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Effect of portable HEPA filters on COVID-19 period prevalence: an observational quasi-interventional study in German kindergartens

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ABSTRACT

Objectives The aim of the study was to evaluate the effect of high-efficiency particulate air (HEPA) filters on COVID-19 period prevalence in kindergartens.

Design The observational study follows an intervention design with the intervention group using HEPA filters and the control group not.

Setting The study was conducted in 32 (10 intervention, 22 control) kindergartens (daycare centres) in Rhineland Palatinate (Germany).

Participants Data of 2360 children (663 intervention, 1697 control) were reported by the kindergarten heads. Data were collected on institutional level without any identifying information on individuals. Thus, all children of all facilities were included; however, no demographic data were recorded.

Interventions The study followed a quasi-interventional design, as no formal intervention was conducted. A charity foundation equipped kindergartens with HEPA filters. These kindergartens were enrolled as intervention group. The control group was recruited from the neighbouring communities and districts.

Outcome measures The primary outcome measure was the number of COVID-19 cases reported by the kindergarten heads, converted into period prevalence rates per 1000 population.

Results The mean COVID-19 period prevalence rates of the control and intervention groups were 186 (95% CI: 137.8 to 238.9) and 372 (95% CI: 226.6 to 517.6) per 1000 children, respectively. The one-sided Wilcoxon rank-sum test indicates a p value of 0.989; thus, the hypothesised preventive effect of HEPA filters could not be confirmed in the kindergarten setting.

Conclusions While HEPA filters can significantly reduce the viral load in room air, this does not lead to reduced COVID-19 prevalence in the selected kindergartens in Germany. It is known that contagion mainly occurs via direct face-to-face air exchange during play and that the contaminated air does not necessarily pass through the filter prior to air exchange between children. The use of HEPA filters may also lead to a sense of security, leading to reduced preventive behaviour.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Evaluation of high-efficiency particulate air filter's effect on actual COVID-19 period prevalence.
⇒ Inclusion of all children of the studied kindergartens.
⇒ Data are on the institutional level without further information on the cases.
⇒ The intervention group was preselected (no random group allocation).

BACKGROUND

The COVID-19 pandemic has caused severe disruptions of everyday public activities across the globe. Different degrees and duration of lockdowns and restrictions on public life have resulted in immense social and economic problems. A particular challenge was the closure of schools, kindergartens and daycare centres, as these not only deprived the children of education and essential social contact, but also placed a high burden on parents and other caregivers. In Germany, reopening schools and kindergartens had a high political, social and economic priority, while also trying to avoid children becoming spreaders of the disease. SARS-CoV-2 is an airborne pathogen that can spread via three relevant routes: directly via droplets, indirectly via fomites and via airborne transmission, that is, aerosols that remain in the ambient air for prolonged periods.[1] In enclosed indoor environments, where close interaction occurs over longer periods, the highest risk of contagion is evident.[2] Reopening of schools and kindergartens was therefore only possible under strict hygiene and prevention measures, including wearing of personal protective equipment (PPE) (particularly facemasks), regular ventilation (every 30 min), mass testing and social distancing through reductions in group size. While these measures could be enforced quite well in schools with older children, for kindergarten children (aged 1–6 years), particularly wearing masks all day, was difficult to enforce. Kindergarten in Germany is defined as a facility for the care and promotion of the

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development of children of preschool age, that is, daycare centre. Whereas regular or even constant ventilation is easily realised during the warmer month; however, once temperatures drop into the single digits, frequent ventilation is unlikely. Therefore, spending prolonged time periods in confined indoor spaces with a large number of people will place them at risk of infection. A potential solution that has been widely discussed both politically and academically is the use of high-efficiency particulate air (HEPA) filters.

