Title

Evaluating an Innovative Photo-Based Vaccination Card Collection Approach in the Democratic Republic of the Congo and Central African Republic

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Evaluating an Innovative Photo-Based Vaccination Card Collection Approach in the Democratic Republic of the Congo and Central African Republic

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in Epidemiology

by

Kastin Pan

2024

ABSTRACT OF THE THESIS

Evaluating an Innovative Photo-Based Vaccination

Card Collection Approach in the Democratic

Republic of the Congo and Central African Republic

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Master of Science in Epidemiology

University of California, Los Angeles, 2024

Professor Anne W. Rimoin, Chair

Background: Monitoring childhood vaccination coverage is crucial as many low- and middle-income countries continue to work toward disrupted immunization goals post COVID-19. A proposed method to improve vaccination data collection efficiency in resource-limited settings involves capturing images of paper vaccine cards in the field, then entering the information later at a centralized location – potentially saving resources and time spent in the field.

Objective: To comprehensively assess the photo-based method's efficiency and effectiveness for childhood vaccination coverage surveys in resource-limited settings such as the Democratic Republic of Congo and the Central African Republic.

Methods: The photo-based method was assessed based on three quantitative metrics: time savings, accurate coverage estimates, and error rates compared to the conventional in-person field interview approach, which was possible by matching barcodes and birthdates. Additionally, linear regression was used to explore associations between qualitative photo evaluations and the continuous measure of survey completion time.

Results: The photo-based method averaged 2.9 minutes per survey form, showing a time advantage over the standard field interview method, which required 4.2 minutes on average. However, when vaccination records were matched and then compared against the standard field method records (reference), the photo-based method had an average disagreement of 49.6 ± 14.3% for vaccination dates and 30.2 ± 8.0% for whether a vaccine was marked as received, indicating a substantial margin of error. The photo-based method tended to underestimate vaccination coverage because of these errors. Slow entry times for vaccination card data were influenced by factors such as slightly blurry but legible images, large obstructing objects in pictures, and incomplete vaccination booklets. Image quality factors explained about 5% of survey time variability in the regression model (adj. $R^2 = 0.049$), highlighting the influence of external variables. However, the full regression model significantly predicted survey time, suggesting that aspects of photo quality significantly impact time efficiency.

Conclusion: Initial findings reveal the photo-based method requires less time per vaccination card than the standard in-person interview method, translating to potential savings of several fieldwork days. However, issues such as duplicate data, blurry images, and data entry errors highlight the need for protocol refinement and data quality assurance measures. As technology and protocols continue to improve, photo-based methods have a strong potential to expedite vaccination card data collection in resource limited settings.

The thesis of Kastin Pan is approved.

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University of California, Los Angeles

2024

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INTRODUCTION

Background

Evaluating childhood vaccination coverage provides critical insights into the effectiveness of vaccination programs, as well as a country's advancement toward global vaccination goals. This task has become especially crucial in the post-pandemic era, as disruptions caused by COVID-19 have severely impacted progress made in childhood vaccination over several decades in many low- and lower-middle income countries (LLMICs). Despite global recovery efforts, the rebound has been inconsistent and slower across LLMICs, with many struggling to return to pre-pandemic levels of vaccination coverage.[1] For instance, in the Democratic Republic of the Congo (DRC), the completion rate for the diphtheria-tetanus-pertussis vaccine (DTP3) – a key immunization indicator – substantially declined from 73% in 2019 to 65% in 2022.[2] On the other hand, the Central African Republic (CAR) maintained a stable but low DTP3 coverage estimate of 42% for the same period, reflecting stagnant vaccination coverage progress.[3] As vaccination programs regain momentum, closely monitoring coverage is essential for identifying gaps, optimizing resource allocation, and tracking progress toward global targets.

Vaccination coverage is typically evaluated by household surveys or administrative reports. Administrative reports rely on the number of vaccinations reported through paper-based systems, which are then divided by the estimated target population. Concerns about data quality at the administrative level, including inaccurate or delayed reporting of vaccinations and unreliable population estimates, often result in an overestimation of coverage.[4,5] Consequently, household survey methods are seen as more reliable because they implement probabilistic sampling for a representative sample, rigorous quality control and assurance protocols, and effective data validation methods.[4] Data obtained from household surveys, such as the Multiple Indicators Cluster Survey (MICS) and Demographic and Health Survey (DHS), play a pivotal role in evaluating the progress of immunization programs, such as the Expanded Program on

Immunization (EPI) – a World Health Organization (WHO) initiative designed to enhance global childhood vaccination coverage through providing free vaccines.[4,6,1] Ultimately, the reliability of both administrative and household survey methods depends on information accuracy and availability within records, such as vaccination cards.

Vaccination cards are vital public health tools, documenting a child's immunization history and encouraging adherence to recommended vaccine schedules. Although electronic health systems are efficient, their limited accessibility makes paper vaccination cards a staple record-keeping method in numerous countries. However, relying on physical records presents its own set of challenges such as susceptibility to loss, illegibility, or damage – all of which are significant hurdles for maintaining complete and accurate records.[7] In cases where vaccination records are missing or difficult to obtain from health facilities, a child's vaccination history can be pieced together through interviews with their guardian. For instance, a child could have been vaccinated at multiple health facilities, not recorded in registers during outreach activities, or the caregiver simply forgot to bring the vaccination card.[8,4] Despite being a convenient additional source of information, caregiver interviews can be susceptible to recall errors, social pressures, and information bias.[4,5]

Beyond their role as historical records, vaccination cards also serve as important reminders of upcoming vaccines. Losing these records can delay the timely administration of crucial protective vaccines, thereby prolonging the duration in which unvaccinated children are vulnerable to vaccine-preventable diseases.[6,5] The absence of a vaccination card has also been linked to lower or non-existent vaccination rates among children, particularly in LLMICs.[7] For example, a 2021 study on vaccination timeliness in Sub-Saharan Africa revealed that during Demographic and Health Surveys conducted from 2000 to 2019, a significant proportion of children in the DRC (33.9%) and CAR (24.1%) did not present vaccination cards, indicating either card loss or never receiving a card.[6,7] Compounding this, the Eastern and Central subregions of

Sub-Saharan Africa had the lowest on-time vaccination coverage due to insufficient healthcare systems and infrastructure, presenting additional obstacles for vulnerable children in these regions.[6] In summary, retaining a vaccination card is not only crucial for record-keeping, but also for promoting widespread vaccine uptake, particularly in regions facing structural and healthcare system constraints.

Problem Statement

In 2018, the WHO introduced an updated manual for conducting vaccination coverage cluster surveys, making several improvements to the EPI coverage survey. A key improvement in the revised manual involves the use of digital cameras to photograph vaccination cards. The increased availability and affordability of digital cameras and smartphones, coupled with the added benefit of GPS capability, make them a practical and widespread tool.[8] This advancement is particularly useful in regions, such as the Democratic Republic of the Congo (DRC) and Central African Republic (CAR), where logistical challenges of reaching remote areas and conflict-affected zones make traditional childhood vaccination coverage surveys difficult.[9,9] By using digital cameras, fieldworkers can efficiently capture high-quality images of vaccination cards, reducing time spent in the field, survey costs, and the need for return visits. Photographed vaccination cards can also be used for verification during data entry and cleaning, minimizing errors that typically arise during this stage.[8] Despite these potential benefits, current literature lacks quantitative and qualitative assessments of implementing this proposed method in general and especially within resource-limited settings facing security concerns and geographical barriers such as the DRC and CAR.[11,12]

Objectives

This thesis aims to compare the efficiency of traditional in-person interviews and a photographed-card approach for centralized vaccination data entry and collection across selected health zones and districts in the Democratic Republic of the Congo (DRC) and Central African Republic (CAR). The primary objective is to evaluate quantitative measures such as accuracy, time savings, and consistency when utilizing the proposed method versus standard field techniques. The secondary objective is to determine the qualitative aspects of captured images and vaccination card quality that significantly impact the time needed for data collection.

Evaluating the photo-based method against the standard in-person interview method can provide insights into whether this method gives an advantage in challenging low-resource environments that predominantly rely on labor-intensive, in-person surveys. Ultimately, the goal is to quantify performance within the DRC and CAR to establish best practices for implementing photographic techniques in future vaccination coverage assessments.

METHODS

Study Design

This cross-sectional study utilizes data from a comparative pilot study that evaluated four routine vaccination coverage methods across two health zones in the DRC and three health districts in the CAR, with the goal of informing future public health initiatives in these regions. This pilot study was a collaborative effort involving the University of California, Los Angeles (UCLA) Democratic Republic of the Congo research program, the Kinshasa School of Public Health (KSPH), University of Bangui's Public Health Department, Central African Institute of Statistics, Economic and Social Studies (ICASEES), and the DRC and CAR health ministries.[13]

The four methods compared were the WHO method, a WHO-Kinshasa School of Public Health (KSPH) modified method, a geographical information system (GIS) method, and a lot quality assurance sampling (LQAS) method. Surveyed health zones included N'djili, Kinshasa and Boko, Kwango in the DRC. Surveyed health districts included Bangui II, Begoua, and Bossembele in the CAR. While children aged 6 to 23 months were included, the primary focus were children aged 12 to 23 months with zero DTwP-HepB-Hib (pentavalent) doses. Zero-dose children serve as a proxy for a lack of vaccination service access, and a high proportion of zero-dose children is associated with vaccine-preventable disease outbreaks.[9,13] From this pilot study, a dataset was created for the standard field interview method, and images of vaccination cards were captured during field activities for photo-based data entry in a centralized location.

For comparative analysis, only the vaccination card section from both methods was used, as other survey sections from the field interview questionnaire were not directly comparable with the photo-based method questionnaire. The photo-based questionnaire also qualitatively assessed photo quality, legibility, and card completeness, which will be analyzed as a secondary outcome.

