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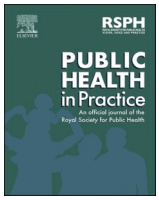

Socioeconomic inequalities in the incidence of COVID-19 in Barcelona students

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ABSTRACT

Objective: This study aimed to assess socioeconomic inequalities in schools regarding the COVID-19 incidence during different epidemic waves among Barcelona students, differentiating by sex and educational stage.
Study design: Cross-sectional ecological study.
Methods: We included in the study all students from childhood to secondary education in Barcelona city. The unit of analysis was the schools. The study covered the epidemic waves coinciding with the 2020-21 and 2021-22 school courses. The cumulative incidence (CI) per school and wave was calculated. Bivariate and multivariate analyses using Poisson regression were conducted to estimate relative risks. The population attributable risk, by sex and educational stage, was calculated as a measure of impact.
Results: In the second wave, higher CI in students was associated with greater school socioeconomic deprivation in all groups. In the younger girls, 24.5 % (5.2–41.4) of the CI was attributed to school socioeconomic vulnerability, increasing to 33.1 % (15.1–47.2) in older girls. During the sixth wave, the impact was lower in the most vulnerable schools in all strata.
Conclusions: Socioeconomic factors significantly impacted the incidence of COVID-19 in schools, reflecting social inequalities in Barcelona. There was an inversion of the pattern of inequalities in the sixth wave compared to the previous ones. The results emphasize the need for urgent action and targeted resources to address health inequalities in education and understand the impact of epidemic dynamics on socioeconomic context.

1. Introduction

Prior studies have increasingly highlighted the association between social determinants of health and COVID-19 [1,2]. In this study, we adopted the conceptual framework of the social determinants of health described by the World Health Organisation [3] in its adaptation to the unequal distribution of COVID-19 [4]. Thus, the general perspective of this study considered the structural and intermediate determinants involved in this pandemic, such as the role of the oppression systems, which may help to understand the relationship between socioeconomic inequalities and the COVID-19 distribution.

In this regard, socioeconomic deprivation has been shown to be a strong predictor of COVID-19 infection and mortality [5]. Thus, socioeconomic status influences health outcomes, including the risk of contracting COVID-19, as shown by a survey of students at nine US universities [6]. In Barcelona, social inequalities were associated with worse indicators related to the impact of the pandemic and the incidence ratios of COVID-19 [7,8] and a time-dynamic effect was found: living in a lower-income area was a risk factor in epidemic waves 1 to 5, but switched to being a protective factor in the sixth wave [9].

In addition, gender is crucial when analysing the impact of the COVID-19 pandemic on health and its inequalities [10,11]. Research indicates that gender can intersect with socioeconomic factors, leading to a widening of pre-existing gender inequalities due to the impact of the

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pandemic [12]. Individuals have distinct vulnerabilities to COVID-19 specifically associated with their gender [13]. These gender-based vulnerabilities may have further contributed to inequalities in the distribution of COVID-19, which created barriers to access to education [14].

Moreover, age should also be included in analyses of the impact of the COVID-19 pandemic on students, as well as intermediate determinants such as family circumstances, type of school, and digital resources [15]. Health impact of COVID-19 is greater in children from vulnerable social environments, especially girls, given that their axes of inequality intersect with each other and with the power structures that already negatively affect them [15].

In Barcelona, variations in COVID-19 transmission patterns in the different educational stages over the various epidemic waves have been explained by distinct behavioural patterns according to age [9]. Younger children in early childhood and primary education, who were not the driving force behind SARS-CoV-2 transmission [16,17], may have less autonomy to adopt individual preventive measures against COVID-19. Their susceptibility to infection may be more strongly influenced by intermediate factors, such as the school and neighbourhood environments [18]. Conversely, older students in secondary education may have increased mobility, social interactions and exposure to external environments, potentially affecting their risk of infection differently [19].

