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SYSTEMATIC REVIEW

Child-centered rabies prevention: A systematic review and meta-analysis of behavioral determinants and intervention effectiveness (2015–2024)

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ABSTRACT

Background and Aim: Rabies is a fatal yet preventable zoonotic disease, disproportionately affecting children in endemic regions. Despite the availability of post-exposure prophylaxis, behavioral gaps in prevention persist. Understanding the determinants of preventive behaviors and evaluating the effectiveness of educational interventions are critical for achieving the global goal of eliminating dog-mediated human rabies deaths by 2030. This study aimed to systematically review the psychosocial, cognitive, and contextual determinants influencing rabies prevention behaviors in children, and to evaluate the effectiveness of related interventions through meta-analysis.

Materials and Methods: This systematic review and meta-analysis was conducted in line with Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines and registered in International Prospective Register of Systematic Reviews (CRD420251085699). Four databases (PubMed, SCOPUS, Google Scholar, and Thai Citation Index) were searched for peer-reviewed studies published from 2015 to 2024. Thirteen eligible studies were included: Six observational and seven intervention studies. Effect sizes were synthesized using random-effects models. Subgroup and sensitivity analyses were conducted to examine heterogeneity and moderator effects.

Results: Environmental factors (r = 0.28), knowledge, attitudes, and practices variables (r = 0.22), health literacy (r = 0.20), and protection motivation theory constructs (r = 0.16) were significantly associated with rabies prevention behaviors. Parental attentiveness showed a strong inverse relationship with risk behaviors (r = −0.30). Interventions demonstrated large pooled effect sizes (standardized mean differences [SMD] = 1.54–2.10), although statistical significance was affected by heterogeneity (I^2 >90%). Short interventions (<2 weeks) were significantly more effective (SMD = 1.93) than longer ones (SMD = 0.31). Eastern country settings yielded greater behavioral improvements than Western contexts.

Conclusion: Children's rabies prevention behaviors are shaped by contextual, cognitive, and parental influences. Short, developmentally appropriate, theory-based interventions – particularly those implemented in schools – demonstrate practical effectiveness. Standardized evaluation frameworks and culturally adapted strategies are essential for improving behavioral outcomes and informing One Health policy efforts in high-risk regions.

Keywords: child behavior, educational intervention, meta-analysis, One Health, rabies prevention, school health education, systematic review.

INTRODUCTION

Rabies remains a neglected yet deadly zoonotic disease, responsible for approximately 59,000 human deaths annually. Children aged 0–14 years are disproportionately affected, accounting for nearly 40% of rabies-related fatalities in Asia and Africa. This heightened vulnerability stems from frequent interactions with dogs, limited awareness of rabies risks, and delays in seeking treatment after exposure. Evidence suggests that children are three times more likely than adults to be bitten by dogs, largely due to their uninhibited behavior and close proximity to animals [1–3]. These factors underscore the urgent need for prevention strategies that prioritize behavioral modification alongside medical treatment.

Although rabies is entirely preventable through post-exposure prophylaxis (PEP) and widespread dog vaccination efforts [4–6], behavioral interventions are

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critical to reducing exposure, especially among children. The impact of PEP is often diminished by financial constraints, geographical barriers, and insufficient public awareness [7–9]. Teaching children specific preventive behaviors – such as avoiding stray dogs, recognizing signs of aggression in animals, and promptly cleaning bite wounds – can minimize dependence on PEP and promote timely responses. The World Health Organization's goal to eliminate human deaths from dog-mediated rabies by 2030 highlights the need for integrated approaches that combine medical, educational, and behavioral strategies [10].

Educational initiatives play a pivotal role in community empowerment, enabling individuals to identify symptoms early and seek appropriate care [11]. For children, such initiatives must focus on behavior-oriented prevention, including identification of rabies vectors, avoidance of high-risk encounters, and adherence to post-exposure care. Equipping healthcare providers with child-centered rabies prevention training – encompassing vaccine administration and age-appropriate communication techniques – is also essential [12]. Interactive, school-based learning approaches, such as simulations, storytelling, and gamified lessons, have shown strong potential in promoting awareness and encouraging safe practices among young learners [13].

Despite these promising strategies, there remains a lack of consolidated evidence regarding the behavioral determinants of rabies prevention and the effectiveness of interventions targeting children [14–16].

Despite the high burden of rabies among children in endemic regions, existing prevention efforts have largely focused on biomedical strategies such as PEP and mass dog vaccination campaigns. While effective, these measures are often constrained by financial, infrastructural, and accessibility limitations, particularly in low- and middle-income countries. As a result, behavioral interventions – particularly those targeting children – are increasingly recognized as essential for reducing rabies exposure and complementing existing control programs. Although several studies have explored knowledge, attitudes, and practices (KAP) related to rabies, few have systematically synthesized the behavioral determinants that influence rabies prevention practices specifically in children. In addition, while various educational interventions have been developed, their effectiveness varies widely depending on theoretical framework, delivery method, duration, and cultural context.