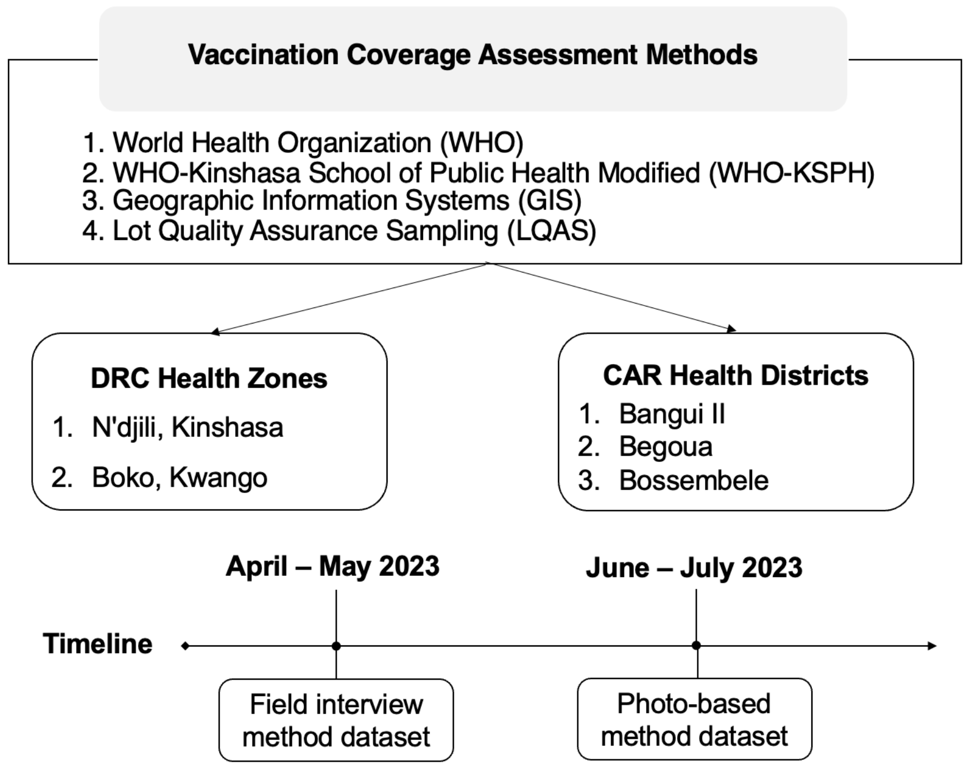


Figure 1. Structure of the pilot study.

Data Collection and Dataset Description

Questionnaires were translated into French, Lingala (DRC), and Sango (CAR) to accommodate local languages in each study area. Interviewers received training on questionnaire administration, digital tablet usage, ethical consent procedures for various sections, and conducting field interviews.

The field method dataset was collected from April to May 2023, resulting in a total of 5,332 vaccination records – 2,264 from the DRC and 3,068 from the CAR. With caretaker approval, children's vaccination cards were photographed during the field interviews for later centralized review at an office location, which formed the basis for the data obtained through the photo-based method. The vaccination card questionnaire section tracked survey timestamps in the background when interviewers entered in the following routine vaccines:

1) Bacillus Calmette-Guérin (BCG)
2) Oral polio vaccine series (VPOb0-3)
3) DTwP-HepB-Hib series (Penta1-3)
4) Pneumococcal series (PCV1-3)
5) Rotavirus series (Rota1-3)
6) Inactivated polio vaccine (VPI)
7) Measles (VAR)
8) Yellow fever (VAA)
9) Meningitis A (MenA)

The photo-based method dataset consisted of the same vaccination card questionnaire section, supplemented by qualitative evaluations of photographed vaccination card quality. Collected from June to July 2023, this dataset comprised 1,144 records from the DRC and 1,996 records from the CAR. Placeholder values (e.g. 999) were present for some missing barcodes in both countries' data. To enable comparison with the combined DRC-CAR field method dataset, the photo-based method's country-specific datasets were likewise merged into a single dataset (N = 3,140).

Due to regional differences in vaccine administration, rotavirus (DRC) and meningitis A (CAR) were not counted towards vaccination completeness and instead evaluated separately by their respective countries of administration.[14,15] Consequently, receiving the remaining 14 routine immunization doses was considered the criterion for a fully vaccinated child in this study.

For the between-method error analysis, vaccination barcodes were matched across the photo-based method and field method datasets. Barcodes appearing at least once in both data sources were compiled into a new comparative dataset (n = 2,102), retaining survey dates, timestamps, immunizations, dates administered, and birthdates. Due to missing data or non-unique placeholder values, only unique barcodes captured in both collection approaches were able to be matched. Given that an expected limitation with both methods is redundancy, 102 reused barcodes (more than once in field dataset, once in photo-based dataset) were not excluded in this analysis.

Statistical Analysis

RStudio (Version 2023.12.0+369) and Excel (Version 16.80) were used for statistical analyses, data management, and generation of figures and tables.

Primary Outcome: Quantitative Efficiency Metrics

Survey Entry Time Efficiency

Two time points were recorded in the background when interviewers began and completed entering vaccination data into a digital tablet survey. An elapsed time variable was created to calculate the total time to complete the vaccination survey form for both methods, allowing for comparison of completion times between the field interview and photo-based methods.

In the photo-based method dataset, 138 vaccination records lacking background time points were excluded from the analysis. Negative elapsed times were addressed with an absolute value function. Reentering the form could have recorded a later start time, while the earlier original end time was retained – resulting in a negative elapsed time. Due to large implausible values (e.g. 1985.9 minutes ≈ 33 hours), elapsed times exceeding 60 minutes were excluded, assuming this survey section regarding 18 routine vaccines should not require more than an hour. After accounting for negatives and missing values, 2,955 records with a valid elapsed survey time remained and was used as the final analytic sample for this method. Elapsed survey times were also assessed per interviewer to provide insight into between-person variability of using the photo-based method.

For the field method dataset, 5,268 vaccination records remained after adjusting for implausible elapsed time values exceeding an hour. However, 58.6% (n = 3,124) records unexpectedly lacked background time points. During field interviews, a total of 3,658 records were presented to interviewers (Supplemental Figure 1), meaning that a high proportion of vaccination records were not automatically timestamped during surveys. Given the high proportion of missing time points, a subset with all NA time elapsed values was created to assess this missingness by vaccination card status, method, country, and health zone and method (Supplemental Table 2). The field method's final sample included 2,144 vaccination records with valid background time points.

Descriptive statistics were generated for both methods following these adjustments. Scatterplots and correlation coefficients were also generated for both photo-based and field method datasets, aiming to identify a relationship between time needed to enter in vaccination survey information and number of received vaccinations. Additionally, a Wilcoxon rank sum test for independent samples assessed whether there was a statistically significant difference between the distributions of the field method and photo-based method's vaccination card entry times.

Comparison of Vaccination Completeness Estimates

Vaccination coverage was computed as a percentage and an absolute number of vaccinated individuals for the photo-based method, field method, and a subset of the field method dataset restricted to vaccination card holders. As previously defined, a child who received the specified 14 routine vaccines was considered completely vaccinated. Each eligible vaccine received by a child contributed to their total number of vaccines. A value of 1 was assigned if a vaccine was received, while a value of 0 indicated otherwise. For the meningitis A and rotavirus vaccines, both percentages and the number of vaccinated children were assessed on a country-by-country basis due to different regional vaccination administrations.

Errors Between Field and Photo-Based Method Datasets

The accuracy of the photo-based method was evaluated against the field method, which was treated as the reference. In the matched barcode dataset (n = 2,102), discrepancies in the data obtained through the photo-based method (n = 1,073) were tallied and compared against the field method dataset vaccination information (n = 1,029). A total of 39 potential errors were possible: 3 pertained to birth date inaccuracies (including day, month, year) and the other 36 regarded the 18 possible vaccines (including whether the vaccine was received and the date of vaccination).

For each paired vaccination card, percentages and counts were calculated for each possible mistake. To evaluate whether the number of errors significantly differed between the two methods, a one-sample Wilcoxon signed-rank test was conducted using the total number of discrepancies found for each photo-based vaccination record compared to its paired field reference record. Since the paired field data was considered the reference, a hypothetical value of zero differences was used as the basis for comparison. The main objective of this analysis was to determine the interviewers' ability to accurately capture exact matches in dates and vaccination information when using the proposed method (see Supplemental Table 1 for an illustrative example).

Secondary Outcome: Qualitative Vaccination Card Photo Evaluation

In the first section of the photo-based method's digital questionnaire, surveyors evaluated vaccination card photo quality, which is the primary limitation of this method. In cases where low-quality images are taken or the records themselves are difficult to read, this may hinder precise and efficient collection of vaccination information compared to the standard assessment of vaccination cards during caretaker interviews. This photo-based evaluation comprised five questions:

1) **Quality**: Is the image blurry, overexposed, distorted to a degree that does not allow you to read the text within the image?
2) **Loss of Information**: Is the information contained in the card lost due to a foreign body hiding the image of the card?
3) **Condition**: Does the card show evidence of physical damage (fading, tearing, wrinkling, mold, rodent cuts, fire marks, moisture, liquid damage...)?
4) **Marks**: Does the card have any highlight marks, punch holes, or staples that reduce the ability to read the information on the card?
5) **Completeness**: Is the image of the card provided in a way that shows the complete information (vaccines page and identity page)?

Quality, loss, condition, and marks had values ranging from 1 to 4 (1 being the best quality, 4 the poorest). Completeness had values of 1 (yes) and 2 (no). Responses were tabulated with percentages and counts, and a linear regression analyzed the connection between these predictors and the continuous outcome, elapsed time to complete the vaccination survey.

RESULTS

Most of the children in both method datasets were aged 12-23 months, with 3,231 (60.6%) children in the field method dataset and 1231 (39.2%) in the photo-based method dataset falling within this age range. The photo-based method dataset had 1020 (32.5%) instances with missing age data due to a lack of birthdate information entries (Table 1).

