


# Attitudes to malaria vaccination in children: what can be learned from their consistency with the temporal dynamics of COVID-19 vaccination intention? A prospective cohort study in rural Senegal (July 2020–November 2023)

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## ABSTRACT

**Introduction** Several sub-Saharan African countries are launching malaria vaccination programmes for children. We assessed how attitudes to malaria vaccination for children could be better understood by considering the individual dynamics of COVID-19 vaccine intention/uptake over the 2021–2023 campaigns, with a view to highlighting barriers likely to affect malaria vaccine uptake.

**Methods** We conducted a six-wave telephone-based survey of 600 randomly selected Senegalese households. A latent class mixed model was used to assess temporal changes in COVID-19 vaccine intention/uptake and to identify clusters of individuals sharing similar intention/uptake patterns across the waves. Time-invariant and time-varying correlates were assessed using logistic and probit models. Attitudes to malaria vaccination (wave 6) were compared with the various COVID-19 patterns.

**Results** Of the 600 households contacted, 558 (93.00%) agreed to participate in the study (558 heads of household and 457 spouses). Very strong positive attitudes to malaria vaccination (65.28% of participants) were associated with higher personal COVID-19 vaccine uptake ( $p < 0.001$ ). With regard to the individual dynamics of COVID-19 vaccination, three temporal patterns were identified: continuously strong intention (34.88% of participants), increasingly strong intention (33.40%) and increasingly less strong intention (31.72%). Along with socioeconomic factors, these patterns were explained by early levels of risk perception and trust in health authorities, and temporal fluctuations of these factors. Households where both surveyed members had continuously strong COVID-19 vaccination intention were also more likely to have strong positive attitudes to malaria vaccination for children ( $p = 0.001$ ).

**Conclusion** Further investigation would be necessary to assess the generalisability of using individual dynamics of COVID-19 vaccination as a reference for studying attitudes to newly offered vaccines. As regards the real-world dynamics of uptake of the four scheduled malaria vaccine doses, targeting of parents who need incentives to address

## WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The unprecedented global media coverage of COVID-19 vaccine hesitancy raised concerns about what people's attitudes might be to newly offered vaccines, especially in sub-Saharan Africa, where COVID-19 vaccine hesitancy had been particularly high.

## WHAT THIS STUDY ADDS

⇒ Focusing on the newly recommended vaccination against malaria for children, our longitudinal study in rural Senegal showed consistency between attitudes to malaria vaccination in children and personal temporal dynamics of COVID-19 vaccine intention/uptake.  
⇒ Factors associated with these dynamics highlighted barriers likely to affect both COVID-19 and malaria vaccination.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Considering that malaria vaccination in children involves a four-dose schedule, analysing the dynamics of COVID-19 vaccination provided a broader view of the barriers likely to affect the dynamics of malaria vaccine uptake.

barriers to compliance could be improved by accounting for their dynamics of COVID-19 vaccination.

## INTRODUCTION

With the end of the COVID-19 pandemic as a public health emergency of international concern (WHO, 30 January 2020–5 May 2023), the issue of losses in uptake of routine immunisation vaccines came to the fore and highlighted the threats associated with

vaccine-preventable disease outbreaks in low- and middle-income countries.<sup>1</sup> Moreover, the unprecedented global media coverage of COVID-19 vaccine hesitancy<sup>2</sup> raised another public health issue about what people's attitudes might be to newly offered vaccines against infectious diseases other than COVID-19. Although the vaccine-specific determinants of vaccine hesitancy<sup>3</sup> should limit the effects of COVID-19 vaccine hesitancy on attitudes to newly offered vaccines, the latter issue reflected the fear of growing public distrust in vaccines.<sup>4</sup>

Due to an unexpectedly rapid availability of vaccines to prevent progression to severe forms of COVID-19 (including the newly developed mRNA vaccines),<sup>5</sup> vaccination campaigns for the general population had been launched at the end of 2020 in Western countries and in 2021 in sub-Saharan African (SSA) countries. COVID-19 vaccine remained freely available throughout the pandemic and the vaccination campaigns were relaunched at times of peak incidence to boost immunisation while encouraging individuals who were not vaccinated yet to do so. Given that individuals had to make successive decisions over time as to whether they would get vaccinated or receive booster vaccines, exploring the individual dynamics of COVID-19 vaccine intention/uptake could provide insight into the issue of consistency between past attitudes to COVID-19 vaccination and present attitudes to newly offered vaccines.

