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Original Investigation

Impact of an Inner-City Smoke-Free Zone on Outdoor Smoking Patterns: A Before–After Study

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Abstract

Introduction: On September 2, 2019, Rotterdam's first inner-city outdoor smoke-free zone encompassing the Erasmus MC, a large university hospital in the Netherlands, the Erasmiaans high school, the Rotterdam University of Applied Sciences and the public road in between, was implemented.

Aims and Methods: We aimed to assess spatiotemporal patterning of smoking before and after implementation of this outdoor smoke-free zone. We performed a before–after observational field study. We systematically observed the number of smokers, and their locations and characteristics over 37 days before and after implementation of the smoke-free zone.

Results: Before implementation of the smoke-free zone, 4098 people smoked in the area every weekday during working hours. After implementation, the daily number of smokers was 2241, a 45% reduction ($p = .007$). There was an increase of 432 smokers per day near and just outside the borders of the zone. At baseline, 31% of the smokers were categorized as employee, 22% as student and 3% as patient. Following implementation of the smoke-free zone, the largest decreases in smokers were observed among employees (–67%, p value .004) and patients (–70%, p value .049). Before and after implementation, 21 and 20 smokers were visibly addressed and asked to smoke elsewhere.

Conclusions: Implementation of an inner-city smoke-free zone was associated with a substantial decline in the number of smokers in the zone and an overall reduction of smoking in the larger area. Further research should focus on optimizing implementation of and compliance with outdoor smoke-free zones.

Implications: A smoke-free outdoor policy has the potential to denormalize and discourage smoking, support smokers who want to quit, and to protect people from secondhand smoke exposure. Implementation of an inner-city smoke-free zone encompassing a large tertiary hospital and two educational institutions was associated with a substantial decline in the number of smokers in the zone, as well as in the larger area. Voluntary outdoor smoke-free zones can help reduce the number of smokers in the area and protect people from secondhand smoke. There is a need to explore effectiveness of additional measures to further improve compliance.

Introduction

Tobacco smoking and smoke exposure have an enormous impact on public health. Tobacco use is the leading preventable cause of premature mortality worldwide; each year an estimated 7 million people die prematurely because of a smoking-related disease.[1] Annually, another 1.2 million people die because of secondhand smoke exposure, and secondhand smoke exposure is responsible for 25 million disability-adjusted life-years worldwide.[2,3]

Several measures to reduce the number of smokers and protect bystanders from the negative health effects of secondhand smoke exposure are available.[1] Smoke-free laws regulating smoking in enclosed public places and workplaces are effective in reducing smoking prevalence and improving population health.[4–6] Increasingly, local and national policies to regulate smoking outdoors are being implemented,[7,8] but observational field studies concerning their effectiveness are scarce.[9–11] A recent systematic assessment of studies assessing effectiveness of outdoor smoke-free policies identified the lack of research involving actual geographic mapping of smoking patterns and visibility of smokers in the area as a key knowledge gap.[12] A smoke-free outdoor policy has the potential to denormalize and discourage smoking, support smokers who want to quit, and to protect people from secondhand smoke.[13–16]

Although the prevalence of smoking is decreasing in the Netherlands, 22% of the Dutch adult population still smoked in 2019.[17] National smoke-free legislation regulating smoking in indoor workplaces (2004) and hospitality venues (2008) is in place. These policies have been criticized for lack of comprehensiveness, and effects on health outcomes and quit attempts are less pronounced than in countries that had more comprehensive policies with better enforcement and compliance.[18–20] In 2019, 69% of Dutch adults felt the number of smoke-free places, particularly those often visited by children, should be increased.[21] Despite, no formal regulation for smoking in outdoor areas was in place until August 2020 (when formal regulation for smoke-free school grounds was implemented) and smoking near buildings and building entrances is still very common. There is however an upcoming Smoke-Free Generation (in Dutch: *Rookvrije Generatie*) movement that is supported by a range of national and regional stakeholders and by the national government via the National Prevention Agreement launched in 2018.[22] This Agreement defines a pathway toward a Smoke-Free Generation and includes a number of planned policies, some voluntary (eg, smoke-free hospital grounds by 2030) and some formally regulated (eg, tobacco tax increases; smoke-free school grounds by August 2020).[22]