Previous reviews on rabies prevention have typically focused on general populations or clinical aspects of post-exposure care, neglecting the unique developmental and cognitive needs of children. Furthermore, no comprehensive meta-analysis to date has assessed the pooled effectiveness of child-focused rabies prevention interventions or identified the most influential behavioral predictors using a theory-informed framework. This gap in the literature limits the ability of public health stakeholders to design evidence-based, developmentally appropriate, and scalable interventions tailored to children – a population at heightened risk. Thus, a critical need exists to consolidate current findings and evaluate which factors most effectively promote rabies prevention behaviors in children, and which types of interventions yield the greatest impact.

This study aims to systematically review and quantitatively synthesize existing research on the determinants of rabies prevention behaviors and the effectiveness of corresponding interventions among school-aged children. Specifically, it seeks to:

1. Identify and assess psychosocial, cognitive, and environmental factors associated with rabies preventive and risk behaviors in children
2. Evaluate the effectiveness of educational and behavioral interventions designed to improve rabies prevention practices
3. Explore potential moderators such as intervention duration, delivery mode, and geographic setting to determine their influence on intervention outcomes
4. Provide theory-informed, practical recommendations for designing age-appropriate, culturally sensitive, and evidence-based rabies prevention strategies targeted at children.

By addressing these objectives, this review aims to inform the development of integrated, behavior-focused interventions that can be implemented through school systems and community health platforms to advance global rabies elimination goals.

MATERIALS AND METHODS

Ethical approval

This study is a systematic review and meta-analysis based on previously published data. As it did not involve the collection of primary data from human participants, ethical approval was not required.

Study period and location

The study was conducted from March 03 to July 31, 2025, at Srinakharinwirot University.

Study design and registration

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines [17], ensuring methodological rigor and transparency. The protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO) database under the registration number CRD420251085699 https://www.crd.york.ac.uk/PROSPERO/view/CRD420251085699. No significant deviations occurred during the review process.

Search strategy

A comprehensive search strategy was developed to identify relevant studies published between January 01, 2015, and December 31, 2024. Four electronic databases were systematically searched: PubMed, SCOPUS, Google Scholar, and the Thai Citation Index (TCI). The search strategy was guided by the PICOS framework, encompassing the following elements:

- Population: School-aged children
- Intervention: Rabies prevention education
- Comparator: Control or baseline group
- Outcomes: Preventive behaviors
- Study design: Cross-sectional, experimental, or quasi-experimental studies.

Two primary Boolean search strings were used. The first targeted studies examining behavioral determinants:

("children" OR "students" OR "school-aged children" OR "adolescents") AND ("factors" OR "predictors" OR "determinants" OR "association" OR "correlation") AND ("behavior" OR "practice" OR "dog safety" OR "rabies prevention" OR "bite prevention") AND ("rabies" OR "dog bite" OR "animal exposure").

The second focused on intervention studies:

("children" OR "students" OR "school-aged children" OR "adolescents") AND ("intervention" OR "education" OR "prevention program" OR "guideline" OR "curriculum") AND ("rabies" OR "dog bite" OR "animal exposure").

Database search dates were as follows: PubMed (March 03, 2025), SCOPUS (March 05, 2025), Google Scholar (March 07, 2025), and TCI (March 09, 2025). Only peer-reviewed articles published in English or Thai were included in the study. Articles in other languages were excluded due to translation limitations.

Eligibility criteria

Studies were included based on the following criteria:

- Observational studies had to assess rabies preventive behaviors – defined as actions that reduce exposure or transmission risk (e.g., avoiding stray dogs and seeking post-exposure care) [18–20] – in school-aged children using a cross-sectional or correlational design
- Intervention studies were required to use experimental, quasi-experimental, or pre-post designs and evaluate rabies prevention programs specifically targeting school-aged children.

Exclusion criteria included:

- Studies lacking measurement of rabies-related behaviors
- Studies focused solely on demographic variables without behavioral analysis
- Reviews, commentaries, case reports, and qualitative research.

All records were managed using EndNote X9 (Clarivate Analytics, Philadelphia, PA, USA) for reference management and duplicate removal. A two-stage screening process was used: Initial title and abstract review followed by full-text assessment. Two independent reviewers conducted the screening, with disagreements resolved through consensus or arbitration by a third reviewer.

Data extraction process

Data extraction was standardized using a pre-tested Microsoft Excel, Version 2024 (Microsoft Corporation, Redmond, WA, USA) template. The template was piloted on three studies to ensure clarity and consistency. For observational studies, extracted data included: author/year, country, sample demographics, behavioral variables assessed, outcomes, and quality ratings. For intervention studies, additional information was recorded: intervention type, design, delivery format, duration, facilitator, comparator group, behavioral outcomes, follow-up period, and key results.

Data extraction was performed independently by two reviewers. Any discrepancies were resolved by discussion or, when necessary, by involving a third reviewer.

Quality assessment

Each study's methodological quality was appraised using the appropriate Joanna Briggs Institute Critical Appraisal Checklist:

- 8 items for cross-sectional studies [21]
- 9 items for quasi-experimental studies [22]
- 13 items for randomized controlled trials [23].

Each item was rated as "Yes" (1), "No" (0), or "Unclear" (0). Items rated "Unclear" were conservatively scored as 0 to uphold methodological stringency. Studies were categorized based on the proportion of criteria met:

- High quality: >80%
- Moderate quality: 60%–80%
- Low quality: <60%.

Two reviewers conducted quality assessments independently, with conflicts resolved through consensus or by a third reviewer. The inter-rater reliability was strong, with a Cohen's kappa coefficient of 0.83.

