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REVIEW ARTICLE

Evaluating School-Based Interventions for Preventing and Reducing Tobacco Use Among Adolescents in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis

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Introduction: Tobacco-related disease and death remain high in many low- and middle-income countries, and most people start using tobacco during adolescence. This study evaluated the effectiveness of school-based interventions in preventing and reducing tobacco use among adolescents in low- and middle-income countries.

Methods: Seven databases were searched until 20 April 2024. The primary outcome was tobacco use prevalence (ever or point prevalence) at the longest follow-up. Risk of bias was assessed, and random-effects meta-analyses were conducted, exploring heterogeneity via meta-regression (PROSPERO registration CRD42022330329).

Results: Twenty-seven studies (N=57,292) were summarized descriptively, and 20 were meta-analyzed. Most studies were from Brazil (*n*=5, 18.5%), India (*n*=5, 18.5%), China (*n*=3, 11.1%), and Pakistan (*n*=2, 7.4%); 12 (44.4%) assessed newly developed and 15 (55.6%) culturally adapted existing interventions; and over half (*n*=14, 51.9%) focused solely on preventing and reducing tobacco use while the rest addressed multiple behaviors. Overall, interventions reduced adolescent tobacco use (OR=0.76, 95% CI=0.64, 0.91; I^2=47%; *n*=20; 50,056 participants). Stratification by outcome measure showed significant reductions in point prevalence (OR=0.69, 95% CI=0.57, 0.85; I^2=32.4%). After adjusting for study duration, interventions with higher contact time had lower effectiveness than shorter interventions (AOR=1.36, 95% CI=1.01, 1.84; *p*=0.045; I^2=22%). Low risk of bias studies demonstrated lower odds of tobacco use among participants (OR=0.66, 95% CI=0.50, 0.87; I^2=14%; n=6).

Discussion: School-based interventions in low- and middle-income countries effectively reduce the proportion of adolescents who use tobacco. Shorter interventions appeared to be effective, suggesting that brief yet engaging interventions may offer practical advantages and could contribute to addressing the tobacco epidemic in low- and middle-income countries. Further research is needed to determine optimal intervention duration and intensity for sustained effectiveness.

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INTRODUCTION

Tobacco use is responsible for more than 8 million deaths annually.[1] Despite efforts to control tobacco use, an estimated 1.3 billion adults continue to use tobacco products globally.[1] Low- and middle-income countries (LMICs) are particularly affected, accounting for approximately 80% of people who use tobacco.[1] While LMICs historically had fewer people who use tobacco during most of the 20th century than high-income countries, recent trends in tobacco use for LMICs are a cause for concern. Between 2000 and 2015, there was a notable increase of 33.3 million people who use tobacco in LMICs, contrasting with a net reduction of 61.9 million people who use tobacco in high-income countries.[2] The disparity in tobacco control efforts and outcomes between high-income and LMICs is concerning, especially given the potential for further expansion of the tobacco industry in LMICs.[1,3]

The WHO introduced the Framework Convention on Tobacco Control (FCTC) in 2003, a legally binding evidence-based treaty aimed at achieving good health and well-being of all people by addressing the use of addictive substances globally. Despite its enactment as international law in 2005 for member countries, poor implementation of law and tobacco industry interference have hindered progress in tobacco control, particularly in LMICs.[3,4] Evidence suggests that the tobacco industry has deliberately targeted school-aged adolescents and young adult who do not use tobacco to increase tobacco uptake.[3]

Adolescence, a critical period of physical, mental, and behavioral development, is when most individuals initiate tobacco use.[5] The Global Burden of Disease study revealed that approximately 155 million individuals aged 15−24 years smoked tobacco worldwide in 2019.[4] Millions more also use smokeless tobacco products, like chewing tobacco, gutka, snuff, and zarda.[6−8] Tobacco use prevalence among adolescents varies widely across regions and forms of tobacco, ranging from 2% to over 30%.[9] The addictive nature of tobacco products and the associated health risks, including lung dysfunction, asthma, and respiratory diseases, underscore the importance of addressing tobacco use during adolescence.[10−12] The health impact from tobacco use in LMICs will continue to be significant in the coming years unless the number of new people who use tobacco is reduced. The Lancet Commission has recommended the development and practice of effective evidence-based policies and interventions to reduce the burden of adolescent mortality and morbidity worldwide.[13]

Schools play a pivotal role in promoting adolescent health and development, reaching a large proportion of adolescents who may not regularly access health facilities.[14,15] School-based interventions have been widely implemented to prevent adolescent tobacco use, encompassing various approaches such as health education, peer-led activities, and policy-based curricula.[16] A previous systematic review found that these interventions appear effective in preventing and reducing tobacco use among school adolescents, but it focused primarily on high-income countries and smoking tobacco.[17] In contrast, smokeless tobacco use, which is prevalent in many LMICs,[7,8,18] poses additional health risks and warrants attention in efforts to prevent and reduce tobacco use.[7,8,19] Other studies have examined school-based interventions addressing theoretical foundations, cultural adaptations, intervention functions, and psychosocial predictors of tobacco use.[20,21] Nonetheless, there remains a need for a comprehensive systematic review and meta-analysis focused on the effectiveness of school-based interventions for preventing and reducing tobacco use in LMICs, considering both smoking and smokeless tobacco.

This systematic review and meta-analysis synthesized evidence from randomized trials evaluating school-based interventions for preventing and reducing tobacco use in LMICs, providing valuable insights for researchers, policymakers, and stakeholders involved in tobacco control efforts. Specifically, the objective was to evaluate intervention effectiveness in preventing and reducing adolescent tobacco use and to assess the impact of specific intervention components on outcomes.

METHODS

Following PRISMA guidelines,[22] 7 databases—MEDLINE (Ovid SP), The Cochrane Library, EMBASE (Ovid SP), CINAHL Plus, ERIC, ASSIA, PsycINFO (Ovid SP)—were searched from the earliest date possible until April 20, 2024. Search terms were grouped into 6 categories: adolescent; school-based; tobacco use; prevention program; study design; and LMIC (Appendix Table 1). The tobacco use category covered names of both smoking and smokeless tobacco products. The LMIC category included the Cochrane Groups LMIC Databases and both country and economy names from the world bank list of economies.[23,24] Details of search strategies for MEDLINE (Ovid SP) database are provided in the supplementary material (Appendix Table 1). Additionally, 3 clinical trial registries were searched for ongoing studies: government registries (www.clinicaltrials.gov and www.clinicaltrialsregister.eu), controlled clinical trials (www.controlled-trials.com), and WHO registries (www.who.int/trialsearch). Grey literature (i.e., unpublished

resources and conference proceedings) and reference lists were also screened to identify further relevant articles. All references were imported into a database for eligibility assessment.