Table 1. Demographics of participants by method.

	Field (N = 5332)	Photo-Based (N = 3140)
Country	n	n
Central African Republic	3068	1996
Democratic Republic of the Congo	2264	1144
Age Group*	n (%)	n (%)
< 6 Months	0 (0%)	7 (0.2%)
6-11 Months	2101 (39.4%)	435 (13.9%)
12-23 Months	3231 (60.6%)	1231 (39.2%)
> 23 Months	0 (0%)	447 (14.2%)
Vaccinations Received		
Mean	7.9	6.4
Median	12	6
St. Deviation	6.0	5.8
Minimum	0	0
Maximum	14	14

*Percentages may not sum up to 100% due to NAs.

Out of the 3,140 vaccination records in the photo-based method dataset, the majority were classified as "other card or photocopy of a card" (36.5%), followed by "printed card with the logo of the Ministry of Health, where the vaccination calendar is placed at the top, with separate date ranges for each vaccine" (34.1%), and "printed card without departmental logo" (18.1%). The remaining six types represent a diverse range of vaccination records, varying in the placements of the vaccination calendar and date range format. 63.6% of records were from the Central African Republic, while the remaining 36.4% of records were from the Democratic Republic of the Congo (Table 2).

Table 2. Description of vaccination card records in the photo-based method dataset by country and card type (N = 3,140).

	n	%
By Country		
Democratic Republic of the Congo (DRC)	1144	36.4
Central African Republic (CAR)	1996	63.6
By Card Type		
Printed card with the logo of the Ministry of Health, where the vaccination calendar is placed at the **top**, with **separate date ranges** for each vaccine	1072	34.1
Printed card with the logo of the Ministry of Health, where the vaccination calendar is placed at the **top**, with a **unique date range** for all vaccines supposed to be **given at the same time**	57	1.8
Printed card with the logo of the Ministry of Health, where the vaccination calendar is placed in the **middle**, with a **single date range** for all vaccines supposed to be **given at the same time**	97	3.1
Printed card with the logo of the Ministry of Health, where the vaccination schedule is placed at the **bottom**, with a **single date range** for all vaccines supposed to be **given at the same time**	44	1.4
Photocopy of card with logo of the Ministry of Health, the vaccination calendar is placed at the **top**, with **separate date ranges** for each vaccine	20	0.6
Photocopy of a card with the logo of the Ministry of Health, the vaccination calendar is placed at the **top**, with a **single date range** for all vaccines supposed to be **given at the same time**	3	0.1
Photocopy of the card with logo of the Ministry of Health, the vaccination calendar is placed in the **middle**, with a **single date range** for all vaccines supposed to be **given at the same time**	63	2.0
Photocopy of the card with the logo of the Ministry of Health, the vaccination calendar is placed at the **bottom**, with a **single date range** for all vaccines supposed to be **given at the same time**	4	0.1
Printed card without departmental logo	569	18.1
Other card or photocopy of a card	1146	36.5
NA	65	2.1

Primary Outcome: Quantitative Efficiency Metrics

Survey Entry Time Efficiency

After accounting for negative time and ignoring NAs, the photo-based method on average requires 2.9 ± 2.0 minutes to fully record a vaccination card's information. In contrast, the standard field interview method requires an average of 4.2 ± 4.0 minutes to record each vaccination card. At first glance, this suggests that using the proposed method could potentially save an average of 1.3 minutes per vaccination card compared to the standard field interview method (Table 3).

Table 3. Descriptive statistics for the elapsed entry times for vaccination forms by method.

Modifications*	N	Mean (mins)	Median (mins)	SD (mins)	Min. (mins)	Max. (mins)	NAs
Photo-Based Method							
None	3140	10.8	2.1	106.7	-203.5	1985.9	138
Negatives addressed	3140	11.2	2.1	106.7	0.1	1985.9	138
Implausible values excluded (> 60 mins)	3093	2.9	2.0	3.9	0.1	59.9	138
Field Method							
None	5332	-19.1	4.0	297.8	-6046.0	2927.0	3124
Negatives addressed	5332	37.4	4.0	296.0	0.0	6046.0	3124
Implausible values excluded (> 60 mins)	5268	4.2	4.0	4.0	0.0	56.0	3124

*Refers to any modifications to the data, such as correcting negative values or excluding large implausible values that skew the distribution of elapsed times.

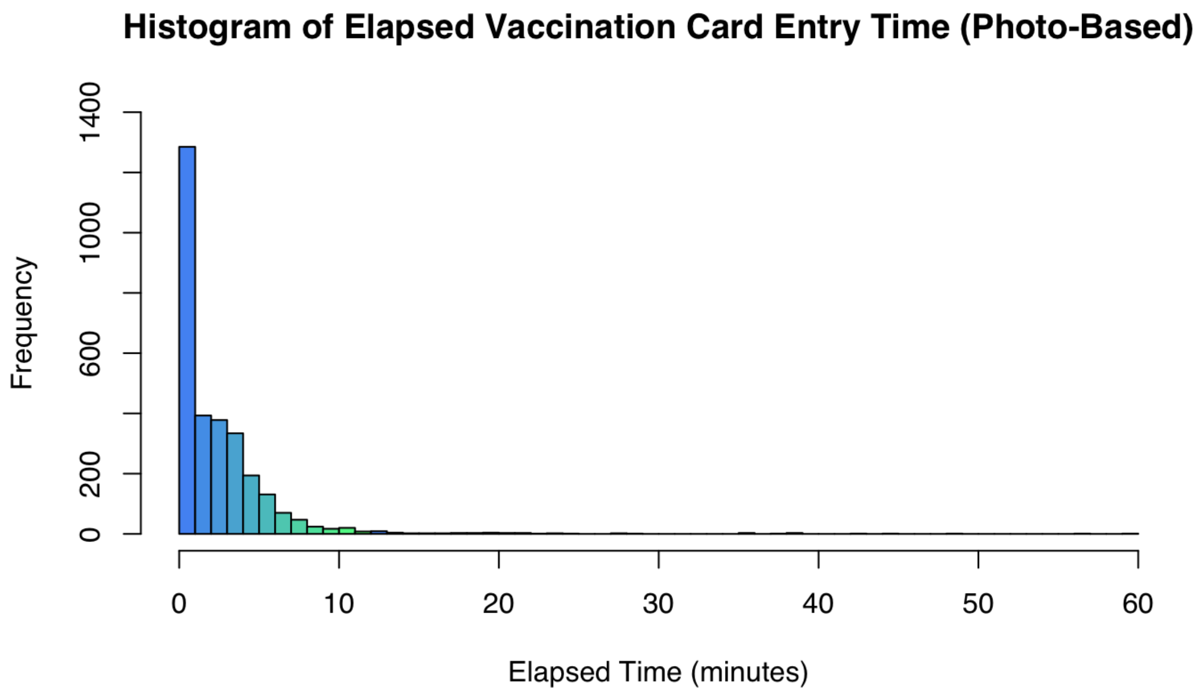


Figure 2. Histogram of the photo-based method's elapsed vaccination card survey times (n = 2,995) after removing implausible values that exceeded the value of 60 minutes and ignoring NAs, with breaks of 60. Elapsed times tend to concentrate within the 0 to 10 minutes bin, appearing as a right-skewed distribution.

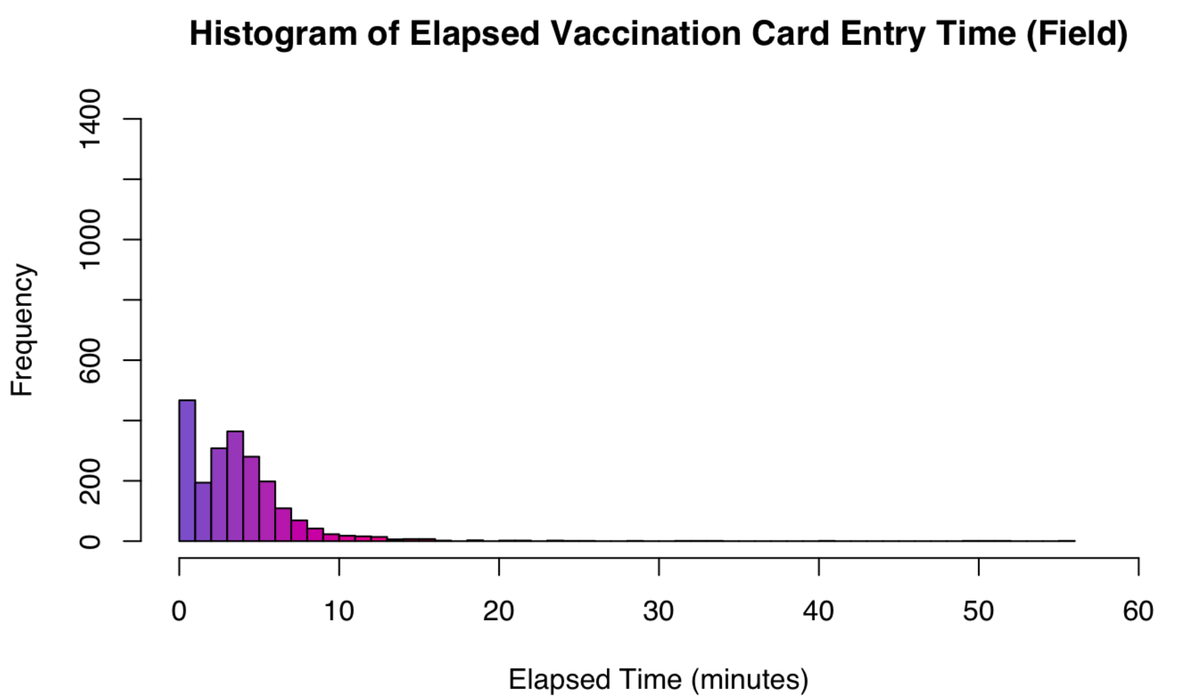


Figure 3. Histogram of the field method's elapsed vaccination card survey times (n = 2,144) after removing implausible values that exceeded the value of 60 minutes and ignoring NAs, with breaks of 60. The elapsed times tend to concentrate within the 0 to 10 minutes bin, appearing as a right skewed distribution.