Statistical analysis

A meta-analysis was conducted to quantitatively synthesize findings from both observational and intervention studies. For observational (correlational) studies, effect sizes included correlation coefficients (r) and standardized regression coefficients (β). Where only β values were reported, corresponding r values were estimated using the formula proposed by Peterson and Brown [24]:

$$r = 0.98\beta + 0.05$$

This transformation allowed for standardized effect size comparison across studies reporting different statistical outputs, though it assumes a linear relationship and should be interpreted with caution.

All r values were transformed into Fisher's z-scores before meta-analysis to stabilize variance and normalize distribution. The pooled effects were subsequently back-transformed into r for interpretability. For intervention studies, standardized mean differences (SMDs) with 95% confidence intervals (CIs) were calculated to compare pre-post changes within groups or between intervention and control groups at post-intervention.

Effect sizes were interpreted according to Cohen's guidelines: small (0.2), medium (0.5), and large (≥0.8) for SMDs; for correlation coefficients: small (0.1), medium (0.3), and large (≥0.5).

A random-effects model was employed throughout, given the expected variability in study populations, intervention types, measurement instruments, and cultural settings [25]. Heterogeneity was assessed using Cochran's Q and I^2 statistics [26], with I^2 values interpreted as low (25%), moderate (50%), or high (75%) heterogeneity.

Subgroup and sensitivity analyses

Subgroup analyses were conducted based on:

- Intervention duration: short (<2 weeks) versus long (>2 weeks)
- Geographic setting: Eastern versus Western countries.

These categories were selected based on the distribution of available studies. Other potential moderators (e.g., delivery mode and age group) were not analyzed due to insufficient subgroup sample sizes.

Leave-one-out sensitivity analyses were performed to evaluate the robustness of pooled effects and to identify influential studies or outliers. Where outliers were detected, results were recalculated after exclusion to observe shifts in effect estimates and heterogeneity.

Handling of missing data

When studies lacked standard deviations or reported incomplete data, imputation techniques were applied. Standard deviations were estimated from standard errors, CIs, or t-values using formulas recommended by the Cochrane Handbook. Where necessary, effect sizes were approximated using established conversion methods (e.g., from p-values or mean differences).

Publication bias assessment

Potential publication bias was assessed using Egger's regression test [27]. Where asymmetry was detected, the trim-and-fill method was applied to estimate and adjust for potentially missing studies. Funnel plots were generated to visually inspect bias and are included in the Supplementary Materials.

Software

All statistical analyses were performed using R software (version 4.3.1) and the "metafor" package

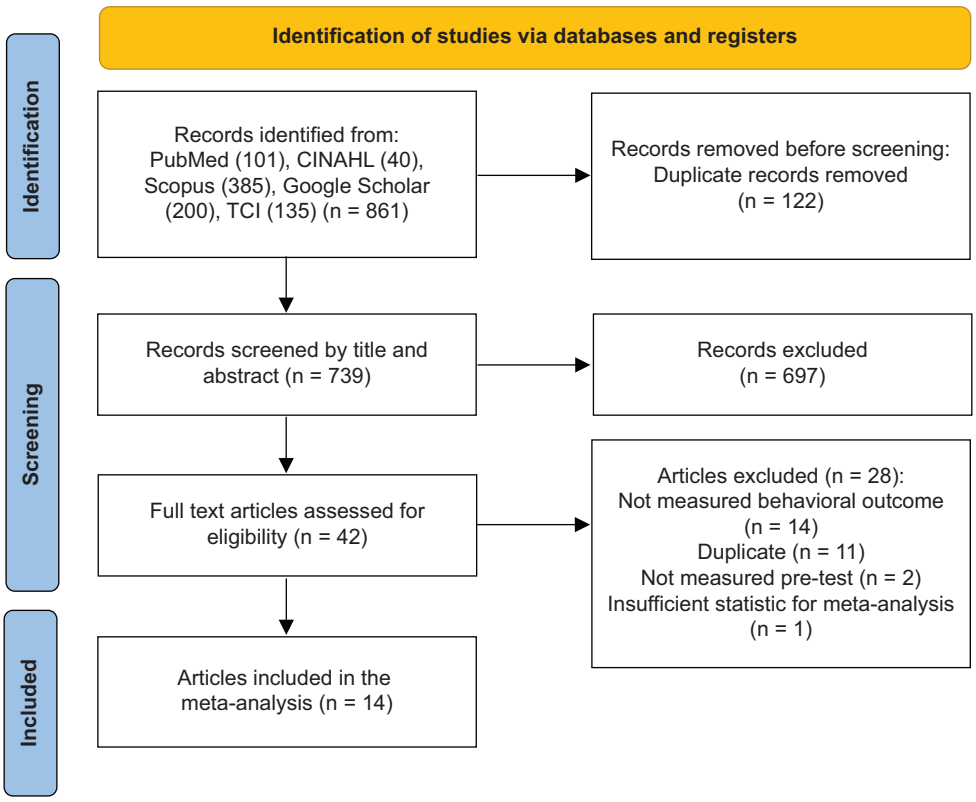

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram showing the article selection process.

