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Evaluation of a hand hygiene intervention in two primary schools using UV-based feedback and AI-assisted image analysis

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ABSTRACT

Objectives: Hand hygiene prevents infectious diseases in schoolchildren, but objective assessment of technique remains largely unexplored in school settings. The aim of the present study is to evaluate a school-based intervention on hand hygiene in primary schools.
Study design: We conducted a controlled school-based community intervention study with school-level allocation, using a before-after repeated-measures design in two primary schools in Tarragona, Spain.
Methods: A total of 126 children aged 8–12 years participated (64 intervention, 62 control). The intervention combined a 30-min session on the 7-step alcohol-based hand rub technique with feedback using fluorescent hand rub and a custom UV device. Hand hygiene quality was measured at baseline and at 1, 3, and 6 months as the proportion of total hand surface area adequately covered, including the palmar and dorsal surfaces of both hands. Images were analysed using an artificial intelligence-assisted tool to support more standardised outcome assessmentLongitudinal effects were analysed exploratorily with a beta mixed-effects regression model.
Results: Adjusted hand coverage was similar between groups at baseline. At 1 month, both schools showed increased adjusted coverage. From 3 months onwards, trajectories diverged. The intervention school showed higher adjusted coverage than the control school at 3 months (adjusted mean difference 0.031; 95% CI: 0.010–0.052) and 6 months (0.041; 95% CI: 0.021–0.061).
Conclusions: This exploratory study suggests that combining structured hand hygiene education with immediate UV visual feedback may contribute to sustained improvements in hand hygiene technique in primary school settings. The AI-assisted image-analysis workflow supported partial standardisation of outcome assessment, although the fluorescence-detection step required human supervision.

What this study adds

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- Provides exploratory evidence that an educational intervention combining structured hand hygiene education with immediate UV visual feedback may support more sustained improvements in hand hygiene technique among primary school children than assessment alone.
- Introduces an AI-assisted image analysis workflow to support more standardised and reproducible quantification of hand surface coverage.

Implications for policy and practice

- Embedding prevention and health promotion interventions in school settings may help generate actionable evidence for public health and education practice.
- UV-based feedback and objective measurement may strengthen school health promotion programmes, although wider implementation will require further validation of the image-analysis workflow and evaluation in a larger number of schools.

1. Introduction

Upper respiratory and gastrointestinal infections are still among the most common causes of morbidity in school-aged children worldwide [1]. More than 90% of 3- to 6-year-olds contract at least one respiratory episode each year, and approximately 50% have one diarrhoea-related infection [2]. Attendance at kindergarten or primary school further amplifies this burden due to frequent physical contact [2,3].

Proper hand hygiene (HH) is the most cost-effective, efficient, and straightforward measure that can be implemented to prevent infectious diseases in children and reduce the school absenteeism associated with these illnesses [1,3]. Importantly, healthy habits formed in early childhood tend to persist into adulthood [4]. Accordingly, the 2009 WHO Guidelines on Hand Hygiene in Health Care promote multimodal strategies that combine education, supplies and real-time feedback to embed safe habits early in life [3]. A systematic review of 18 cluster-randomized controlled trials (RCTs) concluded that such programmes can reduce respiratory-tract infections and sickness-related absence, although methodological quality varied [5]. A quasi-experimental study gave two interactive sessions to 5th–8th graders, significantly raising their hand hygiene scores [6]. In the UK, soap kits and workshops in four primary schools taught the why/-when/how of handwashing, yielding sustained gains in infection-transmission knowledge and washing technique at 4 weeks [7]. Finally, Mbakaya et al. in a quasi-experimental study integrated handwashing into the kindergarten curriculum, improved facilities, and trained teachers with reminder posters and reported significant improvements in both children's knowledge and technique over 3 months [8].

A particularly powerful instructional tool for HH is real-time visual feedback using fluorescent markers under ultraviolet (UV) light. In clinical and educational settings, other products like glow gel are applied to the hands and then viewed under a black light to reveal unwashed areas. Such visual concretizations are powerful pedagogical tools. Fishbein et al. demonstrated that paediatric patients in a waiting room improved hand washing scores two to four weeks later using glow gel hand washing [9]. Another study with 6- to 7-years old children taught WHO's handwashing steps with visual aids and used a UV-sensitive glow gel for one group. Both groups improved, but the glow-gel group had significantly higher technique scores [10]. School-based RCT using UV cabinets plus instruction showed significant improvements in coverage scores compared to standard instruction alone [11]. Conversely, another study found that fluorescent gel without interactive teaching produced negligible improvement, whereas an interactive curriculum alone raised hand washing effectiveness from 15% to 38% [12]. Overall, the weight of evidence suggests that combining interactive education with fluorescent visualisation yields better results. Educational sessions clarify why proper technique matters, while UV-based demonstrations show how well children have washed.

