Supplementary Material

Methodologic details for scale development: Construct validity assessment

To evaluate construct validity, we used exploratory factor analysis (EFA) to analyze the Ghana dataset. In EFA, we used principal axis factor extraction (PAF) with a polychoric dispersion matrix, as this is recommended for analyzing ordinal data collected via Likert-type scales or variables that have few categories such as dichotomous items [18, 19]. EFA based on a Pearson correlation matrix is known to lead to underestimation of the strength of relationships between variables with few categories, with reduced factor loadings compared to EFA based on a polychoric correlation matrix[18], in general because Pearson correlations assume that the underlying variables are continuous. Exploratory factor analysis and reliability assessment were analyzed using a combination of the R *psych* package, MPlus 8, and FACTOR 10 software[20, 21]. For factor rotations, we used promax, an oblique rotation, since we hypothesized some correlation between factors[22], although there is consensus that use of similar oblique rotation procedures (e.g. promin, oblimin) would likely yield similar results[34].

Prior to EFA, we examined the skewness and kurtosis of each CVAS response item; excessive kurtosis can be used as further evidence of the need to use a polychoric correlation matrix[19]. To assess whether the sample size was sufficient to conduct EFA, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were evaluated. The KMO sampling adequacy value varies between 0 and 1, with values >0.60 generally indicating adequacy of the data for EFA, whereas a significant finding for the test of sphericity can indicate rejection of the null hypothesis that the correlation matrix is an identity matrix [35], which can be interpreted that at least some of the variables are correlated and hence the data is adequate for EFA.

Methodologic details for scale development: Reliability assessment

To assess reliability and internal consistency of the derived factor solution, we used the Mislevy & Bock reliability estimate. This estimate is equivalent to the square of the correlation between a single factor score (derived from the values of the items that loaded into that factor) and the true score on the latent variable that the factor is representing [36]. In other words, it reflects the percent of variance in the factor scores explained by the latent variable; a value closer to 1 is desirable. We also examined Cronbach's coefficient alpha and McDonald's omega statistic. The

omega statistic is preferable to use for skewed data and has been shown to be more robust than the alpha statistic for measuring closer to true reliability in these situations[23]. Additionally, the alpha statistic assumes equal factor loadings across items loading onto a factor to properly estimate the true reliability; if this is not the case, then alpha will underestimate reliability[24].

Methodologic details for scale development: Vaccination outcome calculation for vaccination delay

Vaccination delay was defined as number of days under-vaccinated, per the method developed by Luman [25] and described in detail in supplementary materials. In brief, the number of days under-vaccinated was calculated by determining the age at which a child received each examined vaccine dose and comparing it to the recommended age (in days) based on the 2014-2016 Ghana vaccination schedule, accounting for minimum dose intervals and minimum age (supplemental table S1). If the child received a dose >4 days before the minimum acceptable age or interval for the vaccine, the dose was too early and not counted. If the child received a dose beyond the recommended age, we calculated the difference between the child's age at vaccination and the latest age at which it should be received (generally a 31-day buffer period for a timely vaccination). If the child did not receive a scheduled vaccine dose before 12 months of age, then we calculated the difference between the maximum age of interest (365 days) and the latest age in which it should have been received. If a child received a dose in a multi-dose series late (i.e. DTPcv1 late), the calculation of days under-vaccinated for the next dose was based on the end of the minimum interval period and an additional 31 days buffer. Records were excluded if a vaccination was indicated but date of vaccination was either not included or was inconsistent with the date of birth or if the child was missing date of birth.

Supplemental Table S1: Parameters for defining vaccination delay and days under-vaccinated up to 12 months of age

Vaccine	Age of early vaccination (days)	Earliest age for a valid vaccination (days)	Age of late vaccination (days)	length of buffer period (days)	Maximum number of days under-vaccinated
Penta1, PCV1, RV1, OPV1	≤38	42	>69	31	296

Penta2, PCV2, RV2, OPV2	≤66	70	>97	31	268
Penta3, PCV2, OPV3	≤94	98	>125	31	240
Measles1	≤248	252	>279	31	86
All vaccines	NA	NA	NA	NA	2412

*

Ghana survey sample descriptive results

Among all children, 337 (90%) had received DTPcv3, 316 (85%) had received MCV1, and 299 (80%) had received all vaccines. Among those with sufficient data for assessing vaccination delay, 33% were delayed for DTPcv3, 89% were delayed for MCV1 and 94% were delayed for any vaccine. Among those delayed for DTPcv3 and MCV1, the mean days undervaccinated was 36.3 (standard deviation [SD] =78) and 45.7 (SD=34), respectively. Across all vaccines, the mean days undervaccinated was 358 (SD=696).