(R Foundation for Statistical Computing, Vienna, Austria) [28]. Forest plots were used to present pooled effect sizes, 95% CIs, and heterogeneity estimates. A two-tailed $p < 0.05$ was considered statistically significant.

RESULTS

Study selection and screening process

A total of 861 records were initially retrieved from four databases. After removing 122 duplicates, 739 records remained for title and abstract screening. Of these, 697 articles were excluded for not meeting the inclusion criteria. The remaining 42 full-text articles were assessed for eligibility. Ultimately, 13 studies met all criteria and were included in the meta-analysis (Figure 1).

These 13 studies comprised six observational investigations focused on behavioral determinants and seven interventional studies assessing the effectiveness of rabies prevention programs in children.

Behavioral determinants of rabies prevention

Study characteristics

The six studies evaluating behavioral predictors (Table 1) [19, 29-33] were conducted across Germany, China, and Thailand, with Thailand accounting for the majority (66.7%) – reflecting a national emphasis on rabies education. Most studies (83.3%) recruited students directly, while one included caregiver perspectives. Gender distribution showed a predominance of female participants in four of the five student-based studies (60.3%–65.4%).

Key predictors identified

Rabies-related knowledge (66.7%), attitudes, and cognitive constructs such as self-efficacy (33.3%) were frequently examined predictors. One study uniquely explored caregiver attentiveness and permissiveness toward unsafe behaviors. The primary outcome in most studies (83.3%) was rabies-preventive or protective

Table 1: Summary of factors associated with rabies prevention behaviors among children.

Study	Country	Participants	Key factors identified	Behavioral outcomes	Main findings	Study quality
Laorujisawat *et al*. [19]	Thailand	287 students • 62.4% female • 50.9% had a history of dog bite	• Perceived severity • Perceived vulnerability • Response efficacy • Self-efficacy	• Rabies protective behaviors	Enhancing students' understanding through fear-inducing communication and effective education was crucial for promoting preventive behaviors	High
Arhant *et al*. [29]	Germany	402 caregivers (parents) • 82.4% mother • Average age: 33 years • 47% held a bachelor's degree	• Caregiver attentiveness • Allowance of unsafe behaviors	• Child-dog interactions	Caregiver attitudes and behaviors were significantly associated with children's behavior, highlighting the need for early intervention strategies to prevent dog bites	Moderate
Chen *et al*.[30]	China	9380 students • Age: 6–19 years (Mean=12.8) • 50.5% male	• Rabies knowledge • Attitude toward rabies	• Rabies prevention behaviors	Educational interventions to improve awareness and prevention strategies were effective in reducing dog bites among vulnerable children	High
Janeaim *et al*. [31]	Thailand	544 students • Age: 13–17 years • 63.5% female • 57.8% middle school	• Health literacy	• Rabies-related behaviors	Intermediary determinants, access to, and application of rabies-related health literacy significantly influence students rabies-related behaviors	High
Laorujisawat *et al*. [32]	Thailand	290 students • 60.3% female	• Rabies knowledge • Rabies attitudes	• Rabies protective behaviors	Educational programs that improve students' knowledge and attitudes toward rabies prevention significantly promoted protective behaviors	Moderate
Piboon *et al*. [33]	Thailand	156 students • 65.4% female	• Rabies knowledge • Perceived susceptibility • Perceived barriers	• Rabies protective behaviors	Knowledge of rabies, perceived risk, and perceived barriers were significantly correlated with rabies prevention behavior	Moderate

Table 2: Random-effects model of factors associated with rabies prevention behaviors among children.

Outcomes	Factors	k	n	Mean r effect size	95% CI		Test of null		Heterogeneity				Egger's regression		
					Lower	Upper	Z	p-value	Q	df	p-value	I^2	t	df	p-value
Rabies prevention behaviors	Environmental variables	2	1088	0.28	0.16	0.38	4.75	0.000	3.84	1	0.050	74.0	-	-	-
	KAP variables	3	736	0.22	0.15	0.29	6.06	0.000	0.74	2	0.692	0.0	-	-	-
	HBM variables	6	1198	0.07	−0.02	0.16	1.55	0.121	12.07	5	0.034	58.6	−0.60	4	0.583
	HBM variables (leave-one-out)	5	1042	0.11	0.05	0.17	3.69	0.000	1.11	4	0.893	0.0	0.43	3	0.694
	PMT variables	6	1460	0.16	0.10	0.22	5.22	0.000	6.46	5	0.264	22.6	−0.61	4	0.576
	Health literacy variables	4	2176	0.20	0.16	0.24	9.56	0.000	0.86	3	0.835	93.4	-	-	-
Rabies-related risk behaviors	Parental Attentiveness	6	1970	−0.30	−0.35	−0.26	−13.11	0.000	5.57	5	0.350	10.3	−0.77	4	0.483
	Parental allowance of unsafe behavior	6	1934	0.41	0.32	0.50	8.26	0.000	27.42	5	0.000	81.8	0.03	4	0.977
	KAP variables	2	18760	−0.10	−0.30	0.12	−0.87	0.383	226.64	1	0.000	99.6	-	-	-

k=Number of studies, n=Number of subjects, CI=Confidence intervals, df=Degree of freedom, KAP=Knowledge-attitude-practice theory, HBM=Health belief model, PMT=Protection motivation theory

behavior; one study focused on child-dog interaction behaviors.