With regard to new vaccines, major breakthroughs have been achieved in recent years in vaccines against malaria.<sup>6,7</sup> As SSA bears most of the burden of malaria cases and deaths worldwide (with 94% of cases and 95% of deaths globally in 2021),<sup>8</sup> a large-scale clinical study supervised by the WHO was conducted in three SSA countries (Ghana, Kenya and Malawi) with a view to assessing the feasibility of vaccination against malaria in children and associated clinical outcomes.<sup>9</sup> As a result, the first vaccines (RTS,S also known as Mosquirix and R21/Matrix-M) were recommended (in 2021 and 2023, respectively) against *Plasmodium falciparum* malaria,<sup>10</sup> which is the parasite responsible for the high morbidity and mortality from malaria (99% of infections caused by *P. falciparum* in Africa).<sup>7</sup> Intended to reduce the risk of severe forms of the disease in children, the recommended schedule is four doses starting at 5 months of age.<sup>10</sup> Several SSA countries plan to include vaccination against malaria for children in their national Expanded Programme on Immunization (EPI), and three of them (Benin, Liberia and Sierra Leone) launched mass malaria vaccination in children on 25 April 2024.<sup>11</sup>

Exploring attitudes to malaria vaccination for children with respect to past dynamics of COVID-19 vaccine intention/uptake could be especially pertinent in SSA, a context where large-scale international studies have shown that SSA and especially Western/Central Africa had particularly high COVID-19 vaccine hesitancy<sup>12</sup> (ie, delayed uptake or refusal despite availability of vaccination services).<sup>3</sup> After major concerns were expressed at the beginning of the pandemic about the ability

of healthcare systems to resist the burden of COVID-19,<sup>13</sup> SSA has been progressively regarded as one of the world's least affected regions in terms of COVID-19, although possible widescale underreporting was highlighted.<sup>14</sup> In all, COVID-19 vaccine uptake had been relatively low in SSA (as of August 2024, 38.69% in Africa vs 87.28% in South America, 78.38% in Asia, 76.43% in North America, 70.09% in Europe and 64.96% in Oceania).<sup>15</sup> Vaccine intention was higher in rural areas, and age, educational level, perceived risks of COVID-19, level of trust in health authorities and in government, as well as accessibility to health services were found to be main factors in COVID-19 vaccine intention/uptake.<sup>16–20</sup>

The core hypothesis of the present study was that attitudes to malaria vaccination for children could be better understood by studying the dynamics of COVID-19 vaccine intention/uptake over time, with a view to highlighting barriers likely to affect both COVID-19 and malaria vaccination. To our knowledge, this is the first study to explore this hypothesis within the framework of individual decision making under risk, according to which risk perception is a key component of attitudes and behaviours because of its impact on personal exposure to hazards and response to health-prevention interventions.<sup>21,22</sup> The objectives of the study were as follows: (1) to identify temporal patterns of COVID-19 vaccine intention/uptake, and to assess to what extent time-invariant factors (eg, sociodemographic characteristics) and time-varying factors (eg, risk perception, trust in health authorities) explained these patterns; (2) to assess attitudes to malaria vaccination for children, and to compare these attitudes with the temporal dynamics of COVID-19 vaccine intention/uptake.

Specifically, we conducted a longitudinal study in rural Senegal, where 53% of Senegalese people live. With regard to the COVID-19 pandemic, a national curfew (March–June 2020) followed by regional curfews (Dakar and Thiès, January–March 2021) had been instated, and the COVID-19 vaccination campaigns (freely available to all Senegalese) were launched in February 2021 and relaunched in November 2022. As of August 2024, 15.20% of the Senegalese population had received at least one dose of a COVID-19 vaccine.<sup>15</sup> With regard to malaria, incidence in Senegal is relatively low (an average of 48.00 per 1000 individuals at risk in 2022).<sup>23</sup> For comparison, incidence in Kenya and Ghana (two of the three countries in the WHO's pilot implementation study on malaria vaccines) was 63.30 and 216.40 per 1000, respectively, in the same year.<sup>23</sup> Senegal has a long-standing commitment to the fight against malaria<sup>24</sup> and in recent years, several campaigns of mass distribution of long-lasting insecticidal nets have been organised jointly by Senegal and Gambia (9 million in 2019, 7 million in 2022 and 6 million in 2025).<sup>25,26</sup> To date, no announcement has been made about including malaria vaccination in Senegal's national EPI.