A wide range of HEPA filters and configurations exists with differing removal efficiencies (see 3–5). Such filters can be installed in existing air conditioning systems and are also available as portable air filters. Generally, the efficiency of the filter is the same in centrally installed and portable devices; however, with portable filters, the positioning of the filter in the room as well as the correct use are stated as critical factors and need to be considered.[6 7] HEPA filters in compliance with ISO 29463-1[8] guarantee the removal of at least 99.95% of particles between 0.1 and 0.3 µm.[9] The size and power of the HEPA filter will determine the removal rate, with larger systems filtering larger volumes of air.[10] Manufacturers specify the clean air delivery rate, which is the volume of air passing through the system per minute multiplied with the removal rate. This needs to be considered in regard to the room size in which the device shall be used.[10]

Different experimental studies have been performed to test the potential of HEPA filters to reduce or even eliminate the propagation of SARS-CoV-2. The majority of studies did not use the actual SARS-CoV-2 in their experiment but used aerosols, bacteria or viruses of similar size as surrogate particles (eg, 6–11). A more recent experiment confirmed that the infectious SARS-CoV-2 is effectively removed by HEPA filters; however, the authors note airflow is important to consider as air does not pass through the filter evenly.[12] A systematic review[13] explored the efficiency of portable HEPA filters, highlighting that all reviewed studies indicated a significant reduction in airborne particles. An experiment by Curtius *et al*[7] conducted in classroom settings using four HEPA filters highlighted that the filters significantly reduce concentrations in between ventilation periods, however, should be used in addition to ventilation, rather than replacing other preventive measures. Kähler *et al*[14] stated that the position of the air purifier in the room is a critical factor. It is unquestionable that HEPA filters effectively remove particles from the air, as these filters are tested according to ISO standards, and various experiments demonstrated the effective removal of aerosols. However, no study to date has assessed the impact of HEPA filters on the actual COVID-19 incidence.

In our study, we assess the epidemiological effectiveness of portable HEPA filters in a real-life setting, investigating the COVID-19 period prevalence in kindergartens with portable air filters as compared with kindergartens that do not use them. Assuming that the HEPA filters are operated correctly, it is hypothesised that kindergartens which use portable HEPA filters should show lower COVID-19 incidences compared with those not having such filters. This study aims to fill an important knowledge gap between the theoretical and experimental value of using HEPA filters in kindergartens and schools and their actual epidemiological effect. Providing such filters in public facilities prompts a significant financial investment, thus requiring clear evidence. Particularly in kindergarten settings, high mobility of children throughout the day, various close interactions and suboptimal compliance with hygiene measures create a unique situation that does not adhere to the experimental assumptions of previous studies.

METHODOLOGY

Our study used an interventional design with the intervention group consisting of kindergartens equipped with portable HEPA filters and the control group not using any air filters. The intervention group was equipped with DEMA-airtech air purifiers.[15] The specific units were either AP-160, AP-120, AP-90 or AP-40, adapted to the room size. The DEMA-airtech system uses a coarse prefilter, HEPA H13 filter, activated carbon filter, plasma, titanium dioxide photocatalyst filter and ultraviolet-C light, in this order of configuration. The devices are certified and tested with a removal efficiency of 99.99%. The optimal positioning and required size were decided in discussion with the manufacturer and the head of the kindergartens. An independent research institute (SGS Institut Fresenius) conducted experimental tests in selected kindergartens, which simulated an infected person dispersing aerosols into the room air and found that after 4–9 min, the aerosol concentration was halved, while after 15–30 min, reductions of 90% were achieved. All group rooms, common areas, staff rooms and entrance areas were equipped, if existing also activity rooms (gymnasium) and sleeping rooms were equipped. Consequently, all rooms and areas where multiple people interact with each other were equipped with appropriately sized devices. The air filters were installed between July and September 2021 and were thus fully operational during the Omicron pandemic wave.

Sample sizes

Ten kindergartens in the German Federal State Rhineland Palatinate were equipped with the above-mentioned HEPA filters forming the intervention group. In these 10 kindergartens, 663 children were cared for by 147 childcare workers in 35 groups. The intervention group was selected purposively, as these were equipped with air filters by a local charity foundation (Else-Schütz Stiftung). The control group kindergartens (n=22) were recruited from neighbouring villages and districts. Next to active recruitment, the study was also announced in the local newspaper, calling on kindergartens to participate in the study. The 22 kindergartens of the control group consist of 1697 children and 374 caretakers, organised into 65

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Table 1 Sample population

Group	Institutions	Groups	Children	Caretakers
Intervention	10	35	663	147
Control	22	65	1697	374

groups (see table 1). Therefore, the total sample size of the study was 32 kindergartens with 2360 children and 521 childcare workers. This sample size is far beyond the calculated minimum required of 396 children, assuming a 15% difference of population proportions, a 99% confidence level and a 5% margin of error. In total, kindergartens of three districts were enrolled into the study; the three districts did not exhibit significantly different COVID-19 incidences at the population level and are also similar in demographic and social structure.

