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Harnessing R Software and Artificial Intelligence for Inductive Qualitative Insights on Missed Opportunities for Vaccination

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Abstract

Background: Missed opportunities for vaccination (MOV) hinder full immunization coverage, with evidence suggesting that an MOV results from multiple stakeholder factors. Understanding these determinants and finding practical solutions is crucial for improving the Expanded Program on Immunization. This study investigates caregivers' and health workers' perspectives on MOV reasons and reduction strategies in Cameroon. **Methods:** We performed qualitative analysis using data from a cross-sectional study. Open-ended responses underwent R-based processing (tokenization, stop-word removal, topic modeling) and AI-assisted inductive analysis to generate and validate themes through manual review. We proposed an R tutorial to conduct such analyses. **Results:** Caregivers cited vaccine stockouts, service interruptions, lengthy waits, and competing priorities, resulting in frustration or missed doses. Health workers identified training gaps, heavy workloads, documentation problems, and logistical issues. Mapping findings to the COM-B (Capability, Opportunity, Motivation-Behavior) model revealed knowledge gaps, opportunity constraints, and motivational challenges. Recommended solutions included continuous vaccine availability, improved provider-caregiver communication, appointment reminder systems, enhanced staff training, and better supervision. AI-assisted analysis enabled systematic theme identification and validation. **Conclusion:** Reducing MOV requires integrated approaches addressing capability, opportunity, and motivation among caregivers and providers. Combining inductive analysis with AI-driven analysis offers actionable insights for implementing interventions to strengthen immunization systems.

Keywords

Missed Opportunities for Vaccination (MOV), Caregivers, Health Workers, Qualitative Analysis, Inductive, COM-B Model, AI and R

1. Introduction

Qualitative analysis is based on two distinct yet complementary methodological frameworks: the deductive and inductive approaches [1]-[3]. The deductive approach follows a hypothetico-deductive logic, guided by pre-established theoretical models and coding frameworks [1] [4]. It allows for empirical verification of existing concepts or theories by directing the analysis toward predefined thematic categories. In practice, this approach identifies questions directly linked to specific conceptual domains, thus enabling multiple possible answers but within a limited thematic scope [5]-[7]. In contrast, the inductive approach avoids any initial categorization, allowing themes to emerge organically from semantic patterns in the data. In addition, it is particularly suited to automated natural language analysis techniques, such as topic modeling, which extract latent thematic structures from unstructured text [2] [5]. In exploring reasons for and solutions to missed opportunities for vaccination (MOV), the inductive perspective facilitates a deeper understanding of participants' views without imposing external analytical constraints [8].

Multiple conceptual frameworks have been proposed to understand why children remain unvaccinated or only partially vaccinated [9]-[11], and these have been applied in different contexts to highlight important reasons for health status [12]-[14], namely in Africa for the MOV perspectives, or designing behaviour change interventions [13] [15]-[18]. Some factors are specific to particular stakeholders, such as caregivers or health workers, while others are cross-cutting health system issues [13] [14]. The Theoretical Domains Framework (TDF) is one such integrative framework, comprising 14 domains that encompass a broad range of behavioral determinants: knowledge; skills; social/professional role and identity; beliefs about capabilities; optimism; beliefs about consequences; reinforcement; intention; goals; memory, attention, and decision processes; environmental context and resources; social influences; emotions; and behavioral regulation [14]. While TDF offers a comprehensive taxonomy of behavioral influences, it does not in itself guide intervention design [19]-[21]. To address this limitation, the Behavior Change Wheel (BCW) was developed, placing the Capability, Opportunity, Motivation-Behavior (COM-B) model at its core [16]. This model links identified barriers and facilitators to practical intervention strategies [22]. Both TDF and COM-B have been successfully applied in various health contexts, including the pre-implementation phase of quality improvement programs [23], and immunization research. In this study, we extend these frameworks by applying them to qualitative data from caregivers and health workers in the Mifi Health District,

Cameroon. Specifically, we present an integrated analysis to portray the key reasons and solutions reported by caregivers and to map these insights within the TDF and COM-B models, thereby linking participants' lived experiences to theoretically grounded intervention pathways. Although qualitative analysis is often conducted with specialized software such as NVivo or Atlas.ti, particularly under deductive frameworks, few studies, to our knowledge, have leveraged the R programming environment to explore participants' free-text responses [3] [24]. The use of AI in qualitative health research is a recent development [25]-[27]. Our approach therefore contributes to methodological innovation in qualitative research by demonstrating how R can be leveraged to perform inductive text analysis, offering transparent, reproducible, and data-driven insights. Beyond identifying themes, the integration of R and AI-assisted tools provides researchers, especially in resource-limited settings, with practical methods to structure, interpret, and contextualize qualitative findings.

2. Methodology

2.1. Data Availability

We used data from a cross-sectional study (mixed-study design) in 2024 in the Mifi Health District, Cameroon, to explore perceptions around missed opportunities for vaccination (MOV). Preliminary estimates from the West Region suggest that up to 60% of children missed one or more vaccine antigens, while nearly 70% of health workers experienced difficulties identifying contraindications to vaccination [28]. Data were collected from caregivers of children under 24 months and health workers across several health facilities through focus group discussions that were conducted separately for caregivers and health workers.

The present article focuses exclusively on the qualitative dimension with the aim of exploring only viewpoints. This decision was made to allow themes to emerge inductively from the qualitative data, unconstrained by a predefined coding framework, while also showcasing the feasibility of applying R for qualitative analysis. By using R for tokenization, topic modeling, and visualization, we aimed to enhance transparency, reproducibility, and efficiency in qualitative health research. Traditionally, qualitative verbatim data are explored using software such as NVivo and ATLAS.ti, often within predefined theoretical frameworks, although these tools are not always easily accessible to researchers. This work is proposing to use R to enhance and learn more from the data.