RCTs or cluster-RCTs (C-RCTs) were eligible if individuals were randomized to a tobacco-use prevention program, or to a control arm. For C-RCTs, the unit of allocation was either the class, school or institution level. Eligible trials included participants aged 10−19 years at recruitment and in full-time education.[5] Included interventions aimed to prevent and/or reduce the use of smoked and/or smokeless tobacco and included education, counselling, therapy, and policy measures, psychosocial approaches (e.g., enhancing self-efficacy for refusing tobacco products) or life skills development in order to stay abstinent. Studies focusing on multiple substances (e.g., alcohol, cannabis) were included if tobacco use outcomes were reported.

Literature screening was conducted using a checklist. One reviewer screened all titles, abstracts, and descriptors. A second reviewer independently screened 25% of identified articles. Inter-rater agreement was assessed (Cohen's Kappa=0.58; agreement=84.21%). Discrepancies were resolved through consensus, consulting senior reviewers when necessary. Data were extracted using a predeveloped form (Appendix Table 2). One reviewer extracted all data, and a second reviewer independently extracted data from 25% of studies (agreement >95%, Cohen's Kappa=0.83). Missing data were requested from study authors.

No restrictions were applied regarding mode of delivery or intervention personnel. Delivery could occur one-to-one, in groups, or classrooms, via text or printed materials. Intervention operators included researchers, teachers, health professionals, students, peers, or others, based on a recognized ontology.[25] Any duration or intensity of delivery was accepted. Intervention components were classified using the Behavior Change Technique Taxonomy v1 (BCTTv1) method.[26] The components were grouped into the following categories: (a) information only curricula that provides school adolescents information to oppose tobacco use; (b) social competence curricula that focuses on social learning processes; (c) life skills such as problem-solving and decision-making; (d) cognitive skills for resisting interpersonal or media influences, increased self-control and self-esteem, coping strategies for stress, and general social and assertive skills in order to help school adolescents refuse offers to tobacco use by improving their general social competence; (e) social influence curricula that focuses on the awareness of multiple social influences associated with tobacco use, the resistance skills training in which school adolescents are taught how to deal with those influences (e.g., peer pressure) and handle direct and indirect high risk situations; (f) both social influence and social competence approaches (b and e, above); and (g) multimodal school-based programs focused on tobacco control policies that may include programs for parents and teachers. Behavior Change Techniques (BCTs) targeting tobacco prevention and reduction were extracted and coded according to the BCTTv1.[26]

Risk of bias (RoB) was assessed using the Cochrane RoB 2 tool.[27] Domains included sequence generation, allocation concealment, outcome assessment blinding, incomplete data, selective reporting, and other biases, including recruitment bias in C-RCTs. Overall RoB was rated as low risk, some concerns, or high risk.[27]

The primary outcome was preventing and reducing tobacco use, which included both the prevention of initiation, and the reduction of tobacco use among adolescents who already use tobacco. Among the included studies, this was assessed through either (a) the proportion of adolescents who had ever used tobacco at follow-up among those who had never used tobacco at baseline, or (b) prevalence (ever or point prevalence) of tobacco use at both baseline and follow-up. The latter reflects changes in tobacco use, capturing both new initiation and potential reductions among those who were already using tobacco at baseline. Due to the challenges of tracking long-term tobacco initiation and the relatively short follow-up periods common in school-based interventions, prevalence of initiation was used as a proxy for tobacco prevention. This measure reflects the proportion of students who began using tobacco during the follow-up period, providing a practical and feasible assessment of the intervention's impact on new cases of tobacco use. While ideally, this study would focus exclusively on adolescents who did not use tobacco at baseline to track initiation directly, the use of prevalence-based measures enables evaluation of the intervention's effectiveness in a broader, real-world context. To assess these outcomes, data were extracted as values and/or ORs. Where trials did not adjust for clustering, individual-level results were adjusted using intraclass correlation coefficients (ICCs) and design effects. Out of the 20 studies included in the meta-analysis, 7 studies adjusted for clustering and reported ICCs, 2 reported ORs adjusted for clustering but no ICC, 9 neither reported the ICC nor cluster-adjusted results, and 2 reported ICCs but no ORs adjusted for clustering. Sensitivity analyses excluded studies lacking clustering adjustments. A mean ICC (0.030) from 9 studies was used to impute missing ICCs for 11 studies. These imputed ICCs were used to calculate the design effect, which were used to determine the corrected standard errors for those trials. For studies

with more than 2 randomized arms, relevant prevention and control groups were combined. Where available, intention-to-treat analyses using multiple imputation for missing outcome data were included; otherwise, data from participants with complete outcome data were used.

Other characteristics of the interventions assessed included:

- Intervention provenance: classified as newly developed or culturally adapted from existing interventions.
- Intervention focus: categorized as tobacco-only or multiple focuses.
- Intervention category: defined as both social influence and social competence or other categories.
- Tobacco type: differentiated between smoked tobacco only and smokeless tobacco/both smoking and smokeless tobacco.
- Mode of intervention delivery: classified as classroom sessions or multimodal.
- Intervention operator: identified as peer leader and/or schoolteacher versus others (research team, health educator, nurse, medical student, police officer).
- Number of sessions delivered: categorized based on a median split (≤11 vs >11 sessions).
- Control condition: defined as active control or inactive control.
- Follow-up length: categorized based on prespecified cut-off according to the Cochrane guideline (>6 months vs ≤6 months).[28,29]
- Total contact time: calculated by multiplying the number of sessions by the duration of each session and categorized based on a median split (high, >592.5 minutes, versus low, ≤592.5 minutes).
- Intensity of session delivery: calculated by dividing the total contact time (in minutes) by the period (in days) for all session deliveries and categorized based on a median split (high, >4 minutes/day, versus low, ≤4 minutes/day).
- Risk of bias: assessed as low risk of bias versus high/some concerns.
- Number of BCTs used: categorized based on a median split (≥6 vs <6).