Pooled effect sizes

Meta-analysis findings (Table 2) revealed the following significant positive associations with rabies prevention behaviors:

- Environmental variables (r = 0.28, 95% CI [0.16, 0.38])
- KAP variables (r = 0.22, 95% CI [0.15, 0.29])
- Health literacy (r = 0.20, 95% CI [0.16, 0.24])
- Protection motivation theory (PMT) constructs (r = 0.16, 95% CI [0.10, 0.22]).

Health Belief Model (HBM) constructs showed a non-significant association (r = 0.07), although significance emerged (r = 0.11) after removing one outlier focused on perceived barriers.

Parental influence on risk behaviors

Parental attentiveness demonstrated a moderate, negative correlation with risk behaviors (r = −0.30), while permissive parenting – defined by the allowance of unsafe behavior – had a moderate, positive association with risk behaviors (r = 0.41). No significant relationship was observed between KAP factors and rabies-related risk behaviors (RRBs). Heterogeneity across studies was substantial (I^2 = 0.0%–99.6%), but no publication bias was detected (Egger's test).

Interventions to improve rabies prevention behaviors

Study overview

Seven intervention studies (Table 3) [34-40] were conducted in diverse settings: Malaysia, the United Kingdom, Thailand, Bhutan, the United States, Egypt, and China. Participants ranged from 3 to 20 years old, with sample sizes from 45 to 280. Each country con tributed one study.

Intervention Types and Formats:

- Structured education: 3 studies (42.9%)
- Gamified/digital formats: 2 studies (28.6%)
- Video-based testimonial: 1 study (14.3%)
- Theory-based behavior modeling (PMT): 1 study (14.3%).

Intervention durations ranged from single-session lessons to multi-week programs. Delivery formats were context-specific and adapted to local needs.

Effectiveness of interventions

Most studies (6 out of 7; 85.7%) reported statistically significant improvements in either rabies-specific behaviors or general dog safety. One study (14.3%) found no significant behavioral changes between intervention and control groups. Methodological quality was high in six studies and moderate in one.

Meta-analysis of pre/post-test data

Table 4 presents pooled results:

- Overall SMD: 1.54 (95% CI [−0.21, 3.29]), indicating a large but not statistically significant effect
- After removing outliers: SMD increased to 2.10 (95% CI [−0.23, 4.43])
- Heterogeneity: Extremely high (I^2 = 98.3%–98.4%)
- Publication bias: Not detected (Egger's test).

Despite wide CIs, the large effect sizes suggest meaningful improvements in rabies prevention behaviors following intervention exposure.

Subgroup analysis of pre/post-interventions

- Duration-based analysis:
  - <2 weeks: SMD = 1.64 (95% CI [1.15, 2.13]) – statistically significant and practically scalable
  - >2 weeks: SMD = 2.45 (95% CI [−1.76, 6.65]) – larger magnitude but non-significant
- Region-based analysis:

Table 3: Summary of intervention aimed at improving rabies prevention behaviors among children.

Authors (year)	Country	Participants characteristics	Intervention type/Description	Duration/ Frequency	Comparison group	Behavioral outcomes	Main findings	Study quality
Halim *et al*. [34]	Malaysia	Ages 13–14 Exp: n=222 Cont: n=188	Rabies Hunter game application Approach: Gamification and One Health Contents: Safety knowledge related to recognizing dog behavior, perceived vulnerability, precautionary behaviors around dogs, and help-seeking actions following dog bites	40 min/ session, over 4 weeks	Not specified	• Precautionary behaviors around dogs • Help-seeking behavior following dog bites	Help-seeking behavior significantly improved in the intervention group, with no similar change in the control group. Although knowledge and behavior improved immediately post-intervention, these effects were not sustained at follow-up	High
Lakestani and Donaldson [35]	UK	Ages 3–5 Exp: n=36 Cont: n=34	Dog bite prevention Contents: Training on interpreting dog behavior to recognize emotional cues	1 day	Same structure, but focused on wild animals	• Recognition of dogs' emotional states	The intervention group showed a significant increase in correct responses regarding dog behavior at post-test. Their behavioral performance improved significantly, whereas no meaningful change was observed in the control group.	High
Laorujisawat *et al*. [36]	Thailand	Ages 8–10 Exp: n=23 Cont: n=22	Rabies prevention behavior promotion activity Approach: Protection motivation theory Contents: Perceived vulnerability, perceived severity, response efficacy, and self-efficacy	15–20 min/ session, over 6 weeks	Did not participate in any activities	• Rabies preventive behaviors	Following the intervention, there was no significant difference in rabies preventive behaviors between the experimental and control groups	High
Lungten *et al*. [37]	Bhutan	Ages 14–20 Exp: n=94 Cont: n=35	Awareness education program Contents: Causes of rabies, transmission routes, symptoms, preventive measures, first aid procedures, and appropriate behavior around dogs	75 min in a single session	Did not participate in any activities	• Dog bite safety measures	Safety behavior scores in the intervention group improved significantly compared to the control group, both immediately after the educational session and at the 3-month follow-up	High
Schwebel *et al*. [38]	USA	Ages 4–5 Exp: n=35 Cont: n=34	Dog Safety Website Contents: Basic safety skills for interacting with dogs, including practice and learning of relevant cognitive skill	90 min/ visit×2 visits, with a 3 weeks interval	Transportation of Safety Website	• Safe behavior with dogs	Children who complied with the intervention protocol scored significantly higher in knowledge and recognition of safe behavior with dogs compared to the control group	High
Sharaa and Ali [39]	Egypt	Ages 14–15 Exp: n=100	Educational program about rabies Contents: Causes, modes of transmission, symptoms, treatment and possible first aid measures of rabies	30–45 min/ session, two sessions per week (Total 8 sessions)	-	• Practice toward rabies	There was a significant difference in the mean score of practice of students regarding rabies before and after implementation of the program	Moderate

(Contd...)