2.2. Data and Methods

Six focus groups were conducted: 12 caregivers (all women) from two health facilities (CMA Djeleng and CS Sainte Union), and 25 health workers from four health facilities (CMA Djeleng, CMA Lafe, Baleng, CS Sainte, and HD Famla Union). Data collection followed ethical approval (reference: 480/30/06/2023/CE/CRERSH-OU), with written and verbal consent obtained from participants. Discussions were audio-recorded, transcribed into text, and reviewed for accuracy. Initial content was

in French, organized in Excel by facility and participant type. Data cleaning started in Excel with removal of accents, and use of semi-columns to separate sentences. After data import, data cleaning continues in in R using tools for text cleaning, tokenization, and translation from French to English for publication. Indeed, the textual corpus underwent standard preprocessing, including punctuation removal, lowercasing, and normalization. A tokenization step was applied to break the text into lexical units called tokens, and common stopwords were removed to focus on semantically meaningful terms. After the data cleaning process in R, the texts (initially recorded in French) were exported in Excel, transcribed into English for publication purposes and re-imported in R as a CSV dataset file. The R tutorial used for the analysis is available in supplementary materials.

We initiated our analysis by visually examining word frequency distributions and generating word clouds to emphasize prominent terms. Latent Dirichlet Allocation (LDA) was then used to uncover topic clusters based on co-occurring words [29], utilizing both single-word and bigram analyses. The identification of bigrams (pairs of consecutive words) helped reveal meaningful multi-word themes relevant to missed opportunities for vaccination [30] [31].

We selected nine topics (k = 9) for our study, aligning with common literature practices [32] [33]. For each topic, we extracted the main keywords and we then used artificial intelligence to group these words into a single semantic field, enabling us to assign a meaningful label or title that best reflected the set of words.

The AI provided initial guidance, and we contextualized the results in relation to the studied theme, the identified reasons/solutions, and the expected outcomes, after submitting the entire corpus to AI-assisted analysis. We manually compiled the results into tables.

To this end, we first provided the AI with the definition of MOV and the 2017 WHO document [34]. We also communicated the three levels of reasons and solutions, namely: personnel, parents, and the health system. The raw text (translated into English) was submitted to AI with the condition of extracting concepts related to missed opportunities for vaccination (MOV), both for the underlying reasons and the proposed solutions. This data-driven approach uncovered dominant themes in participant discourse, highlighting perceived causes of missed opportunities for vaccination as well as practical recommendations for strengthening immunization uptake. Each dominant theme was supported by illustrative quotes extracted from participants' responses. Indeed, after the identification of titles that best reflect the set of words, we asked AI to identify relevant quotes that best match the titles, and we verified within the text if the choice was correct. Analyses were conducted separately for caregivers and for health workers.

2.3. Using the COM-B Model to Present Our Findings

Concepts related to the Theoretical Domains Framework (TDF) and the COM-B model were defined based on previous studies [35]. Capability was defined as the caregiver's capacity to access and utilize immunization services for their child during contact with a health facility. This includes domains such as knowledge, skills,

memory, attention, and decision-making processes. Opportunity was defined as contextual factors, both environmental and social, external to the caregiver that influence the uptake of immunization services for their child during contact with a health facility, including domains such as environmental context and resources, and social influence [36]. Motivation was defined as the caregiver's cognitive processes that shape behavior toward immunization. This includes domains such as social or professional role and identity, beliefs about capabilities, optimism, beliefs about consequences, reinforcement, intention, goals, emotions, and behavioral regulation. We mapped the "reasons" and "solutions" identified by caregivers and health workers into the relevant TDF domains and then consolidated them into the broader COM-B categories. Text processing and paragraph structuring in this manuscript were made or refined using generative AI tools (ChatGPT4.5 by OpenAI) under the supervision of the authors. Final interpretations and conclusions remain the responsibility of the researchers.

3. Results

3.1. Overview of Analytical Outputs

Among the 20 most frequently mentioned words by health workers, the majority referred to the child, vaccination, and the health personnel themselves, as shown by the word clouds and bar charts, along with other action verbs such as "vaccinate" or "vaccine" (**Figure S1**). This reflects the context in which the interview took place (**Figure S1**). Theme-by-theme presentation from the LDA model showed 9 themes with their corresponding words (**Figure S2**). The two-by-two relationship between the views of health workers revealed several reasons for MOV and strategies for strengthening immunization activities (**Figure 1**). These included contraindication to vaccination like severe illness, parents' refusal, vaccine shortages, enhancing awareness and health education, addressing vaccine shortages, improving vaccination registries and consultation processes (**Figure 1**).

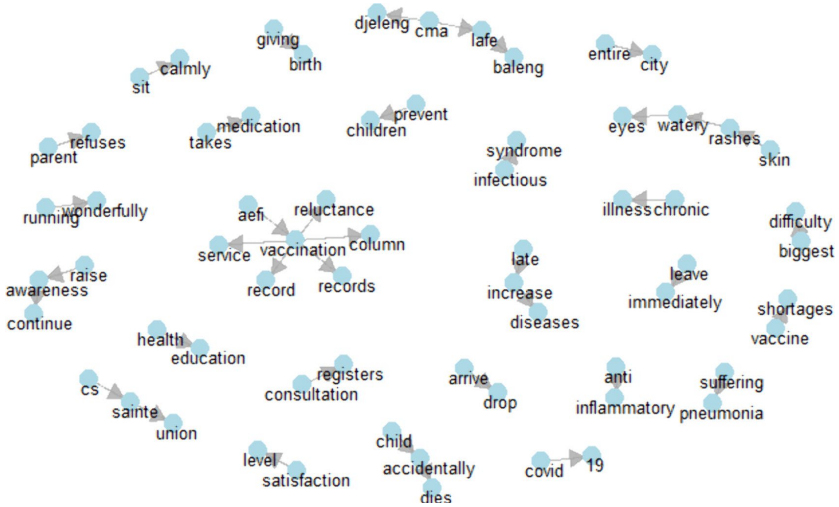

Figure 1. bigram describing connection among views expressed by health workers in the Mifi health district, 2024.

Among caregivers, the most frequently mentioned topics included vaccine stockouts, the child, and vaccination (Figure S3). These concerns were likely linked to themes such as Vaccine stockouts, Interrupted services, Caregiver frustration, Impact on children's health, and Passive acceptance of system failures (Figure S3). In addition, the most frequently cited words by thematic category are presented in Figure S4. Bigrams revealed vaccine shortages occurred, and waiting time as views emerged from caregivers (Figure 2). This type of figure is especially important to connect multiple words, and provide an overall meaning, or theme.