Adjusted ORs were calculated for each study for the primary outcome, with interventions considered effective if fewer participants used tobacco in the intervention group compared to the control group (i.e., OR <1). Meta-analysis was performed using STATA version 18.5, estimating pooled ORs with 95% CIs using the random-effects model. Subgroup analyses were performed for characteristics listed above to reduce heterogeneity. Multivariable meta-regression analyses, adjusted for the length of follow-up, were performed to determine if the tobacco prevention effect size was influenced by characteristics of the interventions. Based on a priori knowledge of the natural progression of tobacco use, longer study follow-up is expected to result in lower effect sizes and is therefore treated as a covariate in the meta-regression of intervention characteristics. Heterogeneity was assessed using the I^2 statistic. Values were interpreted according to Cochrane guidelines: 0%−40% (low), 30%−60% (moderate), 50%−90% (substantial), and 75%−100% (considerable).[27] Publication bias was evaluated via visual inspection of funnel plot asymmetry and Egger's regression test. The study is registered with PROSPERO, CRD42022330329.

RESULTS

A total of 2,133 articles were identified through the literature search, of which 104 proceeded to full-text screening. Ultimately, 27 studies,[30−55] published between 2002 and 2024 met the inclusion criteria and were included in this systematic review (Figure 1; Table 1). All the included studies were cluster randomized, with a combined total of 57,292 participants; sample sizes from individual studied ranged from 170 to 14,063 participants, with a median of 1,353. The studies were distributed across WHO-defined regions as follows: 2 (7.4%) each in African and Europe, 4 (14.8%) in the Western Pacific, 6 (22.2%) each in the Americas and the Eastern Mediterranean, and 7 (25.9%) in South-East Asia (Table 1). Five (18.5%) of 27 studies were conducted in each of Brazil[39,44,49−51] and India,[34,35,43,54,55] 3 (11.1%) in China,[31,37] 2 (7.4%) in Pakistan,[41,48] and 1 (3.7%) in each of Czech Republic,[32] Indonesia,[53] Iran,[46] Jordan,[38] Lebanon,[47] Mexico,[42] Nigeria,[52] Romania,[33] Saudi Arabia,[45] South Africa,[30] Taiwan,[40] and Thailand[36] (Appendix Figure 1).

Of the 27 studies, 12 (44%) evaluated newly developed interventions,[35,37,39−41,46−48,53−55] and 15 (56%) tested culturally adapted existing interventions.[30−34,36,38,42−45,49−52] Regarding targeted health behaviors, 14 (52%) were focused solely on tobacco prevention,[31,33,34,37,38,41,43−48,53] 9 (33%) addressed multidrug substance prevention along with tobacco,[30,32,36,40,42,49−52] and 4 (15%) targeted multiple noncommunicable disease risk factors in addition to tobacco prevention.[35,39,54,55]

RoB assessment rated 26% of studies as low risk, 15% as moderate risk or with some concerns, and 59% as high risk (Appendix Figure 2). In terms of randomization and recruitment, 25 studies (92%) were rated as at low RoB (Appendix Figure 3). However, 52% showed

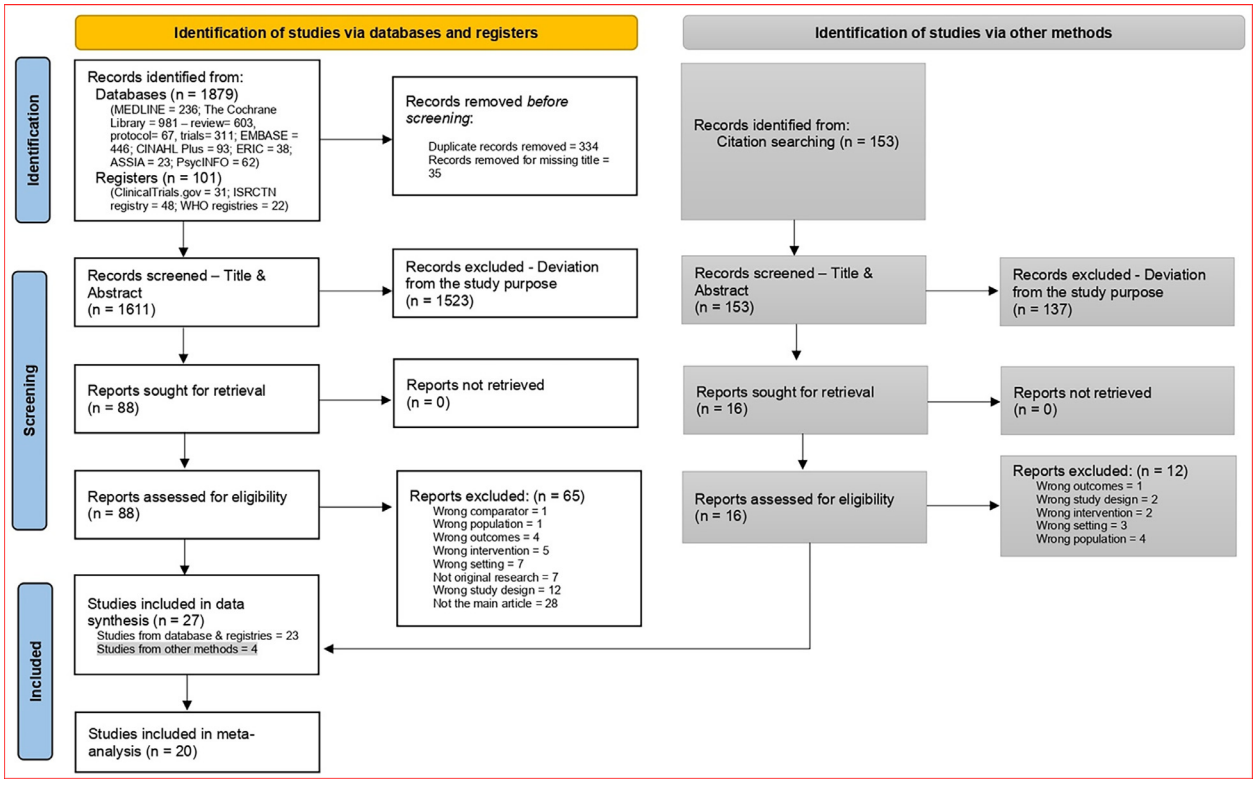

Figure 1. Study selection (PRISMA flowchart).