Methods

The study collected data on the institutional level with the head of the kindergartens serving as respondent. Due to the mandatory reporting requirement to the health authority, data accuracy can be assumed. The data collection involved two instruments: a baseline survey and continuous case documentation. Both instruments were self-administered and conducted online. The data entry mask was hosted on university servers, and each institution received a username and password for data entry. The baseline survey focused on establishing the number of children and childcare workers, prevention measures and previous COVID-19 cases in the kindergarten. Among the prevention measures, facemask wearing, ventilation frequency, surface decontamination frequency and group intermixing were included. Additionally, it was established when the HEPA filters were installed and in which rooms of the individual kindergarten. The retrospective COVID-19 cases were reported according to the waves of the pandemic: wave I (March–April 2020), summer plateau 2020 (May–September 2020), wave II (October 2020–February 2021), wave III (March–May 2021), summer plateau 2021 (June–October 2021) and wave IV (November 2021–March 2022). The baseline survey was conducted between 24 March and 11 April 2022. Starting from 8 April 2022, the continuous case documentation was initiated, which was continued until March 2023. This instrument involved the documentation of all COVID-19 cases occurring in the individual kindergarten. The documentation has been conducted in 14-day intervals, with automated reminders sent to the kindergarten heads on Friday mornings. In the documentation, the numbers of newly infected children and childcare workers during the respective 14-day period were reported. Additionally, closure of the facility, due to quarantines, holidays or similar reasons were noted.

Analysis

As the HEPA filters were only operational starting from September 2021, this paper only reports on the Omicron wave, that is, November 2021 until end of May 2022. For each group, period prevalence rates were calculated by dividing the number of cases by the total number of children and multiplying the result by 1000 to produce the prevalence rate: cases per 1000 children. Here it should be noted that all cases were summed over the time period; therefore, a period prevalence is reported. These period prevalence rates were then compared between the intervention and control groups using a one-sided Wilcoxon rank-sum test with continuity correction. This test was performed to test the hypothesis that the intervention group, that is, kindergartens with portable HEPA filters, have lower period prevalence than the control group. Essentially, testing if a preventive effect of the HEPA filters is observed. A non-parametric test was chosen, as the data were not normally distributed (Shapiro-Wilk test was significant). Additionally, differences between the two groups in preventive measures were tested using Fisher's exact test for binary variables or X^2 test for categorical variables. Statistical significance was considered at $p<0.05$.

Patient and public involvement

Patients or the public were not involved in the design, reporting or dissemination of the research.

RESULTS

The sample population included children of 32 kindergartens. The 2360 children were divided into 663 children in the intervention group, that is, with HEPA filters, and 1697 children in the control group, that is, without HEPA filters (see table 1). Throughout the reporting period, the number of children remained constant.

In the majority of kindergartens (94%), facemasks were worn outside of the group setting, that is, in the hallways and common areas. During the actual childcare activities, which are occurring in the group setting, only 25% of kindergartens indicated childcare workers wearing facemasks. Consequently, in the remaining 75% of kindergartens during the majority of time spent in the kindergarten, no facemasks were worn. No difference between control and intervention kindergartens is evident (see table 2).

In 72% of kindergartens, group allocation was fixed, that is, children were always in the same group and groups were not intermixed. However, only in 6% of kindergartens group intermixing was also prohibited outside, that is, during break time occurring outdoors. In these 6% of kindergartens, outdoor playtime was staggered, so that individual groups did not mix at all. Contact between childcare workers responsible for different groups was restricted in 65% of kindergartens. No significant difference was observed between the control and intervention groups (see table 2).