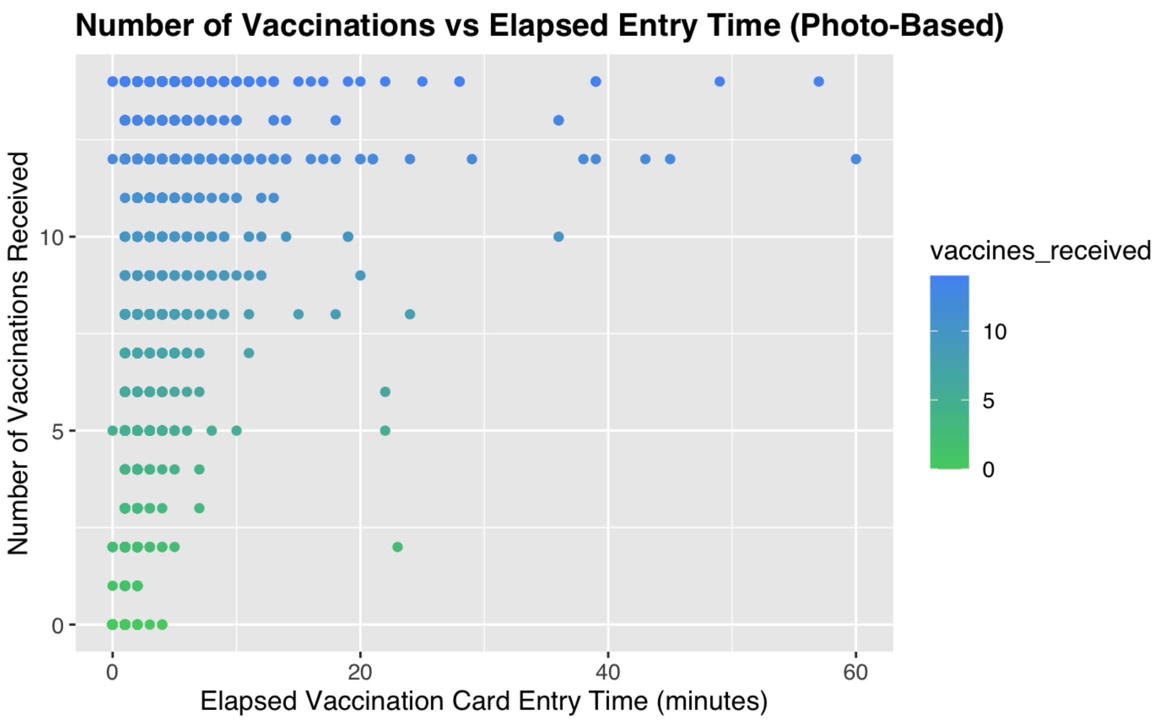


Figure 4. Scatter plot of the photo-based method's elapsed vaccination card recording times versus vaccinations received (out of 14 possible), after removing implausible values that exceeded 60 minutes (n = 2,995).

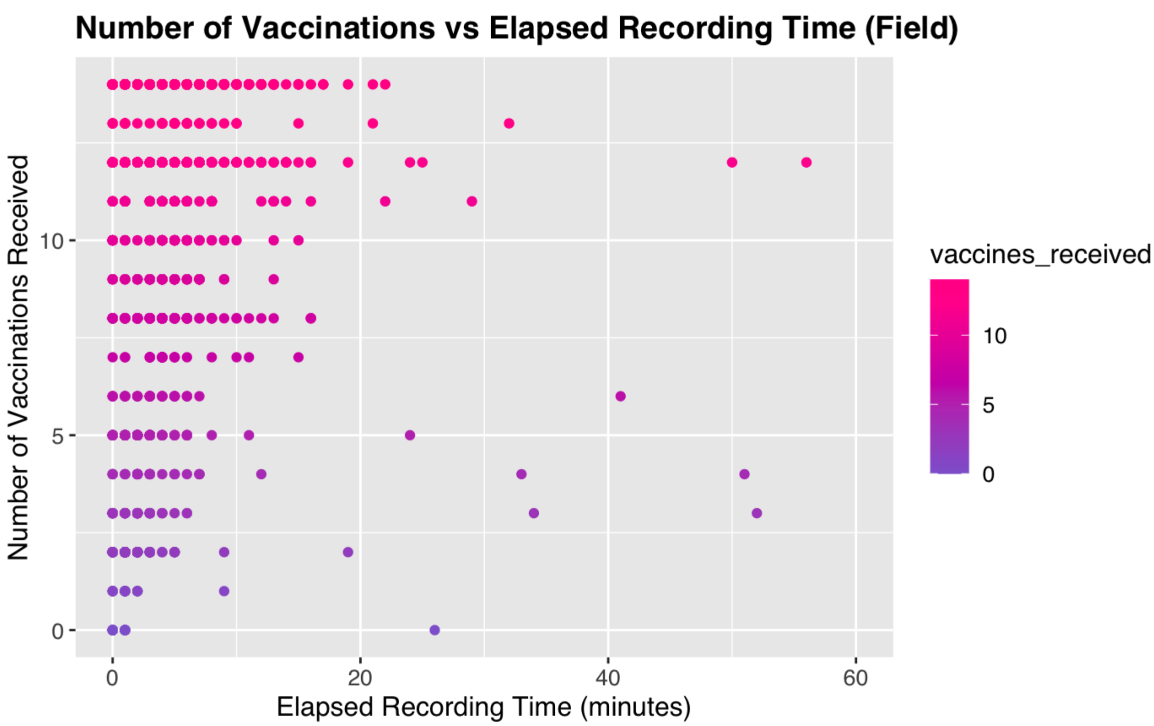


Figure 5. Scatter plot of the field method's elapsed vaccination card recording times versus vaccination received (out of 14 possible), after removing implausible values that exceeded 60 minutes (n = 2,144).

For both methods, the scatter plots visually suggest that with more vaccines received, more time is needed to record vaccination card information (Figures 4 & 5). This logically makes sense, as more information would generally require more careful entry and review time. To quantify this relationship, correlation coefficients were generated to determine the relationship's strength and direction for both methods. For the field method, the correlation coefficient of 0.202 indicates a weak positive correlation. This suggests that during field interviews, the number of vaccinations negligibly impacts the time needed to enter vaccination card information into the survey form.

Conversely, the photo-based method's correlation coefficient of 0.517 indicates a moderate positive correlation. This implies there is a noticeable trend that as the number of recorded vaccinations increases, the time required to enter vaccination card information into the survey form also increases. Furthermore, this suggests that more time spent using the photo-based method is correlated with more complete records. While this confirms the logical reasoning from earlier, exploring other factors such as the quality of the pictures taken of the cards may offer more practical insights into the efficiency and practical implications of using the photo-based method.

A Wilcoxon rank sum test compared the elapsed vaccine card entry times from the field interview method and photo-based method datasets. There is strong evidence to suggest that there is a significant difference between the distributions of the elapsed vaccine entry times from the field method and photo-based method datasets ($W = 4167599$, $P < 0.01$). This result further supports the observed differences in the average and median elapsed vaccination card recording times.

Survey Entry Times by Interviewer

Due to the substantial implausible values of elapsed times in the photo-based method dataset, it became necessary to evaluate the time taken by each interviewer. This would provide insight into potential logistical improvements for the photo-based method, particularly by identifying if there is a specific interviewer taking longer than others or if the workload for each interviewer may affect the time required to evaluate vaccination cards.

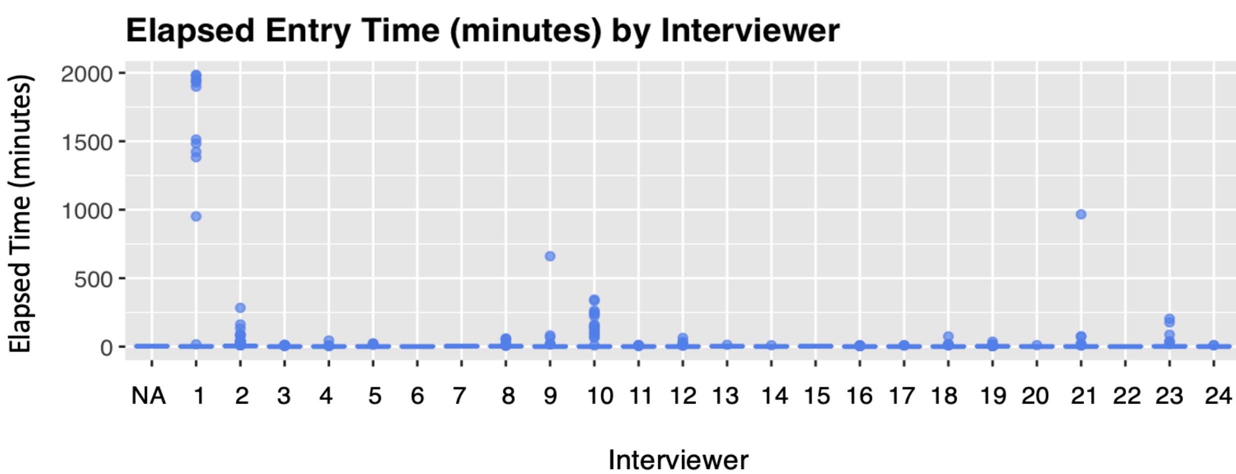


Figure 6. Boxplot of elapsed survey entry times (minutes) by 24 interviewers, retaining implausible values from the photo-based method dataset (N = 3,140).

