.1–11.0)	368
Should take a lab-processed 'PCR' coronavirus test (results typically within a day or two)	17.8 (16.5–19.0)	651
Selected both options	60.0 (58.4–61.6)	2200
Selected neither option	12.2 (11.1–13.2)	446

the previous 3 years and no other relationships or activities that could appear to have influenced the submitted work.

Authors' contributions

All authors conceptualised the study and contributed to survey materials. L.S. completed analyses, and analyses have been verified by H.W.W.P. L.S. wrote the first draft of the article. All authors contributed to, and approved, the final manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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Public Health 198 (2021) 85–88

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Short Communication

Essential public healthcare services utilization and excess non-COVID-19 mortality in Greece

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ARTICLE INFO

Article history:
Received 22 March 2021
Accepted 24 June 2021
Available online 10 July 2021

Keywords:
COVID-19
Essential health services
Health services utilization
Excess mortality
Excess non-COVID-19 deaths

ABSTRACT

Objectives: Ensuring access to care for all patients—especially those with life-threatening and chronic conditions—during a pandemic is a challenge for all healthcare systems. During the COVID-19 pandemic, many countries faced excess mortality partly attributed to disruptions in essential healthcare services provision. This study aims to estimate the utilization of public primary care and hospital services during the COVID-19 epidemic in Greece and its potential association with excess non-COVID-19 mortality in the country.

Study design: This is an observational study.

Methods: A retrospective analysis of national secondary utilization and mortality data from multiple official sources, covering the first nine months of the COVID-19 epidemic in Greece (February 26th to November 30th, 2020), was carried out.

Results: Utilization rates of all public healthcare services during the first nine months of the epidemic dropped significantly compared to the average utilization rates of the 2017–19 control period; hospital admissions, hospital surgical procedures, and primary care visits dropped by 17.3% (95% CI: 6.6%–28.0%), 23.1% (95% CI: 7.3%–38.9%), and 24.8% (95% CI: 13.3%–36.3%) respectively. This underutilization of essential public services—mainly due to supply restrictions such as suspension of outpatient care and cancelation of elective surgeries—is most probably related to the 3778 excess non-COVID-19 deaths (representing 62% of all-cause excess deaths) that have been reported during the first 9 months of the epidemic in the country.

Conclusions: Greece's healthcare system, deeply wounded by the 2008–18 recession and austerity, was ill-resourced to cope with the challenges of the COVID-19 epidemic. Early and prolonged lockdowns have kept COVID-19 infections and deaths at relatively low levels. However, this "success" seems to have been accomplished at the expense of non-COVID-19 patients. It is important to acknowledge the "hidden epidemic" of unmet non-COVID-19 needs and increased non-COVID-19 deaths in the country and urgently strengthen public healthcare services to address it.

Introduction

The COVID-19 pandemic poses enormous challenges on health systems around the world, testing their preparedness in controlling the spread of the epidemic and managing its social and health consequences in a constantly changing environment. As far as healthcare services are concerned, this "dynamic preparedness" challenge entails their ability to manage COVID-19 morbidity effectively while ensuring unobstructed access to essential health services for all non-COVID-19 patients.[1]

Keeping the appropriate balance among restrictive measures for controlling the epidemic, shifting and scaling up healthcare resources for treating COVID-19 patients, and sustaining essential healthcare services for all other patients are complex tasks. During the pandemic, most countries have been reporting serious disruptions in the delivery of services and low utilization rates of even essential healthcare services,[2] such as emergency department attendances and all-medical hospital admissions.[3,4]

These sharp declines in healthcare services utilization have been interpreted in various ways. Some researchers suggest that

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https://doi.org/10.1016/j.puhe.2021.06.025
0033-3506/

such declines may reflect the lower incidence of certain diseases during the pandemic, such as respiratory infections and cardiovascular events due to reduced air pollution and behavioral changes (more exercise, home-prepared meals) related to stay-at-home orders, and fewer injuries from work and traffic accidents related to social isolation measures such as lockdowns.[4] Others suggest that the observed declines in services utilization can be explained as the result of supply restrictions (e.g. cancelation of elective care, repurposing of essential services like intensive care units (ICU) to COVID-19 ones, and redeployment of health workers to COVID-19 clinics) and increased barriers to access (e.g. patients not presenting to outpatient care due to fear of infection, explicit instructions for patients to avoid face-to-face clinical care, patients' difficulties in traveling to healthcare facilities using public transport, and financial barriers that hinder access to care). These problems may lead to delayed or inadequate treatment of conditions that might result in excess non-COVID-19 mortality.[1–4]

COVID-19 epidemic and public health and healthcare response in Greece

The COVID-19 epidemic in Greece started on February 26, 2020, with imported cases initially from Italy and later from Israel. The early introduction of social distancing measures in early March and the timely introduction of a general stay-at-home order (lockdown) quickly resulted in the control of the first epidemic wave of COVID-19, keeping infected, hospitalized cases and related deaths at relatively low levels compared to other EU countries.[5] After 42 days of lockdown, restrictive measures were gradually withdrawn starting with the lifting of the stay-at-home order on May 4, 2020, and the full restoration of cross-country mobility (opening for travel and tourism) on July 1, 2020. The second epidemic wave in Greece started in early August and slowly escalated to an exponential increase in ICU cases and COVID-19 related deaths all through November and early December. In response to this second severe epidemic wave, public health authorities introduced a second nationwide lockdown on November 7, 2020.

The Greek healthcare system was heavily impacted by the 2008–2018 recession and the neoliberal Economic Adjustment Programme that the country implemented as part of its loan agreement with the “Troika”, a coalition of the International Monetary Fund, European Commission, and European Central Bank.[6] Being ill-prepared and poorly resourced, the Greek public healthcare system responded to the ongoing epidemic crisis by ceasing most of its regular activities and redirecting available resources to COVID-19 treatment in order to avoid being overwhelmed by the sudden increase in the demand for care.[5] During the first epidemic wave on March 11, 2020, 10 days before the first lockdown, elective surgeries and outpatient departments in public hospitals treating patients with chronic diseases were suspended, surgical departments and ICUs were repurposed for treating COVID-19 patients, primary care centers downsized their clinical activities due to the lack of guidelines and personal protective equipment, and primary healthcare workers were redeployed to NHS hospitals.[5] These supply restrictions for non-COVID-19 patients were partly counterbalanced by the introduction of telemedicine and e-prescription services in early April and publicly reimbursed referrals of non-COVID-19 hospitalized patients from public hospitals to private clinics. Disruptions in public clinical services were restored eventually in June. During the second epidemic wave, on October 9, 27 days before the second general lockdown, the above supply restrictions were gradually reintroduced.

Utilization of public healthcare services and excess mortality in Greece

From January to November 2020, Greece experienced 74 days of lockdown and almost 120 days of full or partial suspension of public elective care services.

During these 9 months, according to nationwide aggregated data from the Greek Ministry of Health, utilization of essential public hospital services reduced significantly compared to the average respective period of 2017–19. All-medical admissions in public hospitals dropped by 17.3% (95% CI: 6.6%–28.0%), visits to emergency and non-emergency public hospital departments declined by 30.4% (95% CI: 18.2%–42.7%) and 33.3% (95% CI: 16.0%–50.5%) respectively, while 23.1% (95% CI: 7.3%–38.9%) fewer surgical procedures were carried out in public hospitals compared to the control period (Fig. 1A, Supplementary Table S1).

It is estimated that approximately 3.9 million outpatient visits, 253 thousand admissions, and 108 thousand surgical procedures have been missed in Greek public hospitals during the pandemic, compared to the expected ones based on the pre-COVID-19 trends (Supplementary Table S1).

These significant declines in hospital services utilization were not counterbalanced by the increased use of primary care services; visits to public primary care centers dropped by 24.8% (95% CI: 13.3%–36.3%) between January and November 2020 compared to the control period (Fig. 1A, Supplementary Table S1).

The most significant declines in public health services utilization (e.g. up to 81% reduction for non-emergency visits and 65% decline for surgeries) took place between March–May and October–November 2020, periods that coincide with the cessation of elective services in public hospitals and the introduction of social isolation measures (Fig. 1A).

In Greece, according to weekly official data from the Hellenic Statistical Authority, 6100 more deaths have been reported during the period February 26 to November 29, 2020, compared to the expected deaths based on the average respective period of 2015–2019 (Fig. 1B, Supplementary Table S2). In other words, the observed all-cause deaths during the first two epidemic waves in the country increased by 6.8% compared to the expected ones.

Of these excess deaths, 62% (3779 deaths) are not directly related to COVID-19 infection. The majority of non-COVID-19 excess deaths (61.0%; 2305 deaths) occurred between May 6 and October 6 (ISO weeks 19–41 in Fig. 1B).

Discussion

Excess mortality has been reported in several countries during the pandemic. For example, during the first epidemic wave, Italy and England were reporting excess deaths, 20% and 25% of which respectively could not be directly attributed to COVID-19 infection.[7,8] Excess non-COVID-19 deaths typically can either be related to underreporting of COVID-19 deaths (especially if observed during COVID-19 resurgences) and/or inadequate management of non-COVID-19 diseases.

In Greece, excess non-COVID-19 deaths represent the majority (62%) of excess mortality reported during the first nine months of the epidemic in the country. Most of these excess non-COVID-19 deaths took place during summer and autumn—between the two epidemic waves in the country—when levels of SARS-CoV-2 spread in the community were very low, suggesting that they cannot be attributed to the under-certification of COVID-19 deaths.

In contrast, the sharp nationwide declines in the utilization of essential public hospital and primary care services reported in this study suggest that excess non-COVID-19 deaths in Greece are most probably related to the inadequate treatment of chronic or life-

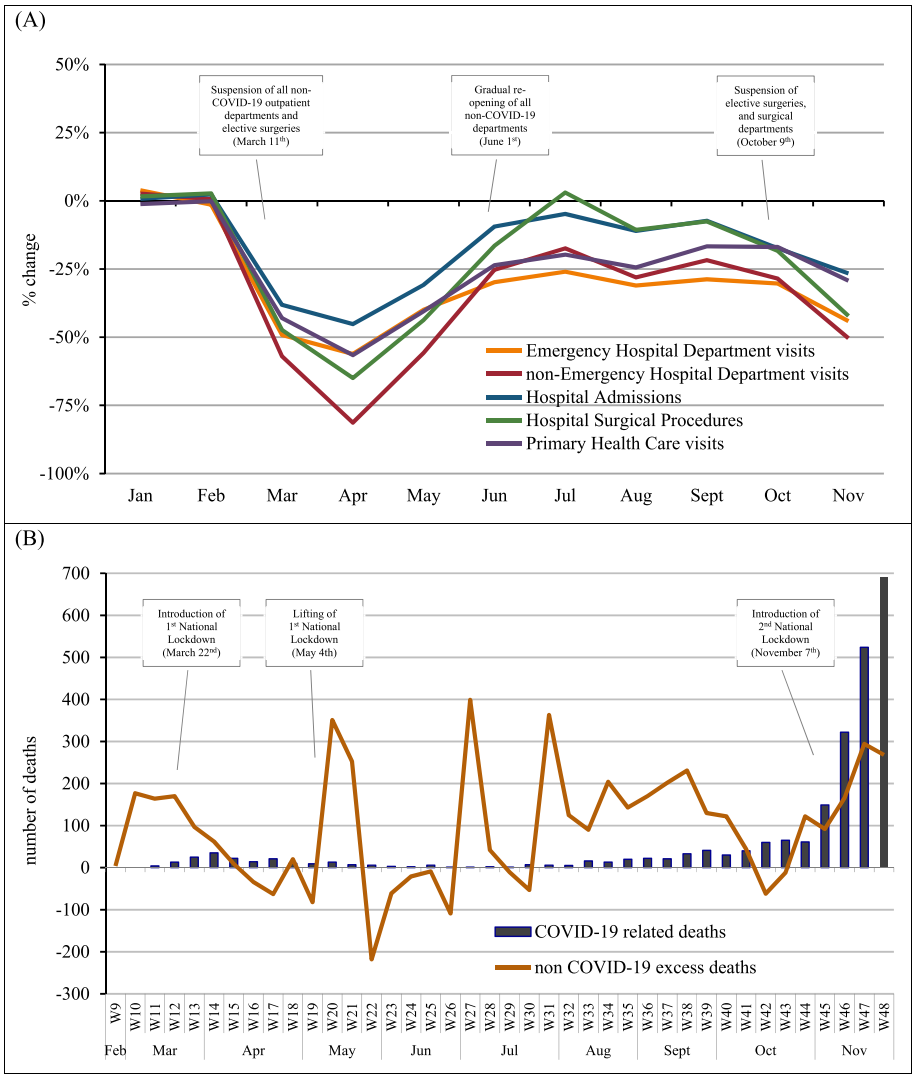

Fig. 1. (A) Public healthcare services utilization in Greece (Jan 1–Nov 30, 2020), compared to the average respective time period of 2017–19 (B) Excess deaths in Greece (ISO weeks 9–48; Feb 22–Nov 29, 2020), compared to the average respective time period of 2015–2019. **Notes and Sources:** (A) Authors' calculations are based on monthly aggregated data from all public hospitals and public primary care centers in Greece, as reported by the Greek Ministry of Health. Data were grouped by the type of facility (hospital vs primary care) and the type of service (emergency or non-emergency hospital visits, hospital admissions and surgical procedures, and total primary care visits), and utilization rates were calculated for each month from January until November 2020. The control period covers the average monthly utilization rates during the period 2017–19. (B) Authors' calculations are based on weekly data of all-cause deaths as reported by the Hellenic Statistical Authority and daily data of COVID-19 deaths as reported by the National Public Health Organisation in Greece. Excess non-COVID-19 deaths were calculated by extracting COVID-19 deaths from total all-cause excess deaths. The control period covers the average weekly all-cause deaths during the period 2015–19.

threatening conditions. Earlier studies from Greece, using small samples, have reported serious disruptions in the provision of critical care, in line with this hypothesis. For example, studies from Greek public hospitals and specific public hospital departments have reported significant drops in cardiac surgical procedures[9] and significant drops in emergency department visits for patients with critical conditions such as cancer, confirmed or suspected hemorrhage, and acute cardiovascular events.[10]

Future research (when data on causes of mortality become available) will shed more light on the origin of the observed excess mortality in Greece. However, this early evidence suggests that the majority of excess deaths in the country are most probably associated with the underutilization of public healthcare services during the epidemic mainly due to supply restrictions and accessibility barriers.

Greece's health response to the COVID-19 epidemic has often been presented as a “success story”. However, these early findings demonstrate how an ill-resourced health system, after years of austerity, can lose balance while coping with a public health threat, sacrificing access to essential health services for chronic patients that mostly depend on them in order to cope with the epidemic. Acknowledging this “hidden epidemic” of unmet non-COVID-19 healthcare needs and consequent excess deaths is of vital importance and urgency. Strengthening public hospital services provision and scaling up primary healthcare are necessary prerequisites for ensuring safe and unobstructed access to care for all patients, including those with non-COVID-19 related conditions.

Author statements

Ethical approval

No ethical approval is required for this type of study. All data used are anonymized, aggregated data, publicly available.

Funding

The authors received no funding for this research.

Competing interests

All authors (EK, FT, and AB) have no competing interests to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.06.025.

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Public Health 198 (2021) 106–113

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Factors associated with non-essential workplace attendance during the COVID-19 pandemic in the UK in early 2021: evidence from cross-sectional surveys

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ARTICLE INFO

Article history:
Received 8 June 2021
Received in revised form
1 July 2021
Accepted 1 July 2021
Available online 17 July 2021

Keywords:
COVID-19
Workplace attendance
Sociodemographic variables
Personal circumstances

ABSTRACT

Objectives: Working from home where possible is important in reducing the spread of COVID-19. In early 2021, a quarter of people in England who believed they could work entirely from home reported attending their workplace. To inform interventions to reduce this, this study examined associated factors.
Study design: Data from the ongoing COVID-19 Rapid Survey of Adherence to Interventions and Responses survey series of nationally representative samples of people in the UK aged 16+ years in January–February 2021 were used.
Methods: The study sample was 1422 respondents who reported that they could work completely from home. The outcome measure was self-reported workplace attendance at least once during the preceding week. Factors of interest were analysed in three blocks: 1) sociodemographic variables, 2) variables relating to respondents' circumstances and 3) psychological variables.
Results: 26.8% (95% confidence interval [CI] = 24.5%–29.1%) of respondents reported having attended their workplace at least once in the preceding week. Sociodemographic variables and living circumstances significantly independently predicted non-essential workplace attendance: male gender (odds ratio [OR] = 1.85, 95% CI = 1.33–2.58); dependent children in the household (OR = 1.65, 95% CI = 1.17–2.32); financial hardship (OR = 1.14, 95% CI = 1.08–1.21); lower socio-economic grade (C2DE; OR = 1.65, 95% CI = 1.19–2.53); working in sectors such as health or social care (OR = 4.18, 95% CI = 2.56–6.81), education and childcare (OR = 2.45, 95% CI = 1.45–4.14) and key public service (OR = 3.78, 95% CI = 1.83–7.81) and having been vaccinated (OR = 2.08, 95% CI = 1.33–3.24).
Conclusions: Non-essential workplace attendance in the UK in early 2021 during the COVID-19 pandemic was significantly independently associated with a range of sociodemographic variables and personal circumstances. Having been vaccinated, financial hardship, socio-economic grade C2DE, having a dependent child at home and working in certain key sectors were associated with higher likelihood of workplace attendance.

Introduction

Workplaces have been identified as settings for the spread of COVID-19,[1,2] with outbreaks and clusters being reported in a variety of occupational settings in the UK and Europe.[3] Factors associated

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https://doi.org/10.1016/j.puhe.2021.07.002

with workplace outbreaks have been found to include occupations associated with low socio-economic status, workers in essential settings who cannot work from home and workplaces without robust 'COVID-19–safe' policies and procedures.[1] Understanding the factors that contribute to people attending the workplace when they do not need to will inform interventions to reduce this practice.

In the UK, national lockdown restrictions were interspersed with regional tiered restrictions to reduce the nature and extent of interpersonal contacts that lead to infectious disease transmission. These restrictions have taken various forms and have had varied effects, with stringent restrictions shown to outperform more relaxed restrictions in terms of their impact on behaviour, hospitalisations and deaths.[4] It is therefore likely that contact between people in workplaces contributes to transmission within workplaces and between workplaces and homes.[5] Indeed, 40% of people testing positive for COVID-19 reported prior workplace or education activity, and the emergence of clusters has been interpreted to be the result of widespread failure to control risks of airborne and surface transmission in workplaces.[6,7]

In many cases, attending the workplace is not essential, either because workers can be furloughed or because people can work from home. However, in the lockdown in early 2021, the third lockdown in England, the Office for National Statistics reported that 48% of working-age adults had travelled to work at least once in the past seven days,[8] compared with 37% in the first lockdown in May 2020.[9] This may have been associated with more furlough requests having been turned down.[10]

Concern has been raised that many people who are attending work at present do not need to do so and could instead work from home.[11] The UK COVID-19 Rapid Survey of Adherence to Interventions and Responses [CORSAIR] national survey of 2000 people found that in February 2021, 35% of those who could work from home had been out to work at least once in the previous week, with 12% at least five times.[12] A national poll of nearly 1000 employees commissioned by the Trades Union Congress (TUC) and conducted by YouGov found that 19% of those still working were going into offices or other workplaces for part or all of their working week despite being able to work from home.[13] The main reason given was pressure from employers (40%).

There may be many factors influencing workplace attendance when home working is possible. These may include factors relating to sociodemographic characteristics such as age, gender and ethnic group. For example, young people may perceive themselves to be less at risk from COVID-19 and therefore are more likely to attend their workplace. Second, they may include factors relating to people's circumstances, for example, the type of job that they do or their living circumstances. For example, people may feel pressure from their employer to attend the workplace or worried about losing their job if they work from home, or they may be able to work from home but not have adequate equipment to make this easy. And third, they may include factors relating to knowledge and attitudes, for example, being less concerned about the harmfulness of COVID-19 after vaccination.

Uptake of vaccination has been high in the UK, unlike in some other countries.[14] The rollout of the vaccination programme in the UK has raised concerns that it may create a sense of reassurance about getting, being harmed by and spreading COVID-19 and that this may lead to more risky behaviours.[15] This concern arose from evidence of risk compensation and reduced protective behaviours after vaccination from other programmes,[16,17] in addition to the UK survey finding that 29% of respondents said that they would adhere less strictly than before vaccination[18] and 22% said they believed that those who had been vaccinated should not be subject to any more coronavirus restrictions.[19] Real-world data have shown spikes in infection rates in the nine days after vaccination in both Israel[20] and the UK,[21] with some suggesting that this may reflect more risky behaviours after vaccination.[22]

Understanding factors influencing non-essential workplace attendance during a critical period in the COVID-19 pandemic in the UK could provide useful information to inform interventions aimed at reducing it. This study aimed to examine factors associated with attending the workplace amongst those who could work entirely from home. To do this, we analysed data from the CORSAIR study, designed to collect information during the pandemic to help inform policies and interventions.[23] This is an ongoing series of surveys carried out weekly or fortnightly with nationally representative samples of UK-based adults. Questions are added in specific waves to address issues of concern at that time.

The variables of interest were analysed according to a model whereby the sociodemographic factors may be expected to have their effect through, and be supplemented by, situational factors which may, in turn, have their effect through and be supplemented by psychological factors. In practice, because it is not possible to measure all the potential predictors of unnecessary workplace attendance with sufficient accuracy, the more distal factors may independently predict attendance, operating through more proximal factors that have not been measured or have not been measured with sufficient precision.

The research question addressed by this study was which variables independently predict non-essential workplace attendance in terms of 1) sociodemographic factors only, 2) sociodemographic factors, personal circumstances and situational factors and 3) sociodemographic factors, personal circumstances and psychological factors?

Methods

Design

The study used data from an ongoing series of cross-sectional online surveys, conducted by BMG Research, a Market Research Society Company Partner, on behalf of the Department of Health and Social Care. The survey began in January 2020 and has continued into 2021 either weekly or fortnightly. Further details are described in the study by Smith et al.[23] Three waves of the survey were used in which a question about working from home was included: 25–26 January 2021, 8–9 February 2021 and 22–23 February 2021 (waves 42, 43 and 44). Because of the need for rapid turnaround for data collection during a rapidly evolving crisis, the surveys used standard opinion polling methods including non-probability sampling, an approach common within market research, political polling and social science. Quota samples aim to minimise bias by filling predetermined targets so that the social and demographic characteristics of the participants match the national population. As such, participants who belong to a quota that has already been met are prevented from completing the survey. Therefore, response rate is not a useful indicator of response bias in quota samples.

Setting

United Kingdom.

Participants

The sample included those who said they could fully work at home, recruited from two specialist online panel providers, Respondi and Savanta.[23] Participants were eligible for the study if they were aged 16 years or older and lived in the UK. If a respondent

completed the survey, they were unable to participate in the following three waves. Quotas were applied based on age and gender (combined) and reflected targets based on data from the Office for National Statistics.[24] Therefore, the sociodemographic characteristics of participants in each survey wave were broadly similar to those in the UK general population. Participants were reimbursed in points which could be redeemed in cash, gift vouchers or charitable donations (up to 70p per survey). The total sample from the three survey waves was 6033, of whom 3271 reported that they were in work. Of these, 1422 reported that they could fully work at home, and this formed the sample for the present study.

Measures

For the outcome measure, participants were asked to 'Please enter the number of times you have been out of your home in the last seven days, for each of the following reasons' with 'to go out to work' listed as one of the reasons. Responses were dichotomised into any workplace attendance (1) versus none (0). Because the sample had reported that they could work fully at home, we have taken this as a measure of non-essential workplace attendance.

Potential predictor variables were 1) sociodemographic variables (gender, age, educational level, ethnic group,[25] English not as first language, Government Office Region in England plus Scotland, Wales and Northern Ireland, survey wave), 2) variables relating to the respondents' circumstances (marital status, living alone, having a dependent child in the household, employment status, manual occupation of main earner [socio-economic grade C2DE[26]], working in one of a number of potentially risky types of workplace, Index of Multiple Deprivation in quartiles,[27] COVID-19–related financial hardship, having a chronic illness that heightens risk of severe illness from COVID-19, having a household member who has a chronic illness, having been vaccinated) and 3) psychological variables (worry about COVID-19, perceived risk to self from COVID-19, believing that one has had COVID-19, belief that government information on COVID-19 is biased and willingness to leave home if they had symptoms). Full details of all the measures are provided in the Supplementary file.

The categories used in the question on work sector were chosen to identify those who work in a key occupational sector. People were asked to 'indicate if you work in any of the following sectors or roles? Please include any voluntary work'. This categorisation may thus not represent a person's main employment.

Ethics

This work was conducted as part of service evaluation of the marketing and communications run by the Department of Health and Social Care and so did not require ethical approval.

Patient and public involvement

Lay members served on the advisory group for the project that developed our prototype survey material; this included three rounds of qualitative testing. Owing to the rapid nature of this research, the public was not involved in the further development of the materials during the COVID-19 pandemic.

Power

The sample size of approximately 1400 (depending on the analysis) provided >90% power to detect an odds ratio (OR) representing a 'small' effect size ($f^2 = 0.02$) with 2-tailed alpha of 0.05 in a multivariable regression with 24 potential predictor variables entered together.

Analysis

The sample was weighted by age, gender and Government Office Region to match the UK population aged 16+ years. The full weighted sample size was 1428. Missing values were excluded on an analysis-by-analysis basis leading to smaller sample sizes in some cases. Frequencies and percentages were calculated for prevalence, and multivariable logistic regressions were undertaken to determine associations between the primary outcome and predictor variables.

First, all predictor variables in Block 1 (sociodemographic variables) were entered. Then, variables from Block 2 (respondents' circumstances) were added to the model. Then, variables from Block 3 (psychological variables) were added.

The analyses plan was not preregistered, and so the analyses should be considered exploratory.

Results

Of a weighted sample of 1428, 26.7% (n = 382, 95% confidence interval [CI] = 24.5–29.1) attended the workplace in the preceding seven days. Table 1 shows the characteristics of the sample, overall and by attendance at their workplace.

Table 2 shows the results of the multivariable logistic regression analysis in the three blocks. In the first block, age, gender, ethnic group and educational level were predictive of workplace attendance. With the addition of the second block, age and educational level were no longer significant predictors of workplace attendance, while having dependent children at home, socio-economic grade C2DE, financial hardship, having been vaccinated and working in a certain sectors (health and social care, education and childcare, key public services, food and essential goods, public safety and security and transport) were associated with higher likelihood of workplace attendance. Working part-time or being self-employed was associated with lower likelihood of workplace attendance. None of the psychological variables included were significantly associated with workplace attendance.

Discussion

A substantial percentage of the UK population were attending their workplace in early 2021 even though they reported being able to work fully from home, contrary to UK Government guidance.[28] Our estimate (27%) is similar to that reported by another survey also conducted in January to February 2021, which found that 31% of working adults were working on business premises.[29] This suggests that there may be scope for reducing transmission by reducing the prevalence of this behaviour. Having been vaccinated, financial hardship, socio-economic grade C2DE, having a dependent child at home and working in certain key sectors were associated with higher likelihood of workplace attendance. Women were less likely to attend the workplace than men. These findings showing that different sociodemographic groups have been affected very differently by the pandemic, even within occupational groups such as scientists, are consistent with findings beyond the UK.[30,31] Several of the predictors of workplace attendance could reflect targets for interventions aimed at reducing COVID-19 transmission.

The association between financial hardship and workplace attendance could mean that people who are struggling to meet their living costs feel greater pressure to attend than others. This may reflect a more precarious working environment, and there is evidence of employer pressure playing a role. The TUC has said that

Table 1
Participant characteristics and comparison of those attending and not attending their workplace.