Anticipating this law, local initiatives to make outdoor areas smoke-free have been developed. The Erasmus MC, a large university hospital including facilities for patient care and educational and research activities, is situated in central Rotterdam, the second largest city in the Netherlands. At the opposite end of a public road from Erasmus MC, two educational institutions (Erasmiaans Gymnasium [a high school] and the Rotterdam University of Applied Sciences) are located. Starting spring 2018, these institutions, in collaboration with the municipal government, developed plans to initiate the first inner-city smoke-free zone in Rotterdam encompassing the entire area where the institutions are located. The smoke-free zone was implemented on September 2, 2019, shortly after the first Dutch inner-city smoke-free zone was launched in Groningen.[23] At the time of this study, the smoke-free zone was voluntary, with no formal enforcement, and smokers where requested, but not obligated, to smoke outside the zone. Our study aims to assess spatiotemporal changes in smoking patterns within and around this zone following the implementation of the smoke-free policy.

Materials and Methods

Design

We performed a before–after observational field study to assess patterning of smoking in the zone encompassing the Erasmus MC and two educational institutions before and after the implementation of a smoke-free zone.

Setting and Population

The study was conducted in the area (surface ~0.2 km^2) surrounding the Erasmus MC in Rotterdam, the Netherlands, and the nearby Erasmiaans high school and Rotterdam University of Applied Sciences (Supplementary Figure 1). Starting from September 2, 2019, the zone surrounding the Erasmus MC, the high school and the University of Applied Sciences including the public road in between, has been designated as a smoke-free zone, by the institutions in collaboration with the municipal government.

Before the implementation of the smoke-free zone, smoking policies were set by the three institutions separately. These only formally applied to their respective grounds and did not extend to public areas such as the road and most pavements in the area. Smoking was prohibited on Erasmus MC grounds except in five partially enclosed smoking facilities. The University of Applied Sciences had two small demarcated zones in front of the two main entrances which were designated as smoke-free (Supplementary Figure 2). The high school did not have a formal outdoor smoke-free policy. Before the implementation of the smoke-free zone, the Erasmus MC had only a few small signs outside concerning the smoking policy and there was no formal enforcement (Supplementary Figure 2). The University of Applied Sciences had a few signs and a green line demarcating their smoke-free zones but no formal enforcement (Supplementary Figure 2).

The implementation of the smoke-free zone in September 2019 was preceded by widespread communication within the three institutions and by the municipal government to inform employees, patients, students, and the public. The initiative gained substantial local and national media attention both in anticipation and at the formal launch. An event was organized to launch the smoke-free zone and information was provided via (digital) newspapers, pamphlets, and Web sites of the Erasmus MC and educational institutions. The zone is marked by a blue demarcation line at the main entrance areas, and there are multiple banners, signs, and tiles to indicate the area as smoke-free, provided by each institution and by the municipality for public areas (Supplementary Figure 3). During the first 2 weeks after implementation, initiators of the zone, board members of the hospital, and hired personnel addressed people who smoked within the zone. This surveillance was done several times a day on weekdays and covered the entire smoke-free zone. Furthermore, security guards of the institutions were instructed to address smokers during their surveillance rounds. There was no set format of addressing, and no specific training had been provided to address smokers. The smoke-free zone has been embedded in a broad range of measures to promote a smoke-free Erasmus MC, aimed at protecting bystanders from tobacco smoke and support smoking cessation. As part of that, patients and employees are offered cessation support free of charge.

Data Collection

We conducted a systematic observation of the numbers of smokers and their locations and characteristics before and after implementation of the smoke-free zone. Observations were performed during the same periods in winter (observations by ND from November 2018 till March 2019; and by MB from December 2019 till March 2020) to minimize the potential impact of seasonality. Separate observations were conducted at the Erasmus MC grounds and the grounds surrounding the schools.