concerns regarding deviations from intended interventions, and 32% regarding outcome measurement. A high risk of bias for outcome measurement was identified in 60% of studies, primarily due to inadequate methods or unblinded outcome assessors. Reporting bias was judged high in 12% and of some concern in 16% of studies. Seven studies were excluded from the primary meta-analysis on the basis that they (a) did not measure the right outcome,[48] (b) had insufficient data at follow-up (less than 10 cases per group),[38,42,46,47,53] and (c) had extremely high ICC.[39]

Figure 2 presents a forest plot for the 20 studies[30–37,40,41,43–45,49–52,54,55] that were meta-analysed for the primary outcome. Pooled results show that participants exposed to interventions had 24% lower odds of starting tobacco use compared with those in the control group (OR=0.76, 95% CI=0.64, 0.91). There was moderate heterogeneity in the effect size between trials (I^2=47%), suggesting some variability in the intervention effects across studies. Despite the presence of some outliers and moderate heterogeneity in the meta-analysis, the funnel plot was symmetric overall (Appendix Figure 4). The Egger's test (z= −0.32, *p*-value=0.75) did not find strong evidence to suggest that publication bias influenced the results. When considering only studies with low RoB, the intervention was associated with 34% lower odds of trying or taking up tobacco (O=0.66, 95% CI=0.50, 0.87; I^2=14%; *n*=6; Appendix Figure 5). Baseline prevalence data are provided in Appendix Table 3.

Subgroup analyses revealed that school-based interventions were associated with reduced odds of tobacco use across most subgroups (Table 2). After controlling for a key confounder (follow-up length, ranges from 3 to 24 months), the multivariable meta-regression models showed that interventions with high contact time (AOR=1.36, 95% CI=1.01, 1.84; *p*=0.045; I^2=22.3%) were associated with a lower effect on preventing and reducing tobacco use compared with those with low contact time (see Table 2). Another meta-regression model, adjusted for both intervention focus and follow-up duration, indicated that high contact time remained associated with reduced intervention effectiveness (OR=1.37, 95% CI=1.00, 1.87; *p*=0.049; I^2=26.4%; Appendix Table 4). A further subgroup analysis, stratified by the type of outcome measure, showed that the intervention significantly reduced the point prevalence of tobacco use (OR=0.69, 95% CI=0.57, 0.85; I^2=32.4%), but has no significant effect on ever use (OR=0.91, 95% CI=0.66, 1.26; Appendix Figure 6).

Table 1. Included Studies and Their Characteristics (n=27)

Author	Country	WHO Region	Intervention provenance	Int. focus	Intervention category	Intervention condition	No of sessions	Duration per session (mins)	Period of time over which all sessions delivered (day)	Delivered by	Control condition	Outcome measure	Number randomised	Mean age, years (±SD)	Grade	Sex,[a] male%	Follow-up duration
Resnicow et al.[30]	South Africa	African Region	Culturally adapted	Multidrug	Social influences & Social competence	Decision-making for harm reduction and life skills for substance use prevention	16	45	730	School Teacher (ST)	Education against tobacco	30-day point prevalence	3,267	14.1 (± 1.2)	8	50.5%	24 months
Chou et al.[31]	China	Western Pacific Region	Culturally adapted	Tobacco only	Social influences	Fostered antismoking norms, teaching resistance skills, and emphasizing household smoke avoidance	13	45	98	Health Educator (HE)	No intervention	Ever and recent smoking at follow-up among never smokers at baseline	2,454	12.5	7	52.3%	12 months
Gabrhelik et al.[32]	Czech Republic	European Region	Culturally adapted	Multidrug	Social influences & Social competence	Emphasized knowledge, interpersonal, and intrapersonal skills	12	45	365	ST	Minimal prevention program	30-day point prevalence	1,744	11.4 (± 0.6)	6	50.4%	24 months
Lotrean et al.[33]	Romania	European Region	Culturally adapted	Tobacco only	Social influences & Social competence	Video-led lessons focused on social influences, refusal skills, and peer activities	5	45	60	ST + Peer Leader (PL)	No intervention	7-day point prevalence	959	13.7 (± 0.3)	7	48.8%	6 months
Perry et al.[34]	India	South-East Asia Region	Culturally adapted	Tobacco only	Social influences	Fun and interactive knowledge components, skills building, and normative education	13	70	120	ST + PL	Delayed intervention	30-day point prevalence	14,063	11.2	6 & 8	51.6%	24 months
Reddy et al.[35]	India	South-East Asia Region	Newly developed	Tobacco and alcohol	Social influences	Resist influences, refusal skills, and passive smoking education	3	45	55	ST + PL	No intervention	Ever tobacco use	4,452	11.9	7	50.5%	12 months
Seal et al.[36]	Thailand	South-East Asia Region	Culturally adapted	Multidrug	Social influences & Social competence	Life skills training, substance health risks booklet	10	60	180	Research Team (RT)	Education against tobacco & drug	60-day point prevalence	170	15.6 (± 2.3)	7 to 12	89.4%	6 months
Wen et al.[37]	China	Western Pacific Region	Newly developed	Tobacco only	Multilevel	Antismoking textbook, lectures, films, role plays, coping strategies, parent/ teacher pamphlet, school posters and community persuasion efforts	22	60	330	HE + School nurse (SN)	Education against tobacco	Ever tobacco use at follow-up among never users at baseline	859	12.8 (± 0.8)	7	48.2%	24 months
Wen et al.[37]	China	Western Pacific Region	Newly developed	Tobacco only	Multilevel	Antismoking textbook, lectures, films, role plays, coping strategies, parent/ teacher pamphlet, school posters and community persuasion efforts	16	60	240	HE + SN	Education against tobacco	Ever tobacco use at follow-up among never users at baseline	983	13.9 (± 0.5)	8	49.7%	12 months
Al-Sheyab et al.[38]	Jordan	Eastern Mediterranean Region	Culturally adapted	Tobacco only	Pledge & Social influences	Class smoke-free pledge, health lessons, resistance skills, role-playing and quiz show	3	30	6	PL	Education against tobacco	4-month point prevalence (biochemically validated)	433	12.5 (± 0.5)	7 & 8	100%	4 months
Filho et al.[39]	Brazil	Region of the Americas	Newly developed	Multiple (NCD risk factors)	Social influences & Social competence	Focused on teacher training, health education, and environmental changes, addressing substance use	NS	NS	NS	ST	No intervention	30-day point prevalence	1,085	11 to 18	7 to 9	51.5%	4 months