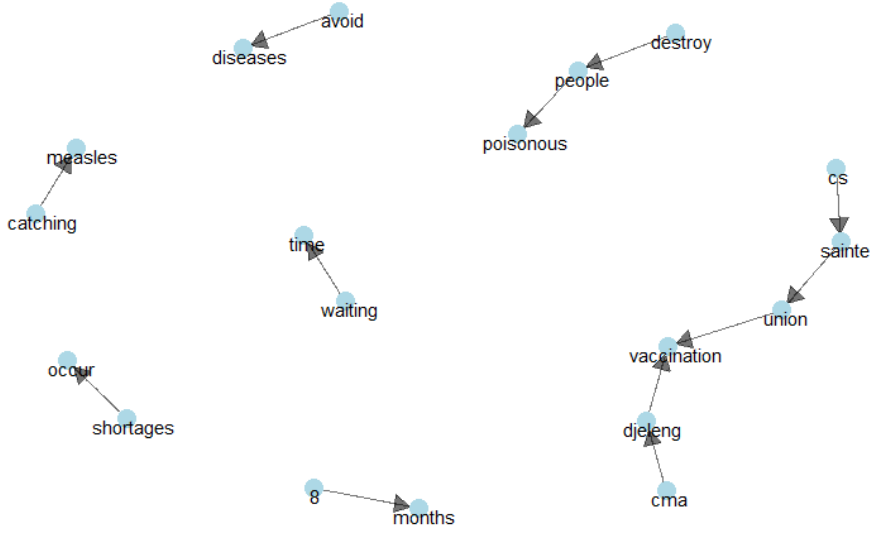

Figure 2. Bigram describing connection among views expressed by caregivers in the Mifi health district, 2024.

3.2. Health Workers' Themes Identified through AI-Assisted Analysis: Overall Analysis

For each theme, we entered the associated top words (Figure S2) into the AI workspace, which generated a preliminary title, an initial interpretation, and illustrative quotes identified from the overall text submitted to AI. These outputs were then complemented and refined by the authors, with all quotes extracted from the original transcripts and cross-verified for accuracy. Themes related to contraindications and febrile children were consolidated and reframed to explicitly distinguish between clinically appropriate deferral of vaccination and missed opportunities arising from inadequate follow-up or communication (Table 1).

Table 1. Thematic synthesis of health workers' perspectives on determinants of missed opportunities for vaccination (MOV), Mifi Health District, 2023, Cameroon.

Merges themes' titles	Themes identified from Figure S2	
Health System Constraints and Organization	Theme 1 ***Theme*** **1**: *Health Personnel Knowledge and Practices Influencing MOV*	Theme 5 ***Theme*** **5**: *Organizational problems and overload in health centers*

	Top words: personnel, to do, child, vaccine, that he, is not, mothers, vaccinate, illness **Interpretation:** This theme highlights the crucial role of health personnel in preventing missed opportunities for vaccination (MOV), particularly through their understanding of vaccination criteria (e.g., not vaccinating a sick child) and their motivation at work. Shortages of staff and lack of motivation are identified as potential causes of MOV. **Illustrative quotes:** • "*More staff are needed. In case of illness, a child with a fever… we do not vaccinate.*" • "*Motivate the staff; unmotivated personnel, even if they have received all the training… it is useless.*"	**Top words:** vaccination, it is, vaccinate, child, that he, mothers, staff, children, vaccine, that we **Interpretation:** Poor organization and staff overload delay vaccinations and discourage mothers, leading to missed opportunities. **Illustrative quotes:** • "*The reception must be improved; sometimes we wait the whole day and are not vaccinated.*" • "*There are too many children and too few staff to manage vaccinations.*" • "*Sometimes children are turned away because the vaccination card was not filled in correctly, even though they were up to date.*"
Caregiver-Related Factors (Knowledge, Behavior, Perceptions)	***Theme* 2:** *Parental Responsibility and Awareness as Factors of MOV* **Top words:** vaccine, child, do, it is, children, case, that he, vaccine, vaccinate, comes **Interpretation:** This theme highlights that MOV can also stem from parental behavior or knowledge, as caregivers do not always bring their children on time for vaccination or express concerns about side effects. The lack of reminders and insufficient awareness-raising play an important role. **Illustrative quotes:** • "*Mothers are afraid of side effects… It is the mother's responsibility to bring the child for vaccination; no one will remind her.*" • "*Mothers do not arrive on time; they come in dribs and drabs—that is the biggest difficulty.*"	
Clinical Decision-Making and Vaccination Eligibility Inconsistent Practices and Variability in Care	***Theme* 3**: *Child Health Status and Vaccination Eligibility Influencing MOV* **Top words:** staff, child, it is, vaccinate, that we, vaccine, vaccination, fever, case **Interpretation:** Health workers sometimes refuse to vaccinate sick children (with fever or infections). While this practice is clinically appropriate, it can contribute to MOV if follow-up visits are not ensured. **Illustrative quotes:** • "*In case of illness—a child with fever, a child who is coughing… we do not vaccinate.*" • "*Indeed, when the child comes with a fever of* 38˚C, *we cannot vaccinate… the child must recover first, then we vaccinate.*" ***Theme* 8**: *Health Worker Practices and Protocol Issues*	***Theme* 4:** *Importance of Mother's Role and Health Personnel in Child Vaccination role of communication in reducing MOV* **Top words**: child, vaccination, staff, vaccine, it is, that we, is not, must, mother **Interpretation:** This theme underscores the need for both mothers and health staff to work together for timely vaccination, noting that poor communication and strained relationships can lead to missed opportunities. **Illustrative quotes:** • "*The staff do not take the time to explain to the mother why her child was not vaccinated.*" • "*Staff are sometimes harsh with mothers, which discourages them from returning.*" • "*The mother does not understand why the child is sent home without vaccination.*"