Breaking down the elapsed recording time by each interviewer reveals a wide variation in vaccination card entry times. The average elapsed survey entry time spans from 1.3 to 186.5 minutes. Additionally, the standard deviations indicate differing levels of consistency in elapsed survey entry times among different interviewers, ranging from 1.1 to 537.9 minutes. Notably, Interviewer #1 had both the highest average elapsed entry time and standard deviation. Workloads were similar across interviewers, with most handling 100 cards, while two interviewers assessed over 400 (Table 4).

Table 4. Summary statistics of elapsed survey entry times (minutes) by 24 interviewers, retaining implausible values from the photo-based method dataset (N = 3,140).

Interviewer	Mean	Median	Standard Deviation	Minimum	Maximum	Cards Seen (N = 3140)
NA	3.0	3.1	1.2	1.5	4.2	5
1	186.5	1.3	537.9	0.2	1985.9	100
2	7.6	4.3	19.1	0.4	283.3	420
3	1.9	0.5	2.8	0.1	12.6	99
4	2.0	0.9	4.6	0.3	44.6	100
5	3.0	0.8	4.0	0.4	23.4	100
6	2.0	0.6	2.2	0.1	8.5	100
7	3.3	3.4	2.7	0.2	10.8	100
8	4.1	3.0	7.0	0.4	59.9	182
9	10.9	0.6	66.5	0.4	660.5	100
10	32.9	0.6	76.7	0.3	344.0	100
11	1.8	0.6	2.3	0.2	11.5	99
12	3.7	0.5	8.4	0.2	63.6	96
13	3.1	2.8	1.8	0.5	13.1	53
14	2.5	1.3	2.4	0.2	10.0	100
15	2.6	3.1	1.4	0.2	5.1	100
16	1.6	0.6	2.0	0.2	9.5	100
17	1.9	0.4	2.3	0.2	10.6	100
18	3.6	0.3	10.4	0.2	74.4	100
19	2.5	2.2	2.2	0.2	36.3	485
20	2.4	0.9	2.3	0.2	10.7	100
21	13.5	0.8	96.9	0.3	966.5	100
22	1.3	0.5	1.3	0.3	4.6	101
23	8.2	1.5	28.1	0.4	203.5	100
24	2.2	0.8	2.2	0.2	10.2	100

Comparison of Coverage Estimates

The standard field interview method had an overall coverage estimate of 30.3% for fully vaccinated children. Restricting only to vaccination card holders from the field method dataset increased the coverage to 42.3%. In comparison, the estimated proportion of fully vaccinated children was 16.8% using the photo-based method. The observed discrepancies of 13.5% and 25.5% from the field dataset and field subset, respectively, indicate that the proposed method tends to underestimate complete vaccination coverage. This underestimation of vaccination coverage is consistent across all vaccine series, including the rotavirus and meningitis A vaccines which were estimated by their respective country of administration (Tables 5, 6, & 7).

Table 5. Coverage estimates by method and vaccination series.

Vaccination Series	Photo-Based (N = 3140)		Field (N = 5332)		Field Card (n = 3658)	
	n	%	n	%	n	%
Completely Vaccinated	527	16.8	1613	30.3	1546	42.3
Bacillus Calmette-Guérin (BCG)	1760	56.1	3664	68.7	3540	96.8
Oral Polio Vaccine (VPOB)						
Dose 0	1705	54.3	3776	70.8	3646	99.7
Dose 1	1746	55.6	3485	65.3	3377	92.3
Dose 2	1554	49.5	3232	60.6	3131	85.6
Dose 3	1388	44.2	2907	54.5	2811	76.8
DTwP-HepB-Hib (Penta)						
Dose 1	1730	55.1	3466	65.0	3356	91.7
Dose 2	1555	49.5	3215	60.3	3114	85.1
Dose 3	1348	42.9	2862	53.7	2766	75.6
Pneumococcal (PCV)						
Dose 1	1677	53.4	3398	63.7	3292	89.9
Dose 2	1499	47.7	3176	59.6	3074	84.0
Dose 3	1317	41.9	2831	53.1	273	74.8
Inactivated Polio Vaccine (VPI)	1255	39.9	2846	53.4	2752	75.2
Measles (VAA)	711	22.6	1739	32.6	1667	45.6
Yellow Fever (VAR)	762	24.3	1752	32.9	1680	45.9

Table 6. Coverage estimates for the rotavirus vaccines by method in the DRC, due to the different vaccine administrations between the DRC and CAR.

Rotavirus Vaccine	Photo-Based (n = 1144)		Field (n = 2264)		Field Card (n = 1497)	
	n	%	n	%	n	%
Dose 1	888	77.6	1479	93.5	1401	93.6
Dose 2	829	72.5	1434	90.6	1360	90.8
Dose 3	713	62.3	1290	81.5	1220	81.5

Table 7. Estimated meningitis A vaccination coverage by method in the CAR, due to the different vaccine administrations in the DRC and CAR.

Method	Meningitis A Coverage Estimate	
	n	%
Photo-based (n = 1586*)	242	15.3
Field (n = 2264)	813	35.9
Field (card only) (n = 2161)	803	37.2

*Due to 410 missing values, the total is lower than the expected 1,996 records from CAR

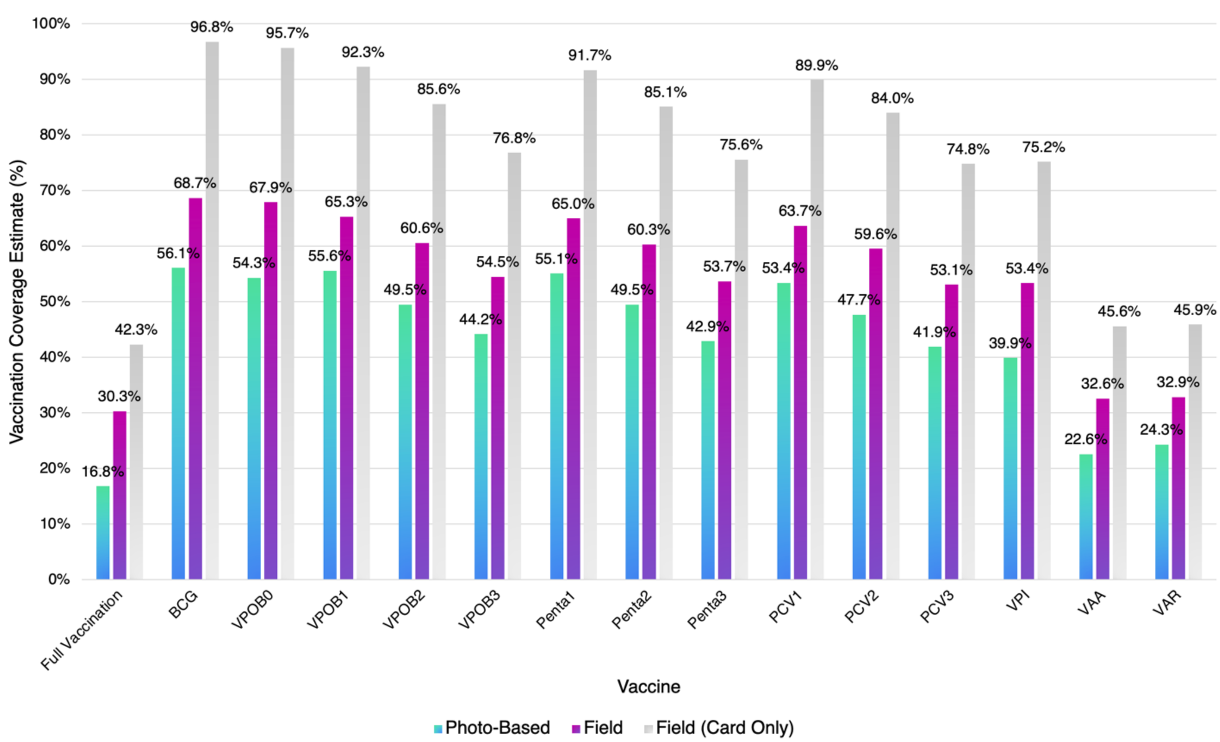


Figure 7. Coverage estimates (%) by method and vaccination series.

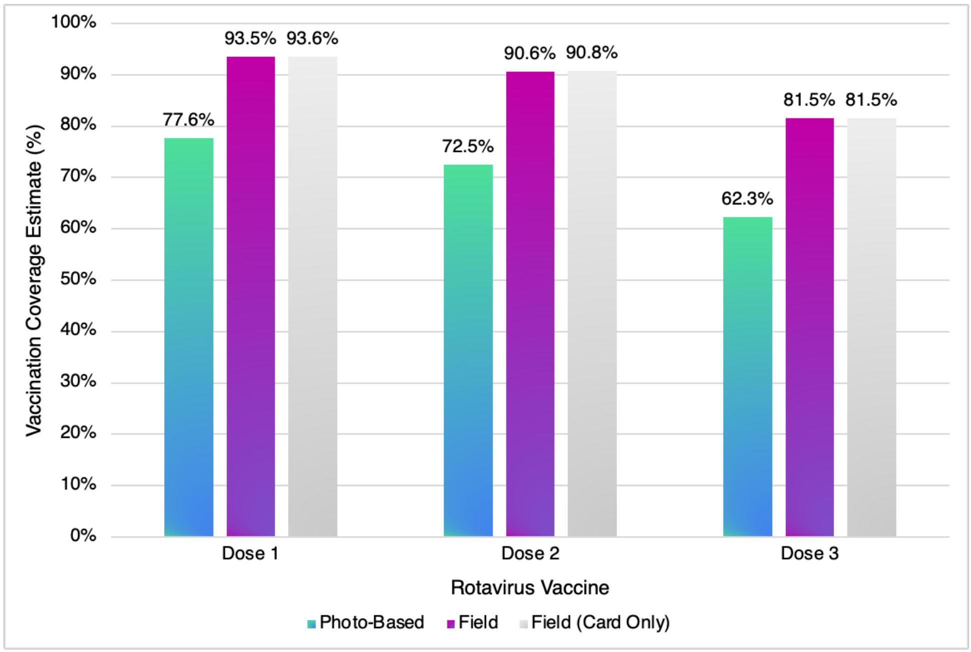


Figure 8. Estimated rotavirus coverage by method, restricted to children living in the DRC.