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Table 1. Included Studies and Their Characteristics (n=27) (*continued*)

Author	Country	WHO Region	Intervention provenance	Int. focus	Intervention category	Intervention condition	No of sessions	Duration per session (mins)	Period of time over which all sessions delivered (day)	Delivered by	Control condition	Outcome measure	Number randomised	Mean age, years (±SD)	Grade	Sex,[a] male%	Follow-up duration
Guo et al.[40]	Taiwan	Western Pacific Region	Newly developed	Multidrug	Social influences & Social competence	Theoretical constructs include attitude, subjective norm, perceived behavioural control, and life skills	16	45	70	ST	Education against tobacco & drug	30-day point prevalence	1,675	13.41 (± 0.6)	7	51.1%	12 months
Hussain et al.[41]	Pakistan	Eastern Mediterranean Region	Newly developed	Tobacco only	Social influences & Social competence	Identify harmful effects, set quit date, manage urges, and withdrawal symptoms	2	30	27	RT	No intervention	30-day point prevalence	1,971	11 to 16	6 to 10	59%	3 months
Kulis et al.[42]	Mexico	Region of the Americas	Culturally adapted	Multidrug	Social influences	Life skills training includes emotional regulation, assertiveness, and drug resistance strategies	12	45	84	ST	Education against tobacco & drug	30-day point prevalence	1,129	11.9	7	50.8%	No follow-up assessment[b]
Mall et al.[43]	India	South-East Asia Region	Culturally adapted	Tobacco only	Social influences	Training covered health risks, communication skills, personal development using interactive methods and diaries	10	60	70	PL	No intervention	Ever tobacco use	631	NS	6 to 9	59%	12 months
Lisboa et al.[44]	Brazil	Region of the Americas	Culturally adapted	Tobacco only	Education against tobacco	Interactive stations cover tobacco risks, facial aging, health effects, and peer pressure resistance using Smoker face app	1	90	1	Medical student	No intervention	30-day point prevalence	1,353	14.8	7 to 11	49.3%	12 months
Mohammed et al.[45]	Saudi Arabia	Eastern Mediterranean Region	Culturally adapted	Tobacco only	Social influences & Social competence	Training covers teamwork, smoking refusal, health effects, peer pressure, alternatives, and nonsmoking commitment	5	45	35	PL	No intervention	7-day point prevalence at follow-up among never smokers at baseline	1,047	13.9 (± 0.6)	8	100%	6 months
Mohammadi et al.[46]	Iran	Eastern Mediterranean Region	Newly developed	Tobacco only	Social influences	Lectures, role-play, and group discussions to discourage smoking, improve knowledge, and change attitudes	4	60	28	PL	No intervention	30-day point prevalence	1,807	15.1 (± 0.8)	7 to 9	50.3%	6 months
Nakkash et al.[47]	Lebanon	Eastern Mediterranean Region	Newly developed	Tobacco only	Social influences	Face-to-face sessions covered tobacco health risks, media analysis, decision-making, refusal skills, and student projects	10	50	150	RT	No intervention	30-day point prevalence	1,279	12.3 (± 1.1)	6 & 7	48.7%	No follow-up assessment[b]
Rozi et al.[48]	Pakistan	Eastern Mediterranean Region	Newly developed	Tobacco only	Education against tobacco	Educational session covered tobacco hazards, short/long-term effects, quitting strategies, and reinforcement via posters, booklet, and video game	2	30	28	Physician	Self-reading educational leaflets	Change in knowledge	1,076	14.2 (± 0.1)	6 to 10	60%	2 months
Sanchez et al.[49]	Brazil	Region of the Americas	Culturally adapted	Multidrug	Social influences & Social competence	Lessons on drug attitudes, social skills, personal skills, with life skill activities	12	50	84	ST	No intervention	30-day point prevalence	3,883	13.2 (± 0.8)	8	50.1%	9 months

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Table 1. Included Studies and Their Characteristics (n=27) (*continued*)

Author	Country	WHO Region	Intervention provenance	Int. focus	Intervention category	Intervention condition	No of sessions	Duration per session (mins)	Period of time over which all sessions delivered (day)	Delivered by	Control condition	Outcome measure	Number randomised	Mean age, years (±SD)	Grade	Sex,[a] male%	Follow-up duration
Sanchez et al.[50]	Brazil	Region of the Americas	Culturally adapted	Multidrug	Social influences & Social competence	Lectures on drug attitudes, social skills, and personal skills	12	50	84	ST	No intervention	30-day point prevalence	3,619	13.0	7 & 8	49.1%	21 months
Sanchez et al.[51]	Brazil	Region of the Americas	Culturally adapted	Multidrug	Social influences	social emotional learning theory skills taught through animated narratives, skill practice, homework, and comic book reinforcement	10	50	70	Police officer	No intervention	Ever tobacco use	1,733	12.3 (± 0.7)	7	51.5%	9 months
Vigna-Taglianti et al.[52]	Nigeria	African Region	Culturally adapted	Multidrug	Social influences & Social competence	Interactive curriculum develops personal and social skills, focusing on normative education and substance consequences	12	60	365	ST	No intervention	30-day point prevalence	2,657	14.2 (±0.8)	7 to 9	61.5%	5 months
Tahlil et al.[53]	Indonesia	South-East Asia Region	Newly developed	Tobacco only	Education against tobacco	Interactive lectures on smoking prevention knowledge focused on health and religion	8	120	56	ST & Health professionals	No intervention	30-day point prevalence	427	11 to 14	7 & 8	41.2%	6 months
Saraf et al.[54]	India	South-East Asia Region	Newly developed	Multiple	Multilevel	Encompassed school, classroom, and family components, integrating health committees, lectures, PT classes, and family orientations	4	38	240	RT	No intervention	30-day point Prevalence	2,074	12.4 (±1.1)	6 & 7	53.5%	10 months
Kaur et al.[55]	India	South-East Asia Region	Newly developed	Multiple	Multilevel	Interactive classroom sessions focused on health effects of tobacco & alcohol, peer awareness, and positive behavior reinforcement	7	30	180	RT	Low intensity standard of care intervention	30-day point prevalence	462	13.5 (±1.5)	8	55%	6 months

NS, not specified; ST, school teacher; HE, health educator; PL, peer leader; RT, research team; SN, school nurse.