In an attempt to minimize intraobserver variability, the two observers performed observations together near the main entrances of the Erasmus MC and the educational institutions for 2 hours. Mean count-per-interval interobserver agreement in these four intervals on the number of smokers was 92.5%.[24]

Observations Around the Erasmus MC

The baseline and follow-up observations in the area surrounding the Erasmus MC were conducted over 30 days: 22 days during working hours on weekdays (9:00 AM till 4:15 PM), 5 days on weekdays in the evening from 5:00 PM till 9:55 PM, and 3 days in the weekend from 10 AM till 2:55 PM. The area surrounding the Erasmus MC was divided into 15 locations, subdivided into 74 sublocations (Supplementary Figure 1). Each location was observed for smokers during observation periods of 15 minutes. In between observations, the observer had 5 minutes to switch between locations, during which no observations were done. As such, during each hour, there were three 15-minute slots of observations, separated by three 5-minute slots with no observations. The observation scheme was designed to minimize the influence of the time of the day and day of the week in which the observations took place. Accordingly, each location was observed once a day, but each day during a different 15-minute time slot. This led to a total number of 22 weekdays of observations. A schematic representation of this staggered scheme is shown in Figure 1. The full observation schemes are provided in Supplementary Table 1.

In addition to the observations during regular working hours, a smaller number of observations were performed during weekend days and evenings. Although these observations were also performed in a staggered manner, given the substantial time commitment needed to undertake the observations, we did not aim to fully complete the evening and weekend observation in such a way that each location was observed during each hour across different days. Thus, the evening and weekend observations should be considered exploratory.

Observations Near the University of Applied Sciences and High School

The baseline and follow-up observations in the area surrounding the University of Applied Sciences and high school were conducted over 7 days each and only on weekdays during working hours (9:00 AM till 4:25 PM). The area surrounding the University of Applied Sciences and high school was divided into five locations, subdivided into 19 sublocations (Supplementary Figure 1). Because there were fewer locations here than at the Erasmus MC grounds, each location was observed for 40 minutes per observation instead of 15 and again there were 5 minutes between each observation to switch between locations. Again, we used a staggered scheme to ensure that each location had been observed once during each hour of the day across the 7 observation days (Figure 1; Supplementary Table 1).

At the time of undertaking the preimplementation observations, the exact demarcation of the smoke-free zone had not yet been determined. As a result, in the follow-up observations, some of the sublocations were partly outside and partly inside the smoke-free zone. As such, we divided all sublocations into three categories: within the smoke-free zone, partly inside and partly outside the smoke-free zone (partly smoke-free), and completely outside the smoke-free zone (not smoke-free).

Collected Data

The observer noted the exact time the smoker was observed and the sublocation in which the person was smoking. If a smoker switched between sublocations while smoking, only the sublocation in which the smoker started smoking was recorded. In the period before implementation of the smoke-free zone, it was also noted whether the person complied with the existing policy at the time (ie, made use of a smoking facility at Erasmus MC grounds or smoked outside one of the two designated smoke-free zones near the University of Applied Sciences entrances). The ambient temperature (in °C, as indicated by the Apple weather app[25]) and weather conditions at the time the smoker was observed were

A

	Day 1	Day 2	Day 3	Day 4-22
9:00-9:15	Location A	Location C	Location B	...
9:15-9:20	Walking time	Walking time	Walking time	...
9:20-9:35	Location B	Location A	Location C	...
9:35-9:40	Walking time	Walking time	Walking time	...
9:40-9:55	Location C	Location B	Location A	...
9:55-10:00	Walking time	Walking time	Walking time	...
10:00-16.15	...	...	...	...

B

	Day 1	Day 2	Day 3	Day 4-7
9:00-9:40	Location A	Location C	Location B	...
9:40-9:45	Walking time	Walking time	Walking time	...
9:45-10:25	Location B	Location A	Location C	...
10:25-10:30	Walking time	Walking time	Walking time	...
10:30-11:10	Location C	Location B	Location A	...
11:10-16:25	...	...	...	...