	Top words: vaccination, vaccinate, it's, vaccinate, staff, that one, problem, vaccine, health, fever **Interpretation:** This theme highlights that vaccinating children with a fever, a known contraindication like pneumonia can lead to MOV. **Illustrative quote:** "Children with fever, pneumonia, or other illnesses are not vaccinated until recovery."	
Communication and Provider-Caregiver Interaction	***Theme* 4**: *Importance of Mother's Role and Health Personnel in Child Vaccination role of communication in reducing MOV* **Top words:** child, vaccination, staff, vaccine, it is, that we, is not, must, mother **Interpretation:** This theme underscores the need for both mothers and health staff to work together for timely vaccination, noting that poor communication and strained relationships can lead to missed opportunities. **Illustrative quotes:** • "*The staff do not take the time to explain to the mother why her child was not vaccinated.*" • "*Staff are sometimes harsh with mothers, which discourages them from returning.*" • "*The mother does not understand why the child is sent home without vaccination.*" ***Theme* 9:** *Communication Gaps and Service Experience* **Top words:** vaccination, child, staff, that he, mother, is not, comes, child, service, it is **Interpretation:** It suggests that poor explanations, lack of guidance, or negative attitudes from staff can discourage mothers from completing the vaccination schedule. Such relational barriers at the point of service can contribute to MOV. **Illustrative quote:** "*We come for vaccination, but they don't explain things clearly. We don't even know why we have to come back.*"	***Theme* 7**: *Perceived Incompetence or Attitude of Health Personnel* **Top Words:** vaccine, personnel, child, vaccinate, illness, problem, that he, mothers **Interpretation:** Caregivers feel health workers may dismiss concerns or communicate poorly, leading to mistrust and missed vaccinations. **Illustrative Quote:** "*Sometimes, even when a problem is reported in the child, the staff still want to vaccinate without properly examining or listening to the mother.*"

3.3. Cross-Cutting Observations among Health Workers and Caregivers

From health workers' perspectives (identified through AI-assisted analysis), missed opportunities for vaccination (MOV) stem from several cross-cutting factors (Table 2). Misunderstandings about vaccine safety and eligibility, inconsistent communication, and negative provider attitudes reinforce caregiver hesitancy. Systemic issues, especially vaccine stockouts and staff shortages, disrupt service delivery and strain caregiver, provider interactions (Table 2). These interconnected problems show MOV is driven by caregiver behaviors, provider capacity, and structural limitations. Addressing these determinants is essential for effective, context-specific interventions (Table 2).

Table 2. Illustration of thematic domains with topic words and quotations from health personnel's views in the Mifi Health District, 2024.

Theme	Level*	Reason Identified	Interpretative recommendations/solutions	Illustrative Quote
1. Barriers in Understanding and Perception of Disease Prevention	Caregiver	Limited understanding of vaccine benefits; belief that the child is not sick	Strengthen communication on vaccine purpose and preventive nature	"Mothers don't understand that it's to prevent illness."
2. Misconceptions About Vaccine Necessity or Timing	Caregiver	Belief that vaccine is only needed when illness is visible or serious	Increase awareness campaigns on vaccination schedule and importance	"If the child is not sick, it's not necessary."
3. Health Personnel Attitudes and Communication	Health worker	Inadequate counseling or explanations by health workers	Train staff on patient communication and respectful care	"We ask questions, but they answer poorly or not at all."
4. Distrust or Confusion Due to Inconsistent Information	Health system	Contradictory or unclear instructions; perceived incompetence	Harmonize messaging and protocols; reinforce staff training	"Sometimes they say to come back, others say no. We don't understand anything."
5. Caregiver Responsibility and Prioritization	Caregiver	Mothers are busy, forget appointments, or don't prioritize vaccination	Use of reminders; involve family support in child health	"I had to go to the field, I forgot the vaccination card."
6. Concerns Over Vaccine Safety and Side Effects	Caregiver	Fear of fever, adverse reactions, or illness after vaccination	Reassure through health education and peer testimonies	"The child had a fever afterward, I didn't want to go back."
7. Perceived Rudeness or Disrespect by Health Staff	Health worker	Poor interpersonal treatment by staff discouraging return visits	Enforce respectful care guidelines; supervision	"The nurses shout at us, it's discouraging."
8. Unavailability of Vaccine or Health Worker	Health system	Vaccine or staff not available during visit, long waiting times	Improve supply chain and staffing; streamline service hours	"We come, they say there's no vaccine or that we have to wait too long."
9. Poor Service Experience and Lack of Guidance	Health system	No clear guidance about follow-up; absence of welcoming atmosphere	Establish better client orientation and return-date systems	"We come for vaccination, but they don't explain things clearly."

*These were the reasons mentioned by health workers and leveled for each stakeholder by the authors. AI assisted categorize each thme (whether it is a health worker perspective of cargiver perspective), identifying illustrative quotes within the text and compiling them into a summary table under the authors' responsibility.

From caregivers' perspectives, only six main themes were analyzed because the last four themes were identical among the expected nine themes (Table 3). While vaccination was considered important, system-level barriers, particularly vaccine stockouts and BCG unavailability, were the chief causes of missed opportunities (Table 3, Table S1). Caregivers described repeated unsuccessful visits de-

spite staff presence, leading to frustration with health facilities. Long waits, scheduling issues, and forgetfulness also delayed vaccination (Table 3, Figure 2). Findings highlight positive attitudes toward immunization but persistent structural challenges within the health system. Despite these constraints, caregivers valued vaccination's protective role, as shown by views like "it is important" and "a good thing" (Table 3).

Table 3. Thematic domains, key terms, and illustrative quotations from caregivers in the Mifi Health District, 2024.

Theme No.	Theme Title	Interpretation	Dominant Words	Illustrative Quote	Concerned Level	Focus: Reason or Solution for MOV
Theme 1	**Missed Vaccination Due to Stockouts and Forgetfulness**	Caregivers highlight vaccine shortages as a primary reason for missed vaccinations. Even when staff are present, vaccines may be unavailable, leading to delays.	shortages, child, it's, time, full, others, well, forget	"Sometimes shortages occur, the child is not given the vaccine, and when the vaccine becomes available, you have even forgotten that the child did not receive it."	Health System/ Caregivers	Reason
Theme 2	**Staff Availability and Workload Balance**	Despite staff being present in sufficient numbers, caregivers mention that long wait times can occur. However, satisfaction with the care remains relatively high.	even, vaccine, it's, work, vaccinate, full, when, child, time	"There are shortages... but the wait is bearable. The work is good here, they are full."	Health Workers	Both reason (workload) and solution (staff motivation)
Theme 3	**Vaccination Viewed Positively, But Systemic Issues Remain**	Vaccination is seen as beneficial, yet shortages and inconsistent availability make the process frustrating. Timing issues are frequently noted.	it's, even, sometimes, vaccination, vaccinate, well, child, when, shortages	"Vaccination is a good thing... But sometimes there are shortages."	Caregivers/ Health System	Reason
Theme 4	**Delays in Vaccination Despite Positive Perception**	Caregivers support vaccination but lament repeated delays due to vaccine shortages. "Even" when they are ready, services may be limited.	vaccine, even, child, vaccination, shortages, it's, well, time, vaccinate	"The vaccine is fine... There are children who are already 8 months old but have not yet received the BCG vaccine."	Caregivers/ Health System	Reason
Theme 5	**Challenges with Timeliness and BCG Availability**	Some caregivers experience structural barriers such as unavailable BCG at birth. These issues are seen as routine and recurring.	it's, sometimes, others, BCG, work, full, only, time, when	"When they arrived on Monday, the BCG vaccine was scarce. They only made it to Foumbot to vaccinate."	Health System	Reason