The onset of the pandemic in March 2020 was characterized by the closure of schools in Barcelona and throughout the country, a measure that continued until September 2020, when schools reopened. In the 2020-21 academic year, the criteria for isolation in the school context and classroom closure were based on the occurrence of new COVID-19 outbreaks. To early identify them among students, the Barcelona Public Health Agency (ASPB) developed a new tool for the automatic detection of case clusters in classrooms [20]. This could have contributed to the fact that only approximately 15 % of the classrooms in Barcelona had to be closed, predominantly maintaining in-person schooling [21]. The ASPB designed a new program to support schools in adhering and following the protocol published by the public administration related to the management of COVID-19 cases [22]. This fact decreased the degree of heterogeneity in the policies adopted by the schools and their professionals in the management of the COVID- 19.

On schools, demographic and socioeconomic factors have played a potential role in the spread of the virus in this setting [23], suggesting the occurrence of a syndemic pandemic [24]. A prior study reported an inverse association between mean income and partial school closure in Barcelona. Children from the lowest-income district faced a six-fold higher risk compared with the highest-income district [25]. This distribution was not observed in the academic year 2021-22, but segmentation by epidemic wave was not evaluated. Furthermore, analyses lacked specific ecological indices for each school, relying on district-level assessment, a more heterogeneous unit in Barcelona.

COVID-19-related social inequalities have become a concern, particularly among socioeconomically disadvantaged youths. While studies show higher incidence rates in these groups [26,27], no evidence supports this phenomenon across an entire urban student population. This study aimed to assess socioeconomic inequalities in schools regarding the COVID-19 incidence during the epidemic waves coinciding with the 2020-21 and 2021-22 academic years in Barcelona city students, differentiating them by sex and educational stage.

2. Methods

2.1. Design and setting

We conducted a cross-sectional ecological study of students enrolled in schools in the city of Barcelona as the study population (N = 176,390 in the 2020-21 academic year; N = 175,202 in the 2021-22 academic year). According to the International Standard Classification of Education 2011 (ISCED) [28], these students were enrolled in early childhood education (ISCED 0; 3–5 years old), primary education (ISCED 1; 6–11 years old) and secondary education (ISCED 2 and 3; 12–16 years old). In Spain, primary and secondary education are mandatory. The unit of analysis was the 418 schools (2020-21 academic year) and 413 schools (2021–22) offering these educational stages.

2.2. Indicators, variables, and information sources

The dependent variable was the cumulative number of COVID-19 cases among students in each epidemic wave. We included cases of COVID-19 in students with a positive rapid antigen test or polymerase chain reaction test during the study period. Clinical data were extracted from the COVID-19 Registry of the Catalan Health Department. These data were then merged with the Catalan Student Register, which includes the school census, provided by the Barcelona Education Consortium. This allowed us to associate each student's health data with their schooling information, extracted from educational databases. The health card code, which is the document that identifies and allows access to the services of the public health system, was our linking variable. It was missing in 17.5 % of the student sample for the 2020-21 academic year and in 20.2 % for the following year.

The independent variables were:

- *School socioeconomic vulnerability*. This variable was categorised into quartiles based on the ratio of vulnerable students in the school, with Q4 representing the most disadvantaged. Various situations were classified as showing socioeconomic vulnerability, including social services records indicating socioeconomic vulnerability related to migratory origin and objective economic well-being of the family. The latter included receiving the minimum income, child benefits, and free school meals [29]. These data were extracted from the Register of Vulnerable Students, curated by the Barcelona Education Consortium. Notably, it has been described how this variable correlates with migratory origin and school segregation [30,31].
- *School neighbourhood deprivation.* The Disposable Family Income for 2019 [32] of the school's neighbourhood was used for this variable and was categorised in quartile indices, with Q4 representing the most disadvantaged. The indicators comprising the index were the following: (1) The rate of people with a higher degree; (2) the unemployment rate; (3) the number of cars per 1000 inhabitants; (4) the percentage of new high-powered cars out of the total number of new cars; and (5) the price of second-hand homes [32]. This information was extracted from the Health and Policy Impact Observatory of the Barcelona City Council.
- *Students passing their exams in the school.* This variable was categorised into quartiles, with Q4 being the worst in terms of academic results. The variable was based on the ratio of students who had passed the basic skills exams in the last year of early childhood and primary education (ECPE) and in the last year of secondary education (SE). This information was provided by the Barcelona Education Consortium.
- *School ownership*. This variable was categorised into public schools, which were administered and owned by the state, and private schools. Most of the latter also received public funding and their enrolment fees were heterogeneous. This category also included religious schools.
- *Students enrolled in the school.* This variable was categorised into quartiles, with Q4 having the highest number of enrolled students. The variable was used to adjust for school size and was extracted from the Catalan Student Register.