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Table 3: *(Continued).*

Authors (year)	Country	Participants characteristics	Intervention type/Description	Duration/ Frequency	Comparison group	Behavioral outcomes	Main findings	Study quality
Shen *et al*. [40]	China	Ages 9–11 Exp: n=143 Cont: n=137	Video-based testimonials intervention Contents: Safety lessons learned from actual dog-bite experiences	36 min in a single session	Video with the same structure, but focused on drowning risk	• Risky behaviors with dogs	Children who watched the educational testimonial video on dog-bite prevention demonstrated fewer risky simulated behaviors with dogs compared to the comparison group	High

Note: Exp=Experimental group, Cont=Control group, UK=United Kingdom, USA=United States of America

- Eastern countries: SMD = 2.98 (95% CI [−0.77, 6.74])
- Western countries: SMD = 0.79 (95% CI [−0.30, 1.89]).

Although not statistically significant, the direction of these effects suggests stronger outcomes in culturally tailored, resource-constrained contexts. Short interventions demonstrated greater consistency and feasibility for implementation.

Meta-analysis of post-intervention-only studies

Risk behaviors and preventive actions

Table 5 summarizes findings:

- RRBs: SMD = −0.40 (95% CI [−0.82, 0.01])
- Preventive behaviors: SMD = 0.73 (95% CI [−0.08, 1.54])
- After removing outliers: SMD = 1.13 (95% CI [0.09, 2.17]), achieving statistical significance.

Heterogeneity remained high (I^2 >90%). Nonetheless, these results support the practical effectiveness of real-world rabies prevention programs when implemented with high fidelity.

Further subgroup findings:

- <2-week interventions: SMD = 1.93 (95% CI [0.78, 3.08]) – significantly effective
- >2-week interventions: SMD = 0.31 (95% CI [−0.10, 0.70]) – lower impact
- Eastern countries: SMD = 1.51
- Western countries: SMD = 0.75.

The data reinforce that short, culturally tailored interventions yield the strongest behavioral outcomes, particularly in high-burden settings with limited resources and higher child exposure risk.

Publication bias evaluation

Funnel plots for both the observational and intervention studies appeared symmetrical (Supplementary Figures S1 and S2). Egger's test did not indicate significant publication bias for observational studies (z = 1.02, p = 0.31) or intervention studies (z = 0.87, p = 0.41). The trim-and-fill method did not suggest the need to impute missing studies. However, given the limited number of included studies (<10/group), the results should be interpreted cautiously due to the low power of these tests.

DISCUSSION

Synthesis of key findings

This systematic review and meta-analysis consolidated existing evidence on the behavioral determinants of and interventions for rabies prevention among children. Thirteen studies met the inclusion criteria – six observational and seven interventional – providing insight into critical behavioral predictors and the practical effectiveness of various child-focused prevention strategies across diverse global settings.

Table 4: Random-effects model of interventions with pre/post-test groups.

Outcomes	Criteria	Subgroup (study)	k	SMD	95% CI (Lower-Upper)	Test of null		Heterogeneity				Egger's regression		
						Z	p-value	Q	df	p-value	I^2	t	df	p-value
Rabies prevention behaviors	All	-	7	1.54	−0.21–3.29	1.73	0.084	380.96	6	0.000	98.4	1.92	5	0.113
	All (remove outliers)	-	5	2.10	−0.23–4.43	1.77	0.077	232.50	4	0.000	98.3	0.48	3	0.662
	Test for subgroup differences													
	Duration	<2 weeks	2	1.64	1.15–2.13	-	-	0.14 (p = 0.708)	1	0.078	-	-	-	-
		>2 weeks	2	2.45	−1.76–6.65	-	-							
	Country	Eastern	2	2.98	−0.77–6.74	-	-	1.20	1	0.272	-	-	-	-
		Western	2	0.79	−0.30–1.89	-	-							

k=Number of studies, n=Number of subjects, CI=Confidence intervals, df=Degree of freedom, SMD=Standardized mean differences

Table 5: Random-effects model of interventions at post-intervention.