Among interviewed caregivers, 20% indicated they had seen an individual with either polio, pneumonia, measles or whooping cough and 13% knew of someone in their family or community who had one of the latter diseases. Nearly all (99%) knew the location of vaccination and days/times of vaccination (94%). Nearly all believed vaccines to be safe (97%), although 22% indicated that people in their community had expressed concerns possible side effects from vaccination. Although nearly all (97%) believed that following a nationally recommended vaccination schedule is a good idea and 96% would want to have any future children get all recommended vaccinations, 22% and 15% had indicated either ever delaying or ever deciding not to have a child receive a vaccination for reasons other than illness or allergy. A slight majority (57%) of caregivers said they were able to discuss concerns about vaccination with their local healthcare provider, although nearly all (97%) trusted the information they received about vaccination from the provider. A sizeable minority (23%) believed that healthy children did not need immunizations and expressed concerns about the number of vaccinations provided, with 41% agreeing that children get more vaccinations than are good for them and 23% disagreeing that children should get two injectable vaccinations in 1 visit rather than one per visit.

Supplemental Table S2: Descriptive characteristics of parents and children interviewed for development of Caregiver Vaccination Acceptance Scale, Ghana, 2017

Characteristic		N (%)
Child's age		
	12-23 mo	201 (54%)
	24-36 mo	172 (46%)
Child's sex		
	Female	176 (47%)
	Male	197 (53%)
Child's birth order		
	first child	80 (22%)
	second or more	293 (79%)
Child has vaccination card		
	Yes	353 (95%)
	No	20 (5%)
Child ever received vaccination		
	Yes	371 (99%)
	No	2 (1%)
Parents' religion		
	Christian	137 (37%)
	Muslim	195 (52%)
	Traditionalist	37 (10%)
	None	4 (1%)
Mother's age (years)	mean (SD)	28.9 (6.6)
	N missing	106
Mother's education		
	Never attended school	261 (70%)
	Primary education	40 (11%)
	Secondary or post-secondary education	70 (19%)
Mother's occupation		
	Farmer/Laborer	214 (57%)
	Artisan/trader/merchant	68 (18%)
	Housewife	32 (9%)
	Other	59 (16%)
Father's education		
	Never attended school	218 (59%)
	Primary education	41 (11%)
	Secondary or post-secondary education	105 (28%)
Father's occupation		
	Farmer/Laborer	270 (72%)
	Artisan/trader/merchant	48 (13%)
	Civil servant	26 (7%)
	Other	29 (8%)

Table S3: Descriptive results for questions in a caregiver vaccination attitudes scale module used in a household survey of 373 parents of children 12-35 months of age, Ghana 2017

Question	*Agree (%)*	*Not sure (%)*	*Disagree (%)*
Children get more vaccinations than are good for them	41%	18%	41%
Healthy children do not need immunizations	23%	16%	62%
Vaccination does more good than harm	85%	6%	9%
It is better for a child to develop immunity by getting sick than to get a vaccination	14%	30%	57%
A parent should be allowed to selectively choose the vaccines which she believe her child needs	15%	10%	75%
It is better for a child to receive two injectible vaccinations in 1 visit rather than 1 injectible vaccination in 2 visits	59%	18%	23%
Many of the illness which vaccinations prevent are severe	84%	13%	3%
When a parent refuses to vaccinate a child, it harms the entire community through risk of disease	66%	17%	17%
People in this community have expressed concerns that a child might have a serious side effect from a vaccination	22%	20%	58%
Following the nationally recommended vaccination schedule is a good idea for a child	97%	2%	1%
Question	*Yes (%)*	*No (%)*	*Not sure (%)*
If the national immunization policy states that 2 injectable vaccines should be given in the same arm/leg would you allow it?	65%	32%	2%
I believe vaccines are safe	97%	3%	0%
I believe vaccines protect my child from vaccine preventable disease.	98%	2%	0%
Have you personally seen someone with either polio, pneumonia, measles or whooping cough?	20%	78%	2%
Do you know of someone in your family or community who had either polio, pneumonia, measles or whooping cough?	13%	84%	3%
Have you ever delayed having your child get a vaccination for reasons other than illness or allergy?	22%	74%	4%
Have you ever decided not to have your child get a vaccination for reasons other than illness or allergy?	15%	83%	2%
If you had another infant today, would you want your infant to get all recommended vaccinations?	96%	3%	1%
Do you know the location where you can have your child vaccinated?	99%	0%	1%
Do you know the days and times when vaccination services are offered in your community?	94%	4%	2%
Are you able to discuss any concerns you have about vaccinations with your child's healthcare provider?	57%	41%	2%
Do you trust the information that you receive from your local healthcare worker about vaccinations?	97%	1%	2%