The stratification variables were:

- *Epidemic wave*: The study covered the second (01/10/20-06/12/20), third (07/12/20-14/03/21), fourth (15/03/21–31/05/21) and sixth (02/11/2021-31/03/2022) epidemic waves of COVID-19. The first (14/03/20-04/07/20) and fifth (13/06/21-01/10/21) epidemic

waves were excluded because schools were closed during these periods. In the first wave, strong measures were implemented to contain the spread of the virus, including the closure of schools throughout this wave. Although the fifth wave mostly affected young people and was associated with extracurricular leisure activities and end-of-year trips [33], it occurred mainly during the school holiday period.

- *Sex* (male/female): Sex was assigned automatically from each student's individual health card. This variable was used as a proxy for gender as health disparities are due to gendered experiences and their social and environmental interactions [34].
- *Educational stage* (ECPE/SE): Although early childhood is a different educational stage from primary education, these stages were categorised together because they showed similar socialisation and COVID-19 transmission dynamics. This group had a lower risk of COVID-19 transmission than secondary school students [35].

2.3. Statistical analyses

For each epidemic wave, sex and educational stage, the cumulative incidence (CI) of COVID-19 per 1000 students and its 95 % confidence intervals (95%CoI) per school were calculated as reported in Moreno-Altamirano et al. (2007) [36]:

$$CI_{school} = \frac{Cumulative\ cases\ of\ COVID - 19}{Students\ enrolled\ in\ the\ school} \times 1,000$$

Bivariate and multivariate analyses stratified by epidemic wave, sex and educational stage were conducted using Poisson regression models with robust error variance. Crude relative risks (cRR) were calculated to estimate associations between the CI and the schools' independent variables. According to statistical and conceptual criteria, the socioeconomic vulnerability of the school was chosen as the main independent variable to calculate the adjusted relative risks (aRR) and 95%CoI for cRR and aRR.

The population attributable risk (PAR) and its 95%CoI were calculated as a measure of impact in each stratum. The PAR represented the proportion of COVID-19 incidence in a specific group that could be attributed to the school's socioeconomic vulnerability and was calculated as discussed in Llorca et al. [37]:

$$\%PAR = 1 - \sum_{i=0}^{k} \left(\frac{proportion\ of\ students\ in\ quartile\ i}{aRR\ in\ quartile\ i} \right) \times 100$$

Positive results indicated the proportion of the CI that could be attributed to higher socioeconomic vulnerability of the school. Negative results showed attribution to lower vulnerability. We used the *punaf* statistical package in STATA v.15 [38].

3. Results

Table 1 provides an overview of the demographic characteristics of the sample and the distribution of ecologic independent variables across the two academic years studied. The composition of the sample exhibited a balanced sex distribution, with approximately 65.7 % of students enrolled in ECPE. Of note, nearly half of the participating schools were dedicated solely to ECPE, while approximately 17 % were high schools offering SE, and the remainder provided both types. Public schools constituted the majority, accounting for 57 % of the total. Age, CI and the type of diagnostic test distribution per each epidemic wave are described in Table S1.