[a]In this study, we define "sex" as a biological classification based on physical and physiological attributes (e.g., chromosomes, hormone levels, and reproductive anatomy), typically assigned at birth.

[b]A postassessment was administered immediately after the intervention delivery was completed.

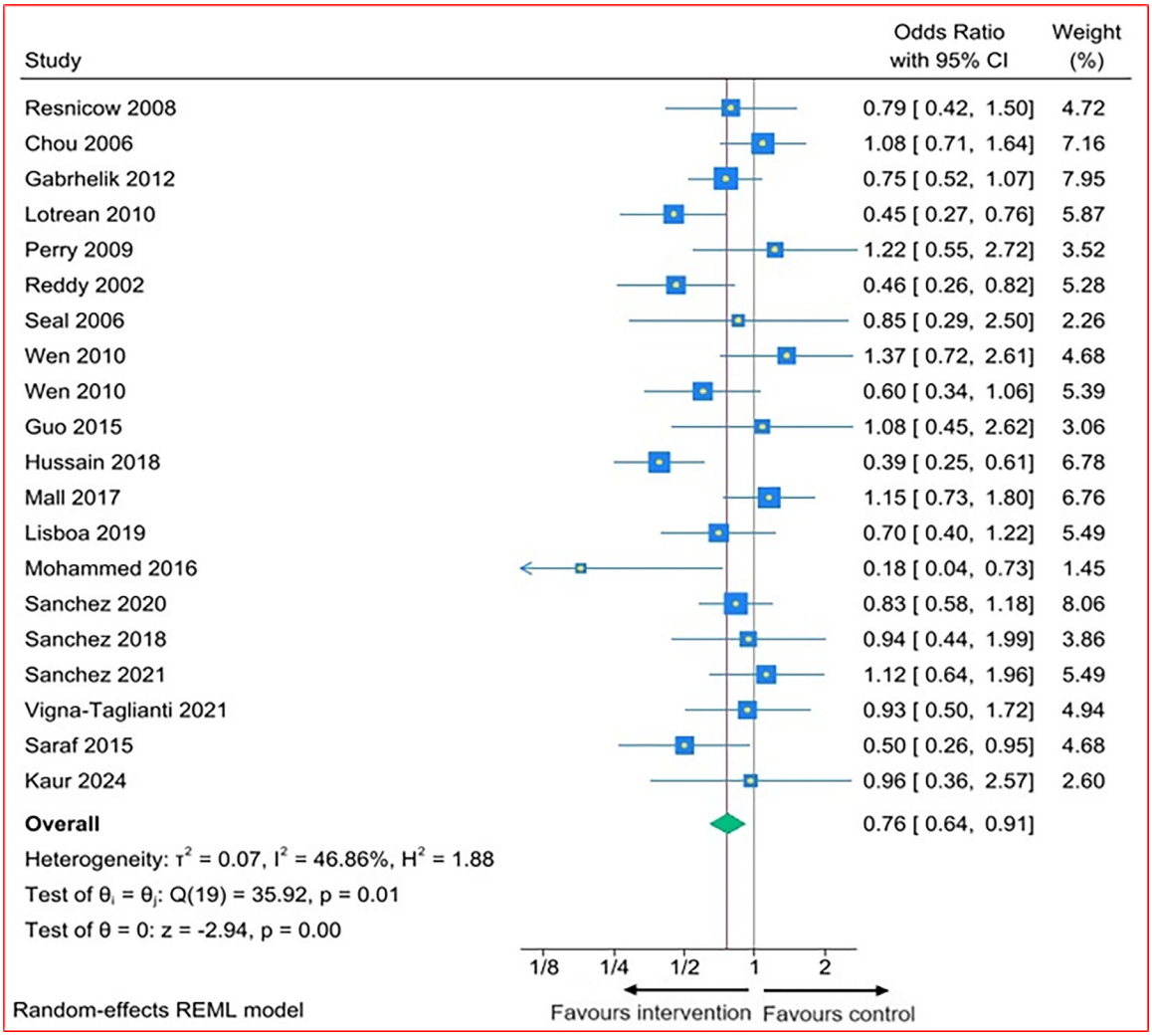

Figure 2. Forest plot for meta-analysis of studies reporting the effect of interventions on tobacco use prevention among adolescents.

To test the robustness of findings, a sensitivity analysis was conducted, excluding studies with imputed design effects. The overall pooled effect size in this sensitivity analysis (Appendix Figure 7) was an OR of 0.83 (95% CI=0.67, 1.03) which was similar to the main analysis with all studies (OR=0.76, 95% CI=0.64, 0.91), as was the heterogeneity; I^2 was 31.6% in the sensitivity analysis and 46.9% in the main analysis. The findings from further subgroup analyses of studies directly accounting for the design effect were consistent with those from the subgroup analysis of all studies (see Appendix Figures 7.1 to 7.11).

DISCUSSION

This systematic review indicates that school-based interventions in preventing and reducing tobacco use appear to reduce tobacco consumption among adolescents in LMICs; the pooled analysis of 20 studies demonstrated that participants exposed to these interventions had 24% lower odds off using tobacco compared to those in the control group. This finding highlights the potential of school-based programs to curb tobacco use in a population at high risk of initiating such behavior. However, there was moderate heterogeneity (I^2=47%), suggesting that the effectiveness of these interventions varied across studies. Although the overall analysis showed a significant reduction in tobacco use, findings should be interpreted cautiously. The evidence for smokeless tobacco use was particularly limited and heterogeneous, preventing confident generalization to all forms of tobacco.