Ventilation forms a key preventive measure against contagion; 81% of kindergartens ventilated the group rooms once per hour. About 18% of the control group ventilated the group rooms more frequently, that is, once every 30 min, while 20% of the intervention group

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Table 2 Facemask wearing and group intermixing

Variable	Group	Yes	No	Fisher's exact test
Wearing facemask outside of group	Intervention	8	2	p=0.091 CI: 0.00; 2.32
	Control	22	0	
Wearing facemask during childcare in group	Intervention	2	8	p=1.000 CI: 0.05; 5.03
	Control	6	16	
Fixed group allocation	Intervention	5	5	p=0.096 CI: 0.03; 1.54
	Control	18	4	
Outdoor intermixing of groups	Intervention	1	9	p=0.534 CI: 0.03; 191.39
	Control	1	21	
Contact between childcare workers	Intervention	5	5	p=0.252 CI: 0.43; 16.40
	Control	6	16	

ventilated their group rooms less frequently, that is, every 2–3 hours. The X^2 test indicates a significant difference in the pattern of ventilation between the intervention and control groups with more frequent ventilation in the control group (see table 3).

Surface decontamination was practised in 84% of the kindergartens; however, the frequency of decontamination differs. On average, the surface decontamination frequency is higher among the control group. The X^2 test revealed a significant difference in the pattern of surface decontamination between the intervention and control groups, with a larger proportion of the control group having practised more frequent surface decontamination (see table 4).

Figures 1 and 2 depict the period prevalence for the different COVID-19 waves for children and childcare workers, respectively. It is important to note that although the control and intervention groups are segregated throughout the time period, the HEPA filters were only installed during summer 2021. Therefore, only wave 4 (ie, the Omicron wave) can be used to assess the effect of the HEPA filters. Yet, the figures clearly show that for both children and childcare workers, minor elevations were noted in waves 2 and 3 without significant differences between the control and intervention groups. Only during the Omicron wave a large increase in prevalence was noted in both groups. The COVID-19 period prevalence per 1000 children for the Omicron wave is presented in table 5. The period prevalence of the entire sample population was 236 per 1000 children for the time period (November 2021–May 2022). In the control group, the period prevalence ranged from 0 to 540 per 1000 children, while the period prevalence ranged from 120 to 869 per 1000 children in the intervention group. The mean COVID-19 period prevalence rate was 372 and 186 per 1000 children in the intervention and control groups, respectively. The one-sided Wilcoxon rank-sum test indicates a p value of 0.989 and a CI from $-\infty$ to 299.7. The period prevalence per 1000 childcare workers (table 6) presents similar results. In the control group, the mean prevalence for the period from November 2021 to May 2022 was 529 per 1000 childcare workers, while it reached 1193 per 1000 childcare workers in the intervention group. The one-sided Wilcoxon rank-sum test failed to reach significance. Therefore, no significant preventive effect of the HEPA filters could be found.

Table 3 Ventilation frequency

Group	Every 30 min	Every hour	Every 2–3 hours	X^2
Intervention	0	8	2	p=0.045
Control	4	18	0	

DISCUSSION

Our study showed no significant preventive effect on COVID-19 period prevalence in the kindergarten setting. This finding may be rather surprising, as various experimental studies have demonstrated the effectiveness of HEPA filters in reducing aerosol concentrations in enclosed rooms. It is, however, important to note that the experimental setting is limited in imitation transmission processes.[11] The effectiveness of HEPA filters to remove bacteria, viruses, allergens and other aerosols from the air is, however, not placed in question here. Nevertheless, such removal does not necessary reduce contagion between individuals situated in an enclosed room over prolonged periods of time, in particular if other measures such as mask wearing is not possible. Furthermore, while HEPA filtering systems certainly can decrease aerosol concentrations, direct transmission via larger droplets still occurs. Hence, air circulation, person density, mask wearing and activity type conducted in the room are very likely to affect the risk of infection and consequently the epidemiological effectiveness of HEPA filters.

In the kindergarten, the children, aged 1–6 years, are not stationary, but continuously move through the rooms. Therefore, multiple potential sources of viral emitters are moving through the rooms throughout the day. The children play with each other in close contact while not wearing PPE. Small children as investigated here have no concept of general hygiene measures for preventing transmission in general. Consequently, it is highly likely that direct air exchange and therefore potential contact and droplet transmission occur frequently between multiple children throughout the day. Our data demonstrate that in the majority of kindergartens, facemasks are not worn inside the group setting, thus also childcare workers are exposed to direct contagion throughout the day. Although it has been demonstrated in literature that the viral load in the room air is lower with HEPA filters compared with a situation without HEPA filters,

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Table 4 Surface decontamination frequency