Despite their widespread use, existing UV-based interventions rely on manual or semi-automated scoring of photographs, which is time-intensive and susceptible to variability. Students apply a glowing gel and view the results themselves, or insert hands into UV cabinets/scanners that visualise covered vs missed areas. To our knowledge, no published school-based intervention study has integrated AI-assisted image analysis into UV-based hand hygiene feedback and outcome assessment.

The aim of this study was to assess the impact of a school-based educational intervention that combined a structured educational training session with a fluorescence-enabled device on the quality of students' hand hygiene at 1, 3 and 6 months post-intervention. Additionally, the study introduced a novel AI-assisted image-analysis tool for scoring, thereby facilitating large-scale implementation while minimising observer bias.

2. Methods

2.1. Study design and setting

This study was a school-based community intervention, analysed as a controlled before-after repeated measures study. To minimise cross-arm contamination, allocation was performed at school level, using a single matched pair (one intervention school and one control school). Schools were pair-matched a priori by low-socioeconomic urban context, management type, and school size. After matching, the schools were pragmatically assigned to the intervention and control groups.

The study was conducted in two primary schools from the Sentinel Schools Network of Catalonia (CSSNC) project in the Camp de Tarragona region (Catalonia, Spain) [13] during the 2023–2025 academic period. Participants were recruited in March 2024. Hand hygiene was assessed at baseline (T0), at 1-month post-intervention (T1), 3-month (T2) and 6-month (T3) follow-up.

2.2. Participants and eligibility

A total of 126 pupils aged 8–12 years were enrolled. Eligible participants were students attending third to sixth grade whose parents or legal guardians provided written informed consent. Exclusion criteria were physical or intellectual conditions precluding correct hand hygiene, contraindication to alcohol-based hand rub (ABHR), or school attendance below 80%.

2.3. Procedure

The intervention consisted of a 30-min educational session on the 7-step ABHR technique and the role of hand hygiene in infection

prevention, followed by a practical activity with real-time visual feedback. The session was designed by the Preventive Medicine Unit and Infection Control Group of Joan XXIII University Hospital and delivered to all intervention pupils by the principal investigator, while teachers remained in the classroom without participating. It included a short video, a slide presentation on when and how to perform hand hygiene, and classroom educational materials. No reinforcement activities were conducted between follow-up visits.

Control-school pupils received the educational session after completion of follow-up. During the study, they were exposed to the UV device only during the assessment and did not receive any direct feedback on missed hand areas. However, the UV images allowed them to see their own hand coverage.

For hand hygiene assessment, participants applied approximately 1 mL of fluorescent ABHR (Anios Gel 85 NPC Fluorescent), rubbed their hands, and placed them inside a custom UV device. The device, developed by the same hospital unit, provided a uniform dark background and controlled illumination. Participants were instructed to fully extend their fingers, maintain a neutral wrist position, and avoid overlap between hands. Two photographs were obtained per participant, capturing dorsal and palmar views of both hands under standardised conditions. A pseudonymous participant code remained visible in each image. Images were immediately uploaded to a secure study server accessible only to authorised research staff. The percentage of clean hand surface area, defined as the proportion of the total hand that was adequately covered with hand rub, was calculated.

Sociodemographic variables were collected before the baseline assessment and stored in encrypted REDCap databases linked to study.

2.4. Image processing data tool

2.4.1. Image acquisition and hardware

Image acquisition followed a standardised protocol: two photographs per participant were obtained under standardised distance, framing, and illumination conditions inside the opaque UV device to facilitate fluorescence detection. Images were captured with the same tablet settings for all participants.

2.4.2. Image processing pipeline

A new semi-automated image-processing tool was developed and validated, providing a standardised and reproducible workflow for quantifying fluorescent coverage. The workflow comprised three steps: (i) hand localisation and view/laterality classification using YOLOv8 (Ultralytics) [14]; (ii) hand segmentation using the Segment Anything Model (SAM) (Meta) [15]; and (iii) colour isolation using thresholds in hue, saturation and value (HSV) colour space tuned to the characteristic emission of the fluorescent rub under UV. Because illumination variations could affect fluorescence detection, all images underwent human review and correction when required.