The analysis revealed that interventions with follow-up periods longer than 6 months were associated with smaller effects (OR=0.85, 95% CI=0.72, 0.99; *n*=14) on

Table 2. Multivariable Meta-Regression Results With Subgroup Analysis, Showing Associations Between Intervention Factors and Effect Size of Intervention on Tobacco Use

			Subgroup analysis		Meta-regression analysis[a]			
Variables	**Categories**	**No of studies**	**OR (95% CI)**	**I^2**	**β (SE)**	**Moderation odds ratio (95% CI)[b]**	***p* value**	**I^2**
Intervention provenance[c]								
	Newly developed	7 studies	0.65 (0.45, 0.93)	56.13%	−0.27 (0.15)	0.76 (0.56, 1.03)	0.078	13.28%
	Culturally adapted	13 studies	0.84 (0.71, 0.99)	15.19%		1.00		
Intervention focus[d]								
	Tobacco only	9 studies	0.72 (0.51, 1.03)	70.25%	−0.01 (0.17)	0.99 (0.71, 1.37)	0.948	33.44%
	Multiple substances	11 studies	0.79 (0.66, 0.93)	0.00%		1.00		
Intervention category[e]								
	Both social influence and social competence	10 studies	0.68 (0.53, 0.87)	42.77%	−0.09 (0.18)	0.91 (0.64, 1.30)	0.614	31.33%
	Other categories	10 studies	0.86 (0.67, 1.10)	43.76%		1.00		
Tobacco type[f]								
	Smoked tobacco only	16 studies	0.80 (0.67, 0.94)	24.60%	0.08 (0.21)	1.08 (0.72, 1.63)	0.707	32.94%
	Smokeless tobacco/both smoking and smokeless tobacco	4 studies	0.66 (0.38, 1.15)	72.10%		1.00		
Intervention mode of delivery[g]								
	Classroom session	15 studies	0.75 (0.61, 0.92)	51.94%	0.005 (0.21)	1.00 (0.67, 1.51)	0.982	32.71%
	Multimodal	5 studies	0.81 (0.53, 1.22)	39.55%		1.00		
Intervention operator[h]								
	Peer leader and/or schoolteacher	11 studies	0.77 (0.62, 0.95)	34.12%	−0.007 (0.17)	0.99 (0.72, 1.37)	0.965	33.30%
	Others	9 studies	0.76 (0.56, 1.04)	56.75%		1.00		
Number of sessions[i]								
	≤ 11 sessions	10 studies	0.62 (0.46, 0.85)	58.00%	−0.25 (0.17)	0.78 (0.56, 1.09)	0.147	28.99%
	> 11 sessions	10 studies	0.88 (0.75, 1.04)	0.00%		1.00		
Control condition[j]								
	Active control	6 studies	0.81 (0.64, 1.03)	0.00%	0.03 (0.19)	1.03 (0.71, 1.49)	0.888	33.55%
	Inactive control	14 studies	0.73 (0.58, 0.93)	57.29%		1.00		
Total contact time[k,o]								
	High (> 592·5 min)	10 studies	0.93 (0.77, 1.11)	0.00%	0.32 (0.15)	1.36 (1.01, 1.84)	**0.045**	22.25%
	Low (≤ 592·5 min)	10 studies	0.63 (0.48, 0.83)	59.07%		1.00		

(*continued on next page*)

Table 2. Multivariable Meta-Regression Results With Subgroup Analysis, Showing Associations Between Intervention Factors and Effect Size of Intervention on Tobacco Use (*continued*)

			Subgroup analysis		Meta-regression analysis[a]			
Variables	**Categories**	**No of studies**	**OR (95% CI)**	**I^2**	**β (SE)**	**Moderation odds ratio (95% CI)[b]**	***p* value**	**I^2**
Delivery intensity[l,p]								
	High (> 4 min/day)	9 studies	0.94 (0.79, 1.13)	0.00%	0.27 (0.16)	1.32 (0.97, 1.79)	0.079	12.47%
	Low (≤ 4 min/day)	11 studies	0.65 (0.51, 0.82)	43.63%		1.00		
Risk of bias[m]								
	Low	6 studies	0.66 (0.50, 0.87)	13.88%	−0.14 (0.18)	0.87 (0.61, 1.25)	0.462	30.41%
	High	14 studies	0.81 (0.65, 1.01)	52.09%		1.00		
Number of BCTs[n]								
	BCTs ≥ 6	10 studies	0.90 (0.76, 1.06)	0.00%	0.27 (0.20)	1.31 (0.88, 1.95)	0.177	30.69%
	BCTs < 6	10 studies	0.61 (0.45, 0.82)	52.53%		1.00		

[a]Adjusted for the length of follow-up, categorised as 1 (>6 months) and 0 (≤6 months). The subgroup analysis shows an OR of 0.85 (95% CI=0.72, 0.99; *n*=14) for follow-up >6 months, vs. 0.55 (95% CI=0.37, 0.83; *n*=6) for ≤6 months.
[b]Calculated by exponentiating log-transformed estimates of intervention effect.
[c]Newly developed versus culturally adapted from existing intervention.
[d]Tobacco only versus multiple (tobacco and/or alcohol/substance use/NCD risk factors).
[e]Both social influence and social competence versus other categories (only social influence/education against tobacco/multilevel).
[f]Smoked tobacco only versus smokeless tobacco/both smoking and smokeless tobacco.
[g]Classroom session versus multimodal.
[h]Peer leader and/or schoolteacher versus others (research team/health educator/nurse/medical student/police officer).
[i]Number of sessions delivered in intervention ≤11 vs >11. The categorisation was based on the median value of the variable.
[j]Active control versus inactive control.
[k]Total contact time with the participants high versus low.
[l]High delivery intensity versus low delivery intensity.
[m]Low risk of bias versus high or some concerns over risk of bias.
[n]Number of BCTs used in the intervention ≥6 vs <6.
[o]The total contact time was calculated by multiplying the number of sessions by the duration of each session. The categorisation was based on the median value of the variable (high=greater than the median).
[p]Delivery intensity was calculated by dividing the total contact time (in minutes) by the period (in days) for all session deliveries. The categorisation was based on the median value of the variable (high=greater than the median).
BCTs, behavior change techniques.
Boldface indicates statistical significance ($p<0.05$).

preventing and reducing tobacco use compared with shorter follow-up periods (≤6 months; OR=0.55, 95% CI=0.37, 0.83; *n*=6). This suggests the protective effects of the intervention may decay over time, potentially due to peer influence, a lack of continued support, or natural usage patterns among adolescents. This highlights the challenge of sustaining intervention impacts over longer periods and underscores the need for ongoing support and reinforcement. One-off interventions may be insufficient to sustain behavioral change in school-based tobacco prevention programmes. Given the known influence of follow-up duration on abstinence rates across tobacco use intervention trials,[56] follow-up length was treated as a key confounder and controlled for in meta-regression analyses. The multivariable meta-regression analysis revealed that total contact time with participants was the only intervention characteristic significantly associated with effect size. Interventions with higher contact time were associated with a smaller effect. A possible explanation is that longer interventions may lead to participant fatigue, reduced engagement, or content dilution. Interventions targeting multiple substances, which are often less effective for smoking outcomes,[57] may naturally require longer durations, confounding this relationship. Further analyses adjusting for intervention focus and follow-up duration confirmed this association, suggesting the effect was not solely due to these variables. Further research is warranted to examine the role of content and engagement in shaping intervention effectiveness.