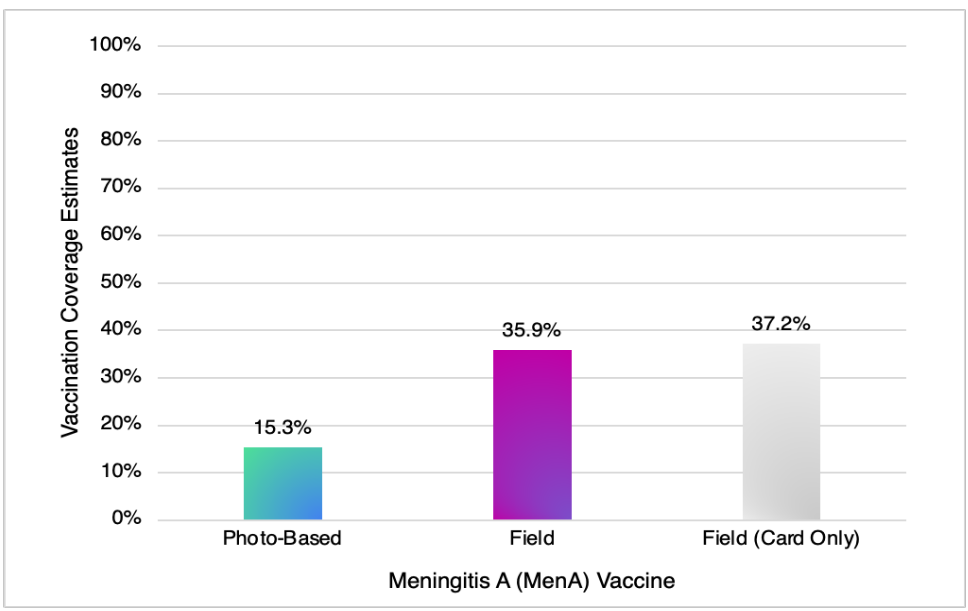


Figure 9. Estimated meningitis A (MenA) coverage by method, restricted to children living in CAR.

For both the rotavirus and meningitis A vaccination coverage estimates, the field and field vaccination cardholder subset yielded similar estimates, but again, the proposed method underestimated the coverage estimate.

Errors Between Field and Photo-Based Method Datasets

In this analysis, 1,073 photo-based method vaccination cards were compared against 1,029 field method vaccination cards. The discrepancy between matched cards is caused by barcode repeats in both the field and photo-based method datasets. The average number of errors was 15.2 out of 39 possible errors (38.9%), with a standard deviation of 9.4 errors (Table 8). (n = 1,073)

Table 8. Descriptive statistics for all 39 types of errors (both birthdate and vaccination information) when comparing the photo-based method to the field method.

N	Mean	Median	St. Deviation	Minimum	Maximum
1073	15.5 (39.7%)	14.0 (35.9%)	9.4 (24.1%)	0	39

*Percentages are calculated as out of 39 possible errors

Notably, vaccination dates tended to have a high inaccuracy rate across all vaccines, ranging from 17.1% to 68.9%, with an average error rate of 49.6 ± 14.3%. The average error rate for whether a vaccine was received was 30.2 ± 8.0%. The meningitis A vaccine had the lowest overall error rate, with only a 15.1% error rate regarding whether the vaccine was received, and a 17.1% error rate for the vaccination date. For multi-dose vaccines, the oral polio vaccine series appeared to have the highest inaccuracy, with an average error rate of 35.5% of whether the vaccine was received, and an average 60.1% error rate in the correct corresponding vaccination date (Table 9). Additionally, a Wilcoxon signed-rank test revealed a statistically significant difference in the number of errors between the photo-based method and the hypothesized zero differences from the paired field method reference ($V = 527878$, $P < 0.001$). In other words, the number of errors observed in the photo-based method is significantly greater than zero, indicating that this method does indeed exhibit inaccuracies compared to the information in reference vaccination records. (n = 1,073).

Table 9. Count and percentage of errors between field and photo-based dataset in matched unique barcode dataset organized by birthdate and vaccination information sections.

Vaccination Card Questionnaire Section	n	%
Birth Date		
Day	307	28.6
Month	292	27.2
Year	261	24.3
Bacillus Calmette-Guérin (BCG)	397	37.0
Vaccination Date	708	66.0
Meningitis (MenA)	162	15.1
Vaccination Date	183	17.1
Inactivated Polio Vaccine (VPI)	382	35.6
Vaccination Date	585	54.5
Oral Polio Vaccine (VPOB)		
Dose 0	456	42.5
Vaccination Date	739	68.9
Dose 1	367	34.2
Vaccination Date	653	60.9
Dose 2	360	33.6
Vaccination Date	625	58.2
Dose 3	342	31.9
Vaccination Date	564	52.6
DTwP-HepB-Hib (Penta)		
Dose 1	367	34.2
Vaccination Date	646	60.2
Dose 2	365	34.0
Vaccination Date	606	56.5
Dose 3	351	32.7
Vaccination Date	575	53.6
Pneumococcal (PCV)		
Dose 1	376	35.0
Vaccination Date	659	61.4
Dose 2	380	35.4
Vaccination Date	620	57.8
Dose 3	376	35.0
Vaccination Date	578	53.9
Rotavirus (Rota)		
Dose 1	189	17.6
Vaccination Date	387	36.1
Dose 2	187	17.4
Vaccination Date	365	34.0

Dose 3	218	20.3
Vaccination Date	349	32.5
Measles (VAR)	273	25.4
Vaccination Date	366	34.1
Yellow Fever (VAA)	284	26.5
Vaccination Date	380	35.4

(n = 1,073).

Table 10. Tabulated birth date errors between the field and photo-based method dataset for each vaccination barcode.

Number of Birthdate Errors	**n**	**%**
None	698	65.1
One	111	10.3
Two	43	4.0
Three (entire birth date)	221	20.6

For birth date errors, a slight majority of vaccination cards (65.1%) had no errors in the day, month, and year when compared to the field method's records. 111 (10.3%) vaccination cards had one error in the birth date, 43 (4.0%) had two errors, and 221 (20.6%) had the entire birth date entered incorrectly (Table 10).

Secondary Outcome: Qualitative Vaccination Card Photo Evaluation

Most vaccination card photos were not blurry or distorted (70.9%), did not have information loss due to a foreign object (90.6%), had no damage (83.9%), and no obstructions (90.4%). However, a slight majority (52.3%) of images lacked a complete vaccination record (vaccine page and ID page) (Table 11). (N = 3,140).

Table 11. Tabulated responses to the photo quality assessment section in the novel method.

Photo Quality	n	%
Is the image blurry, overexposed, distorted to a degree that does not allow you to read the text in the image?		
Not blurry or distorted	2226	70.9
Slightly blurry, but legible	650	20.7
Moderately blurry, partly illegible	191	6.1
Severely blurred, illegible	66	2.1
Is the information in the card lost because of a foreign object that hides the image of the card?		
No foreign body hides the image	2845	90.6
A foreign body hides the image, but **no** information is lost	167	5.3
A foreign body hides the image, **little** information is lost	63	2.0
A foreign body hides the image, **a lot** of information is lost	47	1.5
Does the card show evidence of physical damage (discoloration, tearing, wrinkling, mold, cuts by rodents, traces of fire, humidity, liquid damage, etc.)?		
No damage	2636	83.9
Slight damage, but **no loss** of information	316	10.1
Moderate damage, **small loss** of information	106	3.4
Severe damage, **significant loss** of information	61	1.9
Does the card have highlight markings, punch holes, or staples, which reduces the ability to read the information on the card?		
No, no obstruction	2839	90.4
Yes, slight obstruction of information	185	5.9
Yes, moderate obstruction of information	49	1.6
Yes, significant obstruction of information	53	1.7
Is the image of the card provided in a way that shows the complete information (vaccine page and ID page)?		
Yes, complete with vaccine page and ID page	1436	45.7
No vaccine page and ID page	1643	52.3

Note: Percentage totals may not sum up to 100% due to NA values

Table 12. Linear regression analysis output for elapsed time (photo-based method) and components of vaccination card photo quality.

Coefficient	Estimate	St. Error	t-value	Pr(>ltl)	
Intercept	3.5	0.1	30.5	< 2.0e-16	***
Photo Quality					
Slightly blurry, but legible	1.1	0.2	5.8	7.4e-09	***
Moderately blurry, partly illegible	0.1	0.3	0.4	0.7	
Severely blurred, illegible	-0.1	0.7	-0.2	0.8	
Information Loss					
A foreign body hides the image, but no information is lost	-1.0	0.4	-2.7	6.8e-03	**
A foreign body hides the image, little information is lost	-0.5	0.6	-0.8	0.4	
A foreign body hides the image, a lot of information is lost	-1.8	0.8	-2.2	2.6e-02	*
Condition					
Slight damage, but no loss of information	-0.3	0.3	-1.1	0.3	
Moderate damage, small loss of information	0.5	0.5	1.1	0.3	
Severe damage, significant loss of information	1.4	0.8	1.8	0.1	·
Marks					
Yes, slight obstruction of information	2.6e-2	0.4	0.1	0.9	
Yes, moderate obstruction of information	-0.8	0.7	-1.1	0.3	
Yes, significant obstruction of information	-0.6	0.8	-0.8	0.4	
Completeness					
No vaccine page and ID page	-1.5	0.1	-10.0	< 2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '·' 0.1 ' ' 1
Multiple R-squared: 0.053
Adjusted R-squared: 0.049
F-statistic: 12.32 on 13 and 2869 DF, P-value: <2.2e-16
210 observations automatically deleted due to missingness.