Variable	Attended workplace[a] % (n)	Did not attend workplace[a] % (n)	All[b,c] % (n)
Block 1: sociodemographic variables			
Wave, % (n)			
Wave 1 (25–26 January 2021)	25.7 (132)	74.3 (382)	36.0 (514)
Wave 2 (8–9 February 2021)	25.1 (114)	74.9 (341)	31.9 (455)
Wave 3 (22–23 February 2021)	29.5 (135)	70.5 (323)	32.1 (458)
Region, % (n)			
East Midlands	25.8 (24)	74.2 (69)	6.5 (93)
East of England	22.1 (30)	77.9 (106)	9.5 (136)
London	37.2 (108)	62.8 (182)	20.3 (290)
North East	29.4 (15)	70.6 (36)	3.6 (51)
North West	28.4 (42)	71.6 (106)	10.4 (148)
Northern Ireland	26.5 (9)	73.5 (25)	2.4 (34)
Scotland	20.6 (27)	79.4 (104)	9.2 (131)
South East	15.5 (26)	84.5 (142)	11.8 (168)
South West	21.7 (20)	78.3 (72)	6.4 (92)
Wales	26.8 (15)	73.2 (41)	3.9 (56)
West Midlands	28.8 (38)	71.2 (94)	9.2 (132)
Yorks & Humber	27.6 (27)	72.4 (71)	6.9 (98)
Gender, % (n)[d]			
Female	19.8 (125)	80.2 (505)	44.2 (630)
Male	32.2 (256)	67.8 (538)	55.8 (794)
Age, mean (SD)[d]	36.5 (11.6)	42.1 (13.1)	40.6 (13.0)
Educational level, % (n)			
Non-degree level	26.5 (177)	73.5 (492)	46.8 (669)
Degree level	27.0 (205)	73.0 (554)	53.2 (759)
Ethnic group, % (n)[d]			
White British	24.0 (271)	76.0 (856)	79.2 (1127)
White ethnic minorities	35.2 (37)	64.8 (68)	7.4 (105)
Ethnic minorities (excluding White minorities)	38.2 (73)	61.8 (118)	13.4 (191)
Language, % (n)			
English as 1st language	25.8 (327)	74.2 (941)	88.7 (1268)
English not as 1st language	34.2 (55)	65.8 (106)	11.3 (161)
Block 2: Personal circumstances			
Marital status, % (n)			
Not married/partnered	24.9 (120)	75.1 (362)	33.9 (482)
Married/partnered	27.4 (258)	72.6 (682)	66.1 (940)
Living social status, % (n)			
Live with other(s)	27.3 (327)	72.8 (873)	84.0 (1200)
Live alone	24.0 (55)	76.0 (174)	16.0 (229)
Children at home, % (n)[d]			
No dependent children	18.2 (140)	81.8 (628)	53.8 (768)
Dependent children	36.7 (242)	63.3 (418)	46.2 (660)
Employment status, % (n)[d]			
Full-time	29.0 (339)	71.0 (828)	81.7 (1167)
Part-time	15.5 (24)	84.5 (131)	10.9 (155)
Self-employed	17.9 (19)	82.1 (87)	7.4 (106)
Socio-economic grade, % (n)[d]			
Non-manual occupation	21.7 (234)	78.3 (846)	76.5 (1080)
Manual occupation	43.4 (144)	56.6 (188)	23.5 (332)
Work sector, % (n)[d]			
Other	15.4 (103)	84.6 (564)	46.7 (667)
Health & social care	53.0 (105)	47.0 (93)	13.9 (198)
Education & childcare	33.6 (45)	66.4 (89)	9.4 (134)
Key public service	43.3 (26)	56.7 (34)	4.2 (60)
Local & national govt	18.6 (18)	81.4 (79)	6.8 (97)
Food & essential goods	37.0 (20)	63.0 (34)	3.8 (54)
Public safety & security	44.0 (11)	56.0 (14)	1.7 (25)
Transport	38.1 (16)	61.9 (26)	2.9 (42)
Utilities, comms & finance	25.0 (38)	75.0 (114)	10.6 (152)
Index of multiple deprivation, % (n)			
1st quartile (lowest)	21.1 (62)	78.9 (232)	20.6 (294)
2nd quartile	23.1 (83)	76.9 (277)	25.2 (360)
3rd quartile	24.2 (93)	75.8 (291)	26.9 (384)
4th quartile (highest)	37.1 (145)	62.9 (246)	27.4 (391)
Financial hardship, mean (SD, n)	9.50 (3.01, 371)	7.75 (2.92, 1016)	8.21 (3.05, 1387)
Chronic illness of self, % (n)			
No chronic illness	25.5 (306)	74.5 (894)	85.5 (1200)
Chronic illness	34.5 (70)	65.5 (133)	14.5 (203)
Chronic illness of household member, % (n)			
No chronic illness	26.8 (330)	73.2 (903)	87.9 (1233)
Chronic illness	27.1 (46)	72.9 (124)	12.1 (170)
Vaccination status, % (n)[d]			
Not been vaccinated	23.1 (277)	76.9 (921)	84.0 (1198)

(*continued on next page*)

Table 1 (*continued*)

Variable	Attended workplace[a] % (n)	Did not attend workplace[a] % (n)	All[b,c] % (n)
Been vaccinated	45.4 (104)	54.6 (125)	16.0 (229)
Block 3: Psychological variables			
Worried about COVID-19, mean (SD, n)	2.35 (1.14, 382)	2.46 (1.10, 1046)	2.43 (1.11, 1428)
Risk of COVID-19 to self, mean (SD, n)	3.23 (1.20, 380)	3.15 (1.10, 1034)	3.19 (1.13, 1414)
Believe Gov info is biased, mean (SD, n)[d]	2.62 (1.14, 382)	2.92 (1.23, 1046)	2.84 (1.21, 1428)
Believe had COVID-19, % (n)[d]			
Not had COVID-19 or do not know	24.0 (264)	76.0 (836)	77.0 (1100)
Had COVID-19	36.0 (118)	64.0 (210)	23.0 (328)
Willing to leave home if with symptoms, % (n)[d]			
Not willing	19.1 (160)	80.9 (677)	65.2 (837)
Willing	30.4 (136)	69.6 (311)	34.8 (447)

SD, standard deviation.
[a] Percentages sum to 100 across 'Attended workplace' and 'Did not attend workplace'.
[b] Percentages sum to 100 down level of predictor variable.
[c] Sample sizes vary because of missing values and rounding of weighted totals.
[d] Workplace attendance differs across values of predictor variable $P < 0.001$ by χ^2 test for percentages or analysis of variance for means.

people who could work from home should not be pressured to attend workplaces, nor should they be given the option of doing so voluntarily.[10] Increasing job security and reducing employer pressure could be addressed by government regulation. Greater financial and practical support for those asked to isolate could reduce those going out to work: findings from the CORSAIR study show that more than half of those even with symptoms are not isolating for the full period, and going out to work is one of the reasons given.[22] In terms of the association with the presence of a dependent child in the household, it is notable that this exists even after adjusting for multiple financial variables within the data set.[23] We note that the mental health of parents was affected by the first lockdown in the UK,[32] which is consistent with other findings.[33] One explanation may be that some parents attend work partly in order to reduce distress within the household. Another may be that although they can work at home when children are at school, they cannot do so easily when children are at home.

In April 2020, believing one had already had COVID-19 was shown to be associated with perceptions of immunity against the virus and reduced adherence to several protective behaviours in one UK sample.[34] Although we did not observe an association between perceptions of prior infection and attending work, our findings of a positive association between reports of having been vaccinated and workplace attendance suggests that perceptions of immunity arising from the vaccine are now playing a similar role. Although the rollout of the vaccination programme in the UK has been rapid and is widely considered a success, there have been reported gaps in the provision of verbal and accessible written information explaining that immunity would take three weeks to build up, would be partial and it was possible that people could continue to be infectious, especially before the second dose. The absence of this information may be associated with a recent increase in self-reported breaches of current lockdown restrictions amongst older adults who were among the first to be vaccinated, where 41% of those older than 80 years reported having met someone outside of their household and support bubble less than 3 weeks after vaccination.[35] A month or so into the programme, NHS England has provided scripts, posters and an animation for use alongside the vaccination programme.[36] Hopefully, this will go some way to reducing the increased risky behaviours that can follow vaccination.

Increased workplace attendance in certain sectors suggests that these sectors may be considered for targeted interventions. In the case of health and social care, education and childcare and some other sectors, it could be that the fact that many front-line workers in these sectors need to attend the workplace leading to a culture in which other workers feel compelled to do so even if this is not necessary, something that may also have wider implications for attendance while sick.[33] Personal communication suggests that another key reason for health and social care employees who could work at home not to do so is the lack of adequate digital technology for their work. This merits further examination.

In the UK, the Government's roadmap out of our third lockdown specifies a sequence of changes, starting with the reopening of schools and progressing to the removal of all legal limits on social contact. The need to proceed slowly through these changes has been emphasised repeatedly. Ensuring that a large number of people who can work from home do so is one key measure that can be taken to keep control of the pandemic as restrictions are eased. Given the importance of schools remaining open and the predicted increased transmission from children being at school,[37] it is imperative that other measures are taken to keep COVID-19 under control. Providing a large number of people with the means to work at home when this is possible is one such measure, especially because this would reduce people interacting both in workplaces and on transport.

The limitations of our study include the following: 1) it relies on self-report which may cause reporting bias, particularly concerning whether work can be completed entirely from home – it is possible that although our respondents reported that they believed they could work from home, we do not know the circumstances of their employment to know whether this reflects the requirements of their role, 2) use of an online sample which, even though has been weighted to match major demographic features of the UK population, may nevertheless not be fully representative, 3) collinearity among predictors and 4) possible omission of other relevant variables. In relation to the latter point, research on broader contextual factors such as values and political orientations would provide another layer of understanding for the current findings.[38,39]

Conclusions

Non-essential workplace attendance in the UK in early 2021 during the COVID-19 pandemic was substantial and significantly independently associated with a wide range of sociodemographic variables and personal circumstances. Having been vaccinated, financial hardship, manual occupational group, having a dependent child at home and working in certain key sectors were associated with higher likelihood of workplace attendance. These findings could inform government, employer-led and other interventions aimed at reducing non-essential workplace attendance in the future.

Table 2
Factors associated with attending the workplace at least once in the previous 7 days using multivariable logistic regression.[a]

Predictor	Block 1 (odds ratio, 95% CI)	Block 2 (odds ratio, 95% CI)	Block 3 (odds ratio, 95% CI)
Block 1: sociodemographic variables			
Wave			
Wave 1 (Ref)			
Wave 2	0.95, 0.66–1.35	0.89, 0.61–1.31	0.90, 0.61–1.33
Wave 3	1.35, 0.97–1.88	1.13, 0.78–1.63	1.18, 0.81–1.71
Region			
East Midlands (Ref)			
East of England	0.69, 0.33–1.45	0.62, 0.28–1.41	0.61, 0.27–1.39
London	1.10, 0.58–2.09	0.96, 0.48–1.94	0.95, 0.47–1.93
North East	1.25, 0.53–2.95	1.24, 0.49–3.18	1.28, 0.50–3.29
North West	1.14, 0.57–2.28	1.04, 0.49–2.23	1.02, 0.47–2.22
Northern Ireland	1.37, 0.51–3.69	1.09, 0.37–3.25	1.01, 0.33–3.05
Scotland	0.71, 0.34–1.47	0.72, 0.32–1.58	0.71, 0.32–1.57
South East	0.58, 0.29–1.19	0.56, 0.25–1.23	0.55, 0.25–1.22
South West	0.95, 0.44–2.02	0.73, 0.31–1.71	0.74, 0.31–1.75
Wales	1.22, 0.52–2.86	1.29, 0.51–3.27	1.32, 0.52–3.35
West Midlands	0.96, 0.48–1.93	0.77, 0.36–1.67	0.74, 0.34–1.61
Yorks & Humber	1.02, 0.47–2.19	0.96, 0.41–2.22	0.93, 0.40–2.19
Gender			
Male (Ref)			
Female	**1.89, 1.42–2.53**	**1.83, 1.32–2.54**	**1.85, 1.33–2.58**
Age[b]	**0.97, 0.96–0.99**	0.99, 0.98–1.01	0.99, 0.98–1.01
Educational level			
Non-degree level (Ref)			
Degree level	**0.70, 0.52–0.94**	0.78, 0.56–1.09	0.76, 0.54–1.07
Ethnic group			
White British (Ref)			
White ethnic minorities	1.75, 0.91–3.35	**2.36, 1.15–4.83**	**2.39, 1.16–4.91**
Ethnic minorities (excluding White minorities)	**1.68, 1.09–2.60**	1.49, 0.92–2.41	1.49, 0.92–2.42
Language			
English as 1st language (Ref)			
English not as 1st language	0.78, 0.45–1.37	0.66, 0.36–1.24	0.69, 0.37–1.29
Block 2: Personal circumstances			
Marital status	–		
Not married/partnered (Ref)			
Married/partnered		1.20, 0.79–1.83	1.20, 0.79–1.83
Living social status	–		
Live with other(s) (Ref)			
Live alone		0.83, 0.48–1.43	0.82, 0.47–1.43
Dependent children	–		
No dependent children (Ref)			
Dependent children		**1.60, 1.14–2.24**	**1.65, 1.17–2.32**
Employment status	–		
Full-time (ref)			
Part-time		**0.40, 0.21–0.73**	**0.38, 0.20–0.70**
Self-employed		**0.43, 0.21–0.87**	**0.43, 0.21–0.89**
Socio-economic grade			
Non-manual occupation (Ref)			
Manual occupation		**1.75, 1.20–2.54**	**1.74, 1.19–2.53**
Work sector	–		
Other (Ref)			
Health & social care		**4.26, 2.63–6.90**	**4.18, 2.56–6.81**
Education & childcare		**2.35, 1.40–3.94**	**2.45, 1.45–4.14**
Key public service		**3.50, 1.70–7.20**	**3.78, 1.83–7.81**
Local & national govt		1.06, 0.51–2.22	1.07, 0.51–2.23
Food & essential goods		**2.56, 1.20–5.48**	**2.51, 1.17–5.37**
Public safety & security		**3.60, 1.29–10.1**	**3.90, 1.39–11.0**
Transport		**2.60, 1.18–5.72**	**2.60, 1.17–5.77**
Utilities, comms & finance		1.48, 0.89–2.45	1.45, 0.87–2.42
Index of multiple deprivation	–		
1st quartile (Ref)			
2nd quartile		0.97, 0.61–1.54	0.98, 0.62–1.56
3rd quartile		0.98, 0.62–1.56	0.99, 0.63–1.58
4th quartile		1.02, 0.63–1.65	1.10, 0.62–1.64
COVID-19–related financial hardship (15-point score)	–	**1.13, 1.07–1.20**	**1.14, 1.08–1.21**
Chronic illness of self	–		
No chronic illness (Ref)			
Chronic illness		0.61, 0.37–1.02	0.62, 0.37–1.02
Chronic illness of household member	–		
No chronic illness (Ref)			
Chronic illness		1.15, 0.70–1.86	1.14, 0.70–1.86
Vaccination status			
Not been vaccinated (Ref)			
Been vaccinated		**2.01, 1.29–3.11**	**2.08, 1.33–3.24**

(*continued on next page*)

Table 2 (*continued*)

Predictor	Block 1 (odds ratio, 95% CI)	Block 2 (odds ratio, 95% CI)	Block 3 (odds ratio, 95% CI)
Block 3: Psychological variables			
Worry about COVID-19 (5-point scale)	–	–	1.08, 0.91–1.28
Risk of COVID-19 to self (5-point scale)	–	–	1.12, 0.94–1.32
Believe had COVID-19	–		
Not had COVID-19 (Ref)			
Had COVID-19			0.66, 0.44–1.00
Believe Govt info is biased (5-point scale)	–	–	0.96, 0.84–1.10
Willing to leave home if with symptoms	–	–	
Not willing (Ref)			
Willing			1.05, 0.75–1.48

CI, confidence interval. Bolding denotes a significant association ($P < .05$ 2-tailed).
[a] Weighted sample size for the analysis was 1194.
[b] Age was included as a quantitative variable, so the parameter is the odds ratio per additional year of age.

Author statements

Ethical approval

This work was conducted as part of service evaluation of the marketing and communications run by the Department of Health and Social Care and so did not require ethical approval.

Funding

This work was funded by the National Institute for Health Research Health Services and Delivery Research Programme. LS, RA and GJR are supported by the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response, a partnership between Public Health England (PHE), King's College London and the University of East Anglia. RA is also supported by the NIHR HPRU in Behavioural Science and Evaluation, a partnership between PHE and the University of Bristol. HWWP receives funding from PHE and NHS England. NTF is partly funded by a grant from the UK Ministry of Defence. The views expressed are those of the authors and not necessarily those of the NIHR, PHE, the Department of Health and Social Care or the Ministry of Defence. Surveys were commissioned and funded by the Department of Health and Social Care (DHSC), with the authors providing advice on the question design and selection. DHSC had no role in analysis, decision to publish or preparation of the manuscript. Preliminary results were made available to the DHSC and the UK's Scientific Advisory Group for Emergencies.

Data availability statement

The data are owned by the UK's Department of Health and Social Care, so no additional data are available from the authors.

Competing interests

Authors received financial support from the UK's National Institute for Health Research for the submitted work. RW has undertaken research and consultancy for companies that manufacture smoking cessation medications (Pfizer and GSK). RA is an employee of Public Health England. HWWP receives additional salary support from Public Health England and NHS England. NTF is a participant of an independent group advising NHS Digital on the release of patient data. All authors are members of the UK's Scientific Advisory Group for Emergencies or its subgroups. There are no other financial relationships with any organisations that might have an interest in the submitted work in the previous three years and no other relationships or activities that could appear to have influenced the submitted work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.002.

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Public Health 198 (2021) 129–140

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Review Paper

Measurement and prevalence of adult physical activity levels in Arab countries

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ARTICLE INFO

Article history:
Received 5 January 2021
Received in revised form
14 June 2021
Accepted 9 July 2021
Available online 18 August 2021

Keywords:
Physical activity
Prevalence
Arab countries
Adults
Measurement

ABSTRACT

Objectives: This study aims to examine the reported prevalence of sufficient physical activity among adults in Arab countries and to determine the use of validated instruments for assessing physical activity.
Study design: This is a systematic literature review.
Methods: This review follows recommendations outlined in the Meta-Analysis of Observational Studies in Epidemiology guidelines. The protocol for this study was preregistered with PROSPERO. Cross-sectional, cohort and intervention studies with a minimum of 300 adults aged ≥18 years assessing physical activity using a questionnaire or other self-report measure in the Arabic language were identified from seven electronic databases (MEDLINE, Embase, Cochrane Database of Systematic Reviews, CINAHL, PsycINFO, SPORTDiscu and PubMed). Databases were searched from 1st January 2008 to 17th September 2018. Descriptive analysis was performed using frequency and percentages. The prevalence of physical activity was calculated as the average prevalence for the reported percentages from the studies with similar tools.
Results: Fifty studies involving 298,242 participants were included in this review. The mean (range) sample size was 5964.8.1 (323–197,681). Data were collected from participants in 16 of the 22 Arab countries. Great variation exists across the studies in determining whether adults were sufficiently active or not. Twenty studies reported usable data from the Global Physical Activity Questionnaire and the International Physical Activity Questionnaire (moderate & high categories). In these studies, prevalence of physical activity ranged from 34.2 to 96.9%. It was not possible to compare the other studies owing to variation in instruments used to assess physical activity and in the case definition used for 'physically active'.
Conclusions: This study highlights the need for wider reporting of physical activity and the adoption of valid and reliable instruments to support the development of evidence-informed policy and programmes at both country and regional level. International tools need to be correctly validated, or context-specific tools must be developed to accurately measure physical activity.

Introduction

Physical activity (PA) has a profound effect on health. The World Health Organization (WHO) has determined that physical inactivity is the fourth leading global risk for mortality, responsible for raising the risk of non-communicable diseases (NCDs) and affecting countries across all income groups.[1] It is estimated that worldwide physical inactivity causes 6% of the burden of disease from coronary heart disease, 7% of type 2 diabetes, 10% of breast cancer and 10% of colon cancer.[2]

While globally more than one-third of adults are estimated to not accumulate sufficient PA to meet public health guidelines,[3] there are large differences between regions. The highest prevalence of inactivity is seen in the Eastern Mediterranean Region (43.2%) and the Americas (43.3%).[3] The aforementioned burden of NCDs associated with physical inactivity in the Eastern Mediterranean Region is 8% of coronary heart diseases, 10% of type 2 diabetes, 14% of breast cancer and 14% of colon cancer.[2] However, life expectancy in the region has increased from 51 years of age in 1970 to

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https://doi.org/10.1016/j.puhe.2021.07.010

almost 70 years in 2016; the rapid rise in NCDs has been described as alarming.[4] The Arab world and Greater Middle Eastern region are forecasted to experience a further rise in preventable deaths due to NCDs if no serious action is taken.[5]

Promoting PA will form a key role in preventing and treating NCDs,[6] and this requires an understanding of the challenges associated with this task across regions. The WHO has set a target of a 15% relative reduction in the global prevalence of physical inactivity in adults and adolescents by 2030.[6] This is supported by an earlier call to action by the WHO Regional Office for the Easter Mediterranean.[7] Alongside commonly cited barriers to PA globally, specific issues experienced by those living in Arab countries have been identified. Physical obstacles (e.g., hot weather, unfriendly built environment) and low value placed on PA (e.g., car culture, physical exertion associated with lower status occupations, parental preferences) translate into low interest and motivation to engage in PA.[8] That said, socially and culturally congruent interventions to promote PA in Arab countries are increasing.[9] A thorough grasp of current levels of PA and ongoing monitoring and surveillance is essential if gains in population-level PA are to be realised. The aforementioned global action plan encourages countries to strengthen reporting of physical inactivity.[6]

Recent years have seen a rise in the number of studies examining the prevalence of PA in Arab countries across the Middle East and North Africa. A synthesis of studies across countries and an evaluation of the instruments used to attain prevalence estimates are warranted. Thus, the present systematic review sought to (1) examine the reported prevalence of sufficient PA among adults in Arab countries and (2) determine the use of validated instruments for assessing PA.

Methods

This systematic review follows recommendations outlined in the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) guidelines.[10] The protocol for this review was preregistered with PROSPERO (International prospective register of systematic reviews).[11]

Search strategy

We searched the following electronic databases: MEDLINE, Embase, Cochrane Database of Systematic Reviews, CINAHL, PsycINFO, SPORTDiscus and PubMed. Keywords used for the search included the following: PA, exercise survey, questionnaire, Arab. Search syntax, e.g., explosion, was used when necessary. The full search strategy is provided in Appendix 1. Databases were searched from 1st January 2008 to 17th September 2018.

Study selection

Studies identified through the electronic searches were uploaded to the online software Covidence.[12] Titles and abstracts of studies were screened independently by two review authors (AS, EM). The full texts of studies not excluded at initial screening were then retrieved. Manual searches were carried out, and emails were sent to corresponding authors to retrieve full texts where necessary. Full texts were independently assessed for eligibility by two authors (AS, EM, RM, NA), with disagreements resolved through consensus. Multiple publications from the same study were collated, and the earliest report was used as the primary reference.

In brief, we included studies with a minimum of 300 participants that assessed PA using a questionnaire or other self-report measure in the Arabic language and in adults aged 18 years or older. Articles published in languages other than Arabic and English were excluded. An Arab country was defined as a member of the Arab League. Full inclusion criteria are displayed in Table 1.

Outcomes

Our primary outcome of interest was prevalence of PA (%). We were also particularly interested in the tool used to assess PA and whether the tool used was validated in Arabic.

Data extraction

Data were extracted using a standardised template piloted and agreed upon by the review team. Data were extracted by all members of the research team. Extracted information included study setting, study population, participant demographics, baseline characteristics, study methodology, recruitment and study completion rates, PA outcomes and times of measurement, measurement tool used, definition of PA/inactivity, prevalence of PA and information for assessment of the risk of bias. For PA outcomes, we recorded the definition and summary data for each group (mean prevalence with standard deviation). Inter-rater reliability was evaluated by cross-checking five sets of data imputed by each member of the research team.

Risk of bias

We assessed risk of bias using the tool to assess the risk of bias in prevalence studies developed by Hoy and Brooks.[13] Two review authors independently made judgements (RM, AS), and a third reviewer independently resolved disagreements (EM). The tool uses 10 items to assess four domains of bias: selection bias (3 items), non-response bias (1 item), measurement bias (5 items) and bias related to the analysis (1 item). The judgement options are (i) low risk or (ii) high risk. If there is insufficient information in the article to permit a judgement, then the assessor is required to choose 'high risk'. We deemed trials with low risk of bias for all of the 10 items as low overall risk. Low risk of bias indicates that further research is very unlikely to change our confidence in the estimate.

Data synthesis and analysis

Descriptive analysis was performed using frequency and percentages. The prevalence of PA was calculated as the average prevalence for the reported percentages from the studies with similar tools. Original data were not obtained from the authors.

Table 1
Eligibility criteria.

Population	*Inclusion:* adults aged 18+ years, Arab country (Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, United Arab Emirates and Yemen) *Exclusion:* children and youth (<18 years), participants recruited as a patient through a hospital or clinic
Outcome	Prevalence of physical activity
Instrument	Assessment of physical activity using a questionnaire in Arabic or other self-report tools in Arabic
Study design	*Inclusion:* cross-sectional, cohort and intervention studies with minimum 300 participants *Exclusion:* studies with sample size <300
Other limits	*Inclusion:* Full-text articles in the English or Arabic language *Exclusion:* abstracts or conference papers

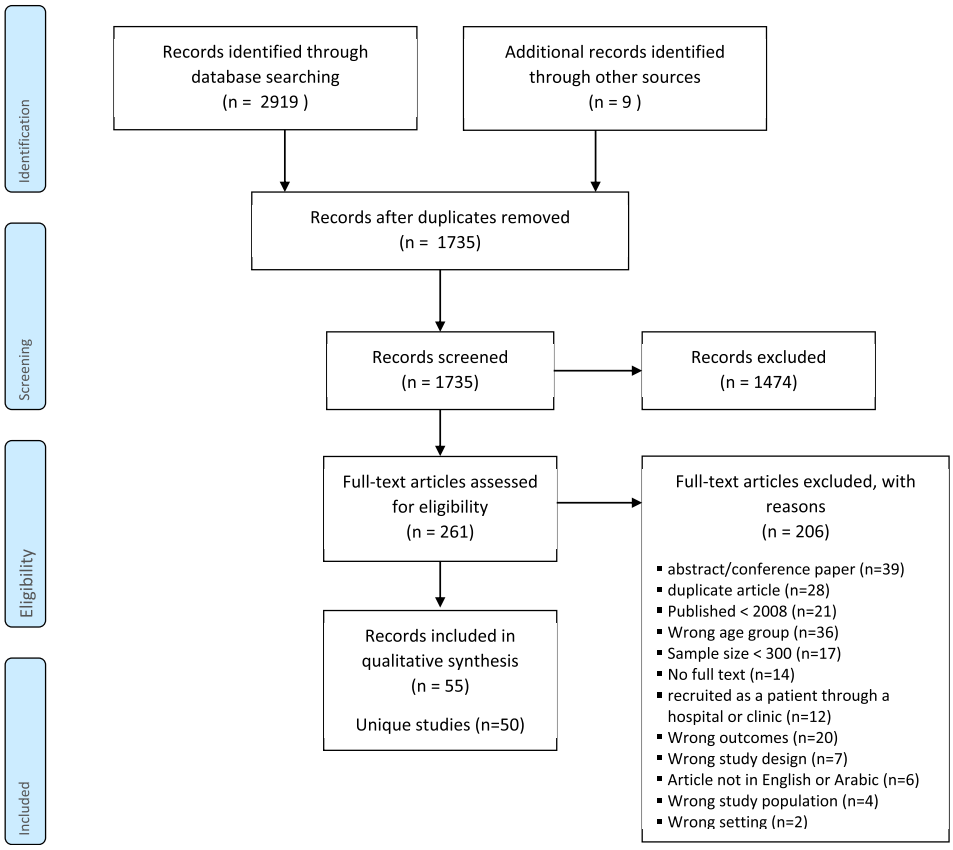

Fig. 1. PRISMA flow diagram.

Results

In total, 2919 search hits were identified for consideration (Fig. 1). Of all, 1735 article titles and abstracts were screened. We identified 261 full-text articles to review, and this led to 55 articles (based on 50 unique studies) for inclusion. Five studies had associated publications[14–18], two articles each.[19–23] The characteristics of included studies are outlined in Table 2.

Study design and setting

All studies collected cross-sectional data; however, several studies represent one point in time in ongoing surveillance efforts. The most popular study setting was at universities (18 studies). Other settings included households (15 studies), healthcare facilities (10 studies), shopping centres (4 studies), miscellaneous workplaces (3 studies), community centres (1 study) and military sites (1 study). Four studies collected data from multiple settings.

Participants

The 50 included studies involved 298,242 participants. The mean sample size was 5964.8 (range, 323–197,681). Only three studies had more than 10,000 participants.[16,18,24] The mean age of all participants was not reported in 24 studies. In the 26 that did provide mean age, the average across studies was 31.1 ± 9.9 years (range, 18.9–52.0). All eligible samples comprised adults; although one study included adolescents older than 15 years, their data were not included in the analysis in this review.[25] Most of the studies include both females and males (mean, 55.7% female). Six studies included only female participants,[15,26–30] and two studies included only male participants.[31,32]

Data were collected from participants in 16 countries (Bahrain, Comoros, Egypt, Jordan, Kingdom of Saudi Arabia [KSA], Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Sudan, Syria, Tunisia and United Arab Emirates) of the 22 countries considered to be Arab Countries. Three studies included data from more than one country.[33–35] The majority of study samples were from KSA (n = 18), followed by Qatar (n = 5), Lebanon (n = 4), Oman (n = 4) and Jordan (n = 3). None of the included studies reported data from Algeria, Djibouti, Iraq, Mauritania, Somalia or Yemen.

Assessment of physical activity

Seven studies used the Global Physical Activity Questionnaire (GPAQ) to assess PA.[14,26,27,36–39] A further four studies reported that their data collection was part of the WHO STEPwise surveillance tool,[18,40–42] and this incorporates the GPAQ. Two studies used the International Physical Activity Questionnaire (IPAQ),[25,43] six studies used the IPAQ short form[33,44–48] and one further study used an adapted version of the IPAQ short form.[49] Two studies used the Arab Teen Lifestyle Study Questionnaire.[15,28] A variety of other instruments including the Kuwait National Nutrition Surveillance System survey[16] and the Youth Risk Behavior Surveillance survey were used.[31] Nineteen studies did not specify the name of the instrument used.

Great variation exists across the studies in determining whether adults were sufficiently active or not. Tables 3 and 4 provide details of the PA categories reported and the definition used to determine if someone was defined as being physically active. Some studies did not clearly define 'physically active'.[50,51] Others determined that

Table 2
Characteristics of included studies.