The CI distribution across different strata and variables is displayed in Table 2. In the second wave, a CI social gradient emerged, with the highest CI in the most disadvantaged categories. Notably, Q4 of socioeconomic vulnerability in SE girls' schools had the highest CI (47.4, 95% CoI 35.9–58.9). In the sixth wave, there was a substantial rise in the incidence of COVID-19, and a gradient reversal, with the most privileged quartiles showing the highest CI. Q1 of socioeconomic vulnerability in ECPE boys' schools had the highest CI (400.2, 95%CoI 384.5–416.0). The CI was higher in SE than in ECPE during the 2020-21 academic year, with this trend reversing in the sixth wave of the subsequent year. The same gradient pattern was observed for the school neighbourhood deprivation and students passed in the school variables in the second wave, and its inversion in the sixth wave. No significant differences were observed for school ownership or students enrolled in the school at the second wave. However, in the sixth wave, the highest CI was found in private schools (boys ECPE: 366.2, 95%CoI 349.5–382.8) and schools with the most students enrolled (girls ECPE: 362.5, 95%CoI 345.2–379.8). Results including the third and fourth waves are shown in Table S2.

Table 1
Description of the sample of students and schools in the academic years 2020-21 and 2021–22. Barcelona, 2020–2022.

	2020-21 academic year		2021-22 academic year	
Sex[a]	N (students)	%	N (students)	%
Boys	74,282	50.98	72,560	51,00
Girls	71,423	49.02	69,718	49,00
Educational stage[a]				
ECPE	95,787	65.74	92,501	65,01
SE	49,918	34.26	49,777	34,99
School ownership[a]				
Public	72,419	49.58	68,004	47,68
Private	73,644	50.42	74,631	52,32
Type of school by educational stage[a]	N (schools)	%	N (schools)	%
ECPE	197	47.13	192	46,49
SE	73	17.46	74	17,92
ECPE and SE	148	35.41	147	35,59
Type of school by ownership[a]				
Public	237	56.70	241	58,35
Private	181	43.30	172	41,65
School socioeconomic vulnerability[b]	Index range		Index range	
Q1	0–0.04		0–0.06	
Q2	0.04–0.09		0.06–0.13	
Q3	0.09–0.22		0.13–0.28	
Q4	0.22–0.96		0.28–1	
School neighbourhood deprivation[a]				
Q1	189–130		189–130	
Q2	124–102		124–102	
Q3	98–85		98–85	
Q4	84–48		84–48	
Students passing their exams in the school[b]				
Q1	0.89–0.65		0.84–0.63	
Q2	0.65–0.58		0.63–0.57	
Q3	0.58–0.50		0.57–0.48	
Q4	0.50–0.14		0.48–0.15	
Students enrolled in the school[a]				
Q1	10–191		10–81	
Q2	194–360		82–258	
Q3	361–595		262–507	
Q4	596–2813		510–2714	

SE: Secondary Education; ECPE: Early Childhood and Primary Education.
[a] No missing data.
[b] missing data <5 %.

Table 3 displays the results of bivariate and multivariate analyses examining the associations between COVID-19 CI in schools and independent variables.

In the second wave, a positive gradient was observed between school socioeconomic vulnerability and CI in all groups, in both the bivariate (e.g., Q4 girls ECPE: cRR = 1.75; $p < 0.01$) and multivariate analyses (e.g., Q4 boys ECPE: aRR = 1.63; $p = 0.02$). SE girls exhibited the highest estimates (Q4: aRR = 1.90; $p < 0.01$). Likewise, higher deprivation in the school neighbourhood was linked to elevated CI (e.g., Q4 girls SE: cRR = 1.83; $p < 0.01$). A similar pattern was noted for passing students. School ownership and enrolment were not significantly associated with

Table 2
Cumulative incidence of COVID-19 in Barcelona schools in the 2nd and 6th epidemic waves, by sex and educational stage. Barcelona 2020–2022.