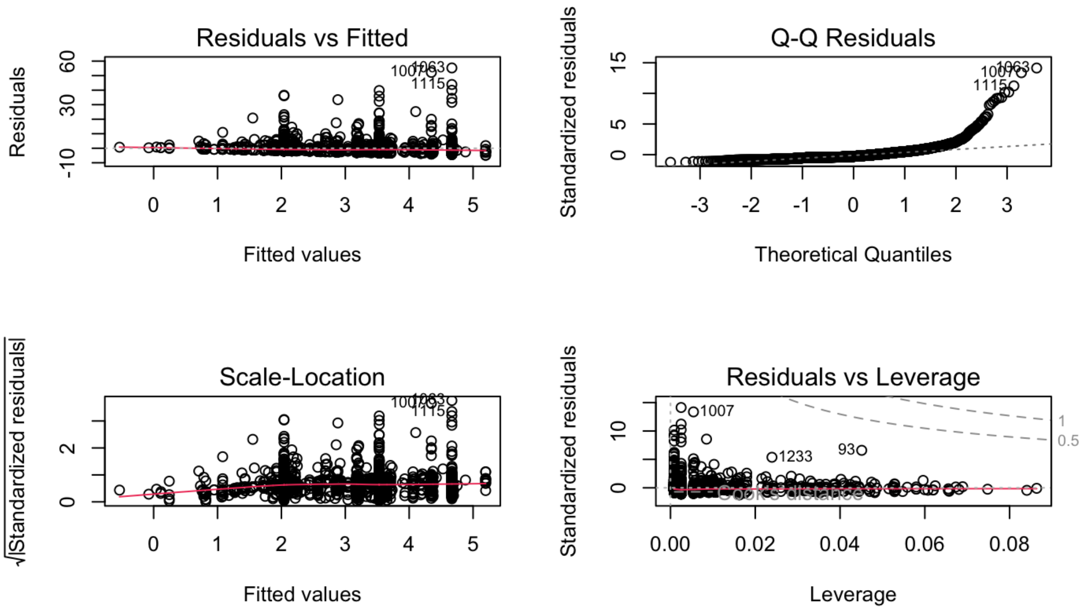


Figure 10. Diagnostic plots for regression analysis. From all four plots, influential values may be impacting the model's predictive value.

The linear regression analysis highlights the significant impact of vaccination card photo quality on data entry time. An undamaged card with no obstructions is associated with a quick entry time of 3.5 minutes ($P < 0.001$). Slight blurriness increases entry time by 1.1 additional minutes ($P < 0.01$), while more extreme distortion has lesser impact. No information loss or complete loss due to obstructions is linked to moderately faster times ($P < 0.05$). Completeness of information on the card also plays a crucial role; not having both the vaccination and ID pages reduces survey time by 1.5 minutes ($P < 0.001$), likely due to less data to record. More damage and highlight marks slow down entry, though not to a statistically significant degree ($P = 0.1$). These factors explained approximately 5% of variability in survey duration in the regression model, indicating additional variables substantially influence time, as shown in the diagnostic plots (Figure 10). However, the full regression model significantly predicted survey time, suggesting photo condition exerts some measurable effect on efficiency.

DISCUSSION

Primary Outcome: Quantitative Efficiency Metrics

Survey Entry Time Efficiency

The photo-based method saves approximately 1.3 minutes per vaccination card when recording data compared to the traditional field interview method. While this efficiency gain may seem minor on an individual card basis, the cumulative effects are substantial. With 3,658 vaccination cards in the field method dataset, the photo-based approach could potentially save around 4,755 minutes or 3 days' worth of data collection and entry time in the field. The results from a Wilcoxon rank sum test further support these observed efficiency gains, showing a clear and significant difference in the distributions of elapsed vaccine entry time between the two methods (W = 4192526, $P < 0.001$). It is worth noting that although most children from both method datasets fell within the 12-23 age group, the field interview method dataset had a greater proportion at 60.6% compared to the photo-based method's 39.2%. Children aged 12-23 months are more likely to have completed a higher number of vaccinations, which could partially explain the longer entry times observed in the field method data.

For household surveys, which require substantial time and resources to conduct, even marginal time savings can be impactful. For instance, an Expanded Program on Immunization (EPI) coverage survey can take 12 months from proposal to final analysis.[4] Applying the photo-based method has the potential to generate even greater cumulative time and cost savings if scaled up to more health administration areas, which would require recording and processing thousands of household vaccination records. By reducing the data collection burden, the photo-based method can not only increase efficiency but also enhance the ability to record greater volumes of vaccination cards within resource-limited settings.

Survey Entry Times by Interviewer

While some variability in data entry times between interviewers is expected when using the photo-based method, the presence of implausible values prompted further investigation. The average per-card data entry ranged from 1.3 to 186.5 minutes across interviewers, with standard deviations ranging from 1.1 to as wide as 537.9 minutes. Notably, Interviewer #1 had both the highest average entry time per card (186.5 minutes) and widest standard deviation (± 537.9 minutes), indicating inconsistent and lengthy data entry times compared to their peers.

Delayed survey uploads or intermittent internet connectivity could have resulted in failed survey submissions and the need to re-enter data. In addition to potential technological issues, human constraints such as experience, uneven workloads, and training may also drive variability. Considering the intensive nature of household surveys, interviewer fatigue poses a substantial threat to data quality and can be worsened by long questionnaires or uneven workload distribution.[4] Though most interviewers assessed 100 cards, two interviewers processed over 400 cards each. While workload size does not necessarily predict efficiency or accuracy (e.g. Interviewer #1 processed 100 cards), equitable workload distribution can help mitigate interviewer fatigue and ultimately improve data quality.

Comparison of Coverage Estimates

Compared to the standard field interview method, the photo-based method consistently underestimated vaccination coverage rates for all vaccines. For children who were completely vaccinated, the photo-based approach's estimate was 16.8%, which was 13.5% lower than the field method's overall estimate of 30.3%. When the field data was restricted to children with vaccination cards, the coverage estimate increased from 30.3% to 42.3%. This inflation in the complete vaccination coverage estimate is because unvaccinated children often lack documentation due to card loss or never receiving vaccination services in the first place to receive a card.[7] Thus, children that retain vaccination cards are more likely to be vaccinated.

Since the photo-based method relies on captured vaccination card images, its coverage estimates were expected to closely align with the field method's card-only subset. Instead, a significant 25.5% discrepancy was observed. Although part of the reason for this discrepancy could be due to the different sample sizes, the photo-based method's estimate was unexpectedly low. This implies the photo-based method may suffer from data entry mistakes or other data processing issues, contributing to the lower coverage estimates.

Errors Between Field and Photo-Based Method Datasets

For the paired vaccination cards, there was a concerning average error rate of 38.9% (15.2 out of 39 possible errors) when comparing the photo-based method's vaccination records to the reference field records. This substantial difference between the two methods was further corroborated by the results of a Wilcoxon signed-rank test, which indicated a statistically significant level of discrepancies between paired vaccination cards ($V = 527878$, $P < 0.001$).

While most vaccination cards had accurate birth dates (65.1%), over a fifth of cards (20.6%) were entered with completely incorrect birth dates compared to field reference data. Reusing barcodes for multiple children could have contributed to the completely incorrect birth dates. Smaller birthdate discrepancies were also common, with 10.3% and 4.0% demonstrating one or two mistakes, respectively, in any of the three birth date fields.

For the remaining 36 possible mistakes related to the 18 vaccine doses and their dates, inaccuracy persisted. Date discrepancies had an average error rate of 49.6 ± 14.3%, though for multi-dose vaccines, the vaccination date errors tended to decrease with each additional dose. A possible explanation for this trend is that the number of children receiving additional doses in a multi-dose vaccine series decreases with each subsequent dose (Table 5).

Errors for whether a vaccination was received ranged from 15.1% (meningitis A) to 42.5% (oral polio virus dose 0), with an average error rate of 30.2% ± 8.0%. Among multi-dose vaccines, the oral polio vaccine series reflected the lowest agreement, with only 64.5% agreement for whether the vaccine was received and an average 39.9% agreement for vaccination dates. These findings support the suspicion that inaccurate data entry contributed to the underestimated vaccination coverage rates when using the photo-based method.

Secondary Outcome: Qualitative Vaccination Card Photo Evaluation

Most of the 3,140 vaccination card photos assessed were high quality, with 70.9% avoiding blurriness, 90.6% showing no information loss from foreign objects, 83.9% exhibiting no damage, and 90.4% were free of obstructions such as markings or punch holes. However, over half (52.3%) lacked complete vaccination booklets with both vaccine and identification pages. The missing information could have contributed to the high error rates and missing birthdate information observed previously.

According to the regression analysis, pristine photo conditions correlate with faster entry. A perfect condition vaccination card photo takes only 3.5 minutes to completely record ($P < 0.001$). Slight blurriness was the only significant quality issue which significantly increased survey times by an estimated 1.1 minutes ($P < 0.01$). Although increased damage and obstructions such as marks or highlights did lengthen data entry times, this effect was not statistically significant. Counterintuitively, incomplete vaccination booklets ($P < 0.001$) and high information loss due to a foreign object ($P < 0.05$) were associated with faster data entry, likely reflecting less information to enter into the survey form overall.

Altogether, these aspects of photo quality explained just 5% of variability in data entry times in the regression model (adjusted $R^2 = 0.049$). The low percentage of explained variability suggests how external factors such as error-prone data entry or interviewer fatigue may affect survey times and data quality. However, the full regression model significantly predicted survey times, suggesting photo condition does exert some measurable effect on efficiency ($P < 0.001$). Confronting quality gaps such as slightly blurred images or missing pages through enhanced staff training and oversight can help scale up marginal time savings with a data quality control and assurance mindset.