Group	Multiple times per day	Daily	Multiple times per week	Weekly	No	X^2
Intervention	2	2	0	3	3	p=0.001
Control	0	18	2	0	2	

an air filter that is not in direct physical proximity of the infected person cannot reduce the risk of transmission by direct exposition.[11] Air filters may reduce the risk of transmission by reducing the virus burden in the air,[6 7 14 16] but are not able to stop the direct transmission if the infected child stays in direct contact to a susceptible child or childcare worker as indicated by our results. For this reason, it appears that the use of preventive measures, such as facemasks, frequent ventilation and surface decontamination, remain important regardless of HEPA filters being used. Other studies have also highlighted the importance of combining multiple prevention measures to induce effective protection.[7 17] The data obtained in our study provide some indication that the use of HEPA filters leads to a reduction in preventive behaviour. Lower ventilation and surface decontamination frequencies were especially noted in the intervention group. It is suspected that the use of HEPA filters induces a sense of security among the childcare workers, which might lead to a reduced adherence to preventive measures. Hammond *et al*[4] state in their review on portable air filters in homes and workplaces that the existing research lacks important evidence regarding the effectiveness of reducing indoor transmission of respiratory infections, including SARS-CoV-2.

Consequently, there are two suspected reasons why the expected preventative effect of HEPA filters on the period prevalence of COVID-19 could not be confirmed in the kindergarten setting: (1) the close interaction between children during play leads to direct face-to-face air exchange and direct contact, which leads to the exchange of aerosols/droplets that were not previously filtered through the HEPA filter; (2) the presence of the HEPA filters might induce a sense of security that leads to reduced adherence to other preventive measures, such as frequent ventilation, surface decontamination and wearing of facemasks. The background COVID-19 incidence was considered as a confounding factor; however, no significant differences were observed between the