## MATERIAL AND METHODS

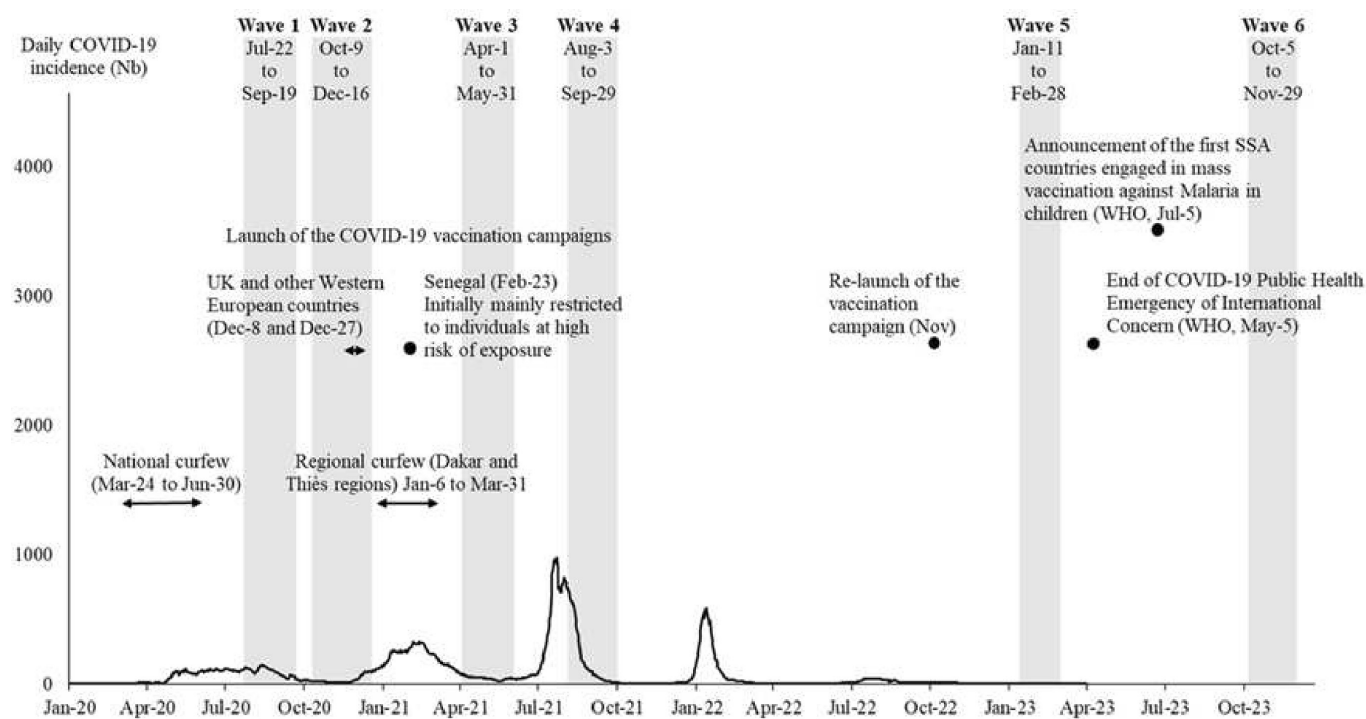
The study design of the CO3ELSER study has already been published.<sup>27</sup> Briefly, the study was conducted in the Niakhar area (Fatick region, 135 km East of Dakar) covered by the Niakhar Health and Demographic Surveillance System (HDSS)—the oldest HDSS in Senegal and one of the oldest in West Africa.<sup>28</sup> The main economic activity in the area is agriculture with food cultivation (millet) and a cash crop (peanuts), in addition to small-scale cattle breeding. The study participants (adults aged 18 years and over) were selected using a two-stage stratified sampling design. All 30 villages in the area had previously been classified as either rural (n=27) or semi-urban (n=3), based on their infrastructure and available facilities. In the first stage of sampling, 12 villages were selected for inclusion in the study (3 semi-urban villages and a simple random sample of 9 rural villages). In the second stage, 600 households were randomly selected from the 1756 households located in the 12 selected villages. Simple random sampling was used again to ensure unbiased household selection. The sample size of 600 households was not based on a formal sample size calculation, but rather reflected a compromise between methodological rigour and the study's logistical and budgetary constraints. In each household, the study involved surveying heads of households and their spouse (in the case of polygamous households, the spouse in charge of managing the household).