Continued

Theme 6	**Persistence of BCG Shortages Despite Staff Presence**	Even when staff are available and ready to vaccinate, persistent vaccine shortages (especially BCG) prevent timely immunization.	even, sometimes, times, BCG, only, when, vaccine, shortages, personnel, vaccinate	"There's my sister. When they gave birth on Monday, BCG was scarce. In the end, they only managed to get as far as Foumbot to vaccinate."	Health System	Reason

*We chose 9 topics. However, we retained only 6 among caregivers because the last 4 themes were identical.

3.4. Summary of Key Themes and Similarities: Caregivers and Health Workers

From the health workers' perspective, nine themes explained missed opportunities for vaccination (MOV) at multiple levels (Table 2). At the caregiver level, poor understanding of vaccines, misconceptions about timing, and safety concerns were key barriers. Providers identified communication issues and negative attitudes as weakening trust. System-level factors, including inconsistent protocols, vaccine stockouts, understaffing, and limited guidance, further contributed to MOV (Table 2). Overall, MOV resulted from a mix of caregiver behaviors, provider practices, and health system constraints, highlighting the need for integrated interventions.

From the caregivers' perspective, six main themes were identified (Table 3). The most cited issue was vaccine stockouts, especially of BCG, which caused delays and frustration. Long waiting times and logistical challenges also played a role. Even though caregivers valued vaccination and recognized staff efforts, inconsistent supply and the absence of reminders led to missed doses (Table 3).

Both groups reported similar causes for MOV as found in Table S2. Caregivers noted long waits, scheduling challenges, and household burdens, while health workers cited staffing shortages and weak tracking systems (Table 2 & Table 3). Proposed solutions included improved communication, reliable vaccine availability, flexible service hours, and community outreach. These insights call for multilevel strategies that address both behavioral and structural aspects of immunization services (Table 2 & Table 3).

3.5. From the TDR/COM-B Model Perspectives

Among health workers, structural and organizational constraints, mapped to the Opportunity dimension (Table 4), were most prominent. They frequently cited vaccine shortages, limited staff, and poor integration of vaccination with other child health services. While acknowledging the need for refresher training to address knowledge gaps and improve adherence to immunization protocols (Capability), health workers' Motivation to support child health remained strong (Table 4).

For caregivers, barriers to vaccination primarily involved Capability and Opportunity components (Table 5). Many caregivers lacked knowledge about vac-

cination schedules and timing, and held misconceptions about contraindications, reflecting gaps in psychological capability. Opportunity issues included long waits, vaccine unavailability, and poor communication with health personnel, all discouraging timely vaccination. Despite these obstacles, caregivers were strongly motivated to protect their children, suggesting that bolstering knowledge and access could help turn motivation into action (Table 5).

Table 4. Health workers' perspectives with TDR/COM-B model in the Mifi Health District, 2024.

Theme	Level	Illustrative Quote	Interpretative Recommendations	TDF Domain (s)	COM-B Component (s)
1. Limited awareness and misconceptions about MOV	Individual	"Some mothers think the vaccine can make the child sick, so they refuse, but they are not well informed."	Strengthen health worker training on MOV definition, causes, and prevention strategies.	Knowledge; Beliefs about consequences	Capability (Psychological)
2. Inadequate communication with caregivers	Interpersonal	"We explain, but some mothers do not understand us; sometimes we lack time to talk."	Implement structured communication tools and counseling guidelines for routine immunization.	Skills; Communication	Capability (Psychological); Opportunity (Social)
3. Workload and staffing constraints	Organizational/ System	"There are many children, few vaccinators; sometimes we cannot attend to all."	Advocate for additional staff allocation and workload balancing to reduce missed opportunities.	Environmental context and resources	Opportunity (Physical)
4. Vaccine and supply stock-outs	Organizational/ System	"Sometimes we send them back because the vaccine is not available."	Improve supply chain forecasting and monitoring to avoid vaccine and consumable shortages.	Environmental context and resources	Opportunity (Physical)
5. Gaps in supportive supervision and feedback	Organizational/ System	"We rarely have supervision focused on vaccination problems."	Introduce regular MOV-focused supervision with feedback loops for continuous improvement.	Social influences; Behavioral regulation	Opportunity (Social); Motivation (Reflective)
6. Perceived caregiver barriers	Interpersonal	"Some mothers come late or without the child's vaccination card."	Strengthen appointment reminders and integrate community engagement for timely attendance.	Social influences; Memory, attention, and decision processes	Opportunity (Social); Capability (Psychological)

Overall, the COM-B framework revealed that caregivers faced knowledge and access barriers, while health workers encountered systemic and logistical challenges. Both groups showed strong motivation, indicating that interventions focused on communication, training, and service logistics could help reduce missed opportunities for vaccination (MOV).

Table 5. Caregivers perspectives with TDR/COM-B model, Mifi Health District, 2024.