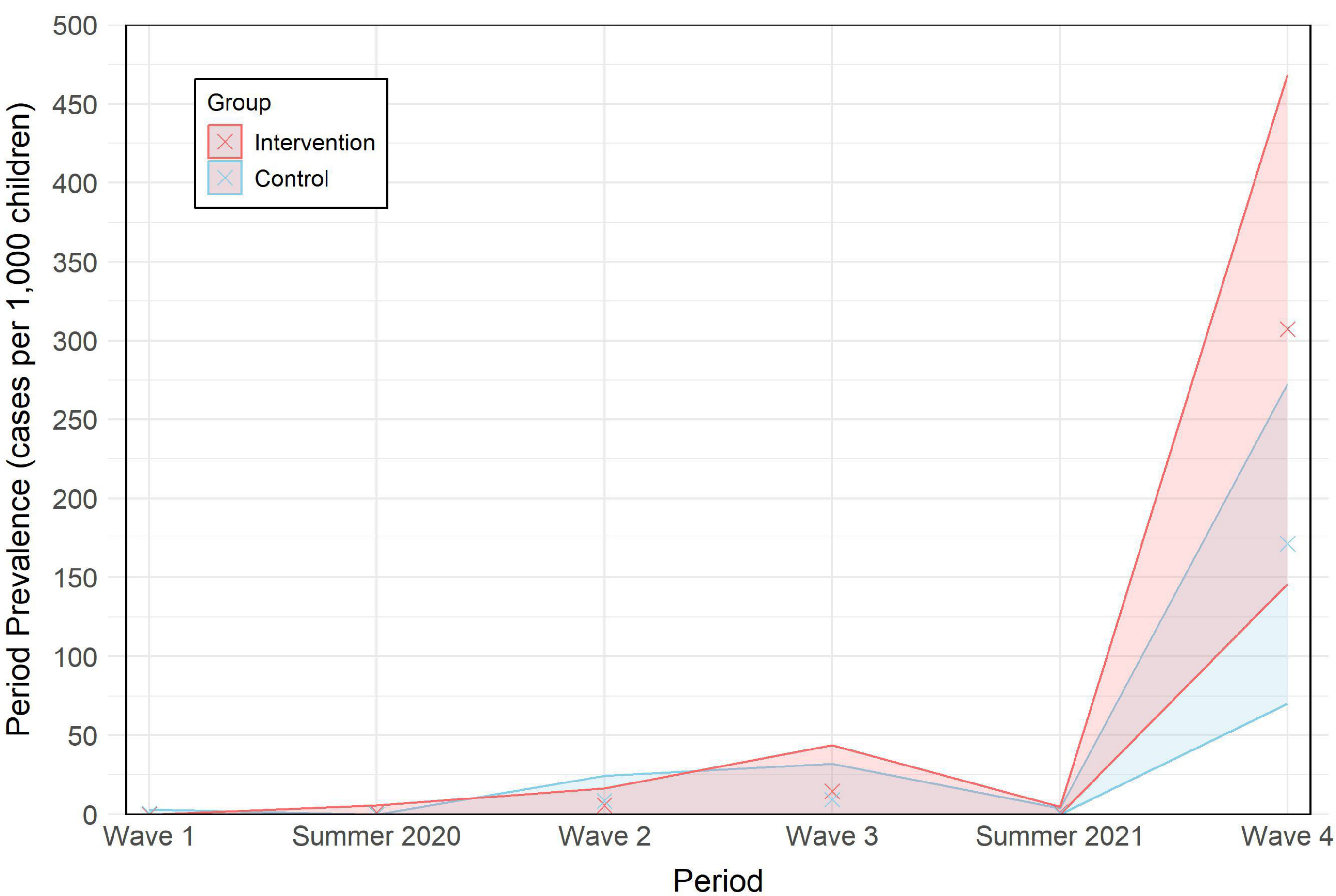

Figure 1 Period prevalence of children by pandemic waves segregated by control and intervention groups. 'X' represents the mean, the upper and lower lines are ±1 SD (values below 0 were omitted).

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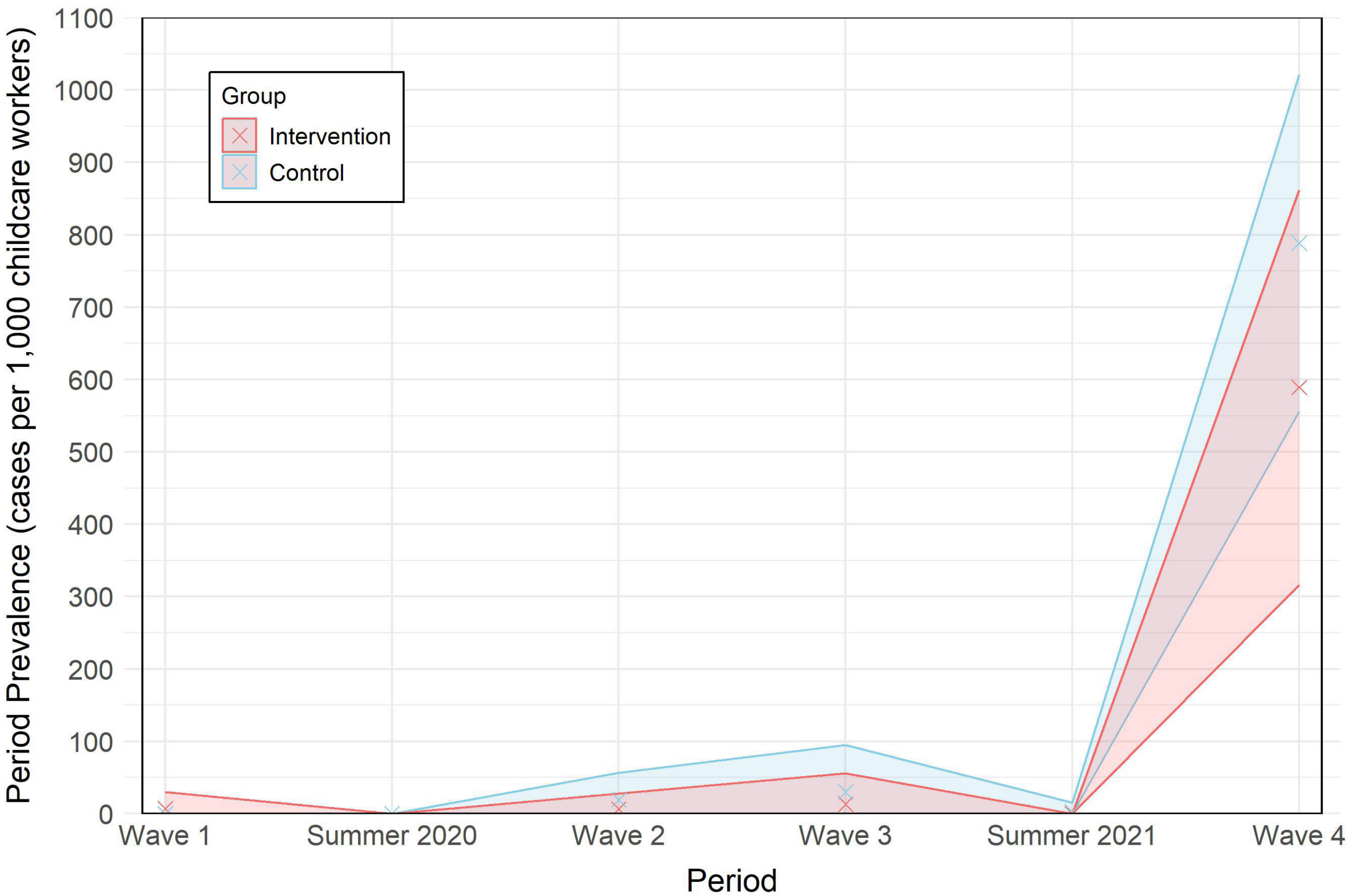