Figure 1. (A) Schematic overview of staggered observation scheme near Erasmus MC . (B) Schematic overview of staggered observation scheme near schools.

also noted. Possible weather conditions were cloudy, half-cloudy, sunny, light rain, rain, light snow, and snow. The observers had a specified form on their cellphone in which they recorded all their observations.

Smokers around the Erasmus MC were categorized as employees (internal or external), patients, or others. Internal employees were classified as such if they visibly wore an Erasmus MC uniform or employee card and were subdivided into health care providers (white uniform) and others (other uniform or only a visible employee card). External employees were people who were present on the site for work purposes but not employed by Erasmus MC (eg, construction workers and taxi drivers), as categorized based on their uniform or attributes (eg, tools or taxi). Smokers were categorized as patients if any of the following characteristics were visible: patient ID (bracelet), intravenous catheter, urine catheter, bandages, hospital wheelchair, or other clear patient characteristics. If smokers had none of these characteristics or if in doubt, the smoker was categorized as "other" (Supplementary Figure 4).

Around the University of Applied Sciences and the high school, smokers were categorized into four groups: patients, employees, students, and others. In the employee category, a distinction was made between health care providers, other internal employees of the Erasmus MC, external employees, employees of the University of Applied Sciences, and employees of the high school. If possible, a distinction was made between the University of Applied Sciences students and high school students, based on estimated age and whether they were entering or leaving a specific school building. When in doubt, the smoker was categorized as "other" (Supplementary Figure 4). During the observations, we furthermore noted whether smokers who violated the current smoking policy were addressed by others and asked to smoke elsewhere (interpretation of the observer, based on body and spoken language), henceforth referred to as "addressed."

Data Analysis

From the observed numbers of smokers, we extrapolated numbers of smokers per day, accounting for the time in between observations that the observer was switching locations, and for the difference in total duration of observations around the Erasmus MC and the educational institutions, according to the following formula:

$$\textit{number of smokers per day} = \frac{\textit{observed number of smokers}}{\textit{total duration of observations per day (minutes)}} \times \textit{minutes between } 9:00 \textit{ am and } 4:25 \textit{ pm}$$

In March 2020, the COVID-19 pandemic rapidly spread in the Netherlands and, as a consequence, restrictive measures were introduced on separate occasions starting March 9. At the time, we had finalized all follow-up observations except for 1 full observation day (eight observations of 40 minutes each) at the educational institutions. To account for these missing observations, we performed multiple imputation using a predictive mean matching method. We imputed five datasets of the extrapolated numbers of smokers at the sublocation level (total number, numbers per subcategory of smokers, and the number of smokers being addressed) and used weather conditions and type of sublocation (completely smoke-free, partly smoke-free, and not smoke-free) as predictor variables.

For our primary analysis, we compared the extrapolated number of smokers in the smoke-free zone (ie, the completely smoke-free sublocations) on weekdays during working hours between the preimplementation and postimplementation period using a paired *t* test. Using the same approach, we assessed changes in the numbers of smokers per category and subcategory within the smoke-free zone.

In secondary analyses of our observations during working hours on weekdays, we performed separate analyses for the areas within the smoke-free zone surrounding the Erasmus MC and those surrounding the educational institutions. To assess displacement of smokers, we compared the extrapolated number of smokers before and after the implementation of the smoke-free zone within the partly smoke-free sublocations and those just outside the smoke-free zone. Lastly, we performed pre–postimplementation comparisons of the observed number of smokers on weekday evenings and during weekends. All analyses were performed using paired *t* tests, with statistical significance accepted at $p < .05$. For the primary analyses, we also conducted Wilcoxon signed rank tests to assess whether findings were sensitive to normality assumption. Statistical analysis was performed using SPSS version 25. Findings from the preimplementation assessment have previously been published in Dutch.[26]

Ethical Approval

According to Dutch law, ethical approval was not required because the rules concerning the Medical Research Involving Human Subjects Act (in Dutch: *WMO*) did not apply to this observational field study.

Patient and Public Involvement

Patients and the public were not involved in this study.