Limitations

This study has several limitations. Firstly, while ten types of vaccination records were categorized, record type was not accounted for in assessing time efficiency or variability. Over 30% of records processed by the photo-based method were classified as another type of card or photocopy, and 18% were printed cards without department logos. The wide variability in vaccination record structure and formatting could have potentially impacted assessment times.

Secondly, the high degree of missingness in background timestamps in the field method dataset suggests improvements are needed during the digital tablet survey design stage. It is unclear why these background timestamps were not automatically recorded. Ultimately, this highlights the need for more thorough pilot testing of tablet surveys before deploying them in the field. This can help catch any data collection issues and decrease the chances of missing data.

Thirdly, the proposed method consistently underestimated vaccination coverage compared to both the standard field method and a subset of field data restricted to cardholders. The photo-based method's coverage estimates were expected to be the most similar to the field interview method's card-only subset, as the photo-based method solely relies on information from vaccination cards. Restricting comparisons to only to cardholders can introduce bias, due to potential socioeconomic differences between those who retain cards and those who do not, as well as the fact that cardholders are more likely to be vaccinated in the first place.[5] As such, coverage estimate results solely based on vaccination cards should be interpreted with caution.

Lastly, the high mismatch rates between matched vaccination cards from the proposed method and field method raise data quality concerns. Cards were only matched if barcodes were unique and appeared at least once in the field dataset and in the proposed method dataset. Missing, placeholder, or incorrectly entered barcodes prevented accurate record pairing, reducing expected matches from the full 3,140 down to 1,073 photo-based records. The presence of reused barcodes also points to much needed optimization, as cards should be checked off to prevent duplicated assessments. Alternatively, an additional review stage by another interviewer after entering vaccination card details could help catch data entry errors early to advance quality assurance.

CONCLUSION

This thesis makes a unique contribution to the limited research on the innovative photo-based vaccination card data collection method, offering both quantitative and qualitative assessments.[11,12,16,8] While this method has the potential to significantly reduce fieldwork time by streamlining the capture and processing of vaccination cards, current challenges such as high error rates and coverage estimate discrepancies limit its full implementation in field surveys. Nevertheless, pictures of vaccination cards can still serve as a valuable reference for later use and should be a part of coverage surveys moving forward, even if the extracted data quality is not yet optimal. Overall, these results present an exciting opportunity for refinement.

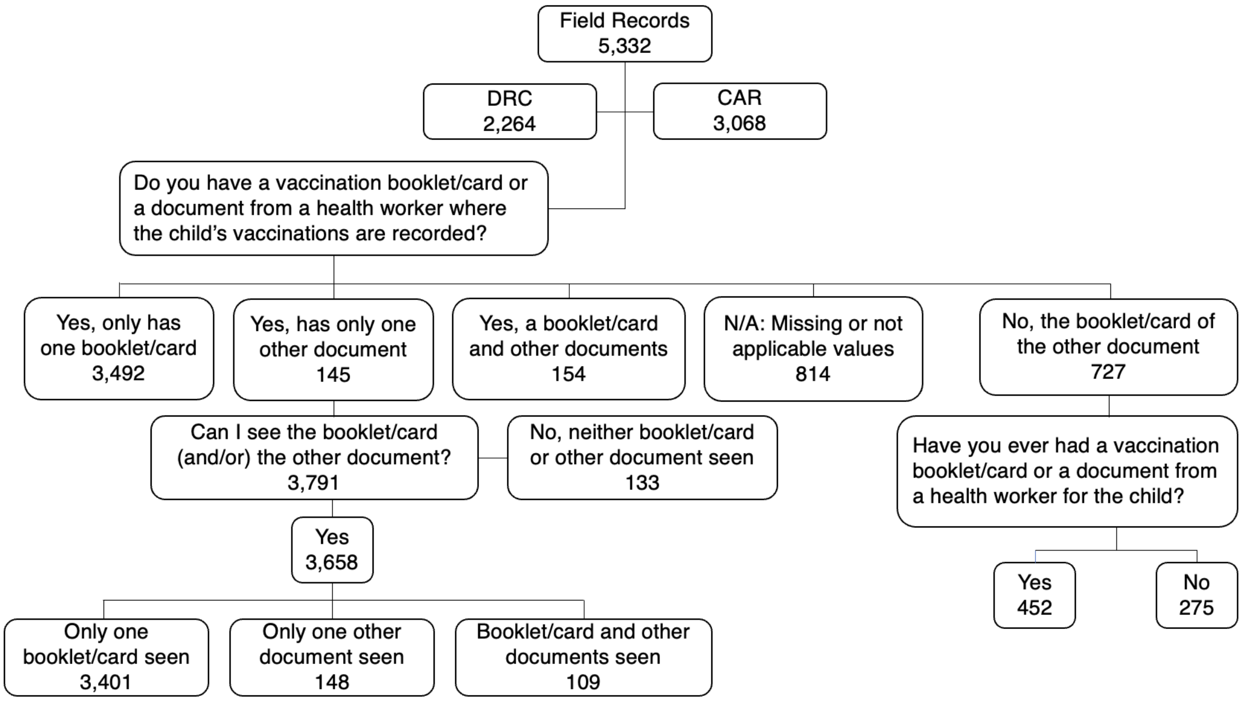
Future work should explore sustainable workloads for interviewers to strike a balance between speed and accuracy. Introducing a data entry review stage, along with regular audits of collected information, can help catch data entry errors early, thereby enhancing data quality and reliability. Although most photos were high quality, establishing clear guidelines for taking and processing images can minimize potential mistakes resulting from poor quality. Furthermore, as data quality, technology, and connectivity continue to advance in developing countries, using artificial intelligence (AI) to visually optimize and extract large amounts of information from digitized vaccination card images is a promising avenue for future exploration. AI is already being applied within resource-limited settings to help predict potential disease outbreaks, so it seems reasonable it can also be extended to predict shifting trends in vaccination coverage in the future through vaccination card image optimization, extraction, and analysis for coverage surveys.[17]

In conclusion, following rigorous pilot testing, optimization, and future technological advancements, the photo-based vaccination card collection method has immense potential to become a cornerstone within coverage surveys. By streamlining paper-based vaccination data collection, it is well positioned to support global health initiatives in resource-constrained settings.

APPENDIX

Supplemental Table 1. Example calculation of errors for a matched vaccination card.

Barcode	KIN_NDJ_OMS 0123				Error Count
Date Collected	14APR2023		19JUL2023		
Method	Field		Photo-Based		
Day of Birth	20		20		0
Month of Birth	11		11		0
Year of Birth	2022		**2021**		1
Vaccine	1 = Yes I 0 = No	Date Received	1 = Yes I 0 = No	Date Received	
BCG	1	30NOV2021	1	30NOV2021	0
VPob0	1	30NOV2021	1	30NOV2021	0
VPob1	1	04JAN2021	1	04JAN**2022**	1
Penta1	1	04JAN2022	1	04JAN2022	0
Pneumo1	1	04JAN2022	1	04JAN2022	0
Rotavirus1	1	04JAN2022	1	04JAN2022	0
VPob2	1	01FEB2022	1	01FEB2022	0
Penta2	1	01FEB2022	1	01FEB2022	0
Pneumo2	1	01FEB2022	1	01FEB2022	0
Rotavirus2	1	01FEB2022	1	01FEB2022	0
VPob3	1	01MAR2022	1	01MAR2022	0
VPI	1	01MAR2022	1	01MAR2022	0
Penta3	1	01MAR2022	1	01MAR2022	0
Pneumo3	1	01MAR2022	1	01MAR2022	0
Rotavirus3	1	01MAR2022	1	01MAR2022	0
VAR	1	06SEP2022	1	**NA**	1
VAA	1	06SEP2022	1	**NA**	1
MenA	0	NA	0	NA	0
Total Errors					**4**



Supplemental Figure 1. Description of field dataset vaccination card holders and relevant field survey questions (n = 5,332).

Supplemental Table 2. Missingness of elapsed vaccination card entry times described in terms of vaccination card status, method, country, and health zone and method in the field method dataset.

	n	%
Total participants with missing (NA) elapsed times	3124	100.0
By Vaccination Card Status		
Presented a vaccination card to interviewer	1498	48.0
Did not present a vaccination card to interviewer	1626	52.0
By Method		
WHO-KSPH	862	27.6
GIS	854	27.3
LQAS	286	9.2
WHO	1122	35.9
By Country		
Democratic Republic of the Congo	2264	72.5
Central African Republic	860	27.5
By Health Zone (DRC), Health District (CAR), and Method		
Democratic Republic of the Congo		
Boko, Kwango	1121	100.0
WHO-KSPH	308	27.5
GIS	311	27.7
LQAS	87	7.8
WHO	415	37.0
N'djili, Kinshasa	1143	100.0
WHO-KSPH	311	27.2
GIS	309	27.0
LQAS	99	8.7
WHO	424	37.1
Central African Republic		
Bangui II	132	100.0
WHO-KSPH	26	19.7
GIS	22	16.7
LQAS	18	13.6
WHO	66	50.0
Begoua	170	100.0
WHO-KSPH	8	8.0
GIS	51	51
LQAS	38	22.3
WHO	73	43.0
Bossesemble	558	100.0
WHO-KSPH	209	37.4
GIS	161	28.9
LQAS	44	7.9
WHO	144	25.8

Background time points were expected for seen vaccination cards (n = 1498, 48%). Most of the NA values were from the WHO method, followed closely by WHO-KSPH and GIS. The LQAS method had the least number of missing values. All the records from DRC (n = 2264, 72.5%) were lacking valid background timestamps, with only 28% missing values from CAR.

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