As data collection began in July 2020, when social distancing, wearing masks and hand washing were the only prevention measures against COVID-19, it was decided to

conduct a phone survey (using Computer Assisted Telephone Interviewing software). In Senegal, where 64.50% of inhabitants had a mobile phone subscription (2.60% with a fixed telephone subscription, 0.20% in rural areas) in 2020, the estimated penetration rate (households with at least one member having a mobile phone) was 98.00% (96.70% in rural areas).<sup>29</sup> Prior to the first survey, community health workers (locally called *Badienou Gokh*) had visited the selected households to inform them about the study and record the telephone numbers of the households' members who agreed to participate. No problem of cellular phone availability was reported by the *Badienou Gokh*. Interviews were conducted by experienced bilingual (French and Serer) interviewers. In the first survey, the participants were explained the study purpose and were asked whether they consented to participate. Figure 1 presents an overview of the six waves of data collection on COVID-19 intention/uptake from July 2020 to November 2023, along with the evolution of COVID-19 incidence in Senegal over this time period and the dates of curfews, launch and relaunch of the vaccination campaigns.

## Questionnaire

In data collection waves 1–3, participants were asked to indicate how likely they would be to get vaccinated against COVID-19 if a vaccine became available free of charge (4-point Likert-type scale). Following the launch of the Senegalese COVID-19 vaccination campaign (February 2021), in waves 4–6, participants were asked whether they had been vaccinated since the last survey wave and, for



**Figure 1** Overview of the longitudinal data collection. Source: COVID-19 Data Repository, Center for Systems Science and Engineering, Johns Hopkins University (<https://github.com/CSSEGISandData/COVID-19>). SSA countries, sub-Saharan African countries.

those who were not vaccinated, how likely they were to get vaccinated. They were also asked whether they agreed that the aim of COVID-19 vaccines was to prevent severe forms of the disease. COVID-19 risk perception was assessed in all six waves; study participants were asked: (1) how worried they were about getting COVID-19 (from 0/not at all to 10/extremely), (2) how contagious and severe they perceived COVID-19 to be (from 0/not at all to 10/extremely), (3) how worried they were about members of their household getting COVID-19 (4-point Likert-type scale from 'very worried' to 'not at all worried') and (4) their perceived risk of contracting COVID-19 themselves (4-point Likert-type scale from 'very low' to 'very high'). A COVID-19 risk perception score was calculated from a principal component analysis of participants' answers to these five questions (online supplemental table S.1) and it was then rescaled to range from 0/not at all to 10/extremely. The level of trust the study participants had in the government's ability to effectively address the COVID-19 outbreak was also assessed in all six waves (4-point Likert-type scale from 'very high' to 'very low') as was participants' self-perceived health status (from 0/extremely poor to 10/excellent).

Attitudes to malaria vaccination for children were assessed in wave 6. Specifically, study participants were asked whether they were aware that some Western SSA countries (Benin, Burkina Faso, Cameroon, Liberia, Niger and Sierra Leone in Western sub-Saharan Africa) had planned to introduce malaria vaccination in their national EPI ('yes'/'no'). They were also asked how likely they would be to vaccinate their children against malaria if it was offered as part of EPI (4-point Likert-type scale from 'very likely' to 'very unlikely').

### Statistical analyses

We used a latent class mixed model (LCMM) to identify clusters of individuals with similar COVID-19 vaccine intention/uptake over the six survey waves. More specifically, clustering was conducted based on assessed changes over time in individual probability of reporting very strong COVID-19 vaccine intention (understood here as reporting either vaccine uptake since the previous survey wave or reporting to be very likely to get vaccinated).<sup>30</sup> Unlike latent class analysis or latent transition analysis that rely on the assumption of no within-cluster variation, LCMM accounts for heterogeneity within each latent class by incorporating subject-specific random effects.<sup>30–32</sup> As a result, LCMM could be particularly well suited to modeling intra-individual variability in longitudinal data.<sup>33</sup> To address within-household correlation (two members of households being surveyed), we included a random intercept at the household level. Model selection was guided by a stepwise approach, starting with a two-cluster solution and incrementally adding additional clusters. Each model was tested in terms of statistical fit and ability to identify distinct and interpretable longitudinal patterns. Goodness-of-fit was assessed using the Bayesian Information Criterion and the Integrated Classification