Theme	Level	Illustrative Quote	Interpretative Recommendations	TDF Domain (s)	COM-B Component (s)
1. Limited knowledge about vaccination schedules and benefits	Individual	"I didn't know the child had to receive the vaccine exactly on that date."	Develop targeted health education campaigns explaining vaccine schedules and importance.	Knowledge	Capability (Psychological)
2. Misconceptions and fears about vaccine safety	Individual	"Some people say the vaccine can harm the child."	Address myths through trusted community health channels and testimonies from other mothers.	Beliefs about consequences; Emotion	Capability (Psychological); Motivation (Reflective)
3. Negative interactions with health workers	Interpersonal	"Sometimes the nurse shouts at us, so we don't go back."	Train health workers on respectful, client-centered care and interpersonal communication.	Social influences; Professional role and identity	Opportunity (Social); Motivation (Reflective)
4. Logistical barriers to accessing vaccination	Organizational/ System	"The hospital is far and I have no money for transport."	Provide outreach/mobile vaccination services and integrate transport support where possible.	Environmental context and resources	Opportunity (Physical)
5. Competing priorities and time constraints	Individual/ Interpersonal	"I was busy with the farm and could not come."	Implement flexible service hours and integrate vaccination with other community activities.	Memory, attention, and decision processes	Capability (Psychological); Opportunity (Physical)
6. Influence of family and community opinions	Interpersonal	"My husband said we should not take the child because he heard bad things."	Engage community leaders and spouses in pro-vaccination advocacy.	Social influences	Opportunity (Social); Motivation (Reflective)

4. Discussion

An inductive qualitative analysis of open-ended responses on vaccination practices, causes, and strategies to reduce missed opportunities for vaccination (MOV) was conducted. The approach illustrated the potential of integrating artificial intelligence with R-based qualitative analysis.

Health workers emphasized systemic constraints such as vaccine stockouts, staff shortages, workload, and limited community engagement. They linked missed opportunities for vaccination (MOV) to organizational gaps and caregiver hesitancy, suggesting stronger vaccination planning, better communication, and structured catch-up sessions to improve coverage. Caregivers (mothers) expressed strong interest in vaccination but frustration over frequent stockouts, especially BCG delays, and lack of reminders. While some mentioned misinformation, logistical barriers were the main concern. They generally trusted health workers but lamented long waiting times and service limitations.

Shared perspectives revealed complementary views: both groups identified

knowledge gaps, weak communication, and structural constraints as major barriers.

These findings reveal that MOVs are multifactorial, encompassing individual, organizational, and systemic factors. Social and motivational influences, such as family opinions and competing priorities, also shape vaccination behavior. Addressing MOVs, therefore requires an integrated approach combining workforce strengthening, improved vaccine logistics, targeted reminder systems, and enhanced communication with caregivers. Overall, multifaceted interventions spanning educational, interpersonal, organizational, and social dimensions are essential to reduce MOV [37]. Our findings are consistent with those from a qualitative study in Cape Town, South Africa, which similarly identified systemic, organizational, and interpersonal factors behind MOVs, and recommended interventions targeting logistics, staffing, and communication (TDF/COM-B frames) [38] [39]. A broader systematic review across multiple African countries further reinforces that combining workforce strengthening, logistic improvements, and tailored communication approaches is crucial for optimizing immunization adherence [40].

Considerations for the Analysis/Strength and Limitations

Translation of raw responses from French to English was approached to preserve meaning and analytical depth [41] [42]. Working with original-language texts before translating themes or key terms post-analysis reduces semantic distortion, particularly in inductive methods such as thematic modeling [43]. In this study, analyzing French texts and translating synthesized results ensured both fidelity and accessibility. Selecting the optimal number of topics (k) in Latent Dirichlet Allocation (LDA) posed a methodological challenge. As reported in similar public health applications, topic estimation requires balancing statistical coherence with thematic interpretability [44]-[46]. Careful validation ensured conceptually meaningful themes.

One of the key strengths of this work lies in its methodological contribution: it illustrates the feasibility of conducting inductive qualitative analyses using the R software environment, supported by artificial intelligence, even with small datasets. This example may guide public health researchers interested in integrating R-based workflows for qualitative data exploration, offering a transparent and reproducible approach. Another notable strength is the inclusion of perspectives from both caregivers and health personnel, summed in the COM-B model, which helped uncover converging views regarding systemic challenges, particularly vaccine shortages and service delays, that contribute to missed opportunities for vaccination (MOV). These narratives underscore an implicit call for accountability and improvement within the Mifi health system.

Limitations include: qualitative data remain limited in volume and depth, as the discussions were conducted in a single focus group, without in-depth individual interviews; lack of triangulation: although MOVs are inherently multidimensional, involving community, individual, and health system dynamics, the study

did not include testimonies from decision-makers or health system managers, which could have enriched the analysis. Finally, while caregivers' and frontline workers' views provide valuable insights, the absence of triangulation with other qualitative data sources may limit the generalizability of the findings. Nonetheless, findings illustrate the value of AI-assisted and theory-informed qualitative methods to guide implementation research on MOV in low- and middle-income settings [47].

5. Conclusion

This study demonstrates that using R software combined with artificial intelligence tools is a practical approach for conducting inductive qualitative analyses of textual data in public health research. By leveraging this method, key themes related to missed opportunities for vaccination were efficiently and transparently identified. The integration of these technologies provides a foundation for future research, enabling deeper insights into the complex factors influencing health behaviors.

Authors' Contributions

Dr. Solange Whegang Youdom conceptualized and designed the study, conducted the qualitative data analysis using R and AI-assisted methods, interpreted the findings within the COM-B framework, and drafted the original manuscript. She also developed the analytical workflow and prepared the tables and results presentation. Dr. Jules Brice Tchatchueng Mbougua critically reviewed and revised the manuscript for intellectual content, provided methodological and epidemiological input, and contributed to the interpretation of findings within the broader public health context. Both authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Ethical Approval

We are making secondary use of data from previous study. The study received the Ethical approval from the regional Ethics Committee of the West regional delegation, of the Ministry of Public Health in Cameroon (reference number: 480/30/06/2023/CE/CRERSH-OU). All participants gave informed consent to participate.

Biographical Notes

Dr. Solange Whegang Youdom is a Cameroonian statistician and Senior Lecturer at the Faculty of Medicine and Pharmaceutical Sciences, University of Dschang. She holds a PhD in Epidemiology and has recognized expertise in data analysis and statistics, with a specialization in public health and scientific research. Her work focuses on developing statistical methods for analyzing health data, with a strong interest in vaccination, particularly through the secondary analysis of survey databases. She has made significant contributions to scientific research and has authored several publications aimed at advancing knowledge in the field. Passionate about capacity building, she is also actively involved in training initiatives designed to increase the number of women in Francophone Africa who are proficient in statistical tools.