Subgroup analyses indicated that school-based interventions were associated with reduced tobacco use across most subgroups. Significant reductions in tobacco use were observed for point prevalence, defined in most studies as use within the past 30 days, suggesting particular effectiveness in reducing current use. In contrast, ever-use outcomes may reflect experimentation and be less sensitive to intervention effects. Differences in timing, validation, and outcome definitions may have introduced heterogeneity. Sample size limitations prevented comprehensive stratification, and confidence intervals in meta-regression analyses often included null effects, indicating uncertainty. Future research with larger samples and consistent methodology is necessary to identify the most impactful intervention elements. The BCTs analysis provided additional insight into effective components. Interventions including BCTs such as "information about health consequences", "information about social and environmental consequences", "information about emotional consequences", "reduce negative emotions", and "problem solving" appeared more effective in preventing and reducing tobacco use.[32,33,37,41] However, the limited sample size restricted the ability to draw firm conclusions. Future studies with larger samples and more detailed BCT analysis are needed to clarify which components drive effectiveness.

While school-based interventions show promise, they should be part of broader, multisectoral approaches addressing social, economic, and environmental determinants of tobacco use.[58,59] Collaboration among schools, health services, policymakers, and communities is essential to support healthy adolescent development.[59,60] The findings of this study suggest that school curricula should include brief, interactive sessions using proven BCTs, such as those addressing health and emotional consequences and problem solving. These techniques can address both individual and social drivers of behavior. Policymakers should consider integrating school and community-based interventions, particularly in disadvantaged settings, to amplify impact.[61,62] A combined approach may enhance the impact of school-based programs and contribute to a more comprehensive system of adolescent tobacco use prevention. However, the comparative effectiveness of these approaches remains an area for further investigation.

Limitations

There were several limitations with the studies included in this review. First, a substantial proportion of the included studies were judged to have high RoB, particularly in outcome measurement and reporting. Such biases could potentially inflate or deflate intervention effects. Nevertheless, sensitivity analysis restricted to low RoB studies still demonstrated that participants have 34% lower odds of trying or taking up tobacco, suggesting that the intervention effect is robust even when focusing on high quality studies. The meta-regression did not find any clear difference between high and low RoB studies, indicating that the overall intervention effect is relatively consistent across studies with varying levels of bias. Second, there was moderate heterogeneity in effects across studies. Several factors may contribute to this heterogeneity, including differences in intervention design, delivery modes, cultural contexts, and the specific populations targeted.[63−66] Third, while all studies were c-RCTs, not all properly accounted for clustering. In studies where clustering was not accounted for, a crude adjustment by imputing the ICC as the mean of the reported ICCs of other studies in the review was applied. If the true, reported ICC in these studies differs from the imputed value, this could introduce bias.[67] However, effect estimates did not materially change when only focusing on those studies that did account for clustering (or provide ICC that allowed us to account for clustering appropriately). Fourth, studies only provided data on self-reported tobacco use, which could be at

higher risk of performance bias relative to biochemically verified abstinence (e.g., students may be motivated to misreport tobacco abstinence).[68,69] Fifth, although this review aimed to assess the interventions' effect on both preventing and reducing tobacco use, analysis relied primarily on tobacco use prevalence as the outcome measure due to insufficient data and the relatively short follow-up period of the interventions. Ideally, a true prevention trial would focus on participants who do not use tobacco at baseline and track their transition to tobacco use. However, due to the inclusion of both participants who used tobacco and those who did not use tobacco at baseline in most studies, and the practical challenges associated with extended follow-up, the prevalence of tobacco use was used as a proxy for assessing the intervention's effectiveness in preventing tobacco initiation. Future studies with longer follow-up periods and a focus on adolescents who do not smoke at baseline could provide more precise data on tobacco initiation prevention.

Although a study reported on e-cigarette use,[44] the majority of included studies did not provide sufficient data on alternative tobacco products (e.g., e-cigarettes, heated tobacco products). As a result, the interventions' effectiveness in preventing the use of such products could not be explicitly assessed, which limits the scope of the conclusions given the evolving landscape of adolescent tobacco use. In addition, the diversity in intervention characteristics, such as the number of BCTs, total contact time, and intervention duration, presents challenges in drawing broader generalizations. Therefore, in interpreting the findings of this review, it is important to consider the multifaceted nature of tobacco use and the wide range of factors influencing adolescent behavior.

CONCLUSIONS

This systematic review shows that school-based interventions for preventing and reducing tobacco use appear effective for adolescents in LMICs, demonstrating a considerable reduction in the likelihood of tobacco use. Shorter interventions appeared to offer practical advantages, suggesting that brief yet engaging programs that incorporate targeted BCTs, such as providing information on emotional consequences and strategies for reducing negative emotions, may optimize effectiveness. However, evidence regarding long-term prevention of tobacco use remains less clear, and the limited evidence base for certain forms of tobacco, particularly smokeless tobacco, highlights a need for cautious interpretation and further research. While the protective effects of these interventions may diminish over time, it is possible that incorporating refresher sessions and sustained engagement may help maintain their effectiveness. The findings of this review provide impetus for school-based tobacco prevention interventions to be introduced across LMICs. By using the insights gained from this systematic review, stakeholders, policymakers, and researchers can collaboratively design and implement context-specific, evidence-based interventions to mitigate the growing tobacco epidemic and promote the health and well-being of adolescents in LMIC settings.

DATA SHARING

Data collected for this study did not include individual participant data. All aggregate data extracted from published literature or provided by co-authors and analyzed in meta-analysis are available in the manuscript. Data in spreadsheet format and STATA code to reproduce analysis are available from the corresponding author upon reasonable request.

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CREDIT AUTHOR STATEMENT

Sahadat Hossain: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Validation, Visualization, Writing—original draft, Writing—review and editing. Harry Tattan-Birch: Methodology, Investigation, Data curation, Formal analysis, Validation, Visualization, Writing—review and editing. Emma Beard: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Validation, Writing—review and editing, Supervision. Lion Shahab: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Validation, Writing—review and editing, Supervision.

SUPPLEMENTAL MATERIAL

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