In the first stage, the YOLOv8-S model was trained to assess hand localisation and hand surface/side classification performance. A total of 5,197 images containing hands were labelled and augmented to 57,163 images through transformations such as mirroring, rotations, translations, scaling, and illumination transformations to increase variability and improve model learning. Then, 51,446 of those images were used for training and 5,717 for YOLOv8 inner validation purposes. To get the final evaluation metrics, a subset of 2,381 new images were used. The second stage used a pretrained SAM model and required no additional training. Finally, in the third stage, the dorsal and palmar surface areas of the stained hands were obtained separately. The total percentage of clean hand surface was calculated as the arithmetic mean of the two percentages, giving equal weight to both surfaces.

2.5. Statistical analysis

Data were analysed in R statistical software (R Foundation for Statistical Computing, Vienna, Austria; version 4.3.2). Descriptive statistics for sociodemographic variables were presented by school. Comparisons between schools were assessed using Pearson's χ^2 test.

The primary outcome was the proportion of adequately covered hand surface at each assessment, bounded between 0 and 1. It was modelled using a beta mixed-effects regression model with a logit link function with the glmmTMB package. Values equal to 1 were transformed to the open interval (0,1) following Smithson and Verkuilen (2006) [16]. The final model included fixed effects for school group (intervention vs control), time of assessment (baseline, 1 month, 3 months, and 6 months), the school-by-time interaction and sex, as well as a random intercept for pupil to account for within-pupil correlation across repeated measures. Candidate covariates initially evaluated included age, school grade, dominant hand, household size, parental education, and parental employment status; variables that did not improve model fit were not retained in the final model. For interaction effects, we estimated differences between schools at each time point and changes over time within each school relative to baseline.

Because the model uses a non-linear link function, estimated marginal means were re-expressed on the response scale using the regrid() function, and contrasts are reported as adjusted differences in mean proportions, with corresponding standard errors, 95% confidence intervals (CI), and *p*-values. Comparisons over time were adjusted for multiple testing using Dunnett's method, and pairwise comparisons of categorical covariates used Tukey's adjustment. Statistical significance was set at $p < 0.05$.

3. Results

At the baseline visit, 64 pupils from intervention school and 62 pupils from control school participated. A flow diagram is shown in Fig. 1. The participants' sociodemographic profiles are detailed in Table 1. Overall, 43.7% ($n = 55$) were female, ages ranged from 8 to 12 years, with children aged 8–9 years comprising 65.9% ($n = 83$) of the sample. Right-handedness predominated (88.1%, $n = 111$), whereas 9.5% ($n = 12$) were left-handed and 2.4% ($n = 3$) identified as ambidextrous. Regarding parental occupation, 84.9% of fathers were in full- or part-time employment, whereas 52.4% of mothers were primarily engaged in household duties.

Between schools, the age distribution differed significantly ($p = 0.004$), consistent with grade composition: the intervention group comprised pupils in third to sixth of primary school, whereas the control group included only pupils in third and fourth grade. Regarding socioeconomic variables, pupils in the intervention school reported a significantly larger household size compared to those in the control school. A notable proportion of pupils were unsure of their parents' educational level (fathers: 41.6%; mothers: 43.2%). In the control group, participants reported that 24.2% of fathers and 24.6% of mothers had completed secondary education. In contrast, 44.4% of fathers and 50.0% of mothers in the intervention group had only completed primary schooling ($p < 0.001$) (Table 1).

3.1. Validation results of the semi-automated image-analysis tool

To support scalable, objective processing of the hand hygiene image dataset, we implemented an AI-assisted, semi-automated computer-vision workflow composed of three sequential modules as described in Fig. 2. Performance was evaluated at each stage against manually curated reference labels, and the extent of required operator intervention was documented to characterise practical end-to-end automation.

After 247 training epochs, the YOLOv8 model was evaluated on 2,381 labelled hand images, comprising approximately equal numbers of the four classes: right-dorsal, right-palmar, left-dorsal and left-palmar. Based on the number of correct predictions across these four classes, the model achieved an overall accuracy of 94%.