Study	Country	Study setting	Main descriptor of study population	Sample recruited	Mean age	Methods of data collection
Ahmed 2012[16] & Ahmed 2013[21]	Kuwait	Healthcare facility	Kuwaitis going for required government health evaluations	23,732	NR	NR
Alarjan 2015[58]	Jordan	Healthcare facility	Doctors, pharmacists, nurses, lab techs and x ray specialist in one public and private hospital in Jordan	748	NR	NR
Albache 2010[17] & Al Ali 2011[22]	Syria	Household	Aleppo residents	1168	44.7	House survey administered by trained interviewers
Al-Baghli 2008[24]	Saudi Arabia	Healthcare facility	Eastern Providence Saudi Arabia residents	197,681	NR	Face-to-face interview using a structured questionnaire by Arabic-speaking trained teams
Albawardi 2016[28]	Saudi Arabia	Worksite	Female Saudi nationals working in an office in Riyadh, Saudi Arabia	420	31.7	Self-administered questionnaire
Al-Drees 2016[71]	Saudi Arabia	University	College of Medicine, KSU, Riyadh, KSA	409	21.33	Self-administered questionnaire
Alfhaid 2017[72]	Saudi Arabia	University	Health science students	450	22.34	Self-administered questionnaire
Al-Kadi 2018[50]	Saudi Arabia	University	Random sample of general population and students in Unaizah City in KSA	646	30.13	NR
Alkhathami 2017[73]	Saudi Arabia	Shopping centre, university, school, social media	Saudi Arabian adults	2043	NR	Self-administered questionnaire
Al-Nakeeb 2015[74]	Qatar	University	Young adults at Qatar University	732	NR	Self-report questionnaire, administered face-to-face by the researchers
Al-Qahtani 2016[51]	Saudi Arabia	University	Saudi medical students	566	21.33	Self-administered questionnaire
Al Riyami 2010[75]	Oman	Household	Elderly Omanis	2027	NR	Community-based household survey
Al-Tannir 2009[52]	Lebanon	Shopping centre	Lebanese adults	346	NR	Self-reported questionnaire
Al-Tannir 2017[34]	Saudi Arabia	Healthcare facility	Nurses	412	NR	Self-administered questionnaires
Al Thani 2015[26]	Qatar	Household	Qatari women of childbearing age	747	31	Household face-to-face interview
Al Thani 2016[42]	Qatar	Household	Qatari women of childbearing age	418	30.89	Household face-to-face interview
Al-Thani 2016[27]	Qatar	Household	Qatari citizens	2496	NR	Household survey
Amin 2011[14] & Amin 2012[19]	Saudi Arabia	Healthcare facility	Adult Saudis	2316	32.7	Nurse-administered questionnaire
Amin 2017[38]	Egypt	University	Medical students at Cairo University	519	21.6	Self-administered questionnaire
Ammouri 2008[76]	Jordan	Healthcare facility, community centre	Jordanian adults	349	34.4	Face-to-face interview
Ansari 2016[31]	Saudi Arabia	University	Students in Majmaah University	340	NR	Self-administered questionnaire
Bawadi 2011[46]	Jordan	Healthcare facility	Adults in Jordan	340	NR	Interviewer-administered questionnaire
Brocato 2015[53]	Saudi Arabia	Shopping centre	Saudi general population	2686	NR	Self-administered questionnaire
Bull 2009[45]	Saudi Arabia	Household	Saudi adults aged 18–65 years	988	NR	Telephone interview
Chamieh 2015[48]	Lebanon	Household	Adults in Lebanon	2697	NR	Interviewer-administered questionnaire
Donnelly 2018[43]	Qatar	University, healthcare facility	Arab adults aged 18 years and older	1606	NR	Interviewer-administered questionnaire
El Ansari 2014[55]	Libya	University	University students	1567	20.9	Self-administered questionnaire
El Ansari 2014[56]	Egypt	University	University students	3271	18.9	Self-administered questionnaire
El Ansari 2017[35]	Palestine	University	University students	1428	NR	Self-administered questionnaire
El Rhazi 2011[77]	Morocco	Household	Moroccan adults	2891	NR	Interviewer-administered questionnaire
Gharaibeh 2012[47]	Jordan	University	University students at Jordan University of Science and Technology	348	20.7	Self-administered questionnaire
Hashim 2013[78]	United Arab Emirates	Healthcare facility	Dentists living in the UAE	733	38.1	Structured questionnaire
Horaib 2013[18] & Al-Dahi 2013[23]	Saudi Arabia	Military	Military personnel in KSA	10,229	NR	Self-administered questionnaire
Kalaf 2016[30]	Saudi Arabia	Shopping centre, university, worksite	Female Saudi nationals	833	NR	Interviewer-administered questionnaire
Khalaf 2013[15] & Khalaf 2015[20]	Saudi Arabia	University	Female university students	663	20.4	Self-reported questionnaire
Khalil 2017[39]	Sudan	Community	Community-based adults living in Khartoum city, Sudan	323	35.5	Self-administered questionnaire
Mabry 2012[37]	Oman	Household	Omani men and women aged 20 years or older residing in Sur city	1373	36.4	Household survey, face-to-face interviews
Mabry 2016[40]	Oman	Household	Omani adults	4717	NR	Household survey

Table 2 (*continued*)

Study	Country	Study setting	Main descriptor of study population	Sample recruited	Mean age	Methods of data collection
Mabry 2017[36]	Oman	Household	Omani adults	2977	NR	Household survey, face-to-face interviews
Mandil 2016[41]	Saudi Arabia	Healthcare facility	Physicians aged 24–65 years in 4 Riyadh hospitals, Saudi Arabia	360	33.11	Self-administered questionnaire
Merom 2012[57]	Palestine	Research centre	Palestinians and Israelis aged 25–74 years living in East and West Jerusalem	971	52	Face-to-face interviews by trained interviewers
Moradi-Lakeh 2016[25]	Saudi Arabia	Household	Saudi youths aged 15–24 years (extracted data: 20–24)	1113	NR	Interviewer-administered household survey
Musaiger 2015[79]	Bahrain	University	University students in Bahrain	642	20.1	Self-reported questionnaire
Musharrafieh 2008[80]	Lebanon	University	University students in Lebanon	2013	21	Interviewed and self-administered questionnaire
Najdi 2011[49]	Morocco	Household	Moroccan adults >18 years	2613	41.4	Household interview by trained interviewers
Sibai 2013[44]	Lebanon	Household	Lebanese adults aged >25 years	2195	45	Household survey
Sonia 2016[32]	Tunisia	Worksite	Male manufacturing factory employees	1099	33.8	Questionnaire, via interview or self-report
Stefanopoulou 2014[29]	United Arab Emirates	N/R	Perimenopausal and postmenopausal women in the UAE aged 45–55 years: general university academic and administrative staff and students' parents (parents of medical and non-medical staff)	372	49.84	Women completed questionnaires with researchers' support
Stubbs 2017[33]	Tunisia, United Arab Emirates and Comoros	Household	Adults	8221	NR	Face-to-face and telephone interviews conducted by trained interviewers
Torchyan 2016[81]	Saudi Arabia	University	Undergraduate medical students	408	NR	Self-administered questionnaire

NR = not reported.

adults were physically active if they participated in any type of exercise during the week.[34,52,53] The threshold of ≥5 days/week moderate exercise for at least 30 min or ≥3 days/week vigorous exercise for at least 20 min[54] was used in four studies.[35,55–57]

Risk of bias

The risk-of-bias judgements for each study are shown in Fig. 2. Nine studies (18%) were judged to have low risk of bias for all domains.[23,25–27,36,40,44,48,49] Approximately one-third of studies were judged to have high risk of bias for the sampling frame (not a close representation of the target population) and for random selection. Nineteen studies (38%) were judged to have high risk of bias for non-response bias (the response rate was <75%, and analysis was not undertaken to compare characteristics between responders and non-responders). All studies were at low risk of bias for internal validity in relation to collecting data directly from the subjects (as opposed to a proxy). Eighteen studies (36%) did not use, or did not report, an instrument to assess PA that had previously been tested to show acceptable reliability and validity.

Prevalence of PA

Prevalence of PA in the 20 studies that reported useable data from the GPAQ and IPAQ (moderate and high category) ranged from 34.2%[33] to 96.9%[33] (Table 3). In 12 of the 20 GPAQ/IPAQ studies, PA prevalence was ≤60%.[14,25–27,36,39,40,42,44–46,48] It is not possible to directly compare the 30 other studies owing to the variety in the instruments used to assess PA and in the case definition used for 'physically active'. In these studies, prevalence of PA ranged from 8.7% in males ("3 days planned PA per week')[58] to 87% in males ("3 or more days of vigorous activities a week for at least 20 min per day, 5 or more days of moderate-intensity activities a week for at least 30 min per day, 5 or more days of any combination of moderate, or vigorous-intensity activities a week').[57] Findings from individual studies are summarised in Table 4. It was challenging to synthesise data disaggregated by gender because this was not always reported across studies. Furthermore, the age range within studies varied. However, it was clear from the available data that gender differences in PA were evident. Sixteen of the 20 studies that used the GPAQ or IPAQ reported including both females and males (Table 3). The within-study percentage difference in prevalence of PA between males and females ranged from 5.7% in the study by Amin et al.[14,19] with Saudi adults aged 18–64 years to 16% in the study by Amin et al.[38] that included medical students aged 19–23 years.

Discussion

In this review, we aimed to examine the reported prevalence of sufficient PA among adults in Arab countries and determine the extent to which validated instruments for assessing PA were used. Twenty studies reported usable data from the GPAQ and IPAQ (moderate & high categories). In these studies, prevalence of PA ranged from 34.2 to 96.9%. Within-study gender difference in PA ranged from 5.7[14,19] to 16%.[38] It was not possible to compare the other studies owing to variation in instruments used to assess PA and in the case definition used for 'physically active'. In addition, more than one-third of studies did not report whether the instrument used to measure PA was valid and reliable. These shortcomings in the available data greatly influence the extent to which our research questions can be answered with certainty.

Although several of our included studies used the IPAQ and/or GPAQ, the results of PA were reported differently and hence pooling the results to estimate an overall prevalence of PA was not possible. In addition, several studies did not adopt and report the standard IPAQ/GPAQ scoring protocols. We contacted several authors to request more detailed data to run the meta-analysis, but we received minimal response. We have roughly estimated an overall prevalence from studies using similar tools. The estimate was

Table 3
Prevalence of physical activity in studies using the GPAQ or IPAQ.

Study	Country	% Male	Age range	Study dates	Sample size	Instrument	PA categories	Prevalence (%)
Al Thani 2015[26]	Qatar	0	18–45	2012	747	GPAQ	Moderate and high PA level	44.2
Al-Thani 2016[27]	Qatar	42.2	18–64	2012	2496	GPAQ	Average (600–3000 MET-min/week) and high (≥3000 MET-min/week)	51.1
Mabry 2017[36]	Oman	50.1	18-NR	2008	2977	GPAQ	Active	45.1
Mabry 2012[37]	Oman	44.3	20-NR	2006	1373	GPAQ	Work PA: >315 MET-min/day Transport PA: >105 MET-min/day Leisure PA: > 315 MET-min/day	61.3 31.1 23.6
Amin 2017[38]	Egypt	51.3	19–23	2015	519	GPAQ	Sufficiently active: Participants who met the LTPA recommendations meeting the minimum recommendations of 30 min of moderate to vigorous-intensity LTPA or a total of 150 min/week of moderate vigorous intensity/week	64.8
Khalil 2017[39]	Sudan	52.9	18-NR	n/r	323	GPAQ	Physically active	46.2
Amin 2011[14] & Amin 2012[19]	KSA	55.6	18–46	NR	2316	GPAQ Arabic	Sufficiently active	52
Horaib 2013[18] & Al-Dahi 2013[23]	KSA	NR	<30-50	2009–2011	10,229	WHO STEPwise	Practice physical activity at least 30 min daily	69.2
Mabry 2016[40]	Oman	51.1	18-NR	2008	2977	WHO STEPwise	Physically active individuals were those who engaged in at least 150 min of moderate physical activity per week (minimum total 600 MET-min/week)	Males: 54.2 Females: 41.6
Mandil 2016[41]	KSA	61.7	24–65	2013–2014	360	WHO STEPwise	Participation in PA (engagement in any vigorous or moderate-intensity PA)	63.1
Al Thani 2016[42]	Qatar	0	18–45	2012	418	WHO STEPwise (Arabic)	Moderate + high PA	45.8
Donnelly 2018[43]	Qatar	50.1	NR	2013–2015	1606	IPAQ	Moderate + high PA	77.5
Moradi-Lakeh 2016[25]	KSA	44.2	20–24	2013	1113	IPAQ	Moderate + vigorous PA	36.9
Sibai 2013[44]	Lebanon	46.4	25-NR	2008–2009	2195	IPAQ short form	Moderate + HEPA	53.3
Bull 2009[45]	KSA	65.4	NR	2003	988	IPAQ short form	Moderate + high PA	60
Bawadi 2011[46]	Jordan	49.4	18–70	2007	340	IPAQ short form	Moderate + high	49.7
Stubbs 2017[33]	Comoros Tunisia UAE	NR	18-NR	2002–2004	1836 5202 1183	IPAQ short form	Moderate + high PA	96.9 34.2 49.1
Gharaibeh 2012[47]	Jordan	39	18–23	2009	348	IPAQ short form (Arabic version)	Moderate + high PA	86.7
Najdi 2011[49]	Morocco	51.9	26.2–56.6	2008	2613	IPAQ short form	Moderate + high PA	83.4
Chamieh 2015[48]	Lebanon	46.8	20-NR	May 2008 –April 2009	2608	IPAQ short form	Moderate + high PA	54.4

NR = not reported; IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire; LTPA = leisure time physical activity; HEPA = health enhancing physical activity.

broadly similar to the reported estimate from global surveillance of WHO regions;[3] however, it does not align with the worsening epidemiological profile of the Arab countries, with very high rates of obesity and diabetes.[59] It has been suggested that the quantity and quality of research on NCDs in the Arab world does not reflect the disease burden, with a widening disparity between higher- and lower-income countries.[60] Our review identified many studies with small sample sizes and a focus on specific population subgroups, and not as a national initiative that aims to establish NCDs risk factors surveillance system including PA. It is unfortunate that most of the identified studies focussing on PA are small scale. Wider reporting of PA and adoption of valid and reliable instruments would support the development of evidence-informed policy and programmes at both country and regional level.

The development of the IPAQ was to allow multicountry comparable estimates of PA and to help build population surveillance systems.[61] We started this review with the hypothesis that the IPAQ and GPAQ tools were not widely validated in Arab countries and the questions used are context specific. This review has identified a large proportion of studies which used the IPAQ and GPAQ without any reference to their validation – whether by the researcher or in another Arab country or setting. Craig et al.[62] report the validity of the IPAQ across 12 countries. The study included countries from the developed world including the US, Canada, Europe, Japan and Australia and the developing world including South Africa and Guatemala.[62] Arab countries were missing from this study. It was not until 2018 that the Arabic version of the long IPAQ was cross-culturally adapted and validated.[63] We are not aware of any published studies that report the validity of the Arabic version of the short IPAQ. It is therefore likely that the studies included in this review have used a translated version of the IPAQ that have not been validated in context considering language and cultural meaning. The GPAQ questionnaire, on the other hand, has been validated in both the developed and developing countries[64] including two Arab countries, KSA[65] and the United Arab Emirates.[66] The GPAQ is a modified version of the IPAQ with the aim to enhance the IPAQ use in cross-cultural settings.

The WHO encourages countries to establish NCD surveillance systems at the population level using the STEPwise approach to surveillance (STEPS), and the GPAQ contributes to the PA surveillance part.[67] This supports the focus on surveillance noted in the

Table 4
Prevalence of physical activity in studies using other instruments.[a]

Study	Country	% Male	Mean age	Study dates	Sample recruited	Tool used to measure PA	Definition of being physically active	PA prevalence (%)
Ahmed 2012[16] & Ahmed 2013[21]	Kuwait	45.96	NR	2003–2009	23,732	Question in the Kuwait National Nutrition Surveillance System	Deliberate non-work-related exercise outside the home such as walking, running, cycling or swimming	30.3
Alarjan 2015[58]	Jordan	38.1	NR	NR	748	Survey developed by researchers	3 days planned physical activity per week	11.6% F and 8.7% M
Albache 2010[17] & Al Ali 2011[22]	Syria	47.7	44.7	2006	1168	Interviewer-administrated questionnaire	Regular physical activity (>once a week)	18
Al-Baghli 2008[24]	Saudi Arabia	51.2	NR	Aug 2004–Feb 2005	197,681	Face-to-face interview using a structured questionnaire	Moderate PA (exercising ≥3 hrs/wk cycling/ walking/other activities that need effort) + strenuous PA (exercising ≥5 hrs/wk, jogging, swimming)	20.8
Albawardi 2016[28]	Saudi Arabia	0	31.7	NR	420	Modified from the Arab Teens Lifestyle Study (ATLS)	Moderate (600–2999 MET-min/week) and high PA (≥1500 MET-min/week vigorous PA or ≥3000 MET-min/week moderate/vigorous PA)	47.9
Al-Drees 2016[71]	Saudi Arabia	50.1	21.33	Academic year 2012–2013	409	Questionnaire formed after literature review	Physical activity at least 30 min daily	47.2
Alfhaid 2017[72]	Saudi Arabia	82.2	22.34	November 25, 2014 to May 3, 2015.	450	Adapted from the study “lifestyle practice among Malaysian university students"	Exercising regularly	37.6
Al-Kadi 2018[50]	Saudi Arabia	31.3	30.13	March 2013–March 2014	646	Lipid Research Clinics questionnaire	No clear definition was given	37
Alkhathami 2017[73]	Saudi Arabia	NR	NR	Nov.–Dec 2016	2043	Questionnaire about the characteristics, behaviours, risk factors and lifestyle of the participant related to gastro-oesophageal reflux disease	Regular physical activity ≥30 min more than three times a week	13.9
Al-Nakeeb 2015[74]	Qatar	43.7	NR	NR	732	NR	>1680 MET-min per week (60 min × 7 days × 4 METs)	29.6
Al-Qahtani 2016[51]	Saudi Arabia	59.3	21.33	2012–2013 academic year	566	NR	NR	Females 20, males 35
Al Riyami 2010[75]	Oman	48.4	NR	2005	2027	NR	Levels of physical activity based on daily chores and walking, with the cut-off set at 30-min exercise per day	49.4
Al-Tannir 2009[52]	Lebanon	51.2	NR	April 2007–May 2007	346	Questionnaire	Regularly practice any type of PA	55
Al-Tannir 2017[34]	Saudi Arabia	45.6	NR	2014	412	Questionnaire formed after literature review	Asked if they performed physical activity and type of physical activity, duration and availability of physical activity facilities	Female 64.3, male 67.4
Ammouri 2008[76]	Jordan	48	34.4	NR	349	The Health Promotion Lifestyle Profile II (HPLPII)	Physical activity includes regular participation in light, moderate and/or vigorous activity. It could be planned or incidentally as a part of daily life or leisure activity	27.5
Ansari 2016[31]	Saudi Arabia	100	NR	February to March 2015	340	Youth Risk Behavior Surveillance	At least 150 min of moderate to intensity physical activity such as walking, cycling or sports, three or more times a week	33.6
Brocato 2015[53]	Saudi Arabia	50	NR	June 2011–May 2012	2686	N/R	Participants answering ‘yes’ to any exercise were considered physically active, while participants selecting ‘no activity’ were considered physically inactive	35.5
El Ansari 2014[55]	Libya	33.8	20.9	2008–2009	1567	Frequency & duration questionnaire	≥5 days/week moderate exercise for at least 30 min or ≥3 days/week vigorous exercise for at least 20 min	28.5
El Ansari 2014[56]	Egypt	47.5	18.9	2009–2010	3271	Health and well-being questionnaire	≥5 days/week moderate exercise for at least 30 min or ≥3 days/week vigorous exercise for at least 20 min	48
El Ansari 2017[35]	Palestine	41.4	NR	2013	1428	Frequency & duration questionnaire		32.1

(*continued on next page*)

Table 4 (*continued*)

Study	Country	% Male	Mean age	Study dates	Sample recruited	Tool used to measure PA	Definition of being physically active	PA prevalence (%)
							≥5 days/week moderate exercise for at least 30 min or ≥3 days/week vigorous exercise for at least 20 min	
El Rhazi 2011[77]	Morocco	49.5	NR	May 2008	2891	Detailed frequency questionnaire	At least 30 min of physical activity per day	61.3
Hashim 2013[78]	United Arab Emirates	61	38.1	NR	733	N/R	Exercise regularly	39
Kalaf 2016[30]	Saudi Arabia	0	NR	2012–2014	833	Structured questionnaire	≥40 min of activity per week (>2 weekly exercise sessions of at least 20 min each).	26
Khalaf 2013[15] & Khalaf 2015[20]	Saudi Arabia	0	20.4	2010	663	Arab Teen Lifestyle Study questionnaire	Moderately active (611·57–1389·63 MET-min/week) + high active (≥1389·63 MET-min/week)	66.7
Merom 2012[57]	Palestine	53.3	52	2004 to 2008	971	Multi-Ethnic Study of Atherosclerosis (MESA) questionnaire, which was adapted from the Cross-Cultural Activity Participation Study (CAPS), was used	A person who met the following criteria was considered adequately active: 3 or more days of vigorous activities a week for at least 20 min per day, 5 or more days of moderate-intensity activities a week for at least 30 min per day or 5 or more days of any combination of moderate- or vigorous-intensity activities a week.	Female 73, male 87
Musaiger 2015[79]	Bahrain	14	20.1	NR	642	Questionnaire	Practicing physical activity daily	19.6
Musharrafieh 2008[80]	Lebanon	40.6	21	Feb–June 2001	2013	Interview and self-administered anonymous questionnaire	Physical exercise was classified into 'No' (0.5 h per week) and 'Yes' (>0.5 h per week)	26.4
Sonia 2016[32]	Tunisia	100	33.8	2009	1099	Pretested questionnaire in Arabic	Practice physical activity 30 min or more per day, 5 days per week	31.8
Stefanopoulou 2014[29]	United Arab Emirates	0	49.84	Winter (Dec–Mar) and Summer (May–Sept) months, no year stated	372	NR	Exercise 2–7 times/week	11
Torchyan 2016[81]	Saudi Arabia	45.3	NR	NR	408	An adapted 4-level Saltin-Grimby Physical Activity Level Scale (SGPALS) instrument to measure the participants' self-reported leisure-time physical activity (PA)	Regular physical activity and training (moderate PA, MPA): Spending time on heavy gardening, running and swimming and playing tennis, badminton, calisthenics and similar activities, for at least 2–3 h/week 4. Regular hard physical training for competition sports (vigorous PA, VPA): Spending time in running, horseback riding, boxing, swimming, soccer, European handball, etc. several times per week.	22.2

NR = not reported; IPAQ = International Physical Activity Questionnaire; GPAQ = Global Physical Activity Questionnaire.
[a] Studies not using the GPAQ or IPAQ.

Study	Target population	Sampling frame	Random selection	Non-response bias	Direct or proxy data collection	Case definition	Reliability & validity	Standard mode of data collection	Prevalence period	Numerator(s) & denominator(s)
Ahmed 2012[16] & Ahmed 2013 [21]	▲	▲	▲	●	●	●	▲	▲	▲	●
Alarjan 2015 [58]	▲	●	●	▲	●	●	●	●	▲	▲
Albache 2010 [17] & AliAli 2011 [22]	▲	●	●	●	●	●	▲	●	▲	●
Al-Baghli 2008 [24]	▲	●	●	●	●	●	●	●	▲	●
Albawardi 2016 [28]	▲	▲	▲	▲	●	●	●	●	●	●
Al-Drees 2016 [71]	▲	●	▲	▲	●	●	▲	●	●	●
Alfhaid 2017 [72]	▲	●	●	●	●	▲	▲	●	▲	●
Al-Kadi 2018[50]	▲	▲	▲	▲	●	▲	●	●	●	▲
Alkhathami 2017 [73]	●	▲	●	▲	●	●	▲	▲	▲	●
Al-Nakeeb 2015 [74]	▲	●	▲	▲	●	●	●	●	●	▲
Al-Qahtani 2016[51]	▲	▲	●	●	●	▲	▲	●	●	●
AlRiyami 2010[75]	▲	●	●	●	●	●	▲	●	▲	●
Al-Tannir 2009[52]	▲	▲	▲	▲	●	▲	▲	●	●	●
Al-Tannir 2017[34]	▲	▲	●	●	●	●	●	●	●	●
AlThani 2015[26]	●	●	●	●	●	●	●	●	●	●
AlThani 2016[42]	▲	▲	●	▲	●	●	●	●	●	●
Al-Thani 2016[27]	●	●	●	●	●	●	●	●	●	●
Amin 2011[14] & Amin 2012[19]	▲	●	●	●	●	●	●	●	●	●
Amin 2017[38]	▲	●	●	▲	●	●	●	●	●	●
Ammouri 2008[76]	▲	▲	▲	●	●	●	●	●	●	●
Ansari 2016[31]	▲	●	●	▲	●	●	●	●	●	●
Bawadi 2011[46]	▲	●	●	▲	●	●	●	●	●	●
Brocato 2015[53]	▲	▲	▲	▲	●	●	▲	●	▲	●
Bull 2009[45]	▲	▲	●	▲	●	●	●	●	●	●
Chamieh 2015[48]	●	●	●	●	●	●	●	●	●	●
Donnelly 2018[43]	▲	▲	▲	▲	●	●	●	●	●	●
ElAnsari 2014[55]	▲	▲	▲	●	●	●	▲	●	●	●
ElAnsari 2014[56]	▲	●	●	●	●	●	▲	●	●	●
ElAnsari 2017[35]	▲	▲	▲	●	●	●	▲	●	●	●
ElRhazi 2011[77]	●	●	●	●	●	●	▲	●	●	●
Gharaibeh 2012[47]	▲	▲	▲	▲	●	●	●	●	●	●
Hashim 2013[78]	▲	●	▲	●	●	▲	▲	●	▲	●
Horaib 2013[18] & Al-Dahi 2013 [23]	●	●	●	●	●	●	●	●	●	●
Kalaf 2016[30]	▲	▲	▲	▲	●	●	▲	●	●	●
Khalaf 2013[15] & Khalaf 2015[20]	▲	●	●	●	●	●	●	●	●	●
Khalil 2017[39]	▲	▲	▲	▲	●	●	●	●	●	●
Mabry 2012[37]	▲	●	●	●	●	●	●	●	●	▲
Mabry 2016[40]	●	●	●	●	●	●	●	●	●	●
Mabry 2017[36]	●	●	●	●	●	●	●	●	●	●
Mandil 2016[41]	▲	●	●	●	●	●	●	●	●	●
Merom 2012[57]	▲	●	●	●	●	●	▲	●	●	▲
Moradi-Lakeh 2016[25]	●	●	●	●	●	●	●	●	●	●
Musaiger 2015[79]	▲	●	●	●	●	▲	●	●	▲	●
Musharrafieh 2008[80]	▲	●	●	●	●	▲	▲	●	▲	●
Najdi 2011[49]	●	●	●	●	●	●	●	●	●	●
Sibai 2013[44]	●	●	●	●	●	●	●	●	●	●
Sonia 2016[32]	▲	▲	▲	▲	●	●	▲	▲	▲	●
Stefanopoulou 2014[29]	▲	▲	▲	▲	●	▲	●	●	●	●
Stubbs 2017[33]	●	●	●	●	●	●	●	▲	●	●
Torchyan 2016[81]	▲	●	●	●	●	●	●	●	▲	▲

▲ = high risk of bias; ● = low risk of bias

Fig. 2. Risk-of-bias judgements.

earlier mentioned WHO Global Action Plan on Physical Activity 2018–20,130.[6] The STEPS survey was conducted in 14 Arab countries in the Eastern Mediterranean region and three countries in the African region,[68] with the first conducted in 2003 and the most recent one in 2018. Some countries conducted several rounds of the survey. Our study has identified only four studies that reported using this STEPS survey instrument. The small number of publications compared with the number of surveys conducted is worrisome, especially with the high cost of these national surveillance programmes. Capacity building for young researchers in statistical analysis and scientific writing might be needed to maximise the use of such rich data.

Research implications

There is a need for methodologically better designed and reported studies so that issues in relation to risk of bias can be addressed. Our findings highlight several instances where even when standard instruments were used for data collection, data analysis and reporting did not follow the standard protocol. Adoption of standardised, validated tools and scoring protocols are essential to enable data pooling and comparative analysis. We have identified specific Arab countries, e.g., Algeria, Djibouti, Iraq, Mauritania, Somalia and Yemen, where no articles reporting PA prevalence were found. This reflects the disparity in research in high- and low-income countries. Furthermore, representative samples are required to be able to monitor trends and identify population variations with confidence. For example, it would be helpful to identify any disparities in PA prevalence among characteristics that stratify health opportunities and outcomes, as outlined in the PROGRESS framework (place of residence, race/ethnicity/culture/language, occupation, gender/sex, religion, education, socioeconomic status, social capital).[69] Finally, an examination of domain-specific physical acidity is warranted, given observations of a regional trend to higher car use and sedentary occupations.[70]

Study strengths and limitations

Although we could not conduct a meta-analysis to estimate the prevalence of PA in the Arab world in this study, we managed to identify several issues related to PA tool validation and use. We hope that this review will guide researchers interested in PA research to work together to correctly validate the international tools, support the current ones, or put together a context-specific tool that can accurately measure PA. We acknowledge several limitations in this study. We have limited the review to adults aged 18 years and older and excluded younger groups. The review was limited to peer-reviewed published articles and excluded the grey literature. Data synthesis was limited by the variation in instruments used to assess PA. Furthermore, there was great variability among studies in terms of how sufficient PA – or meeting PA guidelines – was defined. Finally, all the data reported are self-reported and it is possible that this may underestimate or overestimate prevalence of PA.

Conclusions

In studies reporting data collected from the GPAQ and IPAQ, prevalence of PA ranged from 34.2 to 96.9%. High levels of variability among studies regarding the use of valid and reliable instruments, the definition of sufficient PA adopted and the scoring protocols used greatly influence the extent to which our research questions can be answered with certainty. Adoption of standardised tools to measure PA will enhance the evidence base and provide periodic and robust data that could inform policy at the country and region level.

Author statements

Acknowledgements

The research project was conceptualised during research visits funded by an Erasmus + International Credit Mobility grant to Mary Immaculate College, Ireland.

Ethical approval

Not required.

Funding

None declared.

Competing interests

The author declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.010.