Figure 2 Period prevalence of childcare workers by pandemic waves segregated by control and intervention groups. 'X' represents the mean, the upper and lower lines are ±1 SD (values below 0 were omitted).

districts. The mean 7-day incidence in the three districts was 668, 726 and 801 per 100 000 population over the reporting period. Due to the mandatory reporting of COVID-19 cases of the kindergarten heads to local health authority, data accuracy can be assumed, and reporting intensity between the intervention and control groups is comparable. Further research is required to explore behavioural changes associated with the use of HEPA filters, that is, qualitative interviews with childcare workers. Furthermore, the real-world effectiveness of HEPA filters in school settings should be explored, as schools do provide a setting in which the children are more stationary and may use PPE while in the classroom setting.

Limitations

The study relies on the kindergarten heads as information providers; therefore, the preventive measures may occasionally be rather institutional policy than actual practice. Additionally, preventive measures have changed throughout the pandemic; the provided information only forms a snapshot of the measures in place in March/April 2022. The study relies on few central assumptions, which need to be verified: (1) the HEPA filters are operated adequately, (2) the position of the HEPA filters was not altered from the optimal position determined during installation, (3) all COVID-19 cases were reported to the kindergarten head. Despite the mandatory reporting requirement, it may be possible that some parents did not inform the kindergarten of their child having contracted COVID-19. Even if the above-mentioned requirements for the operation of the air filters were not met at all times, they correspond to reality and allow an evaluation of the air filters in terms of their effectiveness in practice.

Table 5 COVID-19 period prevalence rate per 1000 children from November 2021 to May 2022

Group	Mean	95% CI	Min/max	N
Intervention	372.1	226.6 to 517.6	120.5/869.0	663
Control	186.5	137.8 to 238.9	0/540.0	1967

Table 6 COVID-19 period prevalence rate per 1000 childcare workers from November 2021 to May 2022

Group	Mean	95% CI	Min/max	N
Intervention	1193.2	584.8 to 1801.6	312.5/3555.6	147
Control	529.7	368.9 to 690.5	0/1500	374

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Conclusion

In this study, the COVID-19 period prevalence of children in German kindergartens was compared between kindergartens with portable HEPA filters and those without HEPA filters during the Omicron wave. It was hypothesised that the HEPA filters will have a preventive effect, thus leading to lower COVID-19 period prevalence among the intervention group. This hypothesis was rejected as the one-sided Wilcoxon rank-sum test with continuity correction did not produce significant results. In fact, the mean period prevalence of the control group was 186 per 1000 children, whereas a mean COVID-19 period prevalence of 372 per 1000 children was observed in the intervention group. Therefore, a preventive effect of HEPA filters against COVID-19 in kindergarten settings was not confirmed. Classic preventive measures, such as wearing of facemasks and frequent ventilation, remain of utmost importance in kindergartens to curb COVID-19 contagion.

Contributors TF designed the study, conducted data collection and analysis, wrote the main manuscript text and acts as guarantor. FW conducted data collection, managed the database, conducted statistical analysis and prepared the figures. NZ contributed to the study design, development and testing of the data collection instruments and drafting of the manuscript. NM and TK contributed to the design of the study, data collection instruments and data analysis. All authors critically revised the manuscript and provided final approval of the version to be published. NM and TK share the last authorship of the paper.