Table S4: Vaccine not received: Multivariable associations with Scale and Factor Score Means (n=373)

		Scale		
Characteristic	Received n (%)	11 items, 5 factors OR (95% CI)	9 items, 4 factors[5] OR (95% CI)	6 items, 3 factors[5] OR (95% CI)
All vaccines (n=373)[1]				
Yes	299 (80%)	0.56 (0.44, 0.70)	0.52 (0.42, 0.63)	0.51 (0.42, 0.62)
No	74 (20%)	Reference	Reference	Reference
DTPcv3 (n=373)				
Yes	337 (90%)	0.57 (0.43, 0.74)	0.50 (0.38, 0.67)	0.50 (0.38, 0.66)
No	36 (10%)	Reference	Reference	Reference
MCV1 (n=373)				
Yes	316 (85%)	0.50 (0.37, 0.68)	0.45 (0.38, 0.54)	0.45 (0.38, 0.54)
No	57 (15%)	Reference	Reference	Reference

1. Includes measles 1st dose, DTP 3-dose series, pneumococcal conjugate vaccine 3-dose series, rotavirus vaccine 2-dose series, polio vaccine 3-dose series
2. Model includes covariates for mother's educational level, mother's age, child's birth order, child's gender, child's household primary sampling unit
3. Odds ratio references are the "non-receipt of vaccination" group for each listed vaccine
4. Definitions: VPD = vaccine preventable disease; OR = odds ratio; CI = confidence interval
5. 4-factor scale does not include "VPD awareness"; 3-factor scale does not include "VPD awareness" or "Trust"

Table S5: Vaccine delay: Multivariable associations with scale and mean days undervaccinated per vaccine for the 3, 4 and 5-factor scales

			Beta coefficient (95% CI)		
Vaccines	Delayed n (%)	Mean % days under-vaccinated1	5-factor scale (11 items)	4-factor scale (9 items)[5]	3-factor scale (6 items) [5]
All vaccine (n=279)[1]	262 (94%)	2.8% (1.0, 4.7)	136.1 (65.7, 206.5)	194.7 (91.9, 297.4)	194.4 (88.4, 300.4)
DTPcv3 (n=344)	113 (33%)	110.6 (100.5)	11.1 (3.7, 18.4)	15.6 (7.5, 23.9)	15.1 (6.8, 23.5)
MCV1 (n=353)	314 (89%)	60% (37%)	5.6 (2.2, 8.9)	4.2 (0.7, 7.8)	4.8 (1.2, 8.5)

1. Vaccinations include measles 1st dose, DTP 3-dose series, pneumococcal conjugate vaccine 3-dose series, rotavirus vaccine 2-dose series, polio vaccine 3-dose series
2. Model includes covariates for mother's educational level, mother's age, child's birth order, child's gender, child's household primary sampling unit
3. Odds ratio references are the "non-receipt of vaccination" group for each listed vaccine
4. Definitions: VPD = vaccine preventable disease; OR = odds ratio; CI = confidence interval
5. 4-factor scale does not include "VPD awareness"; 3-factor scale does not include "VPD awareness" or "Trust"