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Public Health 198 (2021) e25–e26

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Letter to the Editor

Plato's ship of state on the Philippine militarized approach against the COVID-19: a (negative) consequence of representative democracy in public health

Over the last fifteen months since March 2020, the Philippine government adopted a militarized approach in its fight against the COVID-19 pandemic whose council is predominantly a group of former military officers.[1] The executive branch reasoned that the country needs trained men and women in the art of warfare since the health crisis is a battle against an unseen enemy – the coronavirus.[2] In a recent correspondence of the journal, the author argued that this type of wartime strategy is used to evade the lack of public health preparedness which distracts from an appropriate understanding of the problem and the right actions required.[3] Some experts lamented about the Philippine militaristic approach by which officials ended up berating and accusing Filipinos as the cause for the spread of the virus.[4] Consequently, several groups and political representatives call for the replacement with and appointment of medical experts to ensure a comprehensive medical and scientific response.[4–6]

The Philippine health case scenario can be linked to poor governance and democracy in the country. Constitutionally recognized as representative democracy, President Duterte was elected with his promise of (radical) change. Notwithstanding the government's infrastructure achievements,[7] the COVID-19 response generates too many controversies including corruption[8] and military designation. Moving away from medical and socioethical perspectives on COVID-19, the author of this letter believed that a philosophical account can be a significant contribution in examining the country's issue. In Plato's 'ship of state' analogy in *The Republic*,[9] he compared the state with the ship in a storm where a crowd of ignorant and incompetent figures competes for the ship's helm while asserting navigational skills although none of them possess. Based on Plato's ship-analogy, people in a democracy are represented by the ship's captain and the crews are the democratic politicians. From a political philosophy lens, the analogy highlights the value and significance of the expertise and education of a country's leader about justice, morality, law, economy, management, and others. Plato also maintains that ordinary people should not automatically be qualified in running the country because of their ignorance and tendency to elect politicians who can deceive them with untruthful talk.[10]

In the Philippines, such a philosophical argument is best illustrated with the recent statement of the president regarding his position on the West Philippine Sea during the 2016 election campaign period describing it as a mere joke.[11] In the context of the health crisis, although former military generals are just appointees of the president and not elected by the people, the whole framework still provides important two-fold insights into the president-citizens relationship on public health. On the one hand, the president was elected for democratic representation of people's will and proper political functioning. On the other hand, the president appointed ex-military officials who, in the government's view, will and can effectively cater the general health well-being of Filipinos. Nonetheless, political decisions for national interest should not just be based on the personal trust and prior competencies of selected government personnel in their field. It is not an uncommon achievement if former military generals exhibit competence in works as it is a necessary condition of their profession but not an essential function. Therefore, professional expertise and competence are duties, not virtues and supererogatory. Further, adherence to the militaristic approach of the government, thus, commits "Professional Expertise Substitution Fallacy" – the attempt to justify the work substitution and/or non-selection of needed experts to the problem through the work accomplishments and expertise of chosen professionals despite the lack of professional training and knowledge relative to the issue.

Furthermore, while the Filipino people elected the president with majority votes, they do not have direct responsibility for the appointment of military council members. However, the absence of Filipinos' activeness in resisting and questioning this political decision heightens the failure of the government to address the health crisis. In the age of a pandemic, collective efforts and collaboration are not the only keys to solve the problem. Critical and constructive criticisms are necessitous to identify the defects of the government approach. Nevertheless, the government's political allies and supporters together with political oppositions, religious leaders, and private individuals must engage in fault or error identification. People should learn to educate themselves in knowing their political representatives without an immediate acceptance of the latter's politicking and public speeches. A matured citizenry aims for a stable, secured, and healthy society devoid of blind and extreme political ideologies and conformity.

Additionally, even with Plato's philosophical endorsement of philosopher-kings, Philippine political officials can still perform better public services if they take into account at least the two following major conditions: a) the suffering and living circumstances of the people and b) application and adaptation of relevant skills and knowledge related to the specific problem. Irrespective of the government's consistent invocation of the logistics competence of former military generals in securing the COVID-19 vaccines, it is

https://doi.org/10.1016/j.puhe.2021.06.007

clear that other skills and aids are necessary from medical experts. Likewise, rather than exclusively resorting to available vaccines, the government must see the need to address the pandemic and its corresponding implications via mass testing, enhanced contact tracing, food supplies distribution, mental health services or psychological counseling, and so on which requires the crucial participation of specialists under the medical and nutrition services and their allied disciplines.

The existence of the COVID-19 crisis is a great opportunity to reform the government's performance. Yet it is irrational and illogical to depend and wait for devastating challenges before any changes and improvements are implemented.

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25 May 2021
Available online 21 July 2021

Public Health 198 (2021) 211–217

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Recommendations on screen time, sleep and physical activity: associations with academic achievement in Swiss adolescents

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ARTICLE INFO

Article history:
Received 17 March 2021
Received in revised form
14 June 2021
Accepted 21 July 2021
Available online 1 September 2021

Keywords:
Adolescence
Sleep
Screen time
Moderate-to-vigorous physical activity
Recommendations
Media multitasking
Academic achievement

ABSTRACT

Objectives: This study aimed to investigate how meeting international recommendations for screen time (<2 h/day), moderate-to-vigorous physical activity (MVPA; at least 60 min/day) and sleep (8–10 h/night), as well as media multitasking (MMI) as a form of screen time, impact academic achievement in early adolescence.

Study design: A prospective design was used, where self-report measures were collected during the spring semester and academic achievement at the end of the school year.

Methods: A total of 1208 grade 3 middle school students (M_{age} = 13.55 years, SD_{age} = 0.60) in 37 Swiss schools filled out a paper-and-pencil questionnaire including measures of screen time (covering watching television, playing video games, Internet use, smartphone use and social media use), MMI, sleep time and time for MVPA. To evaluate academic achievement, end-term grades were provided by the collaborating education administration for Italian, Maths, Science, History, Geography, Music and Visual arts.

Results: After adjustment for covariates, such as gender, socio-economic status, body mass index and stressful life events, multivariate linear mixed-effect models, nesting participants in schools, showed that meeting recommendations for screen time (B = 0.12, β = 0.105, $P < 0.001$) and MVPA (B = 0.09, β = 0.09, $P = 0.001$), but not sleep (B = 0.05, $P = 0.087$), were associated with higher academic achievement. Considering the number of recommendations met, meeting all three recommendations improved academic achievement the most (B = 0.24, β = 0.21, $P < 0.001$), followed by meeting the guidelines for screen time + MVPA (B = 0.20, β = 0.15, $P < 0.001$) and for screen time + sleep (B = 0.21, β = 0.13, $P < 0.001$). In the fully adjusted model, multitasking with two or more media was related to a worse academic achievement.

Conclusions: Screen time (including MMI), sleep and MVPA impact academic achievement in adolescence; hence, governmental organisations and schools should raise awareness about the positive and negative effects of following or not recommendations for MVPA, sleep and screen time among adolescents and their parents. In addition, support should be provided to promote sufficient sleep and MVPA while limiting overall screen time and parallel device use.

Introduction

Academic achievement is essential for mastering diverse developmental goals. It has been related to higher subjective well-being[1] and career adaptability.[2] Conversely, lower levels of cognitive performance in childhood and adolescence predict diminished well-being, including more frequent psychological disorders[3] and higher risk for health-related issues and mortality later in life.[4]

Different daily behaviours can affect cognitive development in adolescence, such as screen time, moderate-to-vigorous physical activity (MVPA) and sleep. The impact of screen time on children's and adolescents' well-being, including academic achievement, is a subject of growing concern. In Switzerland, in 2020, Swiss adolescents spent, on average, almost 2 h and 44 min on the Internet and 3 h and 47 min on the smartphone during a typical weekday. This time augmented, respectively, to nearly 4 and 5 h during a typical weekend day, partly because of the ongoing COVID-19

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https://doi.org/10.1016/j.puhe.2021.07.027

pandemic.[5] Previous studies showed that screen time (here defined as the total amount of time spent using a smartphone, social media, Internet, television or video games) is related to poorer learning outcomes and augmented risk of premature cognitive decline,[6] already at early developmental stages.[7,8]

According to the 'time displacement hypothesis',[9] screen time interferes with activities such as MVPA and sleep, which are beneficial for academic achievement. Indeed, screen time (especially when ≥2 h/day[10]) is a sedentary behaviour that takes away valuable time for MVPA[11] and augments the risk of overweight and obesity in children and adolescents. Screen time also interferes with sleep by delaying bedtime, interrupting sleep due to incoming notifications and reducing sleep quality due to the continued emotional arousal from screen time before sleep,[12,13] leading to daytime sleepiness and lower academic achievement.[14,15] In a prospective cohort study, the use of electronic devices before bedtime, especially the use of the smartphone, social media and video games, reduced the academic attainment of adolescents,[15] in part by augmenting daytime sleepiness.

Furthermore, the ubiquity of media devices in adolescents' lives has led to a substantial increase in media multitasking, commonly defined as either concurrently engaging in two or more media activities or using media during offline activities (e.g. while doing homework).[9] Previous research highlighted that media multitasking correlates with adverse outcomes, including limited cognitive control capacities and lower academic achievement.[16] According to the 'scattered attention hypothesis',[9] adolescents who frequently multitask on several media have more difficulties in filtering relevant information from their environment due to scattered attention developed during parallel media exposure. Thus, they are more easily distracted in online and offline contexts, with negative consequences for their cognitive processes.

On the contrary, MVPA has been shown to be positively associated with academic achievement.[17] Evidence suggests that MVPA elicits brain plasticity; hence, it is especially beneficial for cognitive functioning, including reaction time, attention, memory, inhibition, as well as multiple domains of academic performance and brain plasticity.[18] A meta-analysis examining the association between MVPA and eight cognitive categories in 4- to 18-year-old subjects found that MVPA was positively associated with better functioning in all domains.[19] Another review found that aerobic exercise was positively associated with cognition and academic achievement in children aged <19 years.[20] Interestingly, moderate-to-vigorous bursts of PA have been found to foster cognitive functions and mental health more than low-intensity PA.[21] In addition, longitudinal findings highlighted that physical fitness in adolescence predicts cognitive performance in young adulthood[22] as well as later in life.[23]

From a biological point of view, the benefits of MVPA include increased expression of molecules (e.g. brain-derived neurotrophic factor) in brain regions important for memory and cognition, increased cerebral blood flow and metabolism, better neurotransmitter regulation, enhanced connectivity between brain regions and modulation of genes' expression.[18] This makes MVPA a crucial component of brain resilience.[24]

Sleep is another pivotal factor in learning and brain development. In youth, inadequate sleep has been associated with negative health outcomes, including somatic and psychosocial health (e.g. increased body mass index [BMI], overweight and obesity, cardiovascular risk, somatic complaints, fatigue, depression, anxiety, inattention, more frequent risk-taking behaviours [e.g. substance use], as well as low academic performance).[25] Shorter sleep time and poor sleep quality and without being consistent in sleep and wake across the week are related to lower grades.[26] On the other hand, good sleep quality and quantity proved to be positively associated with general cognition and academic achievement. A meta-analysis reported that longer sleep duration is related to increased intelligence quotient and verbal skills in children aged 6–13 years.[27] The role of sleep in learning can be well understood for its implications in memory consolidation, during which memory traces are reactivated, analysed and included in long-term memory.[28]

Given the evidence of the impact of screen time, MVPA and sleep on cognitive well-being, different national and international guidelines were formulated. According to the World Health Organisation and the Federal Office of Sport,[29] children and adolescents aged between 5 and 17 years should carry out at least 60 min of MVPA daily.[4] In addition, adolescents between 14 and 17 years should sleep from 8 to 10 h per night, uninterruptedly, as stated by the National Sleep Foundation[30] Finally, recreational screen time should be limited to no more than 2 h per day.[31] Given that many of these guidelines are very recent yet heavily promoted, research is needed to investigate if they are actually met and, if so, what effects they have on academic achievement.

A previous study with US children aged between 8 and 11 years[32] found that participants who met all three recommendations, or at least the screen time recommendation or both the screen time and the sleep recommendations, performed better in psychometric tasks assessing global cognition. Another study[33] with Australian students from grades 12 to 17 years found that meeting recommendations for screen time and/or sleep time was associated with better academic performance in high school students, whereas the strongest association in middle school participants was reported for those who followed all three guidelines. No study, to date, has replicated these findings in the European context and considered media multitasking as an additional risk factor of academic achievement.

Study aims

The present study aims to investigate (1) how many Swiss students aged 13–14 years meet the (inter)national recommendations for screen time, MVPA and sleep; (2) whether meeting none, one, two or all three guidelines predicts better academic achievement; and (3) the role of media multitasking, as an additional measure of screen time that may impact attention and cognition. The study furthermore considers stressful life events as covariates beyond sociodemographic characteristics.

Methods

Study design

The present study used data from the fifth wave of the ongoing longitudinal MEDIATICINO2.0 study, following up students born in 2004/2005 from childhood to adolescence in Italian-speaking Switzerland The study combines students' questionnaire data with end-term school grades obtained from the regional education administration and matched by a unique identifier.

In autumn 2013, all public elementary schools in Italian-speaking Switzerland were invited to participate in the study. Based on this opt-in technique, 39 of 79 schools agreed. Within these schools, 60 grade 4 classes comprised 1083 students were randomly selected. No inclusion or exclusion criteria were specified. In autumn 2015, when the cohort entered middle school, 409 additional students were randomly sampled within schools to compensate for sampling attrition and to ensure that the study sample sufficiently represented all school districts within the region.

Study participation was voluntary. Parents received a letter before their children entered the cohort, informing them about the research, its aims and procedure. They were also informed about the possibility that students could opt-out anytime by simply not completing the questionnaire without any consequences for their evaluation at school. As the anonymity of the students was fully guaranteed, the regional education administration approved the study.

The fifth wave of the MEDIATICINO2.0 study was in 2018 when 1419 questionnaires were distributed among grade 3 middle school students in 37 schools. Of these, 1374 (97%) were returned, of which 27 were blank, and 117 included more than 15% of missing data in the variables of interest. Twenty-two participants were excluded as they reported outlier values (defined as z-scores > ±3.5).

Measures

Screen time

Screen time includes estimates for five different activities during recreational time (i.e. time spent watching television, playing video games, using the Internet, using a smartphone and social media activities). Students were asked to indicate how much time they spend on each activity on a typical school day and on a weekend day. For each question, students estimated their daily media use on a scale with nine-time interval: 0 'never', 1 'up to 0.5 h', 2 'between 0.5 and 1 h', 3 'between 1 and 1.5 h', 4 'between 1.5 and 2 h', 5 'between 2 and 3 h', 6 'between 3 and 4 h', 7 'between 4 and 5 h' and 8 '5 or more hours'. Daily recreational time for each activity was calculated by weighting the interval midpoint for weekdays and weekend days: ([sum of weekday screen time × 5] + [sum of weekend day screen time × 2])/7. A total measure of screen time in hours was then obtained by taking a weighted average of all screen-related activities.

Sleep time

Sleep time was calculated from students' self-report on when they went to bed the day before and when they got up on the day of questionnaire completion. As questionnaires were completed at school, 'the day before' measured sleep time before a school day. Considering that our sample falls in an age range between 13 and 14 years, we decided to use the cut-off value of 8 h 30 min for meeting the recommendation (as a midpoint of the recommendation of 8–10 h for 14-to-17 year-olds and 9–11 h for 11-to-13 year-olds).

Moderate-to-vigorous physical activity

MVPA was measured by asking students to indicate on the abovementioned nine-time interval scale how much time, on a typical school day, they spend doing sports.

Media Multitasking Index

A Media Multitasking Index (MMI) was calculated by asking participants how frequently they engaged in a specific media activity (i.e. watching TV, using the Internet, sending messages and playing video games) with another simultaneous media activity.[34] The response categories ranged from 1 'never' to 4 'very often'. The MMI was then calculated for each activity following Ophir's equation.[34] The MMI indicates the number of additional media an individual is using while using a primary medium.

Academic achievement

Academic achievement was evaluated based on end-term grades in Italian, Maths, Science, History, Geography, Music and Visual arts provided by the regional educational administration. A minimum of 4 is required to pass, whereas the maximum is 6. All grades were pulled together to obtain a general end-term grades score.

Stressful life events

Stressful life events were measured asking participants if one of the following seven events happened in the last year: parents' divorce, a parent with a new partner, a parent's loss of his/her job, a family member who deceased or had severe disease, the worsening of a significant relationship (e.g. with a parent, a teacher, or a friend) or any other negative and significant life event.

Body mass index

BMI was calculated from the reported weight and height. BMI categories were created using the following cut-offs: ≤3rd percentile 'underweight', >3rd and ≤75th percentile 'normal weight', >75th and ≤97th percentile 'overweight' and >97th percentile 'obese'.

Sociodemographic covariates included gender, coded as 0 = male and 1 = female, and socio-economic status (SES), measured by asking participants to rate the financial situation of their family from 0 'definitely not wealthy' to 4 'definitely wealthy'.

Statistical analyses

As data collection was organised at the school level, participant-level associations between self-report predictor variables and academic achievement were fitted using multivariate linear mixed-effects (random intercepts) models, nesting participants' grades within schools (N = 37). Using multilevel modelling allows estimation of the variance between students within the same school and the variance between schools separately. At the first step (Model 1), we tested the model, including only the random intercepts and the covariates. In Model 2, we included participants' screen time, MVPA and sleep recommendations coded as 0 'not met' and 1 'met'. Finally, in Model 3, we tested the effect of meeting one recommendation (screen time or sleep or MVPA) versus two recommendations (screen time + sleep, screen time + MVPA and MVPA + sleep) versus all three recommendations, compared with none met (reference level). The MMI was added as a categorical variable ranging from 0 ('no multitasking') to 4 ('multitasking with four different activities') in Model 2 and Model 3 as an additional measure of screen time. In all models, parameter estimates were calculated with a maximum likelihood algorithm, using the 'lme4' package in R software.

Results

Sample characteristics

The analytical sample included 1208 students (M_{age} = 13.55 years, SD = 0.60), of which 628 (52%) were female and 874 (72.4%) reported to have a good to very good SES. A total of 288 (23.9%) were either overweight or obese. More than half (n = 349 [53.7%]) reported at least one stressful life event. The average end-term grade was 4.78 (SD = 0.52). Most students reported to multitask with one (n = 429 [35.5%]), two (n = 459 [38%]), three (n = 136 [11.3%]) and four (n = 30 [2.5%]) additional media. An overview of the sample characteristics is reported in Table 1.

A Bayesian regression imputation method and a predictive mean matching model were used to impute missing values. All continuous variables were normally distributed with skewness and kurtosis <±1.

Table 1
Sample characteristics (N = 1208).

Variable	n (%)	Mean (SD)
Sex		
Boys	580 (48%)	
Girls	628 (52%)	
Age (years)		13.55 (0.60)
Socio-economic status (SES)		2.85 (0.74)
Not at all good	3 (0.2%)	
Not good	45 (3.7%)	
Adequate	286 (23.7%)	
Good	668 (55.3%)	
Very good	206 (17.1%)	
BMI (kg/m^2)		19.25 (2.68)
Underweight	59 (4.9%)	
Normal weight	861 (71.3%)	
Overweight	252 (20.9%)	
Obese	36 (3%)	
Stressful life events		
None	559 (46.3%)	
One	331 (27.4%)	
Two or more	318 (26.3%)	
Grades (total)		4.78 (0.52)
Italian		4.69 (0.64)
Maths		4.45 (0.76)
Science		4.79 (0.66)
Visual arts		5.19 (0.49)
Media Multitasking Index (MMI)		
No multitasking	154 (12.7%)	
With 1 other media	429 (35.5%)	
With 2 other media	459 (38%)	
With 3 other media	136 (11.3%)	
With 4 other media	30 (2.5%)	

BMI, body mass index.

Recommendations met

Among all students, 905 (74.9%) spent less than 2 h/day on screens, 601 (49.8%) slept for at least 8 h 30 min per night and 813 (67.3%) exercised for at least 60 min per day (see Table 2). With regard to the number of recommendations met, 90 (7.5%) did not meet any of the recommendations, 134 (11.1%) reported doing at least 60 min of MVPA per day, 28 (2.3%) reported sleeping for at least 8 h 30 min, 140 (11.6%) reported spending no more than 2 h on screens and 247 (20.4%) reported following the guidelines for MVPA + screen time, 52 (4.3%) for MVPA + sleep and 153 (12.7%) for sleep + screen time. The remaining 364 students (30.1%) met all three recommendations (see Fig. 1).

Main analyses

The baseline model (Model 1; see Table 3) explained 13.5% of the variance in academic achievement. Being female, having a better SES, having experienced two or more stressful life events and having a higher BMI were all significant predictors of academic achievement. Compared with Model 1, both Models 2 and 3 explained a significant additional proportion of variance. In Model 2 ($R^2 = 0.182$), spending <2 h/day on the screens predicted better academic achievement ($B = 0.12$, $P < .001$), followed by doing PA for at least 60 min/day ($B = 0.09$, $P = 0.001$). In addition, multitasking with two or more other media activities negatively predicted academic achievement in an increasing way ($B_{MMI(2)} = -0.13$, $P = 0.006$; $B_{MMI(3)} = -0.16$, $P = 0.006$; $B_{MMI(4)} = -0.18$, $P = 0.029$). In Model 3 ($R^2 = 0.192$), meeting only one recommendation did not predict academic achievement. However, meeting 2, specifically MVPA + screen time and sleep + screen time, significantly predicted better academic achievement at the end of the school year ($B = 0.20$, $P < 0.001$ and $B = 0.21$, $P = 0.001$, respectively). Meeting all three recommendations was the best predictor of academic achievement ($B = 0.24$, $P < 0.001$). Again, multitasking with two or more media activities predicted worse academic achievement ($B_{MMI(2)} = -0.11$, $P = 0.012$; $B_{MMI(3)} = -0.15$, $P = 0.012$; $B_{MMI(4)} = -0.20$, $P = 0.035$).

Discussion

Academic achievement has been related to (un)healthy behaviours in adolescence. This has led to the formulation of recommendations for screen time, MVPA and sleep, with the aim to promote a healthy lifestyle and development from an early age. The results of the present study, on a Swiss cohort of middle school students aged 13–14 years, adds to those from previous studies in other cultural contexts.[32,33] More precisely, the study found that the majority of adolescents met the recommendations for screen time and MVPA, but only half of them met the recommendations for sleep. In particular, meeting at least two of the three recommendations leads to better outcomes, especially if the recommendation involved screen time. Although it should be kept in mind that the data for this study stem from adolescents' self-report, prone to estimation bias, this result is in line with similar studies based on children's and adolescents' self-report:[32,33] long and frequent media use may have detrimental effects on attention, memory, impulse control and, consequentially, academic performance. Spending no more than 2 h per day in front of screens, sleeping the recommended amount of 8 h and 30 min and exercising at least 1 h per day was associated with better academic achievement. Following the notion of the 'displacement' hypothesis,[9] this demonstrates that reduced screen time should be substituted with more time for sleep and/or MVPA to be beneficial for academic achievements as the latter two activities enhance brain plasticity[18] and memory consolidation.[28]

Furthermore, the present study found that multitasking with two or more media activities leads to worse academic achievement; hence, media multitasking should also be considered as an additional measure of screen time in future research investigating academic achievement. Digital technologies, especially the

Table 2
Average time spent on each behaviour and proportion of students meeting the recommendations.

Behaviour	Time spent [M_{hours} (SD_{hours})]	Recommendation	Number of participants meeting the recommendation (%)
Screen time (total)	1 h 30 min (0 h 58 min)	<2 h/day	905 (74.9%)
Video games	0 h 53 min (1 h 10 min)		1048((86.8%)
Smartphone	1 h 57 min (1 h 26 min)		432 (35.8%)
Social media	1 h 26 min (1 h 21 min)		935 (77.4%)
Television	1 h 11 min (1 h 3 min)		1037 (85.8%)
Internet	2 h 4 min (1 h 25 min)		727 (60.2%)
Sleep	8 h 17 min (1 h 1 min)	8 h 30 min/night	601 (49.8%)
MVPA	1 h 45 min (0 h 58 min)	≥1 h/day	813 (67.3%)

MVPA, moderate-to-vigorous physical activity.

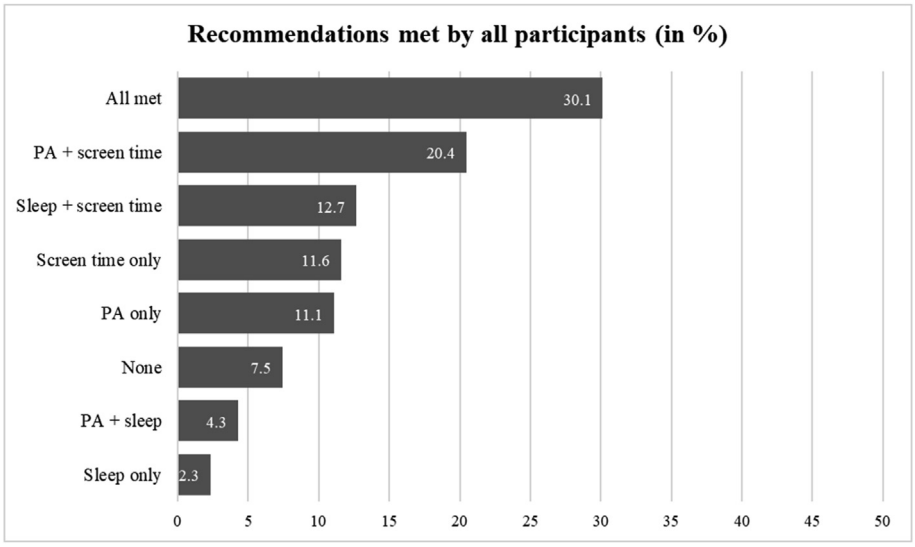

Fig. 1. Recommendations met by all participants (in percentage). PA, physical activity.

smartphone, provide quick and easy gratifications. Adolescents are more willing to use them (simultaneously) to seek short gratifications, particularly when the first, ongoing task is not gratifying enough. According to the 'scattered attention' hypothesis, the parallel use of different media devices impact the capabilities of functioning, reasoning and remembering information in the offline context (e.g. classroom and homework),[35] with negative consequences for academic achievement. It is likely that adolescents who engage in media multitasking (i.e. parallel use of two or more media devices) also engage in multitasking where devices are used while doing other offline activities (such as homework). Limited screen time may not only reduce the interfering effects of screens before bed or while doing homework (e.g. multitasking) but could also substitute them with cognitively engaging and educating activities, such as reading, including in-person social interactions, promoting a healthier lifestyle.

In addition to past studies, the present study also considered sociodemographic characteristics, BMI and stressful life events as potential confounders. Being female and having a better socioeconomic background significantly increased academic achievement, while being overweight and experiencing stressful life events were related to decreased academic achievement. Previous studies

Table 3
Hierarchical regression analyses predicting academic achievement.

Predictors	Model 1		Model 2			Model 3		
	B (95% CI)	*P*	B (95% CI)	β	*P*	B (95% CI)	β	*P*
Intercept	4.50 (4.37 to 4.64)	<0.001	4.37 (4.20 to 0.53)		<0.001	4.39 (4.22 to 4.57)		<0.001
Gender (female)	0.24 (0.19 to 0.30)	**<0.001**	0.28 (0.22 to 0.33)	**0.26**	**<0.001**	0.27 (0.22 to 0.33)	**0.26**	**<0.001**
SES	0.08 (0.04 to 0.12)	**<0.001**	0.07 (0.03 to 0.10)	**0.09**	**<0.001**	0.07 (0.03 to 10)	**0.09**	**<0.001**
Stress events (=1)	−0.00 (−0.07 to 0.07)	0.997	0.02 (−0.04 to 0.09)	0.02	0.510	0.02 (−0.04 to 0.08)	0.02	0.488
Stress events (≥ 2)	−0.12 (−0.19 to −0.05)	**<0.001**	−0.06 (−0.13 to 0.01)	−0.05	0.070	−0.07 (−0.13 to 0.00)	−0.05	0.061
BMI (underweight)	−0.03 (−0.02 to 0.09)	0.638	−0.08 (−0.20 to 0.05)	−0.03	0.229	−0.08 (−0.20 to 0.05)	−0.03	0.224
BMI (overweight)	−0.10 (−0.17 to −0.03)	**0.004**	−0.07 (−0.14 to −0.01)	**−0.05**	**0.032**	−0.08 (−0.15 to −0.01)	**−0.06**	**0.023**
BMI (obese)	−0.18 (−0.34 to −0.02)	**0.029**	−0.11 (−0.27 to 0.05)	−0.03	0.172	−0.11 (−0.27 to 0.05)	−0.03	0.193
Recommendations met (ref = 0 "not met")								
Screen time (<2 h/day)			0.13 (0.06 to 0.20)	**0.105**	**<0.001**			
MVPA (≥60 min/day)			0.10 (0.04 to 0.16)	**0.09**	**<0.001**			
Sleep (≥8 h 30 m/night)			0.05 (−0.01 to 0.10)	0.04	0.104			
MMI (ref = "0")								
With 1 other media			0.02 (−0.07 to 0.10)	0.01	0.717	0.02 (−0.06 to 0.11)	0.02	0.601
With 2 other media			−0.13 (−0.21 to −0.03)	−0.12	**0.006**	−0.11 (−0.20 to −02)	**−0.11**	**0.012**
With 3 other media			−0.16 (−0.28 to −0.04)	−0.09	**0.006**	−0.15 (−0.27 to −03)	**−0.09**	**0.012**
With 4 other media			−0.23 (−0.42 to −0.04)	−0.06	**0.019**	−0.20 (−0.39 to −01)	**−0.06**	**0.035**
Recommendations met (ref = "none")								
MVPA only						0.11 (−0.01 to 0.24)	0.06	0.090
Sleep only						−0.13 (−0.33 to 0.07)	−0.04	0.200
Screen time only						0.02 (−0.10 to 0.15)	0.02	0.704
MVPA + screen time						0.20 (0.08 to 0.32)	**0.15**	**<0.001**
MVPA + sleep						0.04 (−0.13 to 0.19)	0.01	0.670
Sleep + screen time						0.20 (0.07 to 0.33)	**0.13**	**0.001**
All met						0.24 (0.13 to 0.36)	**0.21**	**<0.001**
Explained variance								
R^2	0.135		0.182			0.192		
R^2 change (ref: Model 1)			<0.001			<0.001		

CI, confidence interval; BMI, body mass index; MVPA, moderate-to-vigorous physical activity; SES, socio-economic status.
Results of the hierarchical regression analyses: Model 1 includes covariates only; Model 2 includes if a recommendation is met and multitasking as additional predictors; Model 3 includes more information about the combination of recommendations met and multitasking as additional predictors.

already underlined that factors promoting a sedentary lifestyle, including overweight, are not beneficial for cognitive development.[32] However, future studies should also consider the additional effect of stressful life events: during the developmental years, the brain is still very plastic and thus able to recover from traumatic events when adolescents are guided appropriately. For example, the negative influence of stress may be mitigated by a healthy lifestyle and social support.[36]

Beyond the specific context of academic achievement, the results of this study are also in line with other studies focusing on mental health,[37] internalising and externalising problem behaviours[38] and psychosocial health.[39] In a systematic review of 13 studies,[37] meeting the recommendations for screen time and sleep was associated with mental health (especially lower levels of depressive symptoms), although this association was stronger than the one with meeting the recommendations for MVPA. In addition, meeting recommendations for screen time and sleep, but not MVPA, was associated with a diminished prevalence of internalising and externalising symptoms.[38] Sleep duration and screen time were strongly associated with social behaviour and psychosocial health.[39] In addition, sleep disturbance has been related to higher levels of both internalising and externalising psychopathology in adolescents.[40] However, more studies on the role of meeting recommendations of (un)healthy behaviours on youth well-being are needed, and future research should consider the differential effects of guidelines on cognitive, physical and psychological well-being, making use of longitudinal data.