Outcomes	Criteria	Subgroup (study)	k	SMD	95% CI (Lower–Upper)	Test of null		Heterogeneity				Egger's regression		
						Z	p-value	Q	df	p-value	I^2	t	df	p-value
Rabies-related risk behaviors	All	-	3	−0.40	−0.82–0.01	−1.91	0.056	13.82	2	0.001	85.5	-	-	-
Rabies prevention behaviors	All	-	6	0.73	−0.08–1.54	1.76	0.079	113.84	5	0.000	95.6	1.95	4	0.123
	All (remove outliers)	-	4	1.13	0.09–2.17	2.13	0.033	46.60	3	0.000	93.6	-	-	-
	Test for subgroup differences													
	Duration	<2 weeks	2	1.93	0.78–3.08	-	-	6.86	1	0.009	-	-	-	-
		>2 weeks	2	0.31	−0.10–0.70	-	-							
	Country	Eastern	2	1.51	−0.48–3.50	-	-	0.41	1	0.520	-	-	-	-
		Western	2	0.75	−0.42–1.92	-	-							

k=Number of studies, n=Number of subjects, CI=Confidence intervals, df=Degree of freedom, SMD=Standardized mean differences

Behavioral determinants of rabies prevention in children

Environmental and cognitive influences

Environmental variables emerged as the most robust predictors of rabies prevention behaviors in children, followed by KAP factors, health literacy, and PMT constructs. These findings affirm that children's behaviors are shaped by both contextual environments and cognitive processing, in line with Bronfenbrenner's Ecological Systems Theory [41]. This framework highlights the role of community infrastructure, healthcare access, physical surroundings, and sociocultural conditions in influencing behavioral outcomes. Key factors – such as proximity to healthcare services, the presence of stray animals, and local dog control policies – significantly shape children's risk exposure and responses.

Support from cognitive models

The observed associations also align with cognitive-behavioral frameworks. The KAP model suggests a linear progression from knowledge to attitudes and ultimately to practices [42]. The findings corroborate this model, indicating that improved knowledge and positive attitudes toward rabies prevention lead to safer behaviors in children [43, 44]. Health literacy, as defined by Sørensen *et al*. [45], plays a crucial role in enabling children to access, understand, and apply health-related information – such as recognizing animal aggression or seeking treatment after exposure.

Insights from PMT and HBM

PMT further supports these findings by proposing that behavior is influenced by perceived threat severity, vulnerability, and response efficacy [46]. The positive association between PMT constructs and preventive behaviors mirrors findings from studies on injury prevention and zoonoses [47]. However, constructs from the HBM showed limited association with behavior. On excluding an outlier focused on perceived barriers, a small but statistically significant effect emerged, suggesting that developmental factors may affect how children interpret structural risks like healthcare access [48]. Younger children, often dependent on caregivers, may not perceive or act on barriers in the same way as adults.

Role of parenting

Parental factors also proved influential. Higher parental attentiveness was associated with a significant reduction in risk behaviors, implying that close supervision, clear boundaries, and proactive

communication can help children avoid dangerous animal encounters. In contrast, permissive parenting – marked by inadequate enforcement of safety norms – correlated positively with risky behaviors. Children lacking structured guidance were more prone to provoking or approaching stray dogs [49, 50], underlining the importance of the home environment in rabies prevention.

Effectiveness of rabies prevention interventions

Intervention diversity and theoretical basis

The included interventions varied widely in design, duration, and theoretical foundations. Traditional educational models were the most commonly implemented, followed by gamified interventions, testimonial-based learning, and theory-informed behavior modeling. This diversity underscores the importance of tailoring content to children's cognitive stages and learning preferences [51].

Meta-analytic outcomes

The meta-analysis of pre/post-test data indicated a large overall effect size (SMD = 1.54), which increased (SMD = 2.10) after removing outlier studies. Although not statistically significant due to wide CIs, the magnitude suggests meaningful behavioral improvements. The post-intervention-only studies demonstrated significant effects after outlier exclusion, confirming that structured, developmentally appropriate interventions can yield substantial gains.

Interactive and engaging approaches

Children responded positively to interactive formats – such as storytelling, role-playing, and digital simulations – which enhanced engagement and retention [52, 53]. Despite promising results, notable heterogeneity remained, likely due to variations in delivery quality, participant demographics, and cultural tailoring. These inconsistencies emphasize the need for standardized intervention models and evaluation protocols to enable consistent assessment across settings.

Influence of duration and geographic region

Duration of interventions

Subgroup analyses highlighted the greater effectiveness of brief interventions (<2 weeks), which yielded statistically significant improvements in preventive behaviors (SMD = 1.64). These concise formats are not only developmentally appropriate for children but also practical for large-scale implementation in schools or community settings. In contrast, longer interventions showed higher but statistically non-significant effects, possibly due to fatigue, drop-out, or inconsistent content delivery.

Regional variations in impact

Studies conducted in Eastern countries reported larger effects (SMD = 2.98) compared to Western settings (SMD = 0.79), suggesting that interventions may have greater resonance in high-burden or culturally aligned environments. Although not statistically significant, these regional trends warrant further exploration. The superior performance of shorter, targeted interventions is also supported by cognitive load theory [54], which posits that brief and well-organized instruction minimizes cognitive overload and optimizes learning. Empirical findings consistently support the use of short, focused interventions for children's health education [55, 56].

Theoretical integration

The study's results are deeply rooted in established behavioral and developmental theories. The KAP model, health literacy frameworks, and PMT together offer a multidimensional understanding of how knowledge, motivation, and perceived capability influence child behavior. The limited explanatory power of HBM constructs may indicate a developmental mismatch between its assumptions and children's cognitive capacities, particularly in scenarios requiring independent action. This highlights the necessity of using age-appropriate theoretical models when designing, implementing, and evaluating behavior change interventions in pediatric populations.