Likelihood, with lower values indicating better fit.<sup>30</sup> Quality and stability of cluster assignment were assessed using the posterior probabilities of class membership.<sup>30</sup> Missing data due to dropout were handled under the missing at random (MAR) assumption. The MAR assumption was assessed through logistic regression analysis, in which the missingness indicator (eg, dropout during follow-up) was included as a covariate. Model estimation was carried out using the maximum likelihood approach.<sup>30</sup>

LCMM allowed for the inclusion of both time-invariant and time-varying covariates, thereby enhancing the model's ability to capture both static and dynamic influences on vaccine intention/uptake. A probit model was used to assess the effects of time-varying covariates (risk perception, trust in health authorities and self-perceived health status) on changes in vaccine intention over time. The time-invariant covariates included participants' sociodemographic characteristics, baseline (ie, wave 1) risk perception scores, trust in health authorities and self-perceived health status. A stepwise logistic model was used to assess the extent to which covariates explained the patterns derived from the LCMM.

Finally, the study participants' attitudes to malaria vaccination for children were compared with their COVID-19 longitudinal patterns, using Cochran-Armitage tests. Statistical analyses were conducted using SAS software (V.9.4; SAS Institute, Cary, North Carolina, USA). The LCMM model was estimated using the R software LCMM package.<sup>30</sup>

### RESULTS

Of the 600 households contacted in July 2020 (wave 1), 558 (93.00%) agreed to participate in the study (558 heads of household and 457 spouses) (table 1). Baseline average age at inclusion was 49.35 ( $\pm$ 14.14) years, 59.49% of participants were farmers, 74.21% had no formal education and 12.94% declared they had easy access to the internet. The average attrition rate between consecutive waves was 4.67% (table 1). Among the initial 1015 participants in waves 1 and 2, 795 were still involved in wave 6 (21.67% attrition rate). A comparison between participants who did and did not complete all six waves showed no significant difference in baseline characteristics (online supplemental table S.2).

Very few reported they knew someone who had contracted COVID-19 (from 8 in wave 1 to a cumulative total of 62 in wave 6). At wave 6, a total of 35.60% of the participants reported they had been vaccinated against COVID-19 (table 1). Risk perception scores reflected COVID-19 incidence levels in Senegal (online supplemental table S.3). Specifically, it was highest at the beginning of the pandemic (wave 1), when no vaccine had yet become available, and at wave 4 when COVID-19 incidence increased because of the highly contagious Omicron variant. It was lowest in 2023 when the public health emergency ended (wave 6, table 1). With regard

**Table 1** Study participants' sociodemographic characteristics, their attitudes to COVID-19 and their vaccine intention/uptake in the six consecutive waves of data collection (N=1015)

	Wave 1 (N=1012)*		Wave 2 (N=995)		Wave 3 (N=941)		Wave 4 (N=927)		Wave 5 (N=840)		Wave 6 (N=795)	
	N	%	N	%	N	%	N	%	N	%	N	%
Surveyed individuals												
Heads of household	558	55.14	552	55.48	528	56.11	515	55.56	472	56.19	449	56.48
Polygamous heads of household	123	22.04	120	21.74	115	21.78	111	21.55	103	21.82	97	21.60
Spouse (in charge of managing the household for polygamous couples)	454	44.86	443	44.52	413	43.89	412	44.44	368	43.81	346	43.52
Age (years)												
18–39	273	26.98	262	26.33	230	24.44	236	25.46	205	24.40	199	25.03
40–49	267	26.38	264	26.53	255	27.10	247	26.65	230	27.38	214	26.92
50–59	224	22.13	223	22.41	218	23.17	212	22.87	199	23.69	191	24.03
60–69	162	16.01	162	16.28	155	16.47	153	16.50	144	17.14	135	16.98
>69	86	8.50	84	8.44	83	8.82	79	8.52	62	7.38	56	7.04
Education												
No formal education	751	74.21	738	74.17	695	73.86	682	73.57	620	73.81	585	73.58
Primary education	160	15.81	156	15.68	147	15.62	146	15.75	133	15.83	130	16.35
Secondary education	101	9.98	101	10.15	99	10.52	99	10.68	87	10.36	80	10.06
Occupation												
Farmer	602	59.49	591	59.40	554	58.87	547	59.01	497	59.17	482	60.63
Craftsperson	185	18.28	181	18.19	170	18.07	167	18.02	154	18.33	142	17.86
Employee/blue-collar worker	136	13.44	135	13.57	132	14.03	129	13.92	121	14.40	119	14.97
Other (intermediate/managerial/professional occupations)	30	2.96	30	3.02	29	3.08	30	3.24	22	2.62	16	2.01
Inactive	59	5.83	58	5.83	56	5.95	54	5.83	46	5.48	36	4.53
Number of persons in household												
≤4	31	3.06	31	3.12	26	2.76	28	3.02	19	2.26	22	2.77
5–9	432	42.69	423	42.51	402	42.72	397	42.83	350	41.67	324	40.75
10–14	309	30.53	304	30.55	283	30.07	271	29.23	260	30.95	247	31.07
≥15	240	23.72	237	23.82	230	24.44	231	24.92	211	25.12	202	25.41