Some limitations to this study should be acknowledged. First, self-report data are at risk of recall and estimation bias, especially when different reference periods (e.g. 'weekday', 'weekend day', 'typical day' and 'yesterday') are used, which cannot be controlled for in the analyses. Second, although self-report measures were collected in spring and end-term grades in summer, at the end of the school year, this study offers only limited possibilities to conclude on causality. Hence, longitudinal data should be included in the future to replicate our results. Third, the present study only considered school grades as an indicator of academic achievement, but grading can be biased by teacher characteristics. Standard assessment tools would overcome this bias and generate results that are also more easily comparable across countries.

Author statements

Ethical approval

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. However, the regional education administration approved this study design. Written informed consent from participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements. However, consent was implied via the completion of the questionnaire.

Funding

This research was in part funded by the Swiss National Science Foundation (Grant no. 175874).

Competing interests

None declared.

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Public Health 198 (2021) e18–e19

Contents lists available at ScienceDirect

Public Health

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Letter to the Editor

Same threat, different substrate: protecting vulnerable health systems from digital viral pandemics

COVID-19 is not the first viral pandemic to devastate health systems in the twenty-first century. In May 2017, the WannaCry ransomware infected more than 230,000 computers in at least 150 countries and prevented access to critical digital systems in the UK's National Health Service (NHS).[1] Although WannaCry was a relatively unsophisticated attack that did not specifically target the NHS, the incident reveals the degree to which healthcare digitalisation renders these systems vulnerable to incapacitating cyberthreats and thereby presents substantial dangers to public health on a global scale.

It is widely acknowledged that health and well-being can be reliably enhanced by the implementation and scaling of digital technologies and that the uptake of digital health into nationwide health systems can accelerate progress towards the Sustainable Development Goals.[2] As such, ensuring the adequate cybersecurity of these technologies is paramount to the protection of digitalising health systems that incorporate growing numbers of network-connected medical devices and vast stores of sensitive data, which are otherwise susceptible to attack, exploitation and unintentional loss.[3]

Patient data may be stolen, deleted or corrupted in cyberattacks,[4] such as the 2018 attack on the SingHealth database and the 2014 attack on US health insurance company Anthem, in which cybercriminals illegally accessed the personal information of 1.5 million Singaporeans and 80 million Americans, respectively.[5,6] Simultaneously, the growing network of interconnected medical devices, including hospital-based equipment and implantable sensors, can be hacked, manipulated or entirely disconnected, with potentially devastating consequences for patient privacy and safety.[7] Beyond health systems, the increasing sophistication and technical ability of individual, group-based and state-sponsored cyberadversaries is regularly demonstrated through attacks on financial industries, social media networks and even nuclear power plants. The deployment of such formidable digital weaponry on inadequately protected health systems would have catastrophic implications for millions of patients. Despite this, cybersecurity in these systems remains chronically underfunded, rendering them vulnerably exposed to unacceptable degrees of reputational, financial and patient safety risk.[4]

Concurrently, the COVID-19 pandemic has revealed the indispensable nature of digital technology in modern-day health systems, public health organisations and research institutions globally. The collection, synthesis, processing, storage and distribution of sensitive patient data has proven to be fundamental to dynamic epidemiological and health protection responses, including symptomatology data, biological test results and geolocated contact tracing. The primary care records of millions of people have been used to identify those patients most clinically vulnerable to viral infection, to undertake population-wide observational research[8] and to coordinate the age-prioritised roll-out of mass vaccination programmes. Finally, the clinical management of infected individuals has used virtual care platforms, digital monitoring systems and machine learning algorithms to inform clinical decision-making, guide resource allocation and provide clinical care for large volumes of patients.[9]

Although offering plentiful advantages to the functioning of public health organisations and healthcare services, the complete dependence on digital technologies of the global response to COVID-19 exposes this reliance as a critical vulnerability in modern-day health systems and underscores the urgent need to safeguard these systems with adequate cybersecurity. Despite this, the long-term underinvestment of digital health system resilience is likely to intensify in the coming months as countries divert scarce resources to combating the social, economic and immediate health impacts of the ongoing pandemic. In an environment of rapid health system digitalisation and increasing cybercriminal capability, such deepening neglect of infrastructure protection would render these critical systems intolerably exposed.

The global decision to overlook biological pandemic preparedness has brought chaos and misery on an unprecedented scale during the COVID-19 pandemic. Although the substrate is different, the same failure to prepare for a digital viral pandemic could bring about even greater disruption to vulnerable health systems that increasingly depend on digital technologies. To mitigate this threat to global public health, significant commitments are urgently required to bolster health system cybersecurity and worldwide digital health resilience.

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4 May 2021
Available online 25 June 2021

Public Health 198 (2021) 118–122

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

The impact of national health promotion policy on stillbirth and maternal mortality in South Africa

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ARTICLE INFO

Article history:
Received 15 February 2021
Received in revised form
16 June 2021
Accepted 9 July 2021
Available online 17 August 2021

Keywords:
Health promotion policy
Stillbirth
Maternal mortality

ABSTRACT

Objectives: In 2015, the South African government implemented the national health promotion policy (NHPP), intending to reduce stillbirth and maternal mortality. This study was designed to quantify the impact of the NHPP on stillbirth and maternal mortality in both the South African population and immigrant citizens.

Study design: This was a panel analysis using secondary data issued by Statistic South Africa-Vital Statistics.

Methods: The author exploited the changes in smoking status that the NHPP exerted between 2015 and 2017. The author then builds credible control and treatment groups based on smoking status for both groups. Women who quitted smoking post-NHPP implementation were considered as the treatment group. Women who persisted with smoking post-NHPP implementation were classified as the control group. The author then used a Two-stage Least Squared Model to quantify the impact of the NHPP on stillbirth and maternal mortality in both the South African and immigrant populations.

Results: The model shows that NHPP averts stillbirths by 8.36% in the South African population residing in the urban areas and by 2.84% in the rural segments of the country. NHPP averts South African maternal mortalities by 20.88% in urban areas and by 15.60% in the rural segments of the country.Regarding the immigrant population, the model shows that NHPP averts immigrant's stillbirths by 7.61% in the urban areas and by 2.79% in the rural segments of the country. In addition, NHPP averts immigrant maternal mortalities by 19.22% in the urban areas and by 13.04% in the rural segments of the country.

Conclusions: NHPP reduces stillbirth and maternal mortality outcomes slightly biased toward the South African population. These inequalities reflect immigrant's lack of response to the NHPP framework and inadequate access to the South African health system.

Introduction

There is an ongoing debate about the relevance of health promotion policies in averting mortalities.[1–3] Some authors argue that health promotion policies are critical to improving health outcomes[4] – a view supported by the World Health Organization.[5] These papers support the idea that health promotion policies are essential to avert maternal deaths and stillbirths. However, other authors argue that there is no significant evidence that health promotion yields significant improvement in health outcomes.[6] These inconsistencies invite more novel ideas to re-evaluate the health promotion policies' impact on public health outcomes.

In 2015–2019, responding to the World Health Organisation[5] recommendations, the South African government implemented the national health promotion policy (NHPP) to reduce maternal and child mortality rates.[7] Key to this policy strategy was the mobilization of disadvantaged communities to take ownership of their health.[7] So far, no study has assessed the impact of NHPP on maternal mortality and stillbirth in South Africa. Furthermore, international evidence shows that public health programs often impact differently on different population groups.[8–10] Currently,

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https://doi.org/10.1016/j.puhe.2021.07.009

there is no comparative analysis of NHPP impacts concentrating on various population groups in South Africa. This paper is design to fill these gaps.

Previous studies on health promotion policies suggested that health promotion programs might be a good investment for the health system.[11–15] For example, in 2018, a group of authors published a review of prior research on health promotion programs and found a positive return on investment on such health promotion interventions.[16] However, as the authors noted in that review article, much of the prior literature was limited by the lack of robust samples from low- and medium-income countries (LMICs).

There is a need to advance the health promotion literature with a perspective from LMICs, considering that health promotion programs have been underfunded in LMICs, especially in Africa.[17–19] Furthermore, the current South African literature does not appear to have analyzed how health promotion policies improve immigrant's maternal mortality and stillbirth, despite immigrants being the most vulnerable groups,[20,21] which are often neglected in health services and policy coverage debates.

Currently, South Africa experiences a relatively high influx of immigrants, mainly from other African countries. The female population of immigrants is significantly growing. According to the UN statistics, there were 4.2 million immigrants in South Africa in 2017,[22] which constituted approximately 7.2% of the entire population. Of this group, more than 2 million were women immigrants from under-resourced backgrounds compared with South African women.

Given this evident socio-economic inequality between South African women and immigrant women, it was essential to quantify any possible differences between domestic and immigrant's maternal mortality and stillbirth arising from NHPP impact to assist the achievement of the universal declaration of human rights,[23,24] so that no one is left behind from government interventions. Therefore, this study is designed to quantify the impact of the NHPP on stillbirth and maternal mortality from 2015 to 2017 in the South African population. In addition, the study also quantifies the impact of NHPP on immigrant's stillbirth and immigrant's maternal mortality outcomes.

History of NHPP

The NHPP originated in 2015 from cooperative efforts among private donors, the government department of health, academia, and non-governmental organizations, which brought preventive services at the community level to support public health outcomes. The NHPP was implemented from 2015 to 2019 using various methods, such as home visits done by community health promoters to support the adoption of NHPP recommendations. Other implementation methods included education programs offered at public health facilities targeting pregnant women and various media marketing adverts to promote the ideas of preventive services to avert maternal mortality, stillbirth, and other non-communicable diseases. These methods were mainly communicated in English to mobilize the country to take ownership of their health, especially in low-income communities.

The services of NHPP included educational programs for integrated management of childhood illnesses, breastfeeding, healthy eating programs, immunization campaigns, prevention of violence against women and children, prevention of substance abuse, and tobacco consumption. So far, the NHPP has succeeded in reducing the percentage of the smoking population with an average of 67% in the low-income communities of South Africa (see Figure 1 in the Appendix).

In light of the declining smoking population driven by NHPP interventions, the present study seeks to answer the following questions: (1) What impacts does NHPP exert on the South African population's stillbirth and maternal mortality? (2) Are there regional and educational differences in the impact of NHPP on stillbirth and maternal mortality outcomes? (3) Is the NHPP having positive effects on immigrant's stillbirth and immigrant's maternal mortality outcomes? This article explores findings that demonstrate the potential of the NHPP to improve maternal health.

Methods

The author uses the Vital Statistics panel data provided by Statistic South Africa (Stats-SA) from 2015 to 2017. The Vital Statistics data were released in 2019 and are collected annually on approximately one million individuals, covering leading causes of deaths for South Africans and citizens of other nationalities residing in South Africa. The Vital Statistics database sampling procedure involves explicit stratification by province and within each province by urban and non-urban areas.

Household causes of deaths are drawn under this stratification. Individual characteristics presented in each household unit include the deceased's age, cause of death, the pregnant status of the deceased, gender, education level, job occupation, smoking status of the deceased, smoking status of the remaining next of kin, nationality status, and other general socio-economic status variables. The survey general structure questions for a binary response. For example, households are asked the smoking status of the deceased. The general reply is either yes, the deceased was smoking, or no, the deceased was not smoking. The paper used this binary variable to quantify the changes in stillbirth and maternal mortality outcomes in individuals who accepted NHPP recommendations and quitted smoking vs those who resisted NHPP efforts and persisted with smoking.

In this analysis, the author exploited the changes in smoking status that the NHPP exerted in the South African and immigrant population groups between 2015 and 2017. The author then builds credible control and treatment groups based on smoking status for both groups. Individual women who quitted smoking post-NHPP implementation were considered as the treatment group. Individual women who persisted with smoking post-NHPP implementation were classified as the control group.

The author used the strategy described by Mostert and Vall [25,26] to quantify the impact of the NHPP on stillbirth and maternal mortality in both the South African population and immigrants citizens. In addition, sine smoking is known to be associated with increased stillbirth and maternal mortality risk; the author compared the outcomes by smoking status.

Hence, the author opted to analyze these results in individuals whose smoking status was disclosed to prevent hidden biases. Furthermore, NHPP mainly covered low-income communities. Therefore, the analysis only focuses on households whose job occupations paid <900 US$ per month to prevent any confounding factors (e.g. agricultural and fishery workers, elementary occupations workers, clerical support workers, plant operators, etc.).

The author did not directly compare households who persisted in smoking to those not smoking, as these two groups of households can be different in many additional dimensions that can have direct impacts on stillbirth and maternal mortality outcomes (e.g. differences in income, proximity to health institutions, and social status of the household).

For these reasons, the author did not opt for ordinary least squares (OLS) model estimation because of the possibility of having inflated coefficients.[25,26] Instead, the author opted for a 2SLS model presented below:

$$Y_i^a = \alpha_1 + \beta_1 \sim NHPP_i\partial + AgeFE + \psi Education - FE + \theta PlaceFE + \rho YearFE + \xi Race_i + \sigma Female_i$$
$$NHPP_i^a = \alpha_2 + \beta_2 Treat_i^a + AgeFE + \psi Education - FE + \theta PlaceFE + \rho YearFE + \xi Race_i + \sigma Female_i \quad (1)$$

In the first equation, Y is one of the outcomes for individual at age ɑ, and '~NHPP' is the predicted benefit from the national health promotion policy proxied by no smoking. The regression includes age fixed effects (which capture age differences that can influence maternal mortality and stillbirth outcomes), education fixed effects (which capture the family education dynamics which can influence mortality outcomes), place of death fixed effects (which capture the deaths recorded at home and in healthcare facilities), year fixed effects (which capture the year and seasonality effects which may influence mortality outcomes), race fixed effects (which capture for racial differences that can influence mortality outcomes), and a dummy for female (for the regressions in which the study estimate effects for both males and females).

In the second equation (which corresponds to the first stage regression), participation in the NHPP program is estimated as a function of the treatment dummy variable, which identifies the individuals who responded positively and maintained a no-smoking lifestyle. Thus, in all model estimations, the study needs two assumptions to be fulfilled: first, probability of being treated, and this will be corroborated by the F-test of the first stage equation; and second, the exclusion restriction needs to hold, that is, the instrument should not influence the primary outcome directly through any channel other than treatment.

This assumption means that differences in stillbirth and maternal mortality outcomes between the treated and control groups can only be because of NHPP's influence in reducing smoking. Thus, there is no reason to believe that the treatment group should have better stillbirth and maternal mortality outcomes than the control group observed in the same regions. Furthermore, no other South Africa event explains any difference in stillbirth and maternal mortality outcomes that would affect only the treatment group but not the control group. Thus, the paper is confident that the exclusion restriction is satisfied, meaning NHPP can explain these changes in Figure 2 of the Appendix.

Results

Descriptive analysis

Table 1 presents the exact difference between the treatment and control groups. First, individuals who persisted with smoking recorded a higher probability of stillbirth and maternal mortality than those who accepted the NHPP interventions and stopped smoking.

Table 1
Descriptive statistics.

	Treated	Control
Benefiting from NHPP	99.9%	0.0%
Female	51.1%	51.3%
In rich provinces	53.0%	53.4%
Reported stillbirth	1.3%	3.1%
Reported maternal mortality	3.4%	7.1%
Reported foreign nationals	14.2%	13.1%
Observations	125,751	120,820

NHPP, national health promotion policy.
Source: Own elaboration with data from Stats-SA vital statistics 2015–2017.

Results of two-way 2SLS model

The tables present a comparative picture of how NHPP interventions that drove down smoking also averted stillbirth and maternal mortality. When analyzing the 2SLS model estimations' results, the paper noted that the first stage regression's F-statistic is very large, pointing toward the instrument's strong validity (see Table 2). Furthermore, stillbirths were reduced by 0.13 percentage points in the urban regions. The mean of stillbirth is 1.61 in this region. Therefore, NHPP reduces the rate of stillbirth by 8.36%.

Similarly, stillbirth was reduced by 0.87 percentage points in rural settings. On the other hand, the mean for stillbirth is 2.60 for these regions; therefore, NHPP reduces the stillbirth rate by 2.84%. This estimation shows that the NHPP did not appear to have as great an impact on the rural population as on the urban one.

The study then next examines whether NHPP positively impacts the maternal mortality outcomes, considering that it positively impacts stillbirth. The paper found in Table 3 that NHPP reduces maternal mortality in both urban and rural populations. NHPP reduces maternal mortality by 0.10 percentage points, implying a 20.88% improvement in the urban population. Once again, the NHPP impact was lower in improving maternal deaths in the rural population. Indeed, living conditions are key determinants of maternal healthcare utilization,[27] which could explain these results.

The author examined education-based differences of NHPP's impact on maternal mortality outcomes and repeated the same regressions only for the educated individuals (Grade 12 and other tertiary qualifications) and only for the least educated individuals (Below Grade 12 completion). Table 4 shows that NHPP improves maternal mortality more for the educated population. For example, in the treatment group, maternal deaths were reduced by 21.75% for the educated population and 14.80% for the least educated population.

Table 2
2SLS estimation of the impact of NHPP on stillbirth.

2SLS	Urban	Rural
	Stillbirth	
NHPP	−0.0013[a]	−0.0087[a]
	(0.0002)	(0.0001)
Age fix effect	Yes	Yes
Year fix effect	Yes	Yes
Gender fix effect	Yes	Yes
Race fix effect	Yes	Yes
Place of death fix effect	Yes	Yes
Mean for stillbirth	0.0161	0.0260
Observations	12,049	10,594
F-stat 1st SLS	89.4101	78.2741

Note: The results are from a 2SLS model. In the first stage equation, the dependent variable is the probability of being treated with NHPP. Simultaneously, the instrument is a dummy variable equal to 1 for individuals who responded to NHPP and maintained a no-smoking lifestyle and 0 for individuals who avoided the NHPP recommendation and persisted with smoking. In the second stage regression, the dependent variable is a dummy variable of 'stillbirth'. Both regressions include age, year, gender, race, and place of death fixed effects. Source: Vital statistics provided by Statistic South Africa from 2015 to 2017. NHPP, national health promotion policy.
[a] Significant *P* value at <0.05. Coefficients in brackets represent standard errors.

Table 3
2SLS estimation of the impact of NHPP on maternal mortality.

2SLS	Urban	Rural
	Maternal mortality	
NHPP	−0.0010[a]	−0.0087[a]
	(0.0002)	(0.0001)
Age fix effect	Yes	Yes
Year fix effect	Yes	Yes
Education fix effect	Yes	Yes
Race fix effect	Yes	Yes
Place of death fix effect	Yes	Yes
Mean for maternal mortality	0.0481	0.0560
Observations	126,565	106,630
F-stat 1st SLS	119.9601	104.2201

Note: The results are from a 2SLS model. In the first stage equation, the dependent variable is the probability of being treated with NHPP. Simultaneously, the instrument is a dummy variable equal to 1 for individuals who responded to NHPP and maintained a no-smoking lifestyle and 0 for individuals who avoided the NHPP recommendation and persisted with smoking. In the second stage regression, the dependent variable is a dummy variable of 'maternal mortality'. Both regressions include age, year, education, race, and place of death fixed effects. Source: Vital statistics provided by Statistic South Africa from 2015 to 2017. NHPP, national health promotion policy.
[a] Significant *P* value at <0.05. Coefficients in brackets represent standard errors.

Table 4
2SLS estimation of the impact of NHPP on maternal mortality by education level.

2SLS	Educated	Least educated
	Maternal mortality	
NHPP	−0.0109[a]	−0.0080[a]
	(0.0005)	(0.0011)
Age fix effect	Yes	Yes
Year fix effect	Yes	Yes
Race fix effect	Yes	Yes
Place of death fix effect	Yes	Yes
Mean for maternal mortality	0.0501	0.0541
Observations	116,561	116,634
F-stat 1stSLS	117.9601	109.2201

Note: The results are from a 2SLS model. In the first stage equation, the dependent variable is the probability of being treated with NHPP. Simultaneously, the instrument is a dummy variable equal to 1 for individuals who responded to NHPP and maintained a no-smoking lifestyle and 0 for individuals who avoided the NHPP recommendation and persisted with smoking. In the second stage regression, the dependent variable is a dummy variable of 'maternal mortality'. Both regressions include age, year, race and place of death fixed effects. Source: Vital statistics provided by Statistic South Africa from 2015 to 2017. NHPP, national health promotion policy.
[a] Significant *P* value at <0.05. Coefficients in brackets represent standard errors.

Table 5 shows that the NHPP appeared to reduce stillbirth and maternal mortality rates among the immigrant population. However, the impact of NHPP is lower in reducing immigrant's stillbirth and maternal mortality compared with the South African citizens.

Discussion

The NHPP appears to play a positive role in advancing public health outcomes. The study also finds that the impact of NHPP is more robust for the urban population than for the rural population. These results are consistent with findings reported in Brazil.[28]

The study also analyses differences in the impact of NHPP for the educated and least educated population in South Africa. NHPP improves maternal mortality outcomes to a more considerable extent in the educated segment of the population. These results are consistent with findings from Canada,[29] Ireland,[30] and other international studies,[31] where education was found to play a significant role in advancing public health outcomes.

Table 5
2SLS estimation of the impact of NHPP on maternal mortality and stillbirth of immigrant citizens.

2SLS	Urban	Rural
	Maternal mortality	
NHPP	−0.0106[a]	−0.0077[a]
	(0.0012)	(0.0020)
Age fix effect	Yes	Yes
Year fix effect	Yes	Yes
Education fix effect	Yes	Yes
Race fix effect	Yes	Yes
Place of death fix effect	Yes	Yes
Mean for maternal mortality	0.0551	0.0590
Observations	9849	8948
F-stat 1st SLS	91.3601	87.5501
	Stillbirth	
	−0.0010[a]	−0.0008[a]
	(0.0002)	(0.0001)
Age fix effect	Yes	Yes
Year fix effect	Yes	Yes
Gender fix effect	Yes	Yes
Race fix effect	Yes	Yes
Place of death fix effect	Yes	Yes
Mean for stillbirth	0.0131	0.0290
Observations	6049	5942
F-stat 1st SLS	73.7501	69.4721

NHPP, national health promotion policy.
[a] Significant *P* value at <0.05. Coefficients in brackets represent standard errors.
Source: Vital statistics provided by Statistic South Africa from 2015 to 2017.

Health policies in South Africa tend to perpetuate skewed inequality between educated and less educated populations because the English language is preferred over other local languages. The less educated people, especially in rural areas, are less fluent in English, resulting in meek improvement in public health outcomes.

Hence, the NHPP does not improve stillbirths and maternal deaths equally for all groups, and this inequality of impact has significant implications for the further implementation of NHPP. This paper endorses the strengthening of NHPP to make its utilization practical for both rural and urban areas and educated and less educated groups. More diversification of the NHPP language programs will go a long way in reducing the current inequalities.

Finally, the paper also analyses the impact of the NHPP on the immigrant population. More specifically, the paper finds a robust improvement in stillbirth and maternal deaths in immigrants who responded to NHPP interventions. However, the slightly lower coefficient in the immigrant population group reflects the existing health disparities between the South Africans and immigrants. These results are similar to findings reported in Taiwan.[32] Health promotion programs and preventive care utilization in Taiwan were relatively low among immigrants citizens compared with the locals, resulting in lower health outcomes for the immigrants.

Limitations

The paper acknowledges that the current binary variables do not capture all epidemiological outcomes linked to these women considering that Stats-SA vital statistics is still missing maternal deaths data for 2018 and 2019. Furthermore, there is no advance information on the determinates of stillbirths and maternal deaths in the Vital Statistics panel data. Thus, the author interprets the results as evidence of substantial improvement in stillbirth and maternal mortality outcomes attributed to NHPP while not capturing other qualitative changes that may further explain these health outcomes. For example, stillbirth can also be driven by

unrecognized intrauterine growth.[33] Unfortunately, the Vital Statistics panel data do not contain such information, which should have been controlled in the analysis. Nevertheless, the paper believes such omission will not significantly influence the current estimation considering that smoking is still the primary driver of stillbirth and maternal mortality.[2]

In summary, NHPP plays a crucial role in advancing women's and children's health outcomes. For example, the policy improves stillbirth and maternal mortality for both South Africans and immigrant nationals.

Author statements

Acknowledgements

This research is part of a collaboration project designed to investigate policies which support the engineering of resilient health systems in developing countries.

Ethical approval

Our institution does not require ethical approval for this type of study.

Funding

The author is grateful for the financial support received from the University of Twente.

Competing interests

None declared.

Availability of data and materials

The data that support the findings of this study are available from STATSA on reasonable request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.009.

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Public Health 198 (2021) 230–237

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

The real-life impact of vaccination on COVID-19 mortality in Europe and Israel

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ARTICLE INFO

Article history:
Received 26 May 2021
Received in revised form
14 July 2021
Accepted 26 July 2021
Available online 3 September 2021

Keywords:
COVID-19 mortality
SARS-CoV-2 variants
B.1.1.7 variant
VOC
Vaccination
Mobility

ABSTRACT

Objectives: This study aimed at estimating the real-life impact of vaccination on COVID-19 mortality, with adjustment for SARS-CoV-2 variants spread and other factors across Europe and Israel.
Study design: Time series analysis.
Methods: Time series analysis of the daily number of COVID-19 deaths was performed using non-linear Poisson mixed regression models. Variables such as variants' frequency, demographics, climate, health, and mobility characteristics of thirty-two countries between January 2020 and April 2021 were considered as potentially relevant adjustment factors.
Results: The analysis revealed that vaccination efficacy in terms of protection against deaths was 72%, with a lower reduction of the number of deaths for B.1.1.7 vs non-B.1.1.7 variants (70% and 78%, respectively). Other factors significantly related to mortality were arrivals at airports, mobility change from the prepandemic level, and temperature.
Conclusions: Our study confirms a strong effectiveness of COVID-19 vaccination based on real-life public data, although lower than expected from clinical trials. This suggests the absence of indirect protection for non-vaccinated individuals. Results also show that vaccination effectiveness against mortality associated with the B.1.1.7 variant is slightly lower than that with other variants. Lastly, this analysis confirms the role of mobility reduction, within and between countries, as an effective way to reduce COVID-19 mortality and suggests the possibility of seasonal variations in COVID-19 incidence.

Introduction

The pandemic of the coronavirus infectious disease 2019 (COVID-19) is continuously evolving, driven by the spread of new variants of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). During the second half of 2020 and early 2021, a variety of new SARS-CoV-2 variants emerged. EU2 variant (mutation S:447N), first observed in July 2020 in Western Europe, was found to be capable of increasing virus infectivity.[1,2] Then, several variants of concern (VOCs) have been identified, including B.1.1.7 developed first in the UK in September 2020,[3] B.1.351 in South Africa in December 2020,[4] P.1 in Brazil in January 2021,[5] and the 'Indian' variant B.1.617 reported first in Maharashtra in January 2021.[6] The disease mortality has been increased in these countries after new variants were developed.[7–10] An increased risk of transmissibility, hospitalization, and death associated with the B.1.1.7 variant was reported by a number of authors.[8,11–16] The B.1.351 variant was found to have an increased transmissibility and immune escape[17] and was estimated to be 50% more transmissible than pre-existing variants.[18] Higher incidence of COVID-19 cases in younger age groups was observed in the Amazonas state, suggesting changes in pathogenicity of the P.1 variant.[19] Preliminary findings suggest also a significant increase in case fatality rate in young and middle-aged population for the P.1 mutant.[20] The region of Maharashtra, where the B.1.617 variant emerged, experienced a significant rise in daily infection rate after the new variant appeared.[10]

To control the SARS-CoV-2 spread, a number of different vaccines have been developed and analyzed in clinical trials, including eight vaccines having emergency use or conditional marketing authorizations worldwide or across regions, as of May 2021.[21] The worldwide vaccination campaign started in December 2020 aiming

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https://doi.org/10.1016/j.puhe.2021.07.037
0033-3506/

to provide herd immunity across societies. The threshold for COVID-19 'herd immunity' was placed between 60 and 70% of the population gaining immunity through vaccinations or past disease exposure; however, scientists warn that herd immunity is unlikely to be achieved owing to factors such as vaccine hesitancy and the spread of new variants.[22,23] Israel was far ahead of other countries in terms of the proportion of vaccinated inhabitants, exceeding 62% at the end of April 2021, with the UK reaching 50% and the USA 42% at the same time.[24]

Results of clinical trials on vaccine efficacy revealed that Pfizer-BioNTech had 95% efficacy at preventing symptomatic COVID-19 infection in people without prior infection.[25] Efficacy of 94.1% was reported for Moderna,[26] 70.4% for Oxford-AstraZeneca,[27] 66.5% for Johnson & Johnson,[28] and 96.4% for Novavax,[29] with the latter being still under the investigation before authorization. For the prevention against a severe disease course, Pfizer, Moderna, AstraZeneca, and Novavax reported a 100% efficacy, whereas 84% was observed for Johnson & Johnson; however, the latter was tested on a broader range of countries, including the USA, South Africa, and Brazil, after the new VOCs spread.