In the segmentation stage, the SAM model failed to correctly segment

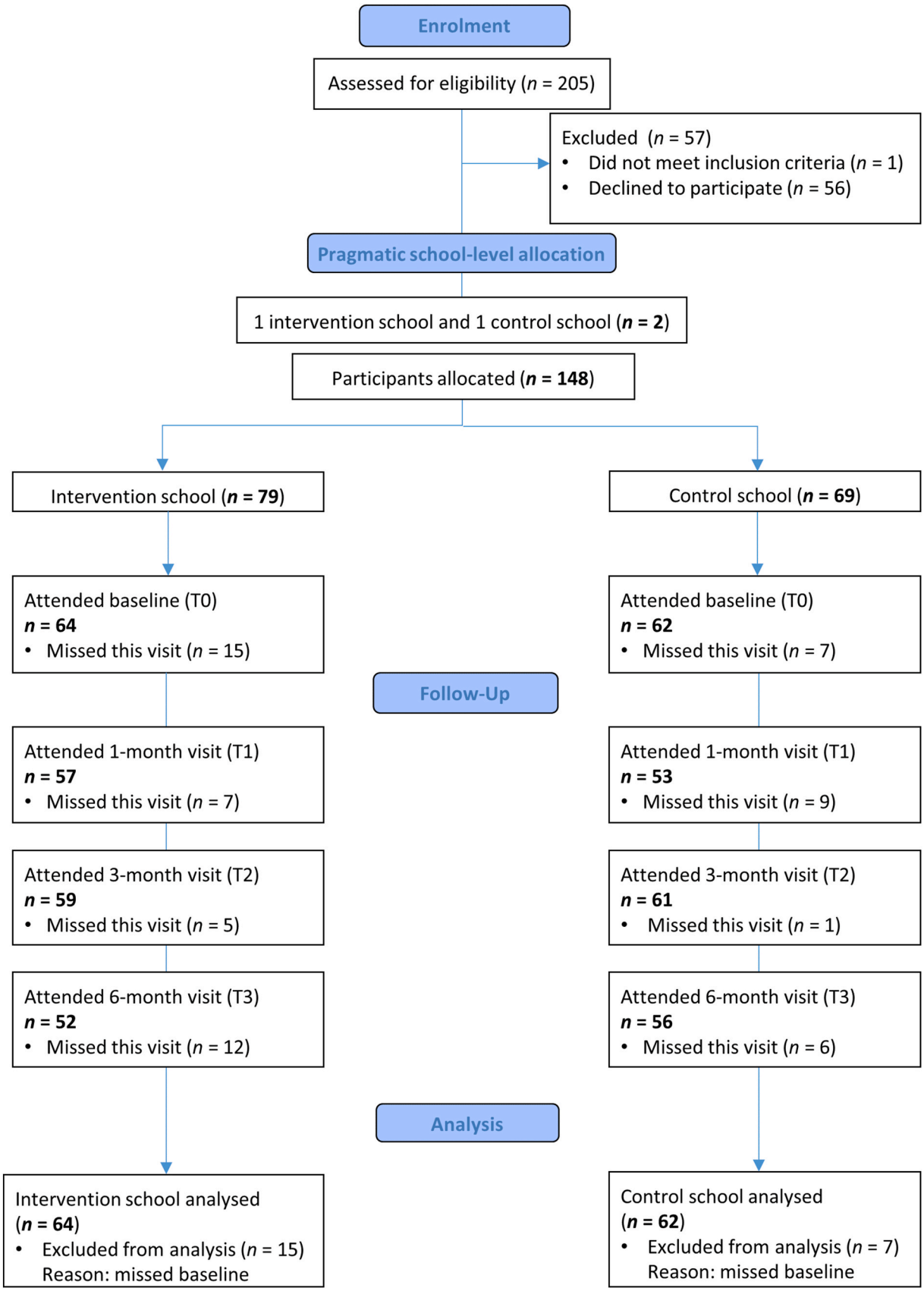


Fig. 1. Participant flow diagram of the study**:** enrolment, allocation and follow-up during the study. *Note*: Numbers at each follow-up time point represent participants with available data for that specific visit. "*Missed visit*" refers to participants who did not attend that specific assessment but remained in the study."

Table 1
Participant sociodemographic characteristics by intervention group.