Table S5: All factor loadings 5-factor scale

		Standardized factor loading (SE) 5-factor scale				
Item	Item mean (SD)	VPD Awareness	Benefits	Past behavior	Efficacy & safety	Trust
Have you personally seen someone with either polio, pneumonia, measles or whooping cough?	1.58 (0.04)	0.93	0.04	0.05	0.07	0.08
Do you know of someone in your family or community who had either polio, pneumonia, measles or whooping cough?	1.71 (0.04)	0.93	0.01	0.03	0.07	0.07
I believe vaccines are safe	0.03 (0.01)	0.02	0.93	0.11	0.16	0.07
I believe vaccines protect my child from vaccine preventable disease.	0.03 (0.01)	0.06	0.95	0.05	0.14	0.14
Have you ever delayed having your child get a vaccination for reasons other than illness or allergy?	0.48 (0.04)	0.06	0.10	0.89	0.03	0.04
Have you ever decided not to have your child get a vaccination for reasons other than illness or allergy?	0.32 (0.04)	0.07	0.04	0.78	0.09	0.03
Vaccination does more good than harm	0.24 (0.03)	-	0.14	0.11	0.85	0.06
Many of the illnesses which vaccination prevent are severe	0.19 (0.02)	0.02	0.20	0.16	0.45	0.08
If you had another infant today would you want your infant to get all recommended vaccinations?	0.07 (0.02)	0.18	0.11	0.04	0.02	0.55
Do you trust the information that you receive from your healthcare worker about vaccinations?	0.05 (0.01)	0.16	0.01	0.04	0.06	0.54
Following the nationally recommended vaccination schedule is a good idea for my child	0.04 (0.01)	0.01	0.04	0.10	0.10	0.66

Figure S2: Range of total scale scores observed among interviewed caregivers, using the 5-factor caregiver vaccine acceptance scale