Educational stage		2nd epidemic wave						6th epidemic wave					
		Boys			Girls			Boys			Girls		
		CI	95 % Conf Interval		CI	95 % Conf Interval		CI	95 % Conf Interval		CI	95 % Conf Interval	
	School socioeconomic vulnerability												
ECPE	*Q1(-vulnerability)*	16.8	12.3	21.3	17.1	12.9	21.3	400.2	384.5	416.0	398.9	386.1	411.8
	Q2	14.5	11.2	17.7	13.6	10.7	16.5	367.2	354.3	380.1	372.4	357.9	386.9
	Q3	20.5	16.1	24.9	20.1	15.8	24.5	334.3	315.5	353.1	326.2	306.5	345.8
	Q4(+ vulnerability)	23.4	19.2	27.5	29.8	24.3	35.3	205.6	188.9	222.4	206.2	189.3	223.1
SE	*Q1(-vulnerability)*	24.4	18.9	30.0	25.0	18.7	31.3	331.1	314.4	347.8	339.6	323.2	355.9
	Q2	29.9	23.7	36.2	27.1	21.3	32.9	291.9	275.3	308.4	295.9	280.5	311.4
	Q3	33.4	25.0	41.8	30.5	23.2	37.8	234.5	217.3	251.7	238.4	223.1	253.6
	Q4(+ vulnerability)	42.9	32.8	53.0	47.4	35.9	58.9	174.8	157.8	191.8	194.2	176.0	212.5
	School neighbourhood deprivation												
ECPE	*Q1(-vulnerability)*	15.4	11.5	19.3	16.0	12.7	19.4	395.7	378.1	413.2	380.9	364.8	397.0
	Q2	19.4	14.9	23.8	16.3	12.3	20.2	358.7	342.8	374.7	373.9	357.3	390.4
	Q3	15.4	12.1	18.6	16.0	12.4	19.6	347.7	332.0	363.4	341.0	321.8	360.2
	Q4(+ vulnerability)	24.0	19.4	28.6	30.9	25.3	36.5	226.8	204.3	249.3	230.8	209.5	252.2
SE	*Q1(-vulnerability)*	25.1	19.5	30.7	23.1	18.1	28.1	322.4	303.8	340.9	339.5	323.2	355.7
	Q2	25.4	19.3	31.5	32.7	25.6	39.7	280.1	257.5	302.7	275.3	254.9	295.8
	Q3	32.8	24.5	41.2	29.3	21.4	37.1	261.6	241.6	281.6	262.6	244.7	280.6
	Q4(+ vulnerability)	43.5	34.3	52.6	42.2	31.5	53.0	199.6	179.6	219.6	218.2	200.0	236.5
	Students passing their exams in the school												
ECPE	*Q1 (best results)*	15.7	12.3	19.1	15.8	12.5	19.2	395.4	379.2	411.7	399.5	385.6	413.5
	Q2	20.7	16.0	25.5	19.2	14.7	23.7	363.0	347.3	378.7	353.0	337.1	368.9
	Q3	17.5	12.9	22.1	20.4	15.9	24.8	305.7	284.5	326.9	301.6	280.9	322.3
	Q4 (worst results)	21.4	17.7	25.2	25.9	20.1	31.8	245.1	218.7	271.5	248.9	222.1	275.6
SE	*Q1 (best results)*	26.8	20.8	32.9	25.7	18.6	32.8	335.1	318.7	351.4	336.1	319.0	353.1
	Q2	28.7	23.1	34.4	28.8	22.7	35.0	282.0	263.5	300.5	302.7	282.5	322.9
	Q3	29.6	21.2	38.1	29.1	20.0	38.3	261.0	238.6	283.5	261.2	241.2	281.2
	Q4 (worst results)	40.8	31.6	50.0	41.1	33.2	49.1	196.7	179.2	214.3	207.9	192.1	223.6
	School ownership												
ECPE	*Private*	17.8	14.4	21.2	19.3	16.0	22.6	366.2	349.5	382.8	361.8	346.4	377.2
	Public	18.9	16.3	21.5	19.6	16.7	22.6	313.3	298.0	328.6	315.7	300.1	331.3
SE	*Private*	30.0	25.1	34.9	29.7	24.2	35.1	300.4	286.6	314.2	305.2	291.2	319.1
	Public	32.9	26.9	38.8	32.3	26.8	37.8	233.9	216.8	251.0	248.0	232.0	264.0
	Students enrolled in the school												
ECPE	*Q1 (fewest)*	18.6	14.2	22.9	19.1	13.4	24.7	266.5	236.3	296.7	265.4	236.5	294.2
	Q2	16.0	12.3	19.7	17.2	12.6	21.8	327.7	306.8	348.5	332.2	309.6	354.8
	Q3	19.2	15.8	22.6	20.2	16.4	24.0	323.8	304.2	343.3	327.7	305.9	349.5
	Q4 (most)	18.8	14.6	23.0	20.1	16.1	24.0	368.2	348.1	388.3	362.5	345.2	379.8
SE	*Q1 (fewest)*	34.8	24.1	45.5	28.4	21.1	35.7	227.9	200.6	255.2	246.3	213.3	279.3
	Q2	32.6	23.5	41.7	34.3	25.1	43.5	218.7	194.6	242.7	250.8	226.7	275.0
	Q3	28.4	23.5	33.3	29.1	23.7	34.4	251.8	232.4	271.2	262.4	241.2	283.6
	Q4 (most)	32.2	25.4	38.9	31.2	24.3	38.2	309.9	293.1	326.7	308.3	292.2	324.5