Results

Weather Conditions

During the observations near the Erasmus MC before the implementation of the smoke-free zone, the mean temperature was 5.5°C (SD 3.4) and there were 8 days with mostly rain. On observation days after implementation, the mean temperature was 7.7°C (SD 2.4) and 3 observation days had mostly rain. During the observations near the schools, this was 8.4°C (SD 1.0) and 7.2°C (SD 1.2), and 2 versus no days of rain, respectively.

Smoking Patterning in the Smoke-Free Zone During Weekdays

Before the implementation of the smoke-free zone, there were 4098 smokers in the area every weekday during working hours (Table 1). Of these, 70% (n = 2876) smoked on Erasmus MC grounds and 30% (n = 1222) did so on the grounds of the educational institutions (Table 1). The largest numbers of smokers were observed near the main entrance of the Erasmus MC (n = 959) and near both entrances of the University of Applied Sciences (n = 1065). After the implementation of the smoke-free zone, there were 2241 smokers per day during working hours on weekdays, a 45% reduction (p = .007) compared to preimplementation. Reductions were similar on Erasmus MC terrain and in the area surrounding the educational institutions (Table 1). Figure 2 provides three area bubble maps indicating the number of smokers per day per sublocation before (A) and after (B) implementation of the smoke-free zone and the difference between those periods (ie, the number of smokers after implementation minus the number of smokers before implementation to visualize changes over time; C). The corresponding numbers are provided in Supplementary Table 2.

During the baseline observations, 31% (n = 1266) of smokers were categorized as employee, 22% (n = 908) as student, and 3% (n = 134) as patient. Most of the employees were internal Erasmus

Table 1. Number of Smokers per Day Before and After Implementation of the Smoke-Free Zone

Area	Number of sublocations	Smokers before implementation	Smokers after implementation	Difference [95% CI]	Difference (%)	*p*
Entire area, daytime						
Locations within the smoke-free zone	75	4098	2241	−1857 [−3200; −514]	−45	.007
Locations partly outside the smoke-free zone	4	227	613	+386 [−198; 970]	+170	.195
Locations outside the smoke-free zone	12	120	166	+46 [−91; 184]	+39	.509
Erasmus MC grounds only						
Locations within the smoke-free zone, daytime	64	2876	1489	−1388 [−2597; −178]	−48	.025
Locations within the smoke-free zone, evening	64	170	151	−19 [−103; 65]	−11	.657
Locations within the smoke-free zone, weekend	64	82	63	−19 [−68; 30]	−23	.451
Educational institution grounds only						
Locations within the smoke-free zone, daytime	11	1222	752	−469 [−1055; 116]	−38	.116

MC employees (Table 2). Following implementation of the smoke-free zone, the largest decreases in the numbers of smokers were observed among patients and employees (Table 2). The decreases among students and "others" were smaller in magnitude and not statistically significant.

Before implementation of the smoke-free zone, 75% of people, who smoked in the area surrounding the Erasmus MC, did not make use of a smoking facility. Around the educational institutions, 25% of smokers smoked inside the small smoke-free areas near the entrances of the University of Applied Sciences. In total, before implementation of the smoke-free zone, 21 smokers were visibly addressed and asked to smoke elsewhere, versus 20 during the follow-up observations.

Smoking Patterning Outside the Smoke-Free Zone During Weekdays

There were 347 smokers in the sublocations that were partly inside and partly outside or completely outside the smoke-free zone before implementation (Table 1). In these locations, 779 smokers were seen smoking after implementation (Table 1).

Smoking Patterning in Evenings and Weekends

In exploratory observations within the smoke-free zone on Erasmus MC grounds, we observed 170 smokers in the evenings and 82 smokers in the weekends before implementation. There were no significant changes in the number of smokers after implementation: 151 in the evenings and 63 smokers in the weekends (p value .657 and .451, respectively).

Sensitivity Analyses

Because of COVID-19, we missed 1 day of observations during follow-up which we handled using multiple imputation. In a sensitivity analysis using complete data only (ie, without imputation of missing values for the unobserved day), we found very similar results to our primary analysis (Supplementary Table 3).