Clinical evidence suggests that newly developed virus variants may affect the protective efficacy of both naturally acquired immunity and vaccinations. Studies on neutralization of convalescent sera against distinct strains showed that VOCs were harder to neutralize than the original strain, an early Wuhan-related strain of SARS-CoV-2. Neutralization titers against the B.1.1.7 variant showed a threefold reduction,[30] a 3.4-fold reduction was observed for the P.1 variant,[31] and a 13.3-fold reduction for the B.1.531 variant.[32] Johnson & Johnson vaccine was found to have 64% efficacy against infection in South Africa and 68% in Brazil after the spread of B.1.135 and P.1 variants, whereas the efficacy against severe-critical disease was 82% and 88% in both countries.[28] Late March 2021, AstraZeneca was observed as having 70.4% efficacy against the B.1.1.7 variant;[33] however, the vaccine did not protect as well against the B.1.351 variant.[34] For Novavax, the initial evidence suggests 86.3% efficacy against the B.1.1.7 variant[35] and 49.4% against the B.1.351 variant.[36] Early May 2021, Pfizer vaccine was found to be 87% effective against infection with the B.1.1.7 variant and 72% against B.1.351 variant, whereas 97.4% efficacy against severe disease course was observed for any of these mutations.[37] On the other hand, Wang et al.[38] observed a reduced neutralization of Moderna and Pfizer vaccine-immune sera against the B.1.351 variant (12.4-fold for Moderna; 10.3-fold for Pfizer), but no significant impact was observed for the B.1.1.7 variant. Next, a 3.8- to 4.8-fold reduced neutralization of Moderna vaccine was observed against the P.1 variant.[31] Preliminary evidence suggests a significant drop in neutralization of B.1.617 compared with other variants, including B.1.1.7 and P.1, with sera of Indian's vaccine, Covaxine.[10]

The other concern is the probability of reinfection after recovery or vaccination. Hansen et al.[39] observed an 80.5% protection against reinfection in a population-level observational study on Danish patients previously tested positive for SARS-CoV-2; however, the study was performed before VOCs spread. The probability of reinfection after vaccination is also a big concern. As reported by the US Centers for Disease Control and Prevention (CDC), there were around 9200 infections among vaccinated inhabitants among 95 million of those who have already been vaccinated in the USA (0.01%) as of 26 April 2021.[40] Despite these optimistic preliminary data, experts alarm that additional data are needed to assess the potential impact of VOCs on future vaccine efficacy.[41] Considering all the concerns associated with new VOC spread, the real vaccination effectiveness becomes hard to assess and judge but can be expected to decrease over time. Also, it is likely that vaccination may favor the emergence of new variants by selection of new, better fitted mutants. Some scientists suggest that, similarly as for seasonal flu vaccines, COVID-19 vaccines will need to be redesigned or even updated periodically to protect against new variants.[42,43]

Vaccination efficacy and distinct variants spread are the only two factors among numerous other variables affecting COVID-19 infection and death rates across the world. A variety of potential predictors were assessed in the literature, including demographic characteristics, mobility and social-distancing measures, environmental and climate variables, as well as health characteristics.[44–53]

This study aims at estimating the real-life impact of vaccination on COVID-19 mortality based on publicly available data from Europe and Israel, using time series analysis with non-linear mixed regression models. Variants frequency, including B.1.1.7 and other variants, as well as country-specific demographic and meteorological characteristics, health indicators, and mobility factors were considered as potentially relevant adjustment factors. Results of the current study should inform policy decision-makers, scientists, and the general public about the role of vaccination and social-distancing strategies in controlling the COVID-19 pandemic in the face of new VOCs spread.

Methods

Data collection

A total of 32 countries were considered in the analysis, including European countries and Israel. The daily number of COVID-19 deaths was the primary outcome of interest. Values were smoothed using 7-day moving average, divided by the number of inhabitants of a given country and reported as daily numbers of deaths per 1 million inhabitants.

The main explanatory variables of interest were proportion of vaccinated inhabitants (vaccination coverage), as well as average proportions of SARS-CoV-2 variants calculated across strains forming 12 Nextstrain clades. The focus was on 20A (EU2), 20E (EU1), and 20I (B.1.1.7) variants, with the two formers being dominant in Europe during the summer 2020 and the latter VOC being most frequent early 2021. Other time-varying covariates were maximum daily temperature, mean daily wind speed, the number of arrivals at two biggest airports of a country, and change in mobility from the prepandemic level (considering the average across retail/recreation, transit stations, and groceries/pharmacies). Additional fixed covariates were proportion of population aged 65 years or older, prevalence of diabetes, and rate of cardiovascular deaths.

Data on COVID-19 deaths and vaccination were obtained from Our World in Data on 15 April 2021.[24] Metadata on SARS-CoV-2 virus variants (clades) identified up to mid-April 2021 were downloaded from the Nextstrain platform.[54–56] We assumed that if a strain was observed on a given date, it could be observed in a range of ±14 days from the observation date. Because the data were not reported daily, linear interpolation was used to impute missing observations, assuming zeros a month before the first and after the last (if up to 1 March 2021) reported occurrence of a variant. Finally, data were smoothed with the use of 14-day moving average.

Countries' characteristics were obtained from Our World in Data, Eurostat, the National Centers for Environmental Information, Aviation Intelligence Portal, and Google COVID-19 Community Mobility Reports.[24,57–60] Data on arrival flights and mobility were smoothed using 7-day moving average.

Statistical analysis

Regression analysis was used to investigate the association between COVID-19 mortality and daily reported time-varying variables and fixed covariates.

The primary analysis of the daily number of COVID-19 deaths was performed with the use of non-linear Poisson mixed model with random country-level intercept and mobility effect. The considered period was from the date of the first reported death in Europe, 29 January 2020, up to 15 April 2021.

Owing to the presence of autocorrelations, and to consider the fact that the number of infections on a given day is dependent on the number of infectious cases in the population over previous days which translates into the respective number of deaths, the model was adjusted for the logarithm of the daily number of COVID-19 deaths reported 7 days earlier. To capture the fact that increasing or decreasing trends in COVID-19 mortality over time are generally stable over several weeks or months, the logarithm of quotient of COVID-19 deaths 7 days before divided by deaths 14 days before the actual date was added as a covariate. All other time-varying variables were considered with a 21-day lag, to account for the virus incubation period, assuming 7 days from contact to symptoms onset, and a delay between symptoms onset and death due to the disease, assuming another 14 days. In addition, heterogeneity between countries was considered with random intercepts and mobility effects varying between countries.

Assuming M indicates mortality with vaccination coverage 'c', M_o is the mortality without vaccination, and 'VE' represents the vaccine efficacy, we have:

$$M = M_0 \cdot (1 - c \cdot VE).$$

After applying the logarithmic transformation and considering a set of covariates $x_1, \ldots, x_k$ and random effects $u_0, u_1, \ldots, u_n$ on intercept and selected $x_1, \ldots, x_n$, this equation was extended as shown in the following to specify the non-linear model:

$$Log(E(M)) = \beta_0 + Log((1 - c \cdot VE)) + \beta_1 x_1 + \ldots + \beta_k x_k + u_0 + u_1 x_1 + \ldots + u_n x_n.$$

For the exploratory analysis, vaccine efficacy against B.1.1.7 and non-B.1.1.7 variants was analyzed using a similar approach. Assuming that there are two classes of virus variants with known proportions equaled p_1 and p_2, the vaccine efficacy could be considered as the average efficacy weighted by variants proportions:

$$VE = p_1 \cdot VE_1 + p_2 \cdot VE_2.$$

The formula for the non-linear model is then as follows:

$$Log(E(M)) = \beta_0 + Log((1 - c \cdot (p_1 \cdot VE_1 + p_2 \cdot VE_2))) + \beta_1 x_1 + \ldots + \beta_k x_k + u_0 + u_1 x_1 + \ldots + u_n x_n.$$

Additionally, three scenarios were tested as sensitivity analyses, varying either the time to symptoms onset or the time between symptoms onset and death. A detailed methodology is presented in Supplementary Materials.

A P-value lower than 0.05 was considered as statistically significant. Akaike's information criterion (AIC) was provided to inform about models' fit statistic. Analyses were performed using SAS, version 9.4, software.

Results

Descriptive statistics

Descriptive statistics of outcomes and covariates across 32 countries included in the analysis, for the period between January 2020 and April 2021, are presented in Table 1. Mean proportions of SARS-CoV-2 variants, EU2, EU1, and B.1.1.7, for each country are presented in Fig. 1. Until mid-April 2021, the variant EU2 was the most frequently spread for vast majority of countries, except Israel and the UK for which B.1.1.7 was more frequent, as well as Spain and Lithuania with EU1 being more commonly observed.

Primary analysis

Analysis of the non-linear Poisson mixed model of the number of COVID-19 deaths revealed that the effect of vaccination effectiveness against mortality was assessed as significant and equaled to 0.720 ($P < 0.001$; Table 2). Other covariates that were found significant in the model were temperature (−0.005, $P < 0.001$), arrivals at airports (0.709, $P < 0.001$), and mobility change from the prepandemic level (0.753, $P < 0.001$). Variables used to account for autocorrelation and minimize the effect of trend were assessed as significant (Log of the number of daily COVID-19 deaths 7 days before: 0.926, $P < 0.001$; Log of the number of COVID-19 deaths 7 days before/14 days before: 0.158, $P < 0.010$). The random intercept variance was statistically significant, which indicated significant unexplained variability between countries (0.014, $P = 0.023$).

Exploratory analysis

Results of the analysis of the exploratory model revealed numerically lower vaccine effectiveness against B.1.1.7 than against non-B.1.1.7 variants, although the difference was not statistically significant (0.697, $P = 0.002$ and 0.778, $P = 0.049$, respectively; Table 3). The same set of covariates was found significant in the exploratory model as in the primary analysis: temperature (−0.005, $P < 0.001$), arrivals at airports (0.703, $P < 0.001$), and mobility change from the prepandemic level (0.753, $P < 0.001$). Variables used to account for autocorrelation and minimize the effect of trend were assessed as significant (Log of the number of daily COVID-19 deaths 7 days before: 0.926, $P < 0.001$; Log of the number of COVID-19 deaths 7 days before/14 days before: 0.158, $P < 0.010$), as was the variance for random intercept (0.013, $P = 0.025$).

Sensitivity analysis

Sensitivity analyses yielded overall vaccination effectiveness estimates against mortality between 0.60 and 0.72 (Fig. 2). Regarding vaccination effectiveness associated with variants, two out of three scenarios provided consistent results with the main analysis, i.e., a trend towards lower effectiveness against the B.1.1.7 variant, and the opposite trend was observed in the remaining scenario (Fig. 2). Detailed results are provided in Supplementary Materials.

Discussion

In this study, we investigated the association between daily mortality due to COVID-19 and vaccination coverage, proportions of SARS-CoV-2 variants, and additional factors, such as demographics, health, mobility, and meteorological variables, analyzing country-level data across Europe and Israel. Results of the analysis suggest that vaccination effectiveness against deaths is equal to 72% and that it is slightly lower against the B.1.1.7 variant than against non-B.1.1.7 variants (difference not statistically significant). These findings suggest lower effectiveness against death than reported efficacy against severe or critical disease course in clinical trials of vaccines (84–100%).[25–29]

This lower-than-expected effectiveness might be explained by the difference in considered populations: clinical trials included restrictive populations, and our study covers general populations, irrespective of age, concomitant therapies, medical condition, and

Table 1
Descriptive statistics of outcomes and covariates across 32 countries (January 2020–April 2021).

Variable	N	Mean	Standard deviation	Median	Lower quartile	Upper quartile	Minimum	Maximum
Number of daily COVID-19 deaths	13,229	3.355	4.618	1.159	0.206	4.933	0	28.770
Proportion of vaccinated inhabitants	13,181	0.018	0.058	0	0	0	0	0.616
Proportion of 20A (EU2) variant	13,106	0.349	0.250	0.313	0.154	0.509	0	1.000
Proportion of 20E (EU1) variant	12,754	0.090	0.159	0	0	0.114	0	0.741
Proportion of 20I (B.1.1.7) variant	13,099	0.124	0.256	0	0	0.065	0	1.000
Max daily temperature	13,008	15.597	9.347	15.833	8.750	22.389	−17.111	43.111
Mean daily wind speed	13,010	6.227	3.353	5.600	3.700	8.100	0.100	25.800
Arrivals at two biggest airports	12,748	140.609	195.648	66.429	27.714	177.929	1.857	1780.143
Mobility change from prepandemic[a]	12,918	−0.217	0.170	−0.201	−0.322	−0.091	−0.792	0.199
Proportion of inhabitants aged ≥65 years	13,229	0.184	0.025	0.190	0.168	0.198	0.117	0.230
Diabetes prevalence	13,229	0.062	0.019	0.058	0.048	0.072	0.033	0.101
Cardiovascular death rate	13,229	2.037	1.124	1.535	1.148	2.783	0.861	5.398

[a] Average mobility change from prepandemic level calculated across retail/recreation, transit stations, and groceries/pharmacies [0.01]. Descriptive statistics were calculated for 32 countries based on daily data between 29 January 2020 and 15 April 2021.

general condition. In particular, vaccinated people in real life are older on average than subjects enrolled in clinical trials (12.2% aged ≥55 years in the AstraZeneca trial; 24.7% aged ≥65 years in the Moderna trial; 33.5% aged ≥60 years in the Johnson & Johnson trial; 42.3% aged ≥55 years in the Pfizer trial). However, our results suggesting lower protection against the B.1.1.7 variant are consistent with reported data so far from in vivo experiments and patient-level studies, providing an external validation of these findings. Laboratory evidence revealed a slight reduction in neutralization against the B.1.1.7 variant compared with the original strain. Neutralization titers against this VOC were threefold lower when analyzing convalescent sera and 3.3-fold and 2.5-fold lower for Pfizer and AstraZeneca vaccinees, respectively.[30] Real-world studies on the B.1.1.7 VOC suggested that it caused increased mortality compared with non-B.1.1.7 variants,[15,61] which, therefore, might not have been contained with similar effectiveness by vaccination. Our results evoke the question of variants evading vaccine antibodies in the future and the need to adapt such vaccine for each new season, which was earlier suggested by experts.[42,43]

While the utilization of individual-level data, collected in real-world setting, could provide more precise estimates of vaccine effectiveness, the use of aggregate data at country level also has a major advantage: the vaccination impact estimated in this analysis should capture the indirect protection provided by vaccination. If the vaccine protects against infection, the number of infectious cases would decrease as more people are vaccinated. The lower number of infectious cases in the population would lead to a reduced probability for susceptible individuals to get in contact

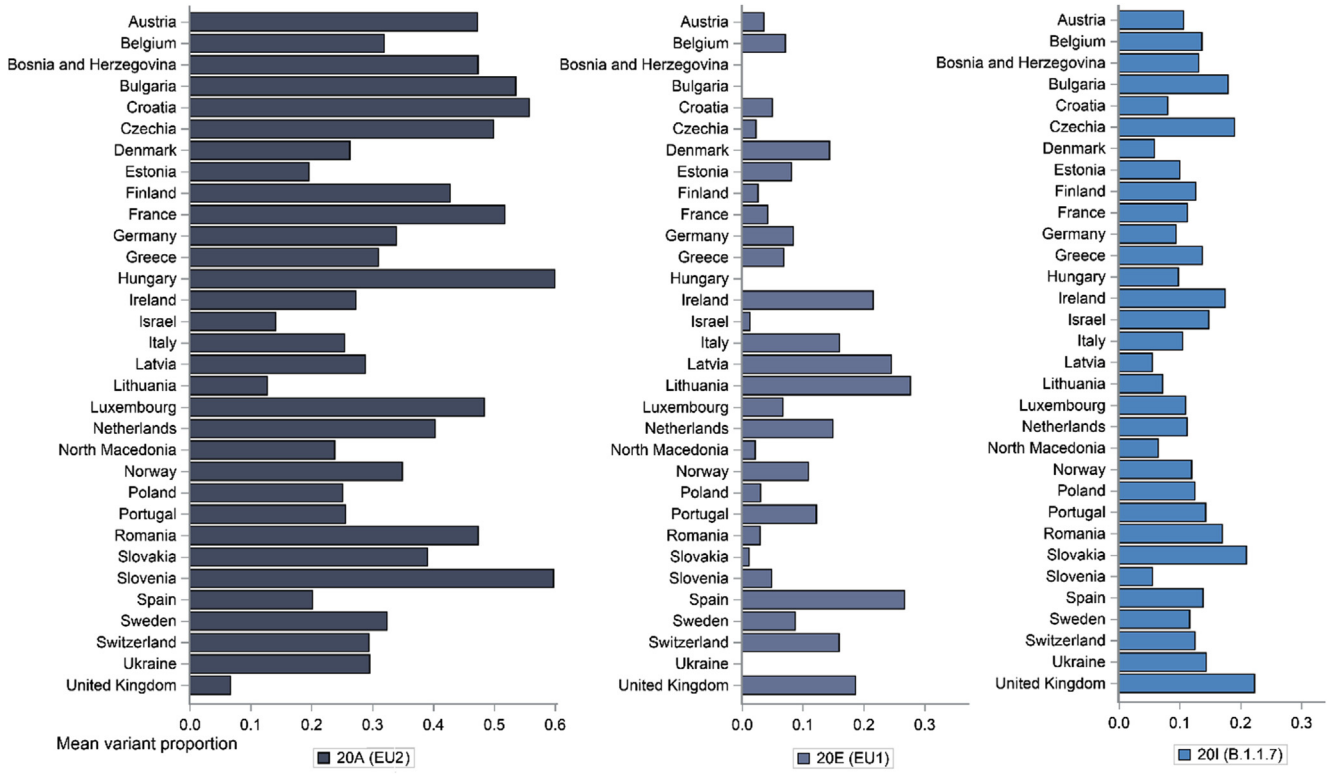

Fig. 1. Mean SARS-CoV-2 variants proportions across countries, between January 2020 and April 2021. Mean proportions of variants were calculated based on daily data on variants proportions across observed strains used to form Nextstrain clades (variants), between 29 January 2020 and 15 April 2021.

Table 2
Results of the non-linear Poisson mixed model of the number of daily COVID-19 deaths.

Variable	Estimate	Standard error	*P* value
Intercept	0.467	0.202	0.028
Logarithm of the number of daily COVID-19 deaths 7 days before[a]	0.926	0.007	<0.001
Logarithm of the number of COVID-19 deaths 7 days before/14 days before	0.158	0.015	<0.001
Proportion of 20A (EU2) variant[b]	0.012	0.036	0.746
Proportion of 20E (EU1) variant[b]	−0.032	0.046	0.501
Proportion of 20I (B.1.1.7) variant[b]	0.059	0.033	0.084
Max daily temperature[b]	−0.005	0.001	<0.001
Mean daily wind speed[b]	−0.002	0.002	0.351
Arrivals at two biggest airports [in thousands][b]	0.709	0.085	<0.001
Mobility change from prepandemic[b,d]	0.753	0.064	<0.001
Proportion of inhabitants aged ≥65 years[c]	−1.238	0.930	0.193
Diabetes prevalence[c]	0.544	1.293	0.677
Cardiovascular death rate[c]	0.023	0.023	0.322
Vaccination effectiveness[b]	0.720	0.132	<0.001
Variance for RE on intercept	0.014	0.006	0.023
Variance for RE on mobility	0.036	0.023	0.126

AIC = 30,184.
Abbreviations: AIC = Akaike's information criterion; mln = million; RE = random effects.
Non-linear Poisson mixed model of the daily number of COVID-19 deaths per 1 mln inhabitants, with country-specific random effects on intercept and mobility. Daily data for 32 countries were included, from 29 January 2020 to 15 April 2021. Assumed time to symptoms onset is 7 days; assumed time between symptoms onset and death is 14 days.
[a] Time-varying variable with a 7-days lag.
[b] Time-varying variable with a 21-days lag.
[c] Fixed variable.
[d] Average mobility change from prepandemic level calculated across retail/recreation, transit stations, and groceries/pharmacies [0.01].

with infectious cases, thus leading to a reduction in incidence among all people, including non-vaccinated people. This indirect protection can be captured when comparing different populations with different rates of vaccination coverage, but could not be captured when comparing vaccinated and non-vaccinated individuals from the same population. Interestingly, the fact that our estimated vaccine effectiveness is relatively low compared with vaccine efficacy reported in clinical trials suggests that there is no or little indirect protection provided by vaccination. This could indicate that the vaccine protects against disease but not against infection or that vaccinated groups of population are not those that contribute to the propagation of the virus.

A positive relationship between the number of arrivals at airports and mortality has been observed in this analysis, similarly as between mobility change and mortality. It suggests that both increased long-distance travel and increased mobility are strong predictors of growth in the daily number of COVID-19 deaths. These findings highlight the role of mobility reduction, both within and between countries, as an effective way to reduce COVID-19 mortality, especially when new virus variants spread across the world. Our results are in line with previous study by Jabłońska et al.[50] suggesting that countries with lower reduction in mobility at the beginning of the pandemic experienced a higher COVID-19 daily deaths peak. The role of social distancing was also underlined by

Table 3
Results of the non-linear Poisson mixed model of the number of daily COVID-19 deaths with interactions between variants proportions and vaccination effectiveness.

Variable	Estimate	Standard error	*P* value
Intercept	0.409	0.204	0.054
Logarithm of the number of daily COVID-19 deaths 7 days before[a]	0.926	0.007	<0.001
Logarithm of the number of COVID-19 deaths 7 days before/14 days before	0.158	0.015	<0.001
Proportion of 20A (EU2) variant[b]	0.012	0.036	0.747
Proportion of 20E (EU1) variant[b]	−0.034	0.047	0.467
Proportion of 20I (B.1.1.7) variant[b]	0.059	0.033	0.085
Max daily temperature[b]	−0.005	0.001	<0.001
Mean daily wind speed[b]	−0.002	0.002	0.346
Arrivals at two biggest airports [in thousands][b]	0.703	0.085	<0.001
Mobility change from prepandemic[b,d]	0.753	0.064	<0.001
Proportion of inhabitants aged ≥65 years[c]	−0.805	0.925	0.391
Diabetes prevalence[c]	0.124	1.285	0.924
Cardiovascular death rate[c]	0.025	0.023	0.278
Vaccination effectiveness against 20I (B.1.1.7)[b]	0.697	0.201	0.002
Vaccination effectiveness against variants other than 20I (B.1.1.7)[b]	0.778	0.379	0.049
Variance for RE on intercept	0.013	0.006	0.025
Variance for RE on mobility	0.035	0.023	0.132

AIC = 30,186.
Abbreviations: AIC = Akaike's information criterion; mln = million; RE = random effects.
Non-linear Poisson mixed model of the daily number of COVID-19 deaths per 1 mln inhabitants, with country-specific random effects on intercept and mobility, including interactions between variants proportions and vaccination effectiveness. Daily data for 32 countries were included, from 29 January 2020 to 15 April 2021. Assumed time to symptoms onset is 7 days; assumed time between symptoms onset and death is 14 days.
[a] Time-varying variable with a 7-days lag.
[b] Time-varying variable with a 21-days lag.
[c] Fixed variable.
[d] Average mobility change from prepandemic level calculated across retail/recreation, transit stations, and groceries/pharmacies [0.01].

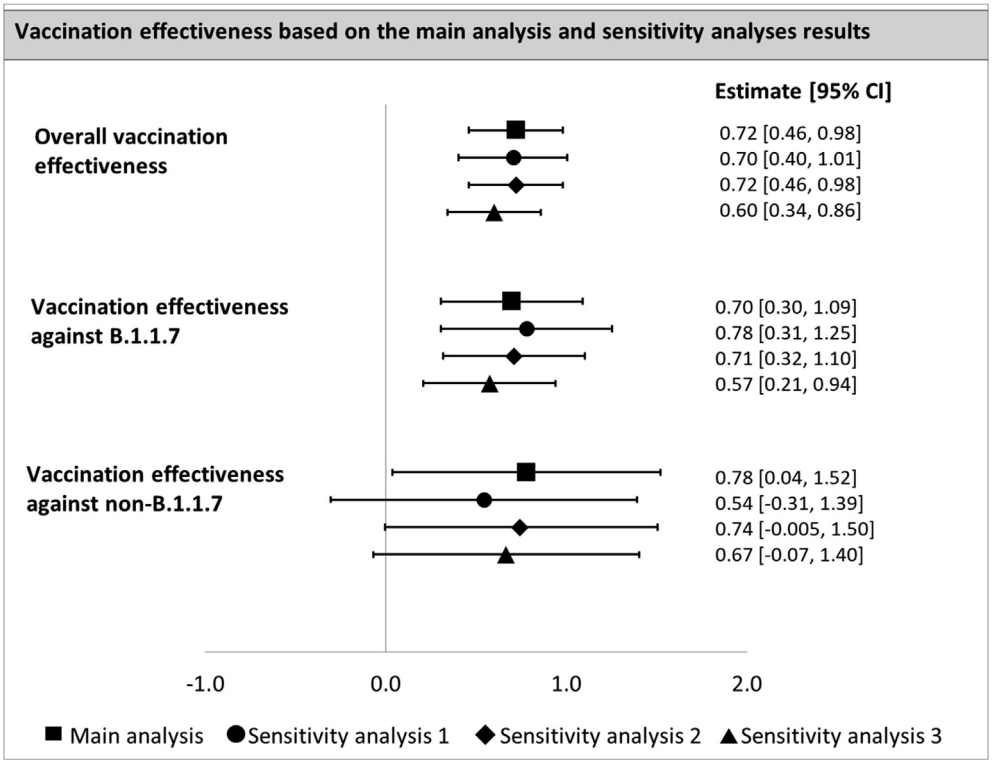

Fig. 2. Estimates of the vaccination effectiveness against mortality – main analysis and sensitivity analyses results. Abbreviations: 95% CI = 95% Confidence Interval. Assumptions of the analyses: Main analysis: time to onset = 7 days, time between symptoms onset and death = 14 days. Sensitivity analysis 1: time to onset = 14 days, time between symptoms onset and death = 14 days. Sensitivity analysis 2: time to onset = 14 days, time between symptoms onset and death = 7 days. Sensitivity analysis 3: time to onset = 7 days, time between symptoms onset and death = 7 days.

Badr et al.[62] who observed a significant impact of mobility on COVID-19 transmission in the USA.

The daily temperature was found as a significant predictor of COVID-19 mortality in this study, with increasing temperature associated with the reduction in the number of deaths. Kerr et al.[63] found no consensus on the impact of meteorological factors on COVID-19 spread in their literature review; however, they suggested existence of environmental sensitivity of COVID-19, but not as significant as non-pharmaceutical interventions and human behavior. Several authors underlined that disease seasonality may exist,[64–67] including Liu et al.[66] who found that COVID-19 infection and mortality rates were higher in colder climates and that the cold season caused an increase in total infections, while the warm season contributed to the opposite effect. Because our analysis covered a full annual cycle of COVID-19, our result suggests the possibility of seasonal variations in COVID-19 incidence. Such seasonality has been well established in temperate climate for other respiratory viruses.[68,69]

Limitations

Our study has several limitations. First, our analysis was conducted on a country-level basis to estimate the vaccination efficacy, which should be seen as a less precise method than analysis of individual-level data, as previously noted. However, given the range of included countries, our results shed light on the problem of vaccination effectiveness from a broader perspective and investigate the effect of vaccination across societies, considering variability of vaccination coverage through time and between countries. Second, the quality of data on variants distribution varied between countries and was low for some of them; therefore, results of the exploratory analysis should be treated with cautious. To limit bias and avoid fluctuations, we used methods of interpolation and smoothing. Countries with limited data were excluded. Third, the set of covariates used in the multivariate analysis can be assessed as non-exhaustive. We decided to consider factors that were previously assessed as significantly impacting the risk of severe illness or mortality from COVID-19 in the literature.[44–53] Also, the significant random intercept observed in our models reflects unexplained between-countries variability resulting from the omission of influential variables. It was previously shown, for example, that COVID-19 mortality may be influenced by economic factors, which were not considered in this analysis.[46] Finally, we were not able to consider other new SARS-CoV-2 VOCs, except B.1.1.7, in the current analysis, which was due to their limited spread in Europe as of April 2021. It rises a need for further research on this topic in the future.

Conclusions

This study confirms a strong effectiveness of COVID-19 vaccination based on real-life public data, in terms of protection against deaths being around 72%, although it appears to be slightly lower than could be expected from clinical trial results. This suggests the absence of indirect protection for non-vaccinated individuals. Results also suggest that vaccination effectiveness against mortality associated with the B.1.1.7 variant is high but slightly lower than other variants (70% and 78%, respectively). Finally, this analysis confirms the role of mobility reduction, both within and between countries, as an effective way to reduce COVID-19 mortality and supports the possibility of seasonal variations in COVID-19 incidence.

Author statements

Ethical approval

Not required. This study does not require ethical approval as it was conducted on country-level data and involved information freely available in the public domain.

Funding

None. This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Competing interests

None declared.

Contributors

MT conceptualized the study. KJ and SA validated the study concept. KJ and SA collected and analyzed the data. KJ, SA, and MT interpreted the results. KJ wrote the first draft of the manuscript. KJ, SA, and MT revised the manuscript and approved the final version.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.07.037.