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Disclaimer The funder had no influence on data collection, study design or analysis, and on the reported results.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval Ethical approval was obtained from the ethics commission of the Medical Faculty of the University of Bonn (Lfd. no. 092/22). No ethical or data protection concerns are evident. Accordingly, informed consent was obtained by the information givers, that is, head of institution. All methods were carried out in accordance with relevant guidelines and regulations.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Please contact the corresponding author for a request for data sharing.

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REFERENCES

1 World Health Organization. Transmission of SARS-Cov-2: implications for infection prevention precautions; (world health organization scientific brief). 2020. Available: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions
2 Tang D, Comish P, Kang R, *et al*. The hallmarks of COVID-19 disease. *PLoS Pathog* 2020;16:e1008536.
3 Mousavi ES, Kananizadeh N, Martinello RA, *et al*. COVID-19 outbreak and hospital air quality: A systematic review of evidence on air filtration and recirculation. *Environ Sci Technol* 2021;55:4134–47.
4 Hammond A, Khalid T, Thornton HV, *et al*. Should homes and workplaces purchase portable air filters to reduce the transmission of SARS-cov-2 and other respiratory infections? A systematic review. *PLOS ONE* 2021;16:e0251049.
5 Nazarenko Y. Air filtration and severe acute respiratory syndrome Coronavirus 2. *Epidemiol Health* 2020:e2020049.
6 Küpper M, Asbach C, Schneiderwind U, *et al*. Testing of an indoor air cleaner for particulate Pollutants under realistic conditions in an office room. *Aerosol Air Qual Res* 2019;19:1655–65.
7 Curtius J, Granzin M, Schrod J. Testing mobile air Purifiers in a school classroom: reducing the airborne transmission risk for SARS-Cov-2. *Aerosol Sci Technol* 2021;55:586–99.
8 ISO 29463-1:2017. ISO 29463-1:2017(En) high efficiency filters and filter media for removing particles from air — part 1: classification, performance, testing and marking [Internet]. 2017. Available: iso.org/obp/ui/#iso:std:iso:29463:-1:ed-2:v1:en
9 Saccani C, Guzzini A, Vocale C, *et al*. Experimental testing of air filter efficiency against the SARS-Cov-2 virus: the role of Droplet and airborne transmission. *Build Environ* 2022;210:108728.
10 Christopherson DA, Yao WC, Lu M, *et al*. High-efficiency particulate air filters in the era of COVID-19: function and efficacy. *Otolaryngol--Head Neck Surg* 2020;163:1153–5.
11 Zacharias N, Haag A, Brang-Lamprecht R, *et al*. Air filtration as a tool for the reduction of viral aerosols. *Sci Total Environ* 2021;772:S0048-9697(21)00022-X.
12 Ueki H, Ujie M, Komori Y, *et al*. Effectiveness of HEPA filters at removing infectious SARS-Cov-2 from the air. mSphere. *mSphere* 2022;7:e00086–22.
13 Liu DT, Phillips KM, Speth MM, *et al*. Portable HEPA Purifiers to eliminate airborne SARS-Cov-2: A systematic review. *Otolaryngol--Head Neck Surg* 2022;166:615–22.
14 Kähler CJ, Fuchs T, Mutsch B, *et al*. Schulunterricht Während der SARS-Cov-2 Pandemie -Welches Konzept ist Sicher, Realisierbar und Ökologisch Vertretbar? 2020. Available: http://rgdoi.net/10.13140/RG.2.2.11661.56802
15 DEMA. Produktübersicht. n.d. Available: https://dema-airtech.com/produkte/
16 Kähler CJ, Fuchs T, Hain R. *Können mobile Raumluftreiniger eine indirekte SARS-CoV-2 Infektionsgefahr durch Aerosole wirksam reduzieren?* Universität der Bundeswehr München, 2020. Available: https://www.unibw.de/lrt7/raumluftreiniger.pdf
17 Villers J, Henriques A, Calarco S, *et al*. SARS-Cov-2 aerosol transmission in schools: the effectiveness of different interventions. *Swiss Med Wkly* 2022;152:w30178.

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