Using nonparametric tests, findings of our primary analysis were statistically significant across the imputed datasets at p = .002–.001.

Discussion

Implementation of the first inner-city smoke-free zone in Rotterdam was associated with a 45% decline in smokers in the zone during working hours on weekdays. This reduction of 1857 smokers per day was substantially larger than the increase in the number of smokers near the borders of the smoke-free zone (n = 432), indicating an overall decrease in smoking in the area. Very few people who smoked within the smoke-free zone were addressed, providing room for further strengthening of implementation.

In this study, we systematically observed the numbers of smokers to provide an accurate estimate of the effect of implementation of an outdoor smoke-free zone. In previous studies having evaluated smoke-free zones surrounding hospitals, important reductions in the number of smokers,[9] cigarette butts,[27] and in ambient air particulate matter concentrations were found.[27] Although the reduction in smokers observed in our study was far from complete, the changes were larger than those observed in an earlier study, especially among employees and patients.[28] Our study progresses importantly from previous work by actually observing smokers rather than assessing smoking behavior via questionnaires,[28] and by systemically observing smokers during the entire day as opposed to only during peak hours.[9] Very few smokers were actively addressed and asked to smoke elsewhere when smoking within the zone, in keeping with observations elsewhere.[28] The moderate compliance with an outdoor smoke-free policy as seen in our study is in agreement with findings from other studies investigating the effect of outside smoke-free policies.[29–31]

We developed a unique comprehensive and systematic observational approach to assessing the impact of an outdoor smoke-free zone on smoking patterns. A major strength of this research is that by conducting observations in a staggered scheme across a large number of days, we minimized potential bias because of weather conditions and day of the week on the number of smokers per location. Also, we conducted the baseline and follow-up observations in the same season. Despite this, we observed a somewhat higher temperature and slightly better weather conditions during the observations after the implementation. Previous research indicates that people who smoke adapt their smoking behavior to the outside temperature and season and smoke more with better weather conditions.[32,33] As such the better conditions at follow-up may have biased our findings toward the null.

A limitation of this study is that because of walking time between the locations and difference in length of observations, the daily number of smokers is an extrapolation. Because this was the case in both the baseline and follow-up observations, we do not expect this to influence our conclusion. Also, the proportion of unobserved time was fairly small (ie, 26% for Erasmus MC grounds and 10% for the school grounds). Another limitation is that in our categorization of smokers, the category "other" is relatively large because we were not always able to adequately categorize a smoker. Particularly, patients are likely over represented in this category because they are difficult to recognize, especially those visiting outpatient clinics. A third limitation is that we had 1 missing observation day because