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Public Health 198 (2021) 75–81

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

The relationship between depressive symptoms and activity of daily living disability among the elderly: results from the China Health and Retirement Longitudinal Study (CHARLS)

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ARTICLE INFO

Article history:
Received 2 September 2020
Received in revised form
25 February 2021
Accepted 22 June 2021
Available online 5 August 2021

Keywords:
Depressive symptoms
Difficulties in daily living
Elderly adults
China

ABSTRACT

Objective: The acceleration of population aging has brought an unprecedented impact on China's health system. This study is designed to examine the association between depressive symptoms and activity of daily living disability among the elderly in China.
Study design: This is a cross-sectional study.
Methods: Data were drawn from the China Health and Retirement Longitudinal Study (CHARLS). The 10-item Center for Epidemiologic Studies–Depression (CES-D) scale was used to access depressive symptoms, and physical function was assessed by the Activity of Daily Living (ADL) scale. Multivariate logistic regression was used to assess the association between depressive symptoms and ADL among the elderly.
Results: Based on a sample of 5863 elderly people over 60 years old, our results showed that 1999 elderly people are with depressive symptoms, accounting for 34.1%. The mean score of ADL among the elderly with depressive symptoms (20.65 ± 7.14) was much higher than that in those without depressive symptoms (17.40 ± 4.87). After controlling potential confounders, multivariate logistic regression showed that ADL and its specific domains including personal care, transfer, medical care, household, and managing money were associated with depressive symptoms.
Conclusion: This cross-sectional study provides evidence of the association between depressive symptoms and ADL disability among the Chinese elderly. As a result, prevention or reduction of ADL disability may have a positive effect on the medical care of the elderly with depressive symptoms.

Introduction

Depression is one of the most common mental health disorders in the elderly, affecting about 7% of the elderly worldwide.[1,2] Depression has become a major health problem with significant global disease burden;[3,4] it accounts for 12.1% of the total years lived with a disability and 4.5% of the total disability-adjusted life years (DALYs) globally.[5] To date, although the pathogenesis of depression is still unclear, scientific studies have investigated the association between depression in the elderly and social support,[6] suicidal tendencies,[7] and obesity and chronic medical conditions.[8] With China's aging population, the disease burden of depression not only affects the quality of life of millions of people but also brings heavy social loads through long-term medical and nursing services.[9,10] As China has the largest elderly population globally, the challenge of depressive symptoms in the elderly should be given sufficient attention.

The ADL disability is also a common phenomenon among the elderly; the most widely used measurements of daily life disability are the Activity of Daily Living (ADL) scale. As a disease affected by socioeconomic and cultural factors,[11] the association between depressive symptoms and ADL may be heterogeneous for different countries. Moreover, old age disability takes multiple forms and varies greatly in the degree of functional loss, and different dimensions in disability may differ in their relevance to the loss of independence. Although findings have not been entirely consistent, many studies have shown that ADL disability is associated with depressive symptoms.[12–14] Most of these studies only examine the

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https://doi.org/10.1016/j.puhe.2021.06.023

most extreme levels of dysfunction, and studies on more specific domains or functions are not sufficient. Hence, a broader range of disability statuses needs to be studied. So far, most of them have been conducted in western or other high-income countries. However, few studies pay attention to the relationship between them in China. Most of the available evidence comes from studies conducted by the elderly in local areas or medical institutions. Current knowledge about the relationship between depressive symptoms and ADL in the Chinese population is very limited.

A better understanding of the association between depressive symptoms and ADL among the elderly will help in the design of more targeted and appropriate interventions. To do so, we have the following specific objectives. Firstly, we will draw profiles of depressive symptoms and ADL among the elderly using data from the China Health and Retirement Longitudinal Study (CHARLS). Second, we will explore the association between depressive symptoms and ADL and its specific domains. This study may broaden our understanding of the relationship between depressive symptoms and ADL in the Chinese elderly and support relevant policy-making.

Methods

Design and study population

The data were based on the third wave of the CHARLS in 2015, a national representative survey on community-based population, conducted by the National School of Development in China (China Center for Economic Research) at Peking University. The CHARLS utilized a multi-stage stratified probability-proportional-to-size sampling technique to select participants. The primary sampling units were administrative villages in rural areas and neighborhoods in urban areas. A more detailed CHARLS survey design has been described elsewhere.[15] The CHARLS data can be accessed through its official website (charls.ccer.edu.cn/en).

In this study, participants were excluded if they (1) were younger than 60 years old; (2) lacked ADL data; (3) lacked 10-item Center for Epidemiologic Studies Depression (CESD-10) data; and (4) lacked values in main variables. A total of 20,453 participants completed the CHARLS in 2015, 11,383 participants less than 60 years old were excluded, 1684 participants lacking CESD-10 data were excluded, 1464 participants lacking ADL data were excluded, and 59 participants lacking values in main variables were excluded. Then 5863 of them were included in our analysis.

Depressive symptoms assessment

The 10-item Center for Epidemiologic Studies Depression (CESD) scale was used to screen depressive symptoms, the scale was presented in the supplementary material. Participants were asked about the number of days they experienced every item during the previous week. Each item was rated on a four-point Likert scale: 0 (rarely or none of the time; less than 1 day), 1 (some of the time; 1–2 days), 2 (much or a moderate amount of the time; 3–4 days), or 3 (most or all of the time; 5–7 days). The total score ranges from 0 to 30, with a lower score indicating a lower level of depressive symptoms. Previous studies show that a cut-off point of 10 had reasonable levels of sensitivity and specificity in the Chinese elderly.[16,17] In our study, a subject who had a CESD-10 score of more than 10 was defined as having depressive symptoms.

Covariates

Our covariates included sex, age, marital status, education level, residence, health insurance, smoking, drinking, physical exercise, social activities, number of chronic conditions, and self-rated health. Sex was divided into male and female. Age was divided into three groups: 60-, 70-, 80-. Marital status was divided into two groups: married, others (merged with single, divorced, and widowed). Education level was divided into four groups: illiterate, primary, middle, and college or higher. Residence was divided into rural and urban. Health insurance status was categorized into two groups: yes and no. Smoking and drinking statuses were categorized as current, never, and former. Physical exercise status was divided into two groups: yes and no. Participation in social activities in the last month was divided into two groups: yes and no. The number of chronic conditions for each respondent was categorized as none, 1, 2, and ≥3 (chronic diseases included hypertension, diabetes, heart disease, stroke, renal disease, arthritis, tuberculosis, and respiratory and liver diseases). Self-rated health was divided into three groups: good, fair, and bad.

ADL assessment

This study is based on the ADL scale to assess physical function. It was a scale with 14 items that refers to peoples' basic ADL and instrumental ADL.[18,19] Each answer was divided into four levels, and the four response options were 1 = 'No, I do not have any difficulty', 2 = 'I have difficulty but still can do it', 3 = 'Yes, I have difficulty and need help', and 4 = 'I cannot do it'. The higher the score, the worse performance of the elderly in the ADL. Disability was classified as none, mild, and severe (i.e. disabled in 0, 1–2, or ≥3 ADLs, respectively[20]). The ADL scale has been used in research in China and abroad and has shown good reliability and validity.[21]

Besides, 14 items are divided into 5 dimensions: personal care, transfer, household activities, managing money, and medical care.[22] The specific explanation was as follows: (1) personal care: 6 items including dressing, bathing, eating, getting into or out of bed, using the toilet, and controlling urination and defecation; (2) transfer: two items including walking and climbing stairs; (3) medical care: one item refers to taking medications; (4) household activities: four items including doing household chores, cooking, shopping, and making phone calls; and (5) managing money: one item refers to paying bills or managing assets.

Data analysis

Descriptive statistic methods were used to analyze the characteristics of the study subjects. Chi-squared test or variance analysis was used to compare the difference in categorical and continuous variables. We used univariate analysis to check the factors associated with depressive symptoms. Then, we used depressive symptoms as the dependent variable and ADL as the independent variable, and multivariate logistic regression was used to assess the association between depressive symptoms and ADL among the elderly. The data were analyzed using SPSS version 16.0 (SPSS, Chicago, Illinois, USA). The level of significance was set at P-values <0.05.

Results

Basic information of the participants

Table 1 provides the baseline characteristics of the study participants. Among the 5863 older adults, there were 1999 older adults with depressive symptoms, accounting for 34.1%. Generally speaking, the majority of the older adults were female (54.9%), at the age of 60- (62.8%), married (79.2%), with illiterate education level (53.9%), residence in the rural (79.4%), never smoking (59.1%), never drinking (55.5%), with no physical exercise (50.7%), with no social activities (50.2%), with no non-communicable chronic

Table 1
Comparison of sample characteristics between depressive and non-depressive in the elderly.

Characteristics	Total		Depressive		Non-depressive		*P*
	n	%	*n*	%	*n*	%	
Observations	5863	100	1999	34.1	3864	65.9	
Sex							**<0.001**
Male	2647	45.1	709	26.79	1938	73.21	
Female	3216	54.9	1290	40.11	1926	59.89	
Age							**0.006**
60–	3681	62.8	1305	35.45	2376	64.55	
70–	1794	30.6	583	32.50	1211	67.50	
80–	388	6.6	111	28.61	277	71.39	
Marital status							**<0.001**
Married	4653	79.2	1513	32.59	3130	67.41	
Others[a]	1220	20.8	486	39.84	734	60.16	
Education[b]							**<0.001**
Illiterate	3160	53.9	1242	39.30	1918	60.70	
Primary	2142	36.5	620	28.94	1522	71.06	
Middle	433	7.4	117	27.02	316	72.98	
College or higher	128	2.2	20	15.63	108	84.38	
Residence							**<0.001**
Rural	4653	79.4	1697	36.47	2956	63.53	
Urban	1210	20.6	302	24.96	908	75.04	
Health insurance							**0.022**
Yes	5327	90.9	1792	33.64	3535	66.36	
No	536	9.1	207	38.62	329	61.38	
Smoking							**<0.001**
Current	1804	30.8	533	29.61	1267	70.39	
Never	3467	59.1	1294	37.32	2173	62.68	
Former	592	10.1	171	28.89	421	71.11	
Drinking							**<0.001**
Current	1418	24.2	385	27.15	1033	72.85	
Never	3255	55.5	1195	36.71	2060	63.29	
Former	1190	20.3	419	35.21	771	64.79	
Physical exercise							0.783
Yes	2890	49.3	980	33.91	1910	66.09	
No	2973	50.7	1019	34.28	1954	65.72	
Social activities							**0.022**
Yes	2920	49.8	954	32.67	1966	67.33	
No	2943	50.2	1045	35.51	1898	64.49	
NCD[c]							0.082
None	2470	42.1	802	32.47	1668	67.53	
1	1474	25.1	514	34.87	960	65.13	
2	960	16.4	329	34.27	631	65.73	
≥3	959	16.4	354	36.91	605	63.09	
Self-rated health							**<0.001**
Good	627	10.7	115	18.37	511	81.63	
Fair	1711	29.2	456	26.65	1255	73.35	
Bad	3525	60.1	1427	40.48	2098	59.52	

[a] Merged with single, divorced, and widowed.
[b] Primary: primary school and junior high school; Middle: high school, technical secondary school, vocational school; College or higher: some college, junior college, college or higher.
[c] NCD: non-communicable chronic disease.

disease (42.1%), and with bad self-rated health (60.1%). Sex ($P < 0.001$), age ($P = 0.006$), marital status ($P < 0.001$), education ($P < 0.001$), residence ($P < 0.001$), health insurance ($P = 0.022$), smoking ($P < 0.001$), drinking ($P < 0.001$), social activities ($P = 0.022$), and self-rated health ($P < 0.001$) were significantly different in participants with and without depressive symptoms.

ADL and its specific domain scores of different age groups

Table 2 shows the ADL and its specific domain scores by age group; higher age group had higher ADL and domain scores among the elderly, and the differences were statistically significant ($P < 0.05$). As shown in Fig. 1, we found the ADL disability level increased with age in the elderly.

The association between depressive symptoms and ADL

The association between depressive symptoms and specific domains of ADL has been described in detail. As shown in Table 3, the mean scores of ADL in those with depressive symptoms and those without depressive symptoms were 20.65 ± 7.14 and 17.40 ± 4.87, respectively. Both ADL and its specific domains had a significant positive association with depressive symptoms, even after adjusting for sex, age, marital status, education, residence, non-communicable chronic disease, and self-rated health.

As shown in Table 4, we used two sets (model 1 and model 2–6) of logistic regression models to examine the associations between depressive symptoms and ADL and its specific domains. In model 1, we used the total score of ADL to analyze the association with depressive symptoms. We found that sex, age, marital status, education, residence, and self-rated health may be associated with depressive symptoms, and the result also showed that ADL was still significantly positively associated with depressive symptoms. In model 2 to model 6, we included the five domains of ADL into the logistic regression analysis model separately, and all domains of ADL were found to have a significant independent positive association with depressive symptoms, with the odds ratios (ORs) as follows: personal care (OR = 1.21; 95% confidence interval [CI]: 1.17,

Table 2
ADL and its specific domains among the elderly of different age groups.

Domains of ADL	Age in years (M ± SD)			F	P
	60-	70-	80-		
ADL	17.79 ± 5.29	19.35 ± 6.45	21.41 ± 7.77	93.561	**<0.001**
Personal care	7.87 ± 2.01	8.17 ± 2.39	8.41 ± 2.73	18.971	**<0.001**
Transfer	3.41 ± 1.71	3.94 ± 2.00	4.46 ± 2.17	90.488	**<0.001**
Medical care	1.10 ± 0.43	1.10 ± 0.44	1.16 ± 0.56	3.719	**0.024**
Household activities	5.25 ± 2.32	5.98 ± 2.93	7.17 ± 3.70	120.574	**<0.001**
Managing money	1.29 ± 0.79	1.33 ± 0.86	1.38 ± 0.82	3.505	**0.030**

ADL, Activity of Daily Living.

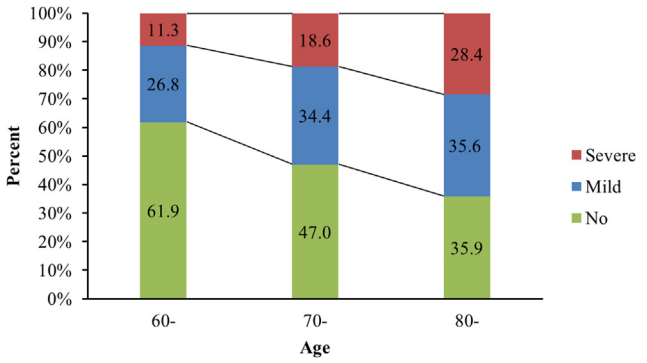

Fig. 1. ADL in elderly people of different age group. ADL, Activity of Daily Living.

1.24), transfer (OR = 1.19; 95% CI: 1.15, 1.22), medical care (OR = 1.15; 95% CI: 1.13, 1.18), household (OR = 1.69; 95% CI: 1.48, 1.92), and managing money (OR = 1.41; 95% CI: 1.32, 1.51).

Discussion

The association between depressive symptoms and ADL and its domains among the elderly was investigated explicitly in our study. When we adjusted for possible confounders, the positive associations between depressive symptoms and ADL and its domains including personal care, transfer, medical care, household activities, and managing money remained though the strength of association was reduced. This study may provide evidence of the association between ADL and depressive symptoms among the Chinese elderly. Specifically, this study has the following valuable findings.

This study used the CESD-10 with a cut-off score of 10, and the result showed that the prevalence of depressive symptoms was 34.1% among the Chinese elderly. We found that the prevalence of depressive symptoms among the elderly in our study was higher than that reported in most countries and regions such as the United States (23.97%),[23] South Korea (16.08%),[24] Singapore (7.8%),[25] Sri Lanka (27.8%),[26] and Taiwan (18.9%).[27] However, due to different cultural backgrounds, environment and application measures, and methodological differences (including the screening scale used and the cut-off point adopted), the prevalence of depressive symptoms varies greatly, and cross-country comparisons should carefully consider various conditions. The findings also show that the older the elderly, the more likely they would experience ADL disabilities, which is consistent with previous studies.[28–30] To prevent the harmful effects on mood status, the elderly with ADL disability need physical rehabilitation and psychological intervention in healthcare and community service.

Several cross-sectional studies have examined the association between depressive symptoms and ADL, and our findings further confirm this result.[31,32] The results from Japan demonstrated that ADL disability was associated with depressive symptoms in the elderly and that living circumstances and marital status do not affect the association.[33] A national survey from the United Kingdom found a strong association between ADL and depression and a possible cumulative effect.[34] Further cohort studies have analyzed the causal relationship between depressive symptoms and ADL disability, and many previous studies have suggested that ADL disability is a risk factor for depressive symptoms.[12,35,36] In China, a longitudinal study in a community of Beijing suggested that ADL disability might have the potential to increase the risk of depressive symptoms of older and their spouses.[37] Besides, a 10-year longitudinal study in the Taiwan region found that ADL was a risk factor for depressive symptoms.[13] In a 9-year longitudinal study in the United States, using monthly assessments of disability and repeated assessments of depression, researchers confirmed that ADL was a significant risk factor for depression in older adults.[14] The stress theory provides a possible perspective on the causes of the effects of ADL on depressive symptoms. ADL disability can be conceptualized as a state of stress, and continuous challenges in managing the necessary instrumental and social activities may damage mental health and increase the risk of depressive symptoms.[38–40] Thus, the state of disability may make a person feel hopeless or worthless due to the loss of independence as a vital identity, which often leads to a negative assessment of its meaning.[41] In addition, it has been suggested that ADL disability and depression might share hormonal and metabolic pathways: depression has been linked

Table 3
Comparisons of ADL in the elderly with and without depressive symptoms.

Domains of ADL	Depressive symptoms		Unadjusted OR (95%CI)	Adjusted OR[a] (95%CI)
	Yes (M ± SD)	No (M ± SD)		
ADL	20.65 ± 7.14	17.40 ± 4.87	1.10 (1.09, 1.11)***	1.09 (1.07, 1.10)***
Personal care	8.66 ± 2.82	7.65 ± 1.68	1.25 (1.21, 1.28)***	1.21 (1.17, 1.25)***
Transfer	4.15 ± 2.01	3.82 ± 1.73	1.24 (1.21, 1.28)***	1.19 (1.15, 1.23)***
Medical care	1.19 ± 0.59	1.06 ± 0.33	1.89 (1.67, 2.14)***	1.70 (1.50, 1.93)***
Household activities	6.38 ± 3.14	5.19 ± 2.31	1.17 (1.15, 1.20)***	1.15 (1.13, 1.18)***
Managing money	1.50 ± 1.01	1.20 ± 0.69	1.52 (1.42, 1.62)***	1.42 (1.33, 1.51)***

*$P < 0.05$,**$P < 0.01$, ***$P < 0.001$.
[a] Adjusted for sex, age, marital status, education, residence, non-communicable chronic disease, and self-rated health.
ADL, Activity of Daily Living; CI, confidence interval; OR, odds ratio.

Table 4
Association of depressive symptoms and ADL and its domains among the elderly.

Characteristics	Model 1[d]	Model 2[e]	Model 3[e]	Model 4[e]	Model 5[e]	Model 6[e]
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sex						
Male	1.0	1.0	1.0	1.0	1.0	1.0
Female	1.72 (1.44, 2.05)***	1.75 (1.47, 2.08)***	1.70 (1.42, 2.02)***	1.76 (1.48, 2.10)***	1.75 (1.47, 2.08)***	1.76 (1.48, 2.09)***
Age in years						
60–	1.0	1.0	1.0	1.0	1.0	1.0
70–	0.78 (0.67, 0.88)***	0.83 (0.73, 0.94)**	0.80 (0.70, 0.91)**	0.79 (0.69, 0.90)***	0.88 (0.78, 1.00)***	0.86 (0.76, 0.98)*
80–	0.49 (0.38, 0.64) ***	0.61 (0.47, 0.79)***	0.57 (0.44, 0.73)***	0.51 (0.39, 0.67)***	0.67 (0.52, 0.86)***	0.66 (0.51, 0.85)**
Marital status						
Married	1.0	1.0	1.0	1.0	1.0	1.0
Others[a]	1.23 (1.07, 1.43)***	1.26 (1.09, 1.45)**	1.24 (1.08, 1.43)**	1.23 (1.07, 1.42)**	1.24 (1.08, 1.43)**	1.29 (1.12, 1.49)***
Education [b]						
Illiterate	1.0	1.0	1.0	1.0	1.0	1.0
Primary	0.83 (0.73, 0.95)**	0.78 (0.68, 0.89)***	0.79 (0.69, 0.90)***	0.83 (0.73, 0.95)**	0.77 (0.68, 0.88)***	0.80 (0.70, 0.91)***
Middle	0.88 (0.69, 1.13)	0.82 (0.64, 1.05)	0.83 (0.65, 1.06)	0.88 (0.69, 1.13)	0.80 (0.62, 1.02)	0.83 (0.65, 1.06)
College or higher	0.55 (0.33, 0.91)*	0.48 (0.29, 0.80)**	0.51 (0.31, 0.84)**	0.53 (0.32, 0.87)**	0.47 (0.28, 0.78)***	0.49 (0.30, 0.81)**
Residence						
Rural	1.0	1.0	1.0	1.0	1.0	1.0
Urban	0.76 (0.65, 0.89)**	0.74 (0.63, 0.87)***	0.75 (0.64, 0.87)***	0.74 (0.63, 0.87)***	0.72 (0.61, 0.84)***	0.73 (0.62, 0.85)***
Health insurance						
Yes	1.0	1.0	1.0	1.0	1.0	1.0
No	0.91 (0.74, 1.10)	0.90 (0.74, 1.10)	0.86 (0.71, 1.05)	0.89 (0.76, 1.07)	0.88 (0.73, 1.07)	0.86 (0.71, 1.05)
Smoking						
Current	1.0	1.0	1.0	1.0	1.0	1.0
Never	0.90 (0.76, 1.07)	0.91 (0.76, 1.08)	0.92 (0.77, 1.09)	0.90 (0.76, 1.07)	0.91 (0.76, 1.07)	0.91 (0.76, 1.07)
Former	0.93 (0.74, 1.16)	0.94 (0.76, 1.17)	0.94 (0.76, 1.17)	0.94 (0.76, 1.17)	0.98 (0.79, 1.22)	1.00 (0.81, 1.24)
Drinking						
Current	1.0	1.0	1.0	1.0	1.0	1.0
Never	1.06 (0.90, 1.24)	1.12 (0.95, 1.31)	1.05 (0.90, 1.23)	1.07 (0.91, 1.25)	1.12 (0.96, 1.32)	1.10 (0.94, 1.29)
Former	1.20 (1.00, 1.43)*	1.25 (1.05, 1.50)*	1.24 (1.04, 1.48)*	1.22 (1.02, 1.46)*	1.30 (1.09, 1.55)**	1.27 (1.07, 1.52)**
Physical exercise						
Yes	1.0	1.0	1.0	1.0	1.0	1.0
No	1.04 (0.93, 1.17)	1.03 (0.93, 1.16)	1.05 (0.93, 1.17)	1.04 (0.93, 1.16)	1.04 (0.93, 1.16)	1.00 (0.89, 1.12)
Social activities						
Yes	1.0	1.0	1.0	1.0	1.0	1.0
No	0.93 (0.83, 1.04)	0.98 (0.87, 1.10)	0.98 (0.88, 1.10)	0.95 (0.85, 1.07)	1.02 (0.91, 1.15)	1.02 (0.91, 1.15)
NCD[c]						
None	1.0	1.0	1.0	1.0	1.0	1.0
1	1.09 (0.94, 1.26)	1.08 (0.94, 1.25)	1.63 (1.29, 2.06)	1.10 (0.96, 1.27)	1.09 (0.95, 1.26)	1.10 (0.95, 1.27)
2	1.01 (0.86, 1.20)	1.01 (0.85, 1.19)	1.03 (0.87, 1.22)	1.03 (0.87, 1.22)	1.03 (0.88, 1.21)	1.01 (0.85, 1.19)
≥3	1.10 (0.93, 1.30)	1.10 (0.94, 1.30)	1.11 (0.94, 1.31)	1.12 (0.95, 1.33)	1.12 (0.95, 1.31)	1.14 (0.97, 1.34)
Self-rated health						
Good	1.0	1.0	1.0	1.0	1.0	1.0
Fair	1.60 (1.26, 2.02)***	1.64 (1.30, 2.08)***	1.63 (1.29, 2.06)***	1.64 (1.29, 2.07)***	1.66 (1.31, 2.10)***	1.70 (1.35, 2.15)***
Bad	2.48 (1.99, 3.09)***	2.66 (2.13, 3.31)***	2.66 (2.13, 3.32)***	2.72 (2.19, 3.39)***	2.95 (2.37, 3.67)***	2.94 (2.36, 3.66)***
ADL	1.09 (1.07, 1.10)***					
Personal care		1.21 (1.17, 1.24)***				
Transfer			1.19 (1.15, 1.22)***			
Medical care				1.15 (1.13, 1.18)***		
Household activities					1.69 (1.48, 1.92)***	
Managing money						1.41 (1.32, 1.51)***
Constant	0.054***	0.049***	0.127***	0.101***	0.110***	0.127***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[a] Merged with single, divorced, and widowed.
[b] Primary: primary school and junior high school; Middle: high school, technical secondary school, vocational school; College or higher: some college, junior college, college or higher.
[c] NCD: non-communicable chronic disease.
[d] Model 1: We used the total score of ADL to analyze the association with depressive symptoms. Adjusted for sex, age, marital status, education, residence, health insurance, smoking, drinking, physical exercise, social activities, NCD, self-rated health.
[e] Models 2-6: We separately included each of the five domains of ADL, including personal care, transfer, medical care, family, and managing money, in a logistic regression analysis model to analyze the relationship with depressive symptoms. Adjusted for Model 1 covariates.
ADL, Activity of Daily Living; CI, confidence interval; OR, odds ratio.

with high levels of cortisol,[42] but it has been hypothesized that physical activity could modulate these levels possibly due to upregulation of the glucocorticoid receptors.[43] Although previous studies found that ADL disability was associated with depressive symptoms, most studies on the relationship between ADL and depressive symptoms only examine the most extreme levels of dysfunction, and studies on ADL more specific domains or functions are not sufficient.

Our study found a significant positive association between depressive symptoms and ADL among the elderly, which was consistent with previous studies. When we controlled for the factors of sex, age, marital status, education, residence, number of chronic conditions, and self-rated health, the associations between depressive symptoms and ADL and its domains remained though the strength of association was reduced. This finding may indicate a potential association between depressive symptoms and ADL among

the elderly. Then, we used a multivariate logistic regression model for further analysis. When we controlled for health insurance, smoking, drinking, physical exercise, and social activities, the association between depressive symptoms and ADL and its domains remained significant. The result confirmed that ADL was a significant correlate of depressive symptoms among the Chinese elderly.

We also analyzed in detail the association between ADL-specific domain and depressive symptoms. Disability in personal care was found to be associated with depressive symptoms. Older adults have a low ability to do daily activities at home and need long-term care from family members or other people. Long-term care may cause tension between the elderly and caregivers, which directly affects the establishment and maintenance of the elderly's social network. It leads to the emergence of depressive symptoms; these factors interacted and undermined each other, leading to a vicious cycle of worsening conditions for the elderly.[44] On the other hand, disability in personal care of the elderly may lead to negative bias formed by negative thoughts and judgments; the elderly may be at increased risk of depressive symptoms due to coping with stress during their health decline.

Besides, our study found that the transfer was related to depressive symptoms among the elderly. The transfer emphasizes necessary abilities such as walking and climbing stairs. Typically, when older adults have disability in transfer, it will affect the elderly's contact with the outside world and affect emotions, resulting in the sense of helplessness; this helplessness may eventually lead to depressive symptoms.[45,46] Moreover, these older adults were susceptible to social exclusions such as discrimination,[47] and the elderly will suffer from mental health deterioration due to failure to fulfill social roles, identity recognition, or social participation behaviors.[48,49]

We found that disability in household activities was associated with depressive symptoms. On the one hand, both new and prolonged disabilities may severely disrupt the physical functions of daily activities and responsibilities, leading to the loss of independence and productivity. Besides, the ADL disabled elderly would consider themselves as a burden to other family members, which may arouse feelings of despair and hopelessness.

We also found the association between ADL and depressive symptoms in the domains of medical care and managing money. Medical care and managing money of ADL highlight the loss of control in critical areas rather than purely limitations in physical activities. Generally speaking, compared with other instrumental activities, the skills of financial management and budgeting are acquired later in life; lack of any of their abilities will lead to the disorder of the older people's daily life. Managing money enables seniors to be financially independent and have a sense of security. The good financial management of the elderly can mitigate poverty-related stress to a certain extent and obtain better medical resources and quality of life.[50]

This study has several limitations that should be mentioned. First of all, this study obtained the information of the study subject through a questionnaire, and information bias might be introduced during the respondent's self-report. For example, the ADL and CESD-10 scales are self-report-based screening tools rather than clinical diagnostic measures, which may deviate from the actual situation. Secondly, this study is a cross-sectional design, caution should be taken when interpreting the findings, and it may be difficult to confirm the causal relationships of depressive symptoms and their determinants. Thirdly, although we controlled for a range of covariates in the analysis, the influence of unknown factors cannot be ruled out in this study. Besides, among the participants included in this study, a total of 12 were taking antidepressants and 17 were taking tranquilizers or sleeping pills. The effect of medication use on the results should be carefully considered, which may lead to some bias. Finally, some of the CESD-10 and ADL data in this study were unavoidably missing, and a potential underestimation of the association between depressive symptoms and ADL may exist due to the exclusion of missing data.

Conclusion

This cross-sectional study provides evidence of the association between depressive symptoms and ADL among the Chinese elderly, and it suggests that depressive symptoms were significantly positive associations with ADL and its special domains including personal care, transfer, medical care, household activities, and managing money. As a result, prevention or reduction of ADL disability may have a positive effect on the medical care of the elderly with depressive symptoms.

Author statements

Acknowledgements

The authors are grateful to the National School of Development of Peking University for providing the data.

Ethical approval

Approval for the original CHARLS was obtained from the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015), and all participants signed informed consent at the time of participation.

Funding

This study is funded by the National Natural Science Foundation of China (71804131 and 71373182).

Competing interests

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.06.023.

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Public Health 198 (2021) 44–52

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Review Paper

What can internet users' behaviours reveal about the mental health impacts of the COVID-19 pandemic? A systematic review

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ARTICLE INFO

Article history:
Received 8 April 2021
Received in revised form
30 May 2021
Accepted 29 June 2021
Available online 5 July 2021

Keywords:
Novel data stream
Mental health
COVID-19
Twitter
Weibo
Google trends
Baidu
YouTube
Systematic review

ABSTRACT

Objectives: At the end of 2019, an acute infectious pneumonia (coronavirus disease 2019 [COVID-19]) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) began in Wuhan, China, and subsequently spread around the world starting a pandemic. Globally, to date, there have been >118 million confirmed cases, including >2 million deaths. In this context, it has been shown that the psychological impact of the pandemic is important and that it can be associated with an increase in internet searches related to fear, anxiety, depression, as well as protective behaviours, health knowledge and even maladaptive behaviours.