ECPE: early childhood and primary education; SE: secondary education; CI: cumulative incidence per 1000 students.

CI.

During the sixth wave, socioeconomic vulnerability became a protective factor in all groups, significant in both crude (e.g., Q4 boys SE: cRR = 0.51; $p < 0.01$) and adjusted models (e.g., Q4 girls ECPE: aRR = 0.52; $p < 0.01$), reflecting lower CI in privileged environments. Notably, public schools and higher number of students enrolled were initially associated with higher CI in crude models (e.g., Q4 girls ECPE: cRR = 1.37; $p < 0.01$), but these associations lost significance in adjusted models. Results including the third and fourth waves are shown in Table S3.

Table 4 illustrates the impact of school socioeconomic vulnerability on COVID-19 CI. In the second wave, among ECPE, no impact on boys was identified. In girls, 24.5 % (5.2–41.4) of the CI was attributed to higher school socioeconomic vulnerability. In SE, this accounted for 33.1 % (15.1–47.2) in boys and 29.1 % (8.9–44.8) in girls.

Conversely, during the sixth wave, among ECPE, 20.2 % (15.2–25.3) and 22.5 % (17.2–27.9) of the CI was attributed to lower school socioeconomic vulnerability in boys and girls, respectively. In SE, this accounted for 18.7 % (12.5–25.1) in boys and 23.1 % (17.7–28.9) in girls.

4. Discussion

Our study shows the robust association between socioeconomic factors in Barcelona schools and the CI of COVID-19 in students across all strata. The CI pattern reversed in the 2021-22 academic year compared with the previous academic year. This shift mirrored the reversal in the general population [9], emphasising schools as reflections of the health status of their surrounding communities.

This study underscores the significant impact of socioeconomic factors on the incidence of COVID-19 within Barcelona schools across various epidemic waves in all strata, showing how a substantial share of the COVID-19 incidence was attributed to the socioeconomic vulnerability of schools.

Prior studies in similar urban settings have also reported socioeconomic inequalities in COVID-19 infection, hospitalisation, and mortality, both in adults [27,39] and children [40]. As in this study, population-based research in Barcelona on the second wave [8] and

Table 3
School socioeconomic characteristics associated with the cumulative incidence ratio of COVID-19 in Barcelona schools in the 2nd and 6th epidemic waves, by sex and educational stage. Barcelona 2020–2022.