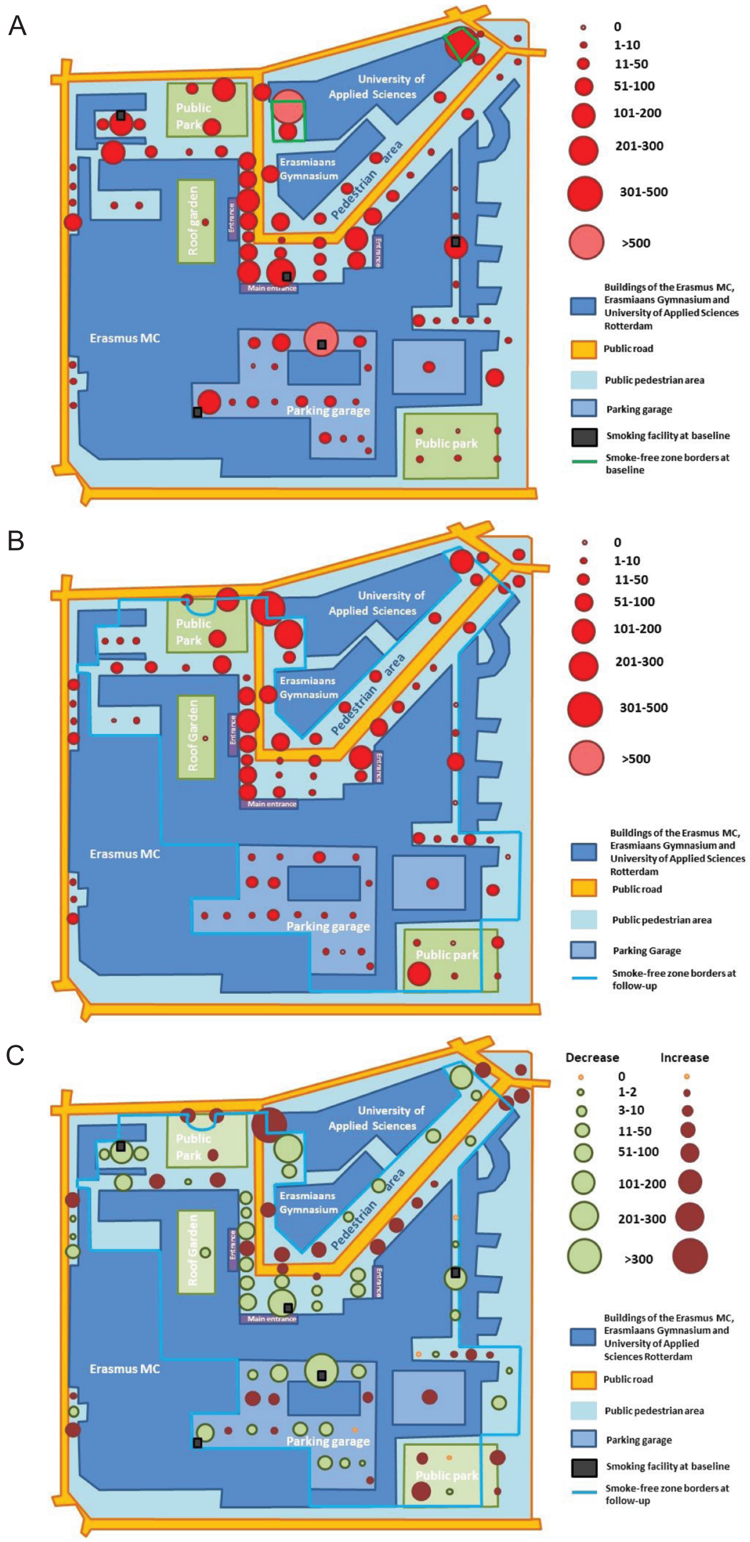

Figure 2. (A) Location and number of people observed smoking at the baseline observations (working hours, weekdays). (B) Location and number of people observed at the follow-up observations (working hours, weekdays). (C) Change in number of people observed smoking at each location after implementation of the smoke-free zone (working hours, weekdays) (green bubbles indicate a decrease in the number of smokers during follow-up compared to baseline; red bubbles indicate an increase in the number of smokers during follow-up compared to baseline).

Table 2. Numbers of Smokers per Category and Subcategory per Day (During Working Hours on Weekdays) Before and After Implementation of the Smoke-Free Zone

Category	Subcategory	Before implementation	After implementation	Difference [95% CI]	Difference (%)	*p*
Employee		1266	429	−837 [−1412; −261]	−66	.004
	Health care provider	162	76	−85 [−190; 20]	−53	.112
	Other internal Erasmus MC	674	256	−418 [−819; −16]	−62	.041
	External	282	60	−222 [−372; −72]	−79	.004
	University of Applied Sciences	141	27	−114 [−209; −19]	−81	.019
	High school	7	9	+2 [−9; 14]	+37	.687
Patient		134	41	−93 [−185; 0]	−70	.049
Student		908	492	−416 [−986; 155]	−46	.153
	University of Applied Sciences	864	470	−394 [−971; 182]	−46	.180
	High school	43	22	−21 [−62; 19]	−49	.299
Other		1790	1280	−510 [−1164; 144]	−28	.126

of the COVID-19 pandemic. We addressed that by using multiple imputation, and given the overall large number of observation days, any impact on our results is likely small. Results from our sensitivity analysis of the expected number of smokers without multiple imputation were in line with the main analysis. Although in our analyses we applied paired *t* tests, which do not take into account that our data are count data, these tests provide good estimations in these type of data structures.[34] Also, similar findings were seen using Wilcoxon signed rank test. Lastly, although our observations are limited in that the baseline and follow-up observations were performed by two different observers, the interobserver agreement indicated excellent agreement between the two observers.