Dr. Jules Brice Tchatchueng Mbougua is a Cameroonian researcher, epidemiologist, and data scientist working at the Centre Pasteur du Cameroun in Yaoundé. Specializing in infectious disease epidemiology, epidemiological surveillance, and advanced statistical modeling, he leverages his data science expertise to analyze complex public health data and inform decision-making. He is the author or co-author of more than 64 scientific publications, cited over 600 times by the international scientific community. His work focuses notably on HIV/AIDS in children, COVID-19 epidemics in Cameroon, and the fight against infectious diseases in Central Africa. He is also proficient in R programming for public health data analysis, making him a key figure in the intersection of data science and epidemiological research in the region.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. In addition, R codes for data analysis are available in the supplementary materials:
https://github.com/twheystats/Supplementary-Materials/blob/main/RCodeIllustrationQualitativeAnalysis.pdf.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

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Supplements

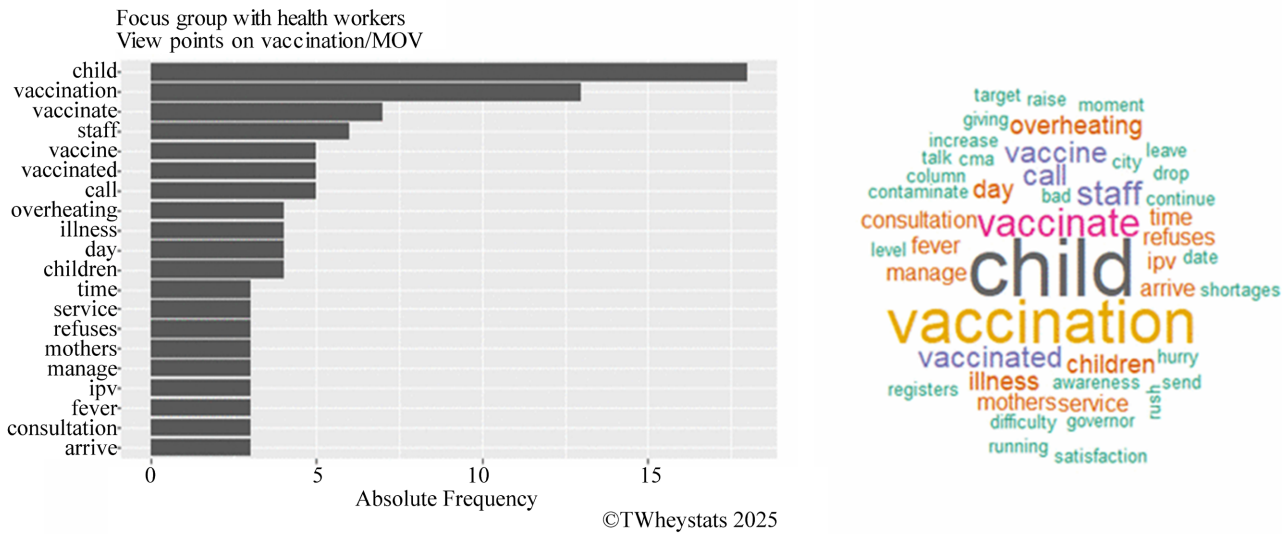

Figure S1. Word cloud from health personnel: this first image is useful to explore main themes (single words) and we can notice that talks from personnel are mainly centered on vaccination, and children.

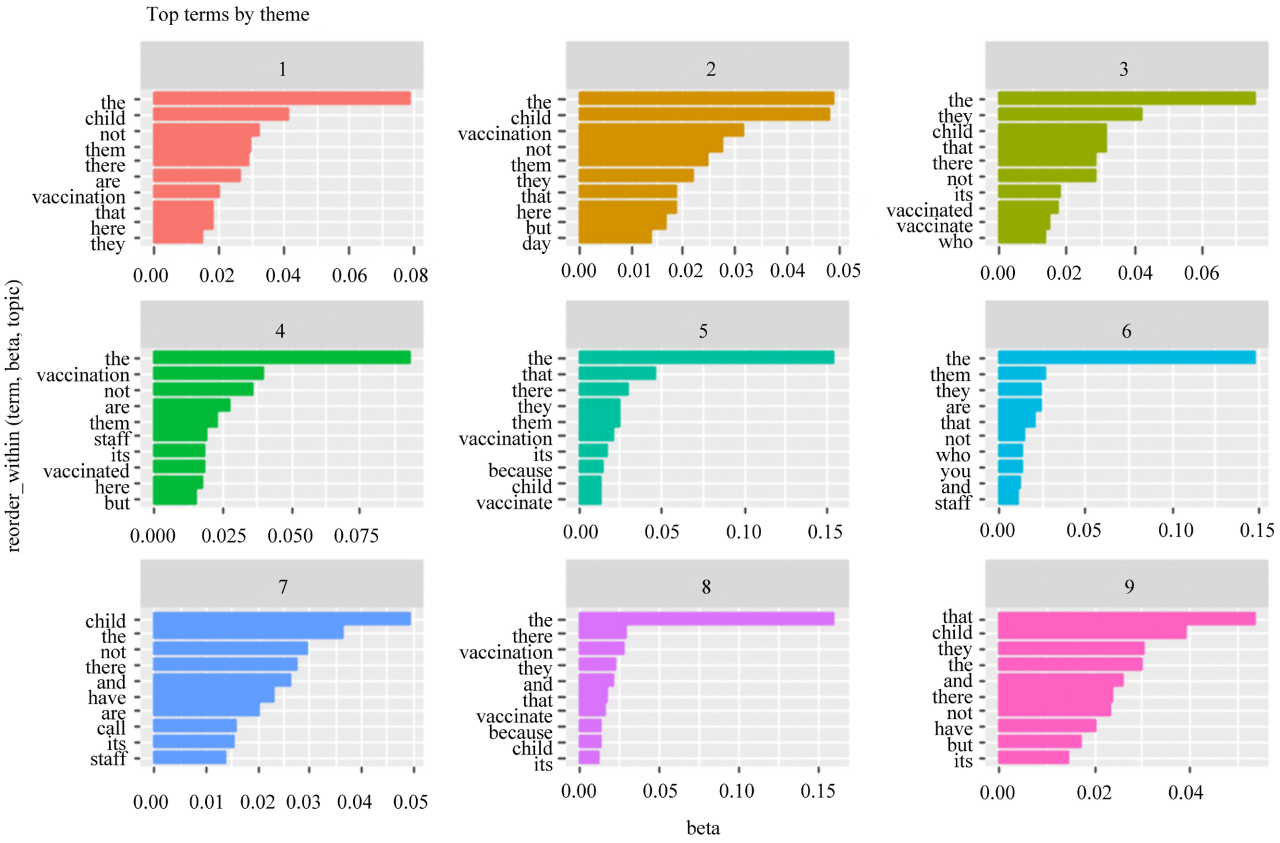

Figure S2. Theme by theme and associated words among health workers.