Educational stage		2nd wave								6th wave							
		Boys				Girls				Boys				Girls			
		cRR	*P*	aRR	*P*	cRR	*P*	aRR	*P*	cRR	*P*	aRR	*P*	cRR	*P*	aRR	*P*
	School socioeconomic vulnerability																
ECPE	*Q1(-vulnerability)*	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	Q2	0.86	0.41	0.94	0.72	0.80	0.17	0.96	0.83	0.92	<0.01	0.91	<0.01	0.93	0.01	0.90	<0.01
	Q3	1.22	0.25	1.40	0.12	1.18	0.33	1.49	0.07	0.84	<0.01	0.82	<0.01	0.82	<0.01	0.78	<0.01
	Q4(+ vulnerability)	1.39	0.04	1.63	0.02	1.75	<0.01	1.70	0.02	0.51	<0.01	0.51	<0.01	0.52	<0.01	0.49	<0.01
SE	*Q1(-vulnerability)*	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	Q2	1.23	0.20	1.38	0.05	1.08	0.64	1.33	0.08	0.88	<0.01	0.90	0.01	0.87	<0.01	0.90	<0.01
	Q3	1.37	0.07	1.86	0.01	1.22	0.26	1.80	0.01	0.71	<0.01	0.75	<0.01	0.70	<0.01	0.78	<0.01
	Q4(+ vulnerability)	1.76	<0.01	2.31	<0.01	1.90	<0.01	2.36	<0.01	0.53	<0.01	0.56	<0.01	0.57	<0.01	0.49	<0.01
	School ownership																
ECPE	*Private*	1.00		1.00		1.00		1.00		1.00				1.00			
	Public	1.06	0.62	0.93	0.64	1.02	0.89	0.94	0.68	0.86	<0.01	1.03	0.44	0.87	<0.01	1.06	0.09
SE	*Private*	1.00		1.00		1.00		1.00		1.00				1.00			
	Public	1.09	0.47	0.89	0.51	1.09	0.50	0.89	0.49	0.78	<0.01	0.99	0.82	0.81	<0.01	1.06	0.09
	Students enrolled in the school																
ECPE	*Q1(fewest)*	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	Q2	0.86	0.37	0.92	0.63	0.90	0.62	0.92	0.61	1.23	<0.01	1.05	0.33	1.25	<0.01	1.07	0.15
	Q3	1.04	0.82	1.17	0.30	1.06	0.74	1.19	0.27	1.21	<0.01	1.01	0.78	1.23	<0.01	1.01	0.78
	Q4(most)	1.01	0.93	1.26	0.18	1.05	0.78	1.26	0.20	1.38	<0.01	1.04	0.42	1.37	<0.01	1.02	0.61
SE	*Q1(fewest)*	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
	Q2	0.94	0.76	0.98	0.63	1.21	0.32	0.98	0.94	0.96	0.62	0.93	0.32	1.02	0.83	1.07	0.15
	Q3	0.82	0.26	0.93	0.30	1.02	0.89	0.99	0.96	1.10	0.17	1.02	0.79	1.07	0.43	1.01	0.78
	Q4(most)	0.92	0.68	1.33	0.18	1.10	0.59	1.35	0.17	1.36	<0.01	1.07	0.26	1.25	<0.01	1.02	0.61

P: p-value; ECPE: early childhood and primary education; SE: secondary education; cRR: crude relative risk; aRR: adjusted relative risk.

Table 4
Impact of school socioeconomic vulnerability on the cumulative incidence of COVID-19 in the 2nd and 6th epidemic waves, by sex and educational stage. Barcelona 2020–2022.

	Educational stage	Boys			Girls		
		PAR (%)	95 % Conf Int		PAR (%)	95 % Conf Int	
2nd epidemic wave	**ECPE**	16.62	−7.74	35.47	25.46	5.23	41.37
	SE	33.08	15.15	47.22	29.13	8.94	44.85
6th epidemic wave	**ECPE**	−20.16	−25.29	−15.24	−22.46	−27.91	−17.23
	SE	−18.66	−25.12	−12.53	−23.14	−28.89	−17.66

ECPE: early childhood and primary education; SE: secondary education; PAR: population attributable risk.

subsequent waves [9] found no significant gender-based differences in the association between the incidence of COVID-19 and socioeconomic factors.

During the epidemic waves coinciding with the academic year 2020-21, we observed a pattern of social disparities in the incidence of COVID-19 within schools, mirroring trends in the broader Barcelona population [7,8]. The greater impact of the incidence of COVID-19 on the most disadvantaged individuals could be because students from lower socioeconomic schools had difficulties in adhering to preventive measures due to living conditions or other cultural barriers that impede physical distancing [41,42]. Moreover, schools with greater socioeconomic complexity, often serving disadvantaged communities, may have encountered resource constraints in implementing effective infection prevention and control measures [43].