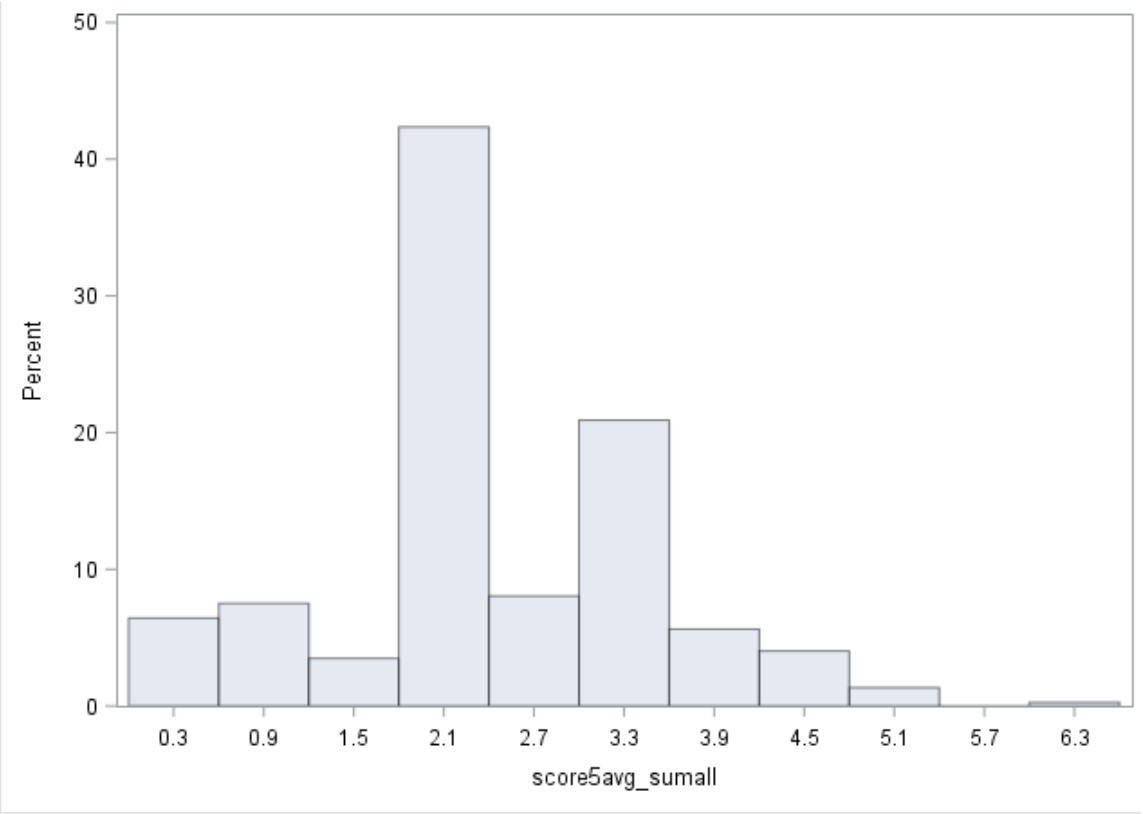
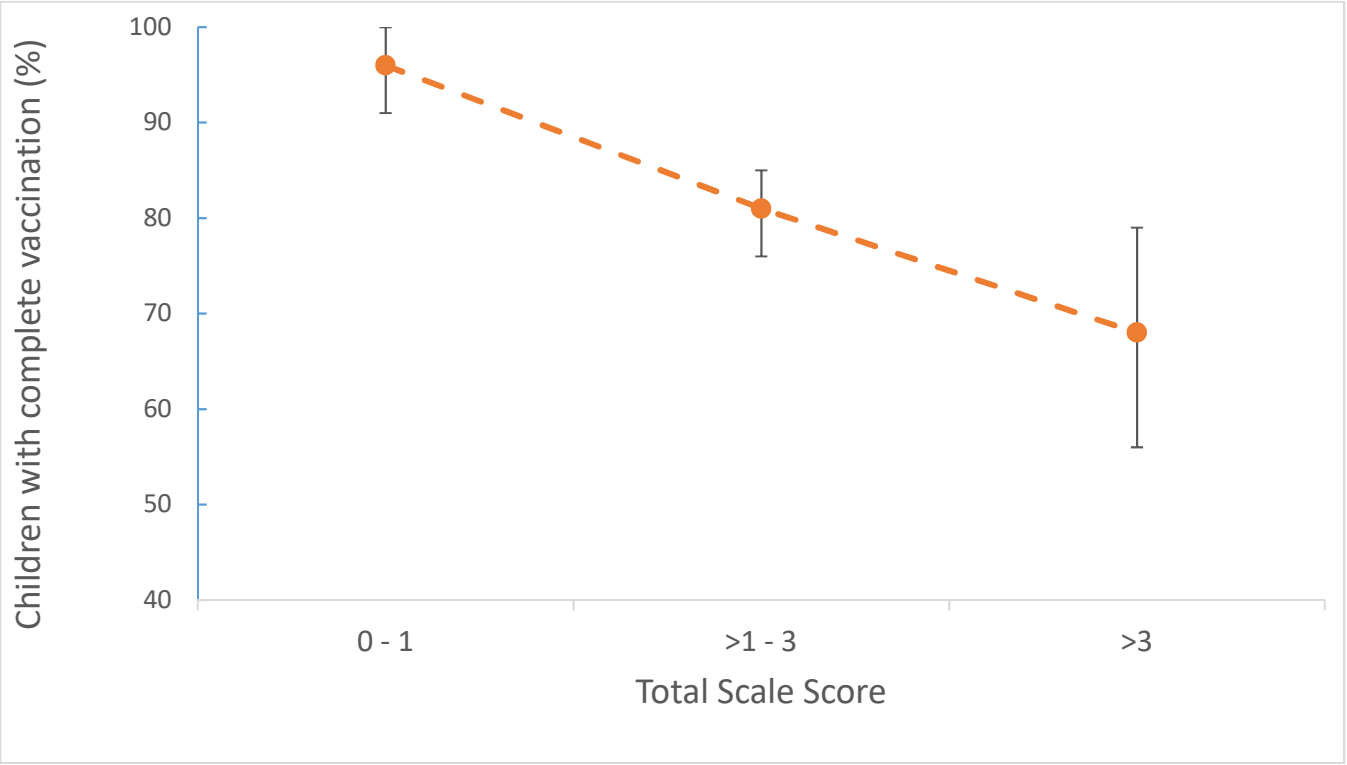
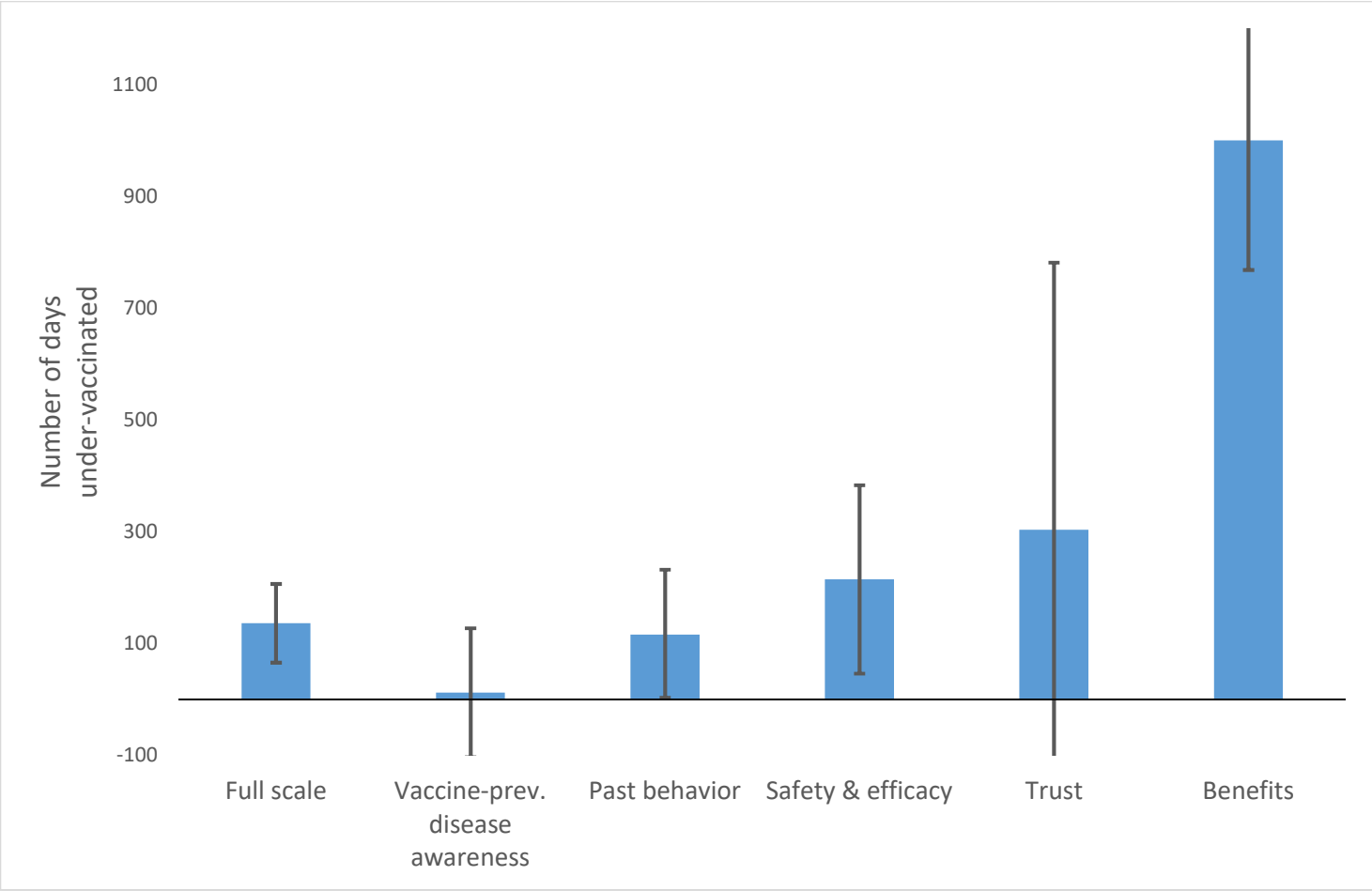


Figure S3: Association of caregiver vaccine acceptance scale total score and receipt of all recommended vaccinations by 12 months of age



1. Error bars indicated 95% confidence intervals

Figure S4: Comparison of the caregiver vaccine acceptance scale score and number of days under-vaccinated by full scale and by each subscale



1. Error bars indicated 95% confidence intervals