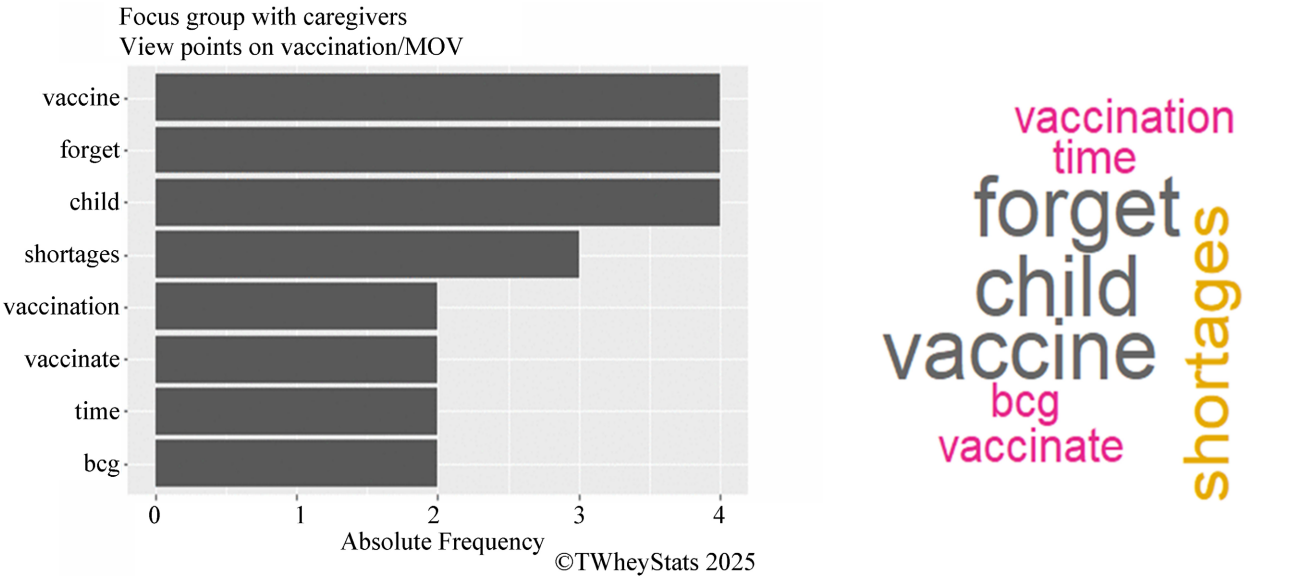

Figure S3. Word cloud and ggplot for the 10 cited words by caregivers.

Figure S4. Terms by theme identification and associated words among caregivers.

Table S1. Caregivers' viewpoints—Mifi Health District, 2024.

Theme	Level	Topic words	Illustrative quote	Interpretative recommendations
Lack of information on vaccination schedules	Individual	ignorance of calendar, unawareness, forgetfulness	"I did not know my child had to return after six weeks for the next dose."	Strengthen caregiver education on vaccination timelines using reminders and community sensitization.
Competing priorities and time constraints	Individual/ Interpersonal	work, household duties, market days, time pressure	"I was busy with work in the fields and could not come to the health centre."	Adapt vaccination sessions to accommodate caregivers' schedules, e.g., weekend or extended hours.
Negative experiences at health facilities	Interpersonal/ Health system	poor reception, long waiting time, rude staff	"Sometimes the nurses shout at us when we arrive late."	Improve patient-provider relationships through training in respectful care and reducing waiting times.
Health system barriers (vaccine stock-outs, limited sessions)	Health system	vaccine shortages, reduced opening days, staff absence	"When I came, they said the vaccines were finished; I had to go back home."	Ensure reliable vaccine supply and maintain regular vaccination days in all health facilities.
Misconceptions and fears about vaccines	Community/ Individual	side effects, infertility rumors, mistrust	"Some people told me the vaccine could make my child sick."	Intensify community-based myth-busting campaigns involving trusted leaders and previous satisfied caregivers.
Distance and transport challenges	Community/ Health system	remote location, transportation cost, lack of means	"I live far from the centre and transport is expensive."	Bring vaccination services closer to communities through outreach or mobile clinics.

Table S2. Side-by-side alignment table of health worker and caregivers' themes mapped by similar concepts.

Main Category	Health Workers' Themes	Caregivers' Themes	Shared Focus
Knowledge & Awareness	1. Limited awareness and misconceptions about MOV	1. Limited knowledge about vaccination schedules and benefits 2. Misconceptions and fears about vaccine safety	Understanding of vaccination importance and timing; addressing myths and misconceptions
Communication & Interaction	2. Inadequate communication with caregivers	3. Negative interactions with health workers	Quality and clarity of communication; respectful care
Workforce & Resources	3. Workload and staffing constraints 4. Vaccine and supply stock-outs 5. Gaps in supervision and feedback	4. Logistical barriers to accessing vaccination	Staffing, supply, and structural challenges limiting access and service delivery
Caregiver Barriers	6. Perceived caregiver barriers	5. Competing priorities and time constraints 6. Influence of family and community opinions	Factors related to caregivers' availability, motivation, and social context

Continued

Motivation & Behavior	5. Gaps in supervision and feedback (motivation aspect)	2. Misconceptions and fears about vaccine safety 6. Influence of family and community opinions	Drivers of motivation, trust, and decision-making around vaccination