In contrast, during the sixth wave, in the academic year 2021-22, there was an inversion of the previously observed inequalities in COVID-19 infection, with the most socioeconomically advantaged schools exhibiting the highest incidence ratios, a phenomenon that paralleled findings in the general population in Barcelona [9]. Notably, the sixth wave began with vaccination of SE students against COVID-19 [44], whereas vaccination for the group aged 5- to 11-years commenced later, following approval by the European Medicines Agency [45]. This difference could potentially explain the discrepancy observed in the CI in SE compared with ECPE in the sixth wave. The shift in the pattern of inequalities did not appear to result in more adverse health impacts in privileged communities, possibly due to the vaccination rates [44] and the presence of the Omicron variant [46].

The reversal of the COVID-19 incidence pattern may be elucidated by three main hypotheses. Firstly, the higher incidence in vulnerable schools during the previous academic year might have contributed to elevated post-infection immunity [47] and improved coordination with public health authorities [21]. These factors may have bolstered resilience against COVID-19 and other infectious diseases in socioeconomically complex schools.

Secondly, social dynamics in socioeconomically advantaged schools, with more extracurricular activities and group trips [33], might have facilitated increased interpersonal contacts and COVID-19 transmission, in agreement with findings from a systematic review on social contact patterns and infectious disease transmission [48].

Thirdly, before the start of the sixth wave (November 2021), there was no possibility of purchasing rapid antigen tests in Spain. After this period, it was possible to access rapid tests for payment through pharmacies. This may have led to underestimation of positive cases in socioeconomically disadvantaged communities, facing heightened economic barriers in obtaining these tests [49]. However, it should be emphasised that a substantial proportion of diagnostic tests were administered on-site within schools, free of charge, during epidemic outbreaks or were prescribed for administration in pharmacies in the event of close contact, irrespective of the student's socioeconomic status [22].

4.1. Limitations and strengths

We were unable to obtain the clinical data of a considerable proportion of the students, as their individual health card codes were not reported. These data were most frequently missing in the least vulnerable students due to the use of private health insurance plans. Nevertheless, we conducted a preliminary analysis with other information sources and observed similar results [50].

Given the study design, it is crucial to minimize the ecological fallacy when interpreting the results. Although the trend in COVID-19 infection cannot be generalised to all students in the studied groups, we have identified patterns of inequality that are in line with published evidence.

This study included a large sample, which allowed stratification by sex and educational stages. Thus, a consistent pattern of inequalities was clearly observed in boys and girls from both ECPE and SE in all studied epidemic waves.

In the assessment of the role of social inequalities in the impact of the pandemic on students, this is the first study to apply the three approaches of inputs, territory and outputs, to the school socioeconomic complexity [51]. By using three specific ecological variables for each school, we were able to more reliably describe a reversal of the pattern of inequalities in the CI of COVID-19.

Our study provides novel evidence that a significant proportion of the incidence of COVID-19 could be attributed to socioeconomic factors in schools in an urban setting in southern Europe. Public policies can be a key factor in addressing socioeconomic inequalities and, as a result, reducing this incidence [21,52].

5. Conclusions

The observed patterns of social inequalities in COVID-19 infection rates mirrored those in the general population. This indicates that factors related to socioeconomic vulnerability had a notable impact on the distribution of COVID-19 infection in students enrolled in Barcelona schools during the different epidemic waves. These findings emphasize the need for targeted interventions and resource allocation to mitigate health inequalities within educational settings. They also highlight the importance of understanding how epidemic dynamics evolve in relation to the socioeconomic context.

Ethical approval

The final study received ethics approval from the Ethics Committee of Parc Salut Mar (2023/11229).

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Author contributions

All authors helped develop the study concept and design. MO contributed to the statistical analysis, data interpretation, and manuscript writing. GP, MR, LF and PM provided support for the data interpretation. MR helped in the statistical analysis. GP and MP provided

overall guidance and critical revision. All authors revised the manuscript and approved the final version.

Data availability

The datasets analysed do not belong to the research team. They have been provided specifically for this study by Barcelona Education Consortium and the Catalan Health Department

Declaration of generative AI and AI-assisted technologies in the writing process

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2024.100527.

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