Study design: This is a systematic review.

Methods: This review aims to collect, analyse and synthesise available evidence on novel data streams for surveillance purposes and/or their potential for capturing the public reaction to epidemic outbreaks, particularly focusing on mental health effects and emotions.

Results: At the end of the screening process, 19 articles were included in this systematic review. Our results show that the COVID-19 pandemic had a great impact on internet searches for mental health of entire populations, which manifests itself in a significant increase of depressed, anxious and stressed internet users' emotions.

Conclusions: Novel data streams can support public health experts and policymakers in establishing priorities and setting up long-term strategies to mitigate symptoms and tackle mental health disorders.

Introduction

From November to December 2019, the acute infectious pneumonia, termed COVID-19 (coronavirus disease 2019), which is caused by a new highly contagious and pathogenic respiratory coronavirus (severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2]), began in China and subsequently spread causing a global pandemic.[1] To date, approximately 1 year after the World Health Organization (WHO) first declared the COVID-19 epidemic a pandemic,[2] >118 million cases and >2 million deaths have been recorded.[3] The world is facing a complex crisis not only from a health perspective but also from a social and economic point of view.[4]

According to Brooks et al., the psychological impact of the pandemic has been moderate to severe, with 17% of adults reporting moderate-to-severe depressive symptoms, 29% moderate-to-severe anxiety symptoms and 8% moderate-to-severe stress levels.[5] This was mainly due to isolation or quarantine measures, the scarce possibility of social interactions and the interruption of work for many with consequent economic loss.[5] Children and adolescents have also experienced profound life changes characterised by emotional isolation and intensive use of the internet, which may increase vulnerability to anxiety, stress and suicidal ideas or exacerbate self-inflicted violence.[6]

The perception of threat associated with a global pandemic may generate fear and lead to negative emotional reactions; fear, in turn, motivates people to initiate behavioural changes and improve their health knowledge.[7,8] Traditional and social media also tend to

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https://doi.org/10.1016/j.puhe.2021.06.024
0033-3506/

report on cases of infection and mortality, while rarely mentioning cases of recovery, thereby, facilitating the spread of fear and quickly generating anxiety or distress.[9] To reduce these effects, the WHO has advised the public to focus less on COVID-19 news, since watching, reading or hearing news about COVID-19 has been shown to exacerbate fear.[10] This is particularly important as a large amount of news (and fake news) is available to the general public who may not always have the appropriate knowledge to understand scientific updates (infodemic).[11,12] Hossain et al.[13] also show that, despite demographic and social differences, the epidemiological distribution of mental health problems (due to the pandemic and associated factors) has been heterogeneously distributed across the general public, as well as among COVID-19 patients and healthcare professionals. This suggests that there is an ongoing psychiatric epidemic parallel to the COVID-19 pandemic, which requires immediate intervention from the public health community.[14,15]

In this context, it is necessary to understand how people cope with the pandemic. Internet searches could help answer this question since the internet represents a primary channel for finding health-related information.[16] It has been shown that a rise in COVID-19 cases can be associated with a surge in internet searches related to fear, anxiety, depression, as well as protective behaviours, health knowledge and even maladaptive behaviours.[17]

The digital era has given rise to new data sources and large amounts of data also known as Big Data; according to De Mauro et al., "[Big Data] represent resources/assets of an informative nature characterised by such a high volume, speed and variety as to require technology and analytical methods specific for its transformation into value".[18] The use of Big Data in scientific research is destined to grow and become increasingly present in daily healthcare practice.[19] Within Big Data, we can include the novel data streams, which are identified as those data whose "content is initiated directly by the user (patient) themselves".[20] Research studies, which are often limited to certain categories of patients, could expand their targets, including several different population subgroups, while the analyses conducted on Big Data could make health care even more personalised at the same time. The magnitude of data available on patients with the same comorbidities and specific rare diseases could facilitate the creation of *ad hoc* individual-level therapeutic plans in the future.[19]

This review aims to collect, analyse and synthesise available evidence on novel data streams for surveillance purposes and/or their potential for capturing the public reaction to epidemic outbreaks, particularly focusing on mental health effects and negative emotions. Indeed, previous research shows that nowadays any mediatic event produces a social reaction on the internet, which, in turn, generates a large volume of data, that can be collected and analysed in order to answer health-related questions and issues.[21–23] For this review, we considered the COVID-19 pandemic as the mediatic event; subsequently, the general public reaction generated a novel data stream, which has been analysed in order to identify any potential impact on mental health.

Methods

The Cochrane Collaboration[24] and the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) guidelines[25] were followed in order to conduct the current systematic review. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses[26] guidelines[27] were used to report the process and results. The structured literature search was conducted on PubMed/Medline and Scopus on 17th February 2021, combining free text words and medical subject headings (MeSH). Keywords were combined using Boolean operators AND and OR. No time filter was applied. The full search strategy is available in Supplementary Table S1.

Inclusion/exclusion criteria

In order to be considered eligible, articles had to meet the following inclusion criteria: (i) article written in English; (ii) reporting original data; (iii) focusing on mental health; (iv) during the COVID-19 pandemic; and (v) addressing the usage of non-conventional data approaches in capturing public reaction to COVID-19 epidemic outbreaks, particularly focusing on adverse mental health effects and emotions. Exclusion criteria were as follows: (i) no original data (i.e. a review, opinion, book chapter, commentary or letter); (ii) article not published in English; (iii) full text not available; (iv) focusing on mental health but not during the COVID-19 pandemic; and (v) assessing outcomes not related to mental health.

Articles were firstly screened based on title and abstract and then assessed in full text. Both article screening phases and data extraction were conducted independently by two authors (VG and OES). Full texts were downloaded only for potentially eligible studies. Data extraction was conducted only for those articles that met all the inclusion criteria and was performed using a pre-defined and pre-piloted spreadsheet elaborated in Microsoft Excel® for Windows. Extracted data included author and year, data source, type of mental health outcome assessed in the study, study period, country where the study was conducted, study aims, keywords used to perform the search, type of analysis conducted and main results. Any disagreement in data extraction was resolved through discussion among the two authors; if any disagreement persisted, a third author was consulted (SP).

Results

Literature search

A total of 113 papers were retrieved on PubMed and 436 on Scopus. Of these 549 articles, 62 were duplicates and immediately removed, leaving a final sample of 487 unique papers. After preliminary screening, based on the title and abstract, 462 articles were removed for the following reasons: unrelated topic (n = 411), review (n = 25), protocol study (n = 17) and article not published in English (n = 9). Out of 25 eligible articles, six articles were removed after full-text assessment because of the following reasons: two articles did not specifically report mental health data;[28,29] one article was a feasibility study;[30] one study referred to pre-COVID-19 times;[31] one article, although using smartphone app usage data, did not correlate depressive symptoms and anxiety (self-reported symptoms) with app data, but with COVID-19 news;[32] and, the last article using passive mobile monitoring platforms, assessed the behavioural changes (i.e. time spent at home) among subjects with psychiatric disorders.[33] Fig. 1 depicts the flow diagram reporting the selection process. At the end of the screening process, 19 articles were included in the systematic review.[34–52]

Characteristics of included studies

Among the 19 retrieved articles, 15 used a single-data source, whereas four used a combination of two or more data sets. In particular, Twitter was the source most frequently used alone (n = 4),[36,46,51,52] and in combination (n = 3) with YouTube and a forum,[37] Geographic information system (GIS)[39] and Weibo.[47] Google Trends was the second most frequently used data source (n = 6);[38,41,43,44,48,49] one study investigated Weibo[40] data and another investigated Baidu[34] data alone. Forums and chats were

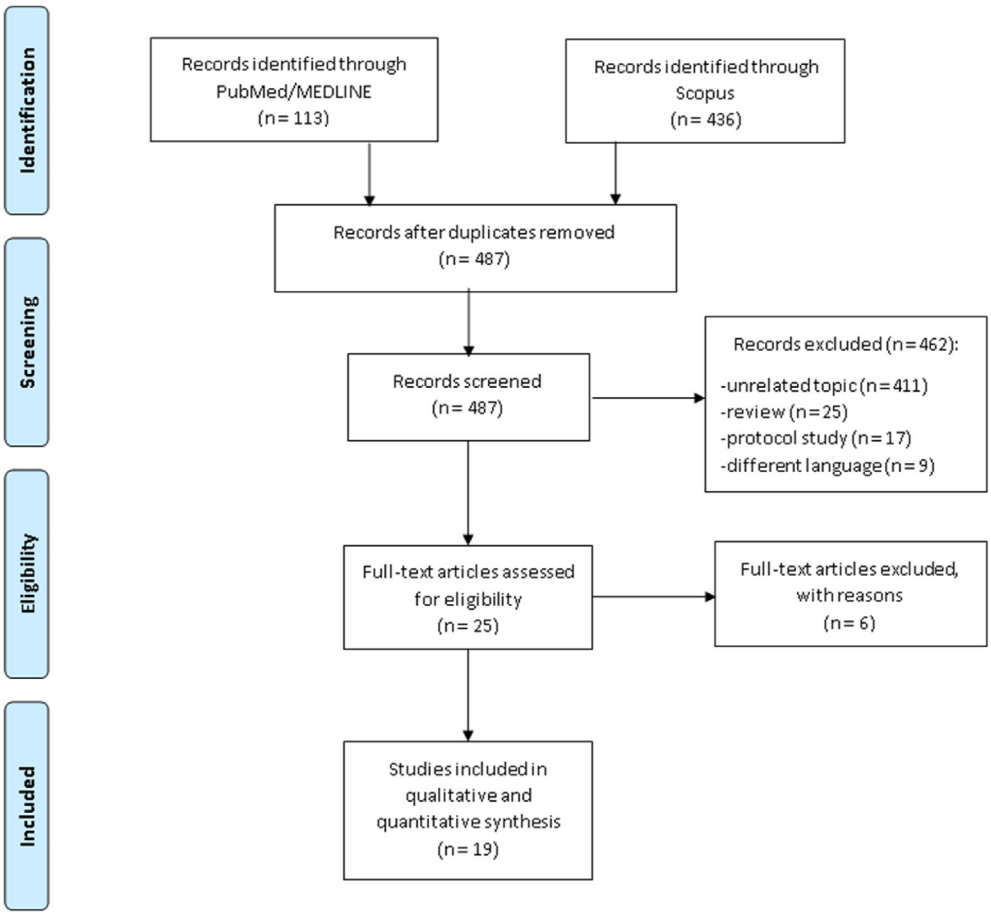

Fig. 1. Flow diagram of the study-selection process.

both used alone (n = 3)[35,42,45] and in combination with other social networks.[37]

Regarding the country where the studies were conducted, four were internationally based,[41–43,52] whereas the rest were carried out in a single country. Specifically, the US was the most frequently explored country (n = 5),[36,38,39,46,50] followed by China (n = 3)[34,40,47] (including one study that compared data between Wuhan [China] and the Lombardy region [Italy]),[47] India (n = 3),[44,48,49] Australia,[35,51] Canada[45] and Spain.[37]

The mental health outcomes assessed were frequently general mental or emotional health, or a combination of selected mental health symptoms (e.g. depression, anxiety, suicide ideation, sleep disturbance, fear and stress), while only three articles focused on a specific mental health disorder (one study focused on stress,[39] one on eating disorders[45] and one on depression[51]).

Almost all included studies performed an analysis of the internet activity content/sentiment in order to explore the predictive value of these searches in forecasting mental health disorders. Some studies assessed how online searches changed throughout the pandemic,[37,38,47,49] whereas, six articles assessed the association between COVID-19 cases or deaths and internet search volume related to mental health.[39,41,43,44,48,51]

All included articles found a significant association with at least one of the explored mental health disorders/symptoms; however, three studies found conflicting results for specific mental health outcomes. In particular, the study conducted using data from Baidu (China) found a significant association between the COVID-19 pandemic and panic and fear, but failed to detect an association with depression, sadness and obsessive-compulsive disorders.[34] An international study performed on Google Trends found an association between insomnia and COVID-19 deaths, but not with depression and suicidal thoughts.[41] Lastly, even an international (24 countries) study found a significant association between COVID-19 cases and deaths and suicide and depression, but no association with insomnia.[43] These differences may be explained by considering the different countries and the length of the study period. Characteristics of included studies and main results are provided in Table 1.

Discussion

Results of our systematic review revealed that the COVID-19 pandemic has significantly impacted internet searches on mental health of entire populations. Indeed, in almost all included articles, a statistically significant increase in negative (seen as depressed, anxious and stressed) internet and social network users' emotions was recorded. These data were confirmed both by associating the number of COVID-19 cases or deaths with internet search volume for specific keywords, as well as by content and sentiment analysis of posts published on social networks. This phenomenon was confirmed in all studied countries, including in those articles where several countries were studied together.

It is interesting to note the parallels drawn by Su et al.,[47] who assessed the psychological states of social network users (Twitter and Weibo) in Lombardy (Italy) and Wuhan (China), the two regions first affected by SARS-CoV-2. Chinese users significantly

Table 1
Characteristics and the main results of included studies (reported in alphabetical order of first author).

First author, year (Reference)	Data Source	Mental Health outcome	Study period	Country	Study aims	Keywords	Analysis	Main results
Chen, 2020[34]	Baidu	Depression, anxiety, sleeping problem, obsessive-compulsive disorder	24 Jan to 22 Feb, 2020	China	To understand psychological public reaction to the COVID-19 pandemic	Depressed, sad, panic, fear, insomnia, obsessive-compulsive disorder, psychological counselling	Non-parametric Mann –Whitney U test	Internet search for panic/fear and psychological counselling were more frequent in 2020 than in 2019 ($P < 0.05$), depressed/sad and obsessive-compulsive disorder were the opposite ($P < 0.05$). No differences for insomnia.
Chivers, 2020[35]	"New mum forum" in Google (831 posts)	Distress, despair	27 Jan to 12 May, 2020	Australia	To examine the public discourse in the context of COVID-19 pandemic	COVID, corona, pandemic	Thematic analysis, sentiment analysis and word frequency calculations	Distress related to external high risk; despair for lack of social and family support. Half of the posts have a negative sentiment. The most frequent word was worry (and similar).
Guntuku, 2020[36]	Twitter	Stress, anxiety and loneliness	Jan to May 2020 vs the same period in 2019	US	To analyse the content of tweets with a specific focus on mental health during the COVID-19 pandemic	Sentiment, stress, anxiety, loneliness and COVID-19-related symptoms	Pre-trained data-driven machine learning models	Stress, anxiety and loneliness were more frequent in 2020 ($P < 0.001$), whereas sentiment was lower in 2020 ($P < 0.001$).
Iglesias-Sánchez, 2020[37]	Twitter, YouTube, Instagram, official press websites and Internet forums (80,091 posts)	Emotional health	Mar to May 2020, split in three stages (characterised by enforcement of containment measures of the first two, and mitigation of the last one)	Spain	To understand emotional health during the COVID-19 confinement time	Anger, fear, joy, sadness, disgust and uncertainty	Content analysis	Anger, fear, sadness and uncertainty were statistically significantly different throughout the three studied periods, but not joy and disgust.
Jacobson, 2020[38]	Google Trends	Mental health symptoms	16–23 Mar 2020 (stay-at-home orders in 11 states)	US	To examine if COVID-19-containment measures produced changes in mental health symptoms	Anxiety, depression, obsessive-compulsive disorder, hopeless, angry, afraid, apathy, worthless, worried, restless, irritable, tense, scattered, tired, avoiding, procrastinate, insomnia, suicidal, suicide	Generalised additive mixed models	Topics related to anxiety, negative thoughts about oneself and the future, sleep disturbances, and suicidal ideation increased prior to stay-at-home orders.
Li, 2020[39]	Twitter and GIS (Geographic Information System)	Stress symptoms	Jan to Apr 2020	US	To detect COVID-19 related stress symptoms at a spatiotemporal scale	Patient Health Questionnaire lexicon	Machine learning	Stress-related tweets rapidly increased from March 8th until April 5th when the number of COVID-19 cases started to decrease.
Li, 2020[40]	Weibo	Psychological traits	13–26 Jan, 2020	China	To explore the predictive value of Weibo in forecasting mental health	Words of positive emotion, negative emotion, anxiety, anger, health, leisure, family, friend, money, death and religion	Sentiment analysis	Between 20 and 26 January, negative emotional indicators of psychological traits increased in anxiety, depression, and indignation, while positive emotional indicators decreased.
Lin, 2020[41]	Google Trends	Insomnia, depression, and suicide	20 Mar to 19 Apr, 2020	International	To explore the predictive value of Google Trends in forecasting mental distress	Insomnia, depression, suicide	Mathematical model	Iran, Spain, US and Italy were the countries with the highest insomnia research volume. COVID-19 death numbers were associated with days at higher insomnia searches, but not for depression and suicide.
Low, 2020[42]	Reddit Mental Health Dataset	General mental health	1 Jan to 20 Apr, 2020	International	To assess changes in the natural language of public commentary	Lexicon built on Linguistic Inquiry and Word Count	Machine learning	Attention-deficit/hyperactivity disorder, eating disorders and anxiety showed the

(*continued on next page*)

Table 1 (*continued*)

First author, year (Reference)	Data Source	Mental Health outcome	Study period	Country	Study aims	Keywords	Analysis	Main results
					posted to mental health support groups on the Reddit website			largest sum of change in negative semantic features during the pandemic. Anxiety emerged as a general theme across Reddit.
Misiak, 2020[43]	Google Trends	General mental health	18 Feb to 13 Apr, 2020	International (24 countries)	To assess if COVID-19 cases and death are associated with mental health-related internet search volume	Suicide, depression, anxiety, insomnia	Spearman rank correlation	Suicide and depression were both associated with COVID-19 deaths and cases, anxiety was only associated with deaths and insomnia was not associated with cases neither deaths.
Rana, 2020[44]	Google Trends	Mental health indicators	4 Mar to 25 Jul, 2020	India	To estimate the correlation between COVID-19 cases and internet search	Suicide, autism, anxiety, depression, dementia	Pearson correlation	Suicide, anxiety, depression and dementia were highly correlated with the number of daily infectious cases.
Richardson, 2020[45]	National Eating Disorder Information Centre instant chat service	Eating disorders	1 Mar to 30 Apr, 2020	Canada	To describe the impact of the COVID-19 pandemic on help-seeking behaviours	Over-eating/binge eating, over-exercising, dieting/restriction, weight preoccupation, perfectionism, purging, anxiety, and depression	Content analysis	The number of contacts during the pandemic period was significantly higher compared to the two previous years. Eating disorder symptoms, anxiety, and depression were higher in 2020. Content analysis detected four themes: 1) lack of access to treatment, 2) worsening of symptoms, 3) feeling out of control and 4) need for support.
Saha, 2020[46]	Twitter (59,096,694 tweets in 2020 compared with 40,875,185 in 2019)	Anxiety, depression, stress, suicidal ideation and emotional support	24 Mar to 24 May, 2020	US	To study the temporal and linguistic changes in symptomatic mental health expressions during the COVID-19 pandemic	Classification based on Diagnostic and Statistical Manual of Mental Disorders, 5th Edition	Machine learning	Anxiety tweets showed the most significant increase in 2020 compared to 2019, followed by suicidal ideation, depression and stress, with a steady decline during the study period.
Su, 2020[47]	Twitter (3,650,380 tweets) and Weibo	Psychological states	23 Feb to 21 Mar, 2020 (Twitter); 9 Jan to 5 Feb, 2020 (Weibo)	Wuhan (China) and Lombardy (Italy) region	To examine and compare the impact of COVID-19 lockdown on individuals' psychological states in China and Italy	Language Inquiry and Word Count dictionary	Psychometric analysis	In Weibo posts, (China) users increased the use of first-person plural pronoun, religion, social, negative emotion and home significantly after the lockdown. Twitter (Italy) users increased the wording discrepancy and home and decreased anxiety.
Talbot, 2021[52]	Twitter (192 tweets)	Mental health of pregnant women	1 Mar to 31 May, 2020	International mostly from US and UK	To characterise the content of an international sample of tweets related to pregnancy and mental health	Several keywords related to COVID-19, pregnancy and mental health	Sentiment and thematic analysis	Individual and company tweets had the same negative tonality. Among the individual tweets, stress about being isolated, depressive symptoms and sleep difficulties were the most frequent. Among the tweets from companies, stress and depressive symptoms that pregnant women may experience during the pandemic, as well as the services offered were the most frequent.
Uvais, 2020[48]	Google Trends	General mental health	12 Mar to 13 Jun, 2020	India	To explore the association of internet search	Depression, anxiety, insomnia, suicide	Spearman rank correlation	COVID-19 cases and deaths in India were significantly associated

Table 1 (*continued*)

First author, year (Reference)	Data Source	Mental Health outcome	Study period	Country	Study aims	Keywords	Analysis	Main results
					volume and COVID-19 cases			with searches for depression, anxiety and suicide. Moreover, suicide and depression were the most frequently searched terms.
Uvais, 2020[49]	Google Trends	General mental health	26 Jan to 24 May, 2020	India	To understand the changes in patient interest in psychiatric search terms during the lockdown	Depression, anxiety, suicide	T-test	Depression, anxiety, and suicide search increased from the pre-lockdown to the lockdown period.
Zhang, 2020[50]	Google Search and YouTube	Depression and anxiety	Jan 2020 vs May 2020	US	To explore the predictive value of YouTube and Google Trends for forecasting depression and anxiety	Not available	Machine learning	PHQ-9 and GAD-7 scores increased during the study period. Some internet behaviours such as late-night online activity, short YouTube intervals between videos and videos containing anxiety and sadness keywords were associated with scores increment.
Zhou, 2020[51]	Twitter (94,707,264 tweets)	Depression	1 Jan to 22 May, 2020	Australia	To explore the predictive value of Twitter in forecasting depression	Classification based on Diagnostic and Statistical Manual of Mental Disorders, 5th Edition	Mathematical model	Depression level increased following the increasing COVID-19 cases and reinforcement of government containment measures.

GIS, Geographic information system; GAD-7, General Anxiety Disorder-7; PHQ-9, Patient Health Questionnaire-9.

increased the use of first-person plural pronouns, religion, social, negative emotion and home after the lockdown. Italian users increased the use of the words 'discrepancy' and 'home' while searching less frequently for anxiety. These results show how the same event can impact differently on communities based on cultural and societal aspects. Despite the posts' common negative and fearful content, the wording between cultures differed, at least partially.

Moreover, it should be considered that, in the e-health era, the diffusion of information by the internet and social media is faster than ever before, even surpassing the velocity of spread of a highly infectious virus such as SARS-CoV-2. Furthermore, information is not always correct or validated, promoting the spread of misleading or incorrect facts on unfiltered internet platforms, which include all major social networks (i.e. Facebook, Twitter, YouTube and several others).

In addition, it is important to note that the COVID-19 pandemic is sustained by an infection with a completely novel and still partially unknown virus.[53,54] This characteristic highly impacts several aspects. Firstly, due to the unknown nature of the virus, even trustworthy sources made mistakes in communication at the beginning of the epidemic, fuelling confusion and a hyperreactive information search among the general public.[11] Secondly, the lack of appropriate therapies and preventive measures (such as vaccines) during the first year of the pandemic incited a sense of powerlessness and fear in the population, which, in turn, drove the search for information and fuelled a widespread sense of stress, uncertainty, anxiety and depression.[55] Moreover, in pandemic times, social deprivation or lack of a well-structured communication of information may strengthen prejudice and stigma towards vulnerable individuals, which, in turn, reinforces a sense of despair, loneliness, depression and anxiety.[15] Also, the implementation of containment measures, such as social distancing, national lockdowns and absence from the workplace, may have pushed people to spend a lot of time on the internet, not only to search for information but also to connect with friends and relatives.[56]

All of these human behaviours generate a significant amount of data on numerous different platforms (Big Data and novel data streams), which contribute to a newly emerging research field aimed at supporting traditional surveillance systems (especially for infectious diseases)[22,57,58] and at understanding human behaviours,[21,23] with the aim of guiding public health decisions.[59,60]

Systematically collecting and examining health-related data generated by these new sources might carry the potential to understand, investigate and interpret events relevant for public health purposes.[61] Several cross-sectional studies, based on online surveys administered to convenience samples, have been published throughout 2020, without any information on the real generalisability and representativeness of results.[62–69] In contrast, these novel data streams might reduce several biases typical of surveys, such as social desirability and recall bias, as well as improving the above-mentioned representativeness of the sample, since thousands or millions of users' data can be analysed together. Moreover, Big Data and novel data streams reduce the time lag between traditional epidemiological data collection and data analysis, as well as the data entry burden and potential errors that can occur with traditional epidemiological systems. Furthermore, novel data streams and Big Data can improve spatial resolution and forecast unanticipated outcomes of interest (such as the current study looking at the mental health impacts of the pandemic), especially for outcomes not routinely surveyed.[20] Big data and novel data streams can help to better understand many disease transmission/process aspects that are not usually captured by traditional surveillance systems. Last, but not least, Big Data and novel data streams are important for improving data dissemination.[20]

Results of this systematic review are extremely relevant because they offer an overview of the general public's psychological reaction to the COVID-19 outbreak, showing how fear, anxiety, stress,

suicidal thoughts and depression are strongly associated with the pandemic. Previous systematic reviews on cross-sectional studies assessing the mental health status of the general public during the COVID-19 pandemic showed that the prevalence of depression increased from 7.2% to 14.6–48.3% during the pandemic.[70] Moreover, in addition to the previously established risk factors for depression, such as female gender, presence of chronic/psychiatric illnesses and unemployment, frequent exposure to news concerning COVID-19 was identified as one of the most important risk factors for depression during the pandemic.[70]

In light of the disease burden already caused by mental disorders,[71] and considering the prolonged exposure to this stressful pandemic event, we might expect long-term psychological consequences. This is especially true considering that, during the pandemic, many healthcare activities have been postponed[72] or substituted by telemedicine.[73] Indeed, telemedicine offers a great opportunity to deliver mental health services remotely, without borders, on a large scale and in a safe way.[73,74] However, telemedicine, in certain cases, has shown some limitations.[5] Even if telemedicine is a more readily accessible option, overcoming the problems related to physical accessibility to services (e.g. remote location, lack of transportation or funds, stigma associated with seeking treatment and physical mobility-related health issues),[75] not all patients have the necessary technology, even just a simple internet line, to be able to use telemedicine services, and some individuals may not have the skills to use these tools.[76] From this perspective, there is a risk that a service designed to reach a large number of people creates inequalities in the population, with the possibility of 'leaving behind' some already disadvantaged groups, such as the poorest, the elderly or those who live in disadvantaged social contexts.[77]

Moreover, evidence has found that during the COVID-19 pandemic, a reduced number of mental health services has coincided with an increased mental health burden, potentially indicating an escalating number of untreated individuals with mental health problems.[78]

We should be aware of the above-mentioned elements in planning future healthcare services. From this perspective, Big Data and novel data streams can support public health experts and policymakers in establishing priorities and setting up long-term strategies to mitigate the symptoms and tackle mental health disorders, with the final aim of facilitating the implementation of future preventive interventions.

Strengths and limitations

Before generalising the results of the current systematic review, some limitations need to be taken into account. Firstly, we limited our search to articles published in English. This might have reduced the total number of potentially eligible studies; however, since English is the most commonly used language in the scientific community, we believe this did not significantly affect our results. Secondly, some authors divided their analyses across several short papers, multiplying the evidence volume but reducing the quality of their discussion and the interpretation of results. Lastly, internet search spikes and contents of tweets may be influenced by different triggers, such as the increased number of cases, increased attention given by mass media or as a reaction to the containment measures adopted by governments, making it difficult to precisely identify a cause–effect association. In light of this, it is not possible to differentiate between the mental health effects of fear of the virus itself from the containment measures adopted, neither to differentiate between negative feelings and diagnosis of mental health disorders. However, previous cross-sectional studies conducted during the pandemic confirmed a variable increase in the prevalence of depression, anxiety and stress in the general population.[70,72,79,80]

Despite the above-mentioned limitations, our review has some important strengths. Firstly, this is a systematic and extensive review offering an exhaustive overview of available evidence on Big Data and mental health during the COVID-19 pandemic. With this overview, we not only synthesised and analysed results obtained by each included study but also provided a picture of the data sources used, the aims of the original studies, as well as the types of analyses performed. Secondly, our search strategy was developed considering several keywords, including both MeSH and free text terms. Lastly, as far as we know, this is the first systematic review addressing the usage of non-conventional data approaches in capturing public reaction to the ongoing COVID-19 pandemic, particularly focusing on mental health and emotions.

Conclusions

To conclude, the results of this systematic review found a statistically significant increase in searches for information about mental health issues by the general public throughout the COVID-19 pandemic. This was observed in both single- and multi-country studies, which analysed data in up to 24 different national contexts. The most-searched-for terms included anxiety, fear, suicide, depression, despaired, stress, solitude and loneliness. While some papers aimed to examine how online expressions of mental health changed throughout the pandemic, others specifically investigated whether containment measures or COVID-19 cases and deaths were associated with mental health internet search volumes. Internet searches and users' behaviour on social networks generated a large amount of data (Big Data) and novel data streams that were used by numerous researchers all over the world. Results obtained from these analyses might prove extremely useful in informing policymakers and health authorities on the implementation of healthcare services and policies, with a focus beyond treating COVID-19 patients, to also provide care to those affected by direct and indirect mental health consequences.

Author statements

Ethical approval

Not required.

Funding

None declared.

Competing interests

None declared.

Author contributions

VG conceptualised, designed the study and performed the literature search. VG and OES performed resource analysis and data extraction. VG and OES wrote the first draft. All authors have read and agreed to the published version of the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.06.024.

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