Research implications

This review reveals both advancements and persistent gaps in rabies prevention research for children. Notable implications include:

- Designing brief, engaging, and developmentally suitable interventions (e.g., gamification and storytelling)
- Applying behavior change theories such as KAP and PMT to enhance intervention effectiveness
- Incorporating regional and cultural contexts for better relevance and uptake
- Strengthening methodological rigor through randomized controlled trials, long-term follow-ups, and objective behavioral measures
- Establishing standardized frameworks for intervention delivery and outcome assessment to facilitate global comparability and policymaking.

These recommendations can guide the development of evidence-based, child-centered strategies by schools, public health institutions, and community-based programs.

Policy and practice recommendations

From a One Health perspective, the findings support the following action points to improve rabies prevention among children, particularly in resource-constrained settings:

- Curricular Integration: Incorporate rabies education into school health curricula to foster early awareness and behavioral safety
- Design of Interventions: Prioritize brief, age-appropriate formats such as interactive storytelling, gamified lessons, and practical demonstrations

- Cross-Sector Collaboration: Foster collaboration between health, education, and veterinary sectors to deliver integrated community-based interventions
- Digital Outreach: Leverage mobile and digital platforms to expand access in remote or underserved areas
- Policy Alignment: Promote inclusion of rabies prevention in national and global health agendas to secure sustained investment
- Evaluation Standardization: Develop consistent evaluation tools to measure behavioral outcomes and support evidence-driven policy decisions.

Together, these strategies present a scalable and theory-driven roadmap for enhancing rabies prevention in children and reducing global public health risk.

Limitations

While methodologically robust, this review faces several limitations:

1. High heterogeneity: Effect size variability (I^2 >90%) reflects differences in study populations, design, and measurement, limiting generalizability
2. Causal inference constraints: The predominance of cross-sectional and quasi-experimental designs restricts causal interpretation. Only a few studies included follow-up assessments
3. Reliance on self-reports: Most studies used self-reported behavioral data, which may introduce recall and social desirability bias. Future studies should incorporate observational or third-party assessments
4. Subgroup limitations: Small numbers within subgroup analyses reduced statistical power for moderator exploration
5. Literature scope: Exclusion of gray literature, conference proceedings, and non-English/Thai studies may have omitted relevant evidence and limited the global applicability of findings.

Future research should address these limitations by expanding language inclusivity, applying rigorous longitudinal designs, and incorporating diverse populations and settings to build a more comprehensive evidence base.

CONCLUSION

This systematic review and meta-analysis provides a comprehensive synthesis of the current evidence on the behavioral determinants of and intervention strategies for rabies prevention among children. The findings affirm that children's preventive behaviors are influenced by a combination of environmental factors, health literacy, and cognitive constructs, particularly those rooted in the KAP and PMT frameworks. Meta-analytic results revealed that environmental variables (r = 0.28), KAP variables (r = 0.22), health literacy (r = 0.20), and PMT variables (r = 0.16) were significantly associated with rabies prevention behaviors. Parental attentiveness was inversely related to risk behaviors (r = −0.30), while permissive parenting was positively associated with unsafe interactions (r = 0.41), underscoring the critical role of caregiving context.

Intervention studies demonstrated large pooled effect sizes (SMDs ranging from 1.54 to 2.10), particularly when brief (<2 weeks) and grounded in behavioral theory. Although high heterogeneity limited statistical significance in pooled estimates, post-intervention-only studies confirmed the effectiveness of short, targeted interventions (SMD = 1.13) in improving preventive behaviors. These results suggest that developmentally appropriate, culturally contextualized programs – especially those delivered through schools and community-based platforms – are both feasible and impactful.

One of the major strengths of this review lies in its rigorous methodology, including PROSPERO registration, a theory-informed framework, dual independent screening and extraction, and detailed subgroup and sensitivity analyses. The inclusion of both observational and interventional data allowed for a nuanced understanding of what influences behavior and what works to change it. This dual focus advances current knowledge beyond descriptive accounts and toward actionable, evidence-based recommendations.

Future research should prioritize longitudinal and randomized controlled trials to establish causal pathways, assess long-term intervention impact, and refine strategies based on age, setting, and delivery mode. Objective measurement tools and standardized outcome frameworks are essential to enhance comparability and reliability across studies.

In conclusion, this review highlights the urgent need to integrate behavioral strategies into global rabies elimination efforts. By leveraging brief, theory-driven, and age-appropriate interventions, particularly in high-burden regions, stakeholders can empower children as key agents of rabies prevention. A One Health approach – uniting health, education, and veterinary sectors – offers a scalable pathway to reducing rabies-related morbidity and mortality among the world's most vulnerable populations.

DATA AVAILABILITY

The R scripts used to perform the meta-analysis, along with other supplementary materials, such as funnel plots, the PRISMA checklist, and related documents, are available from the corresponding author upon reasonable request.

AUTHORS' CONTRIBUTIONS

NJ, UI, and CS: Conceived and designed the study. NJ and CS: Data collection, processing, and analysis, interpreted the results, critical revisions, and played key roles in final preparation and editing, ensuring the manuscript's accuracy and clarity. CS: Interpreted the

results and drafted the manuscript. All authors have read and approved the final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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