Variables	Total ($n = 126$)	Control school ($n = 62$)	Intervention school ($n = 64$)	p value
Sex				0.606
Female	55 (43.7)	29 (46.8)	26 (40.6)	
Age				0.004
[8,9]	83 (65.9)	49 (79.0)	34 (53.1)	
[10-12]	43 (34.1)	13 (21.0)	30 (46.9)	
School grade				<0.001
Third	45 (35.7)	24 (38.7)	21 (32.8)	
Fourth	58 (46.0)	38 (61.3)	20 (31.2)	
Fifth	16 (12.7)	0 (0.0)	16 (25.0)	
Sixth	7 (5.6)	0 (0.0)	7 (10.9)	
Dominant hand				0.066
Right	111 (88.1)	51 (82.3)	60 (93.8)	
Left	12 (9.5)	8 (12.9)	4 (6.3)	
Ambidextrous	3 (2.4)	3 (4.8)	0 (0.0)	
Household size (number of occupants)				0.019
[3,4]	34 (27.0)	22 (35.5)	12 (18.8)	
[5,6]	72 (57.1)	35 (56.5)	37 (57.8)	
> 6	20 (15.9)	5 (8.1)	15 (23.4)	
Father's/parent 1 education level				<0.001
No formal or incomplete primary education	9 (7.2)	1 (1.6)	8 (12.7)	
Primary education, school certificate (up to 8th grade; vocational level 1)	34 (27.2)	6 (9.7)	28 (44.4)	
Secondary education (vocational level 2)	22 (17.6)	15 (24.2)	7 (11.1)	
University education	3 (2.4)	2 (3.2)	1 (1.6)	
Unknown	52 (41.6)	35 (56.5)	17 (27.0)	
Not applicable (no father/parent 1)	5 (4.0)	3 (4.8)	2 (3.2)	
Mother's/parent 2 education level				<0.001
No formal or incomplete primary education	4 (3.2)	2 (3.3)	2 (3.1)	
Primary education, school certificate (up to 8th grade; vocational level 1)	40 (32.0)	8 (13.1)	32 (50.0)	
Secondary education (vocational level 2)	22 (17.6)	15 (24.6)	7 (10.9)	
University education	4 (3.2)	2 (3.3)	2 (3.1)	
Unknown	54 (43.2)	34 (55.7)	20 (31.2)	
Not applicable (no mother/parent 2)	1 (0.8)	0 (0.0)	1 (1.6)	
Legal guardian education level				
University education	1 (0.79)	0 (0.0)	1 (1.6)	1.000
Not applicable (no legal guardian)	125 (99.2)	62 (100.0)	63 (98.4)	
Father's/parent 1 employment status				0.619
Employed	107 (84.9)	54 (87.1)	53 (82.8)	
On sick leave	5 (4.0)	2 (3.2)	3 (4.7)	
Unemployed	4 (3.2)	2 (3.2)	2 (3.1)	
Household duties	3 (2.4)	0 (0.0)	3 (4.7)	
Retired	1 (0.8)	0 (0.0)	1 (1.6)	
Other	1 (0.8)	1 (1.6)	0 (0.0)	
Not applicable (no father/parent 1)	5 (4.0)	3 (4.8)	2 (3.1)	
Mother's/parent 2 employment status				0.007
Employed	51 (40.5)	30 (48.4)	21 (32.8)	
On sick leave	2 (1.6)	2 (3.2)	0 (0.0)	
Unemployed	4 (3.2)	4 (6.5)	0 (0.0)	
Household duties	66 (52.4)	25 (40.3)	41 (64.1)	
Retired	0 (0.0)	0 (0.0)	0 (0.0)	
Other	2 (1.6)	1 (1.6)	1 (1.6)	
Not applicable (no mother/parent 1)	1 (0.8)	0 (0.0)	1 (1.6)	

Data are presented as frequencies (n) and percentages (%), unless otherwise specified. p-values refer to comparisons between control and intervention groups at baseline.

48 hands on the first attempt. Of these, 38 were recovered through minimal manual adjustment of the model setup (e.g., selecting an alternative output mask, re-segmenting with a different input point, or using two input points for segmentation).

In the third stage, colour detection using HSV thresholds showed low agreement with the ground-truth annotations, requiring human supervision for correction and thereby limiting automation of this step. Alternative automated solutions were explored but did not yield improved performance.