This study showed that there are many smokers daily on the grounds around hospitals and educational institutions. Our findings underline the potential for smoke-free zones to contribute to substantial reductions in the numbers of smokers. Although the area did not completely become smoke-free, smokers moved away from entrances after implementation of a smoke-free zone likely resulting in less exposure to secondhand and third-hand smoke for people who enter and leave the hospital and educational institutions.[35,36] For the successful implementation of smoke-free zones, collaboration with different stakeholders (eg, the municipality, nearby institutions, and guards), proper communication and clear signage are important. However, addressing of smokers in the smoke-free zone was rare in our study while enforcement seems important and needs to be improved.[37,38] Previous research indicates that for indoor smoke-free policies, penalties and strict enforcement can help promote compliance.[39] This is less clear for outdoor policies, and a systematic evaluation of strategies to implement smoke-free outdoor recreation areas concluded that the legislative base is not more successful than a voluntary base.[40] In an evaluation of smoke-free park signage in the United States in 2011, counting of cigarette butts in the area showed a 49% reduction following this voluntary restriction, suggesting similar effectiveness to our study.[41] The initial implementation of smoke-free legislation covering indoor public places in the Netherlands was faced with enforcement and compliance issues, but more than 15 years after the indoor smoke-free policy came into place, smoking has clearly denormalized in indoor public areas. This indicates that smoke-free policies need time to become the standard, and this likely also applies to outdoor smoke-free policies.[42]

Our study evaluated the first outdoor smoke-free zone in Rotterdam, with only one other Dutch city (ie, Groningen) having a formal smoke-free zone in place at the time. Additional evaluations are needed to explore the effectiveness of outdoor smoke-free zones in various settings and to investigate facilitators and barriers regarding implementation and enforcement of outdoor smoke-free zones, for example, via interviews with both smokers and nonsmokers. At present, the Rotterdam smoke-free zone is voluntary and further evaluation and comparison to experiences elsewhere is required to explore whether enforcement by law and issuing of fines, or more positive approaches including nudges, may improve compliance. Comprehensive (indoor and outdoor) smoke-free legislation is associated with substantial health benefits among both adults and children.[4,6,43] Additional research is needed to assess whether outdoor smoke-free zones are also associated with population health improvements.

Conclusion

Implementation of an inner-city smoke-free zone encompassing a large tertiary hospital and two educational institutions was associated with a significant decline in the number of smokers in and around the zone. These reductions may have a significant impact on exposure to secondhand and third-hand smoke for people entering and leaving the hospital and educational institutions. However, the reduction in the number of smokers in the outdoor smoke-free zone was far from complete and further research should focus on optimizing implementation of and compliance with outdoor smoke-free zones to make them more effective.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

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Declaration of Interests

JVB is one of the initiators of the smoke-free zone and chaired the Taskforce Smoke-free Erasmus MC. All other authors declare to have no conflict of interest.

Authors' Contributions

LJB supervised the observations and drafted the manuscript. ND performed the baseline observations. MB performed the follow-up observations and drafted the manuscript. MKR and LJB performed the statistical analyses. JVB obtained funding for the study, supervised the observations, and supervised drafting of the manuscript. All authors were involved in interpretation of the findings, performed critical revisions of the manuscript, and read and approved the final manuscript.

Disclosure of Any Prior Publications

The results of the baseline observations have been published in the Dutch Journal of Health Sciences (in Dutch: *Tijdschrift voor Gezondheidswetenschappen*; https://mijn.bsl.nl/een-rookvrije-zone-in-rotterdam-wat-is-er-te-winnen/17620712?fulltextView=true).

Data Sharing

We intend to provide the dataset upon reasonable request.

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