3.2. Model-based effectiveness results

Fig. 3 shows the adjusted marginal means of the proportion of clean hand surface over time by study school group, with the corresponding adjusted marginal mean estimates provided in Supplementary Table S1. At baseline (T0), adjusted estimates were similar between the control (0.888; 95% CI: 0.864–0.907) and intervention schools (0.910; 95% CI: 0.890–0.927). At 1 month, both groups showed comparable improvements (control: 0.937; 95% CI: 0.920-0.950; intervention: 0.943; 95% CI: 0.929-0.954). From 3 months onwards, trajectories diverged: the control school showed partial regression towards baseline (0.913; 95% CI: 0.894-0.930), whereas the intervention school maintained and further increased hand hygiene quality (0.944; 95% CI: 0.929-0.955). At 6 months, the adjusted mean proportion reached 0.958 (95% CI: 0.947–0.968) in the intervention school compared with 0.917 (95% CI: 0.896–0.933) in the control school.

Table 2 summarises adjusted marginal contrasts from the beta mixed-effects regression model (logit link), expressed on the response scale as absolute differences in the adjusted mean proportion of clean hand surface after accounting for repeated measures within pupils and adjusting for multiplicity (Dunnett for time contrasts; Tukey for categorical covariates). Given the two-school cluster structure, the between-school contrasts are treated as exploratory rather than confirmatory cluster-level causal estimates. Additional adjustment for age and school grade, which differed between schools at baseline, did not improve model fit or meaningfully change either the point estimates or the statistical significance of the school-by-time effects.

The school-by-time interaction indicated that adjusted differences between schools were not statistically significant at baseline or at 1 month. At later follow-up, modest but statistically significant between-school differences emerged: at 3 months, the intervention school showed a higher adjusted mean proportion of clean hands than the control school (adjusted mean difference, 0.031; 95% CI: 0.010–0.052), and this difference increased further at 6 months (adjusted mean difference, 0.041; 95% CI: 0.021-0.061).

Within the control school, the adjusted difference in the proportion of clean hands at 1 month versus pre-intervention visit showed a statistically significant increase, while changes at 3 and 6 months were not statistically supported after adjustment. In the intervention school, all follow-up contrasts versus baseline were statistically significant, with the largest gain observed at 6 months.

Hand hygiene was modestly better among female pupils than male pupils. Finally, the model indicated between-pupil heterogeneity, with a random-intercept variance of 0.110 (SD 0.332) on the linear predictor

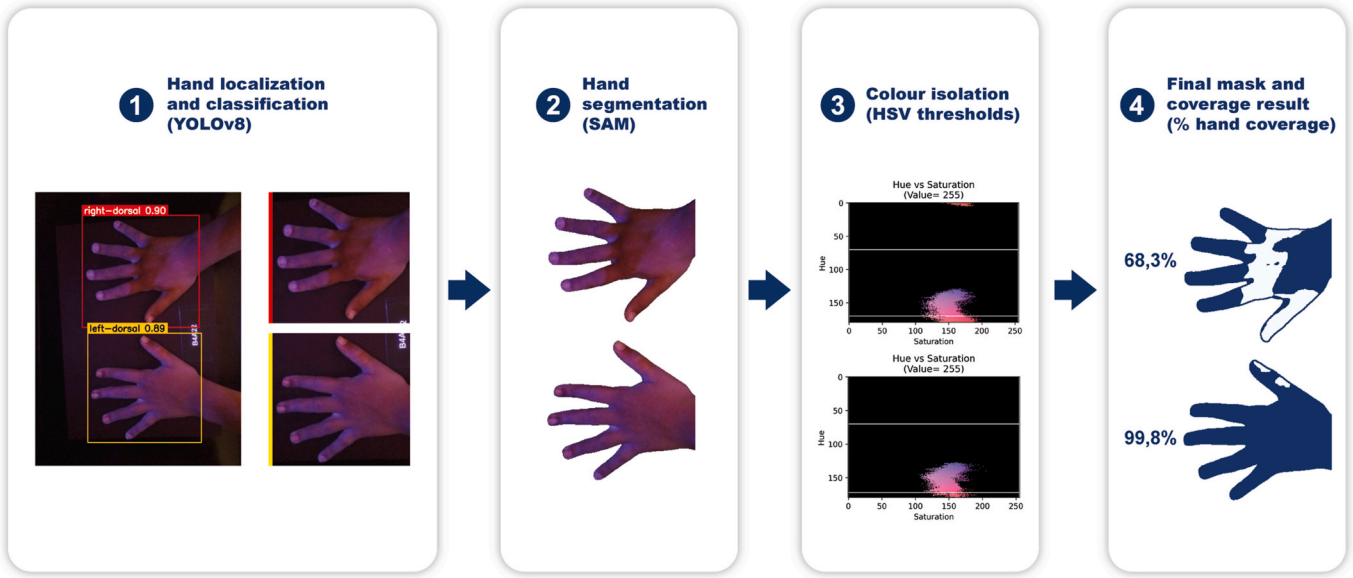


Fig. 2. Processing pipeline to derive binary fluorescence-coverage masks from UV images. *Note:* First, YOLOv8 localises and classifies each hand view (e.g., right/left dorsal/palmar) and the corresponding crops are extracted. Next, each crop is segmented with SAM to isolate the hand from the background. Finally, HSV thresholding identifies fluorescent regions, generating the binary mask (right) used for downstream coverage quantification.

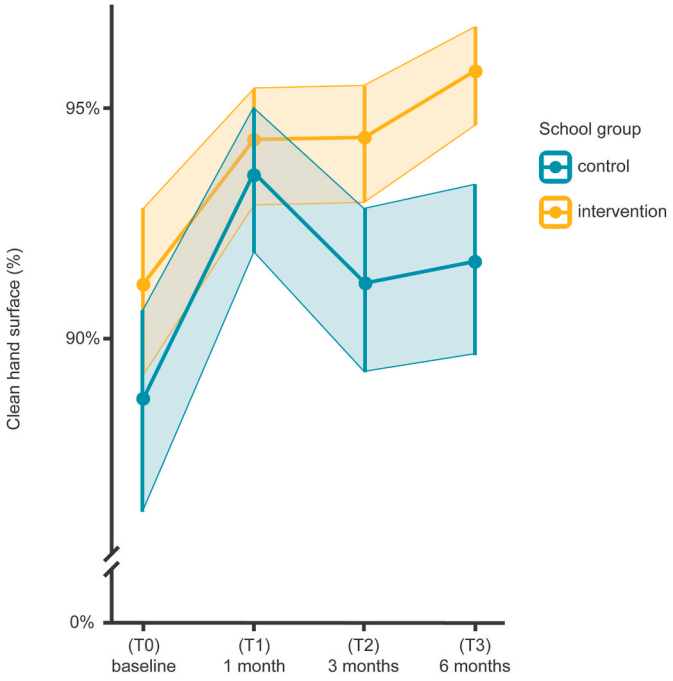


Fig. 3. Changes in clean hand surface percentage over time by study group. *Note:* Adjusted marginal means and 95% confidence intervals of the percentage of clean hand surface over time by study group (control and intervention schools), estimated from a beta mixed-effects model adjusted for sex, with a random intercept for participant. Shaded areas represent 95% confidence intervals. The y-axis is truncated, as indicated by the axis break.

scale, consistent with meaningful baseline differences in hand hygiene performance across children beyond measured covariates.

4. Discussion

In this controlled before-after study in two primary schools, a hand hygiene intervention combining structured education with UV-enabled visual feedback showed evidence of a sustained improvement in objectively quantified hand hygiene coverage. Adjusted trajectories were similar at baseline and at 1 month, when both schools improved, possibly reflecting assessment awareness, implicit feedback from the UV procedure, or limited contamination between school communities. From 3 months onwards, trajectories diverged: the intervention school maintained and further improved coverage, whereas the control school showed partial regression towards baseline. Between-school adjusted differences became statistically detectable at 3 months and increased at 6 months, while within-school improvements were consistently supported across all follow-up visits only in the intervention school. These findings suggest that structured education may have contributed to the more sustained improvement observed in the intervention school. However, given the two-school design, these between-school differences should be interpreted as exploratory and cannot establish a definitive cluster-level causal effect.

Our findings are consistent with the literature: school-based hand hygiene interventions can improve technique, although effect sizes and durability vary across studies and programme designs [4–8]. Visual feedback using fluorescent products under UV light is widely used in educational and clinical settings and is often described as a powerful tool to make missed areas visible [9,11,12]. Studies comparing interactive education with fluorescent visualisation generally suggest that combining education with visual feedback is more effective than either element alone [10–12]. The improvement observed in both schools at 1 month may reflect increased awareness of being assessed and the immediate prompting effect of the UV device itself, which makes uncovered areas visible even in the absence of structured training. The divergence at mid-term follow-up suggests that, without structured reinforcement, gains in technique-related behaviours may attenuate over time, whereas programmes that combine structured instruction plus UV-based feedback can help sustain improvements over time [10, 11].

Beyond its methodological contribution, the intervention may have practical relevance for school health promotion as a brief, visually guided approach to practising and assessing hand hygiene technique.

A further contribution of this study is the attempt to quantify hand hygiene coverage objectively using a semi-automated image analysis tool. To our knowledge, no published study has yet integrated AI-assisted image analysis into this workflow. Previous reports have

Table 2
Adjusted marginal mean differences in the proportion of correctly covered hand surface by group, time, and sex.

Contrast category	Contrast	Adjusted marginal mean difference	SE[a]	95% CI[b]	*p* value
Group × Time	Intervention − Control (T0)	0.022	0.014	[-0.002, 0.052]	0.068
	Intervention − Control (T1)	0.006	0.010	[-0.012, 0.026]	0.470
	Intervention − Control (T2)	0.031	0.011	[0.010, 0.052]	0.003
	Intervention − Control (T3)	0.041	0.010	[0.021, 0.061]	<0.001
Time (Control)	T1 – T0	0.049	0.012	[0.018, 0.080]	<0.001
	T2 – T0	0.025	0.013	[-0.007, 0.058]	0.179
	T3 – T0	0.029	0.013	[-0.003, 0.064]	0.085
Time (Intervention)	T1 – T0	0.033	0.010	[0.005, 0.057]	0.011
Sex	T2 – T0	0.034	0.010	[0.006, 0.057]	0.009
	T3 – T0	0.048	0.010	[0.022, 0.071]	<0.001
	Male − female	−0.017	0.006	[-0.029, −0.004]	0.008

Estimates are model-based marginal mean differences on the response scale from a beta mixed-effects regression model with logit link. The model included group, time, group × time interaction, and sex as fixed effects, with a participant-level random intercept. Time points: T0 = baseline; T1 = 1 month; T2 = 3 months; T3 = 6 months. Significance was considered when p-value <0.05.
[a]SE, standard error. [b]CI, confidence interval.

described related approaches: one based on a UV digital imaging system with segmentation, and another using deep learning to standardise UV-image analysis. However, neither was evaluated within an intervention study [17,18]. We found no other studies using AI-supported UV feedback in school settings.

Some limitations should be acknowledged. The main limitation was the two-school cluster design, which limits generalisability and prevents separation of the intervention effect from unmeasured school-level characteristics. Although the schools were similar in organisation, population profile and geographic area, residual confounding due to baseline differences between schools cannot be excluded. We therefore interpret between-school contrasts as exploratory estimates of effectiveness in these settings. If replicated with a larger number of clusters and diverse school contexts, the approach could be scaled up and integrated into routine school health programmes, especially if measurement and feedback can be delivered with minimal staff burden. A second limitation was incomplete end-to-end automation: HSV-based fluorescence detection was sensitive to image-to-image variability and required human supervision. This could be mitigated by structural modifications to the device to better control light variability or by replacing this part with a more robust automated approach.

Overall, the findings suggest that combining structured hand hygiene education with immediate visual feedback may support modest but sustained improvements in technique over months in primary school settings. The use of standardised UV imaging and objective quantitative scoring strengthens outcome assessment by improving reproducibility and limiting observer bias, and it may facilitate scalable monitoring in school settings.

Ethical statement

The study was approved by the Research Ethics Committee of The Foundation University Institute for Research in Primary Health Care Jordi Gol i Gurina (IDIAPJGol) on 20 December 2023 (code 23/190-P). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and national research committee and with the Helsinki Declaration. Written informed consent was obtained from the parents or legal guardians of all participating students prior to their inclusion in the study. Participation was voluntary, and all the participants retained the right to withdraw from the study at any time without academic or institutional consequences.

Authors' contributions

JB, FML and MG conceived and conceptualised the project. JC provided senior leadership and overall supervision. AB and ACC coordinated and executed the study. AGP, MG and CRR designed and coordinated the educational intervention. JA and EM developed the software. JA, EM, ACC, FML and SM contributed to the operationalisation of the fieldwork procedures, including the design of the field team workflow and implementation logistics. GE and AB performed the statistical analysis. AB drafted the first version of the manuscript. All authors contributed to critical revision of the manuscript and read and approved the final version.

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Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2026.100856.

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