Continued

**Table 1** Continued

	Wave 1 (N=1012)*		Wave 2 (N=995)		Wave 3 (N=941)		Wave 4 (N=927)		Wave 5 (N=840)		Wave 6 (N=795)	
	N	%	N	%	N	%	N	%	N	%	N	%
Number of children— mean (SD)	5.37 (2.55)		5.35 (2.54)		5.33 (2.53)		5.32 (2.53)		5.40 (2.44)		5.42 (2.47)	
Children under 2 years old	137	13.54	137	13.77	132	14.03	129	13.92	114	13.57	109	13.71
Distance to health posts (km)—mean (SD)	1.85 (1.65)		1.85 (1.66)		1.84 (1.66)		1.85 (1.66)		1.88 (1.68)		1.83 (1.65)	
Easy internet access	131	12.94	130	13.07	127	13.50	119	12.84	96	11.43	92	11.57
Self-perceived health status (0–10 scale)— mean (SD)	8.07 (1.77)		8.08 (1.70)		8.09 (1.73)		8.08 (1.66)		8.22 (1.87)		8.16 (2.57)	
Knew someone who had contracted COVID-19	8	0.79	9	0.90	21	2.23	42	4.53	50	5.95	62	7.80
COVID-19 vaccination intention												
Very likely	490	48.42	448	45.03	291	30.92	174	18.77	78	9.29	40	5.03
Quite likely	317	31.32	334	33.57	175	18.60	197	21.25	100	11.90	63	7.92
Quite unlikely	118	11.66	128	12.86	193	20.51	160	17.26	117	13.93	83	10.44
Very unlikely	63	6.23	37	3.72	242	25.72	196	21.14	212	25.24	308	38.74
Do not know	24	2.37	48	4.82	40	4.25	51	5.50	52	6.19	18	2.26
Vaccinated against COVID-19	NA		NA		NA		149	16.07	281	33.45	283	35.60
Agreed that vaccines prevent severe forms of COVID-19	NA		NA		NA		570	61.49	521	62.02	541	68.05
COVID-19 risk perception												
Worried about contracting COVID-19 (0–10 scale)—median (Q1–Q3)	6.00 (3.00–9.00)		3.00 (2.00–5.00)		3.00 (1.00–5.00)		5.00 (3.00–7.00)		1.00 (0.00–2.00)		0.00 (0.00–1.00)	
Perceived contagiousness of COVID-19 (0–10 scale)—median (Q1–Q3)	8.00 (6.00–9.00)		5.00 (3.00–7.00)		5.00 (3.00–6.00)		7.00 (5.00–8.00)		3.00 (1.00–6.00)		1.00 (0.00–3.00)	

Continued

**Table 1** Continued

	Wave 1 (N=1012)*		Wave 2 (N=995)		Wave 3 (N=941)		Wave 4 (N=927)		Wave 5 (N=840)		Wave 6 (N=795)	
	N	%	N	%	N	%	N	%	N	%	N	%
Perceived seriousness of COVID-19 (0–10 scale)—median (Q1–Q3)	8.00 (6.00–10.00)		6.00 (4.00–7.00)	18.79	6.00 (4.00–7.00)	16.05	7.00 (5.00–8.00)	58.36	3.00 (1.00–6.00)	5.83	3.00 (1.00–5.00)	3.27
Very/quite worried about other household members contracting COVID-19	650	64.23	187	18.79	151	16.05	541	58.36	49	5.83	26	3.27
Very/quite high own personal risk perception of contracting COVID-19	152	15.02	42	4.22	123	13.07	157	16.94	3	0.36	1	0.13
High/very high level of trust in government's ability to address the outbreak	598	59.09	596	59.90	578	61.42	589	63.54	528	62.86	502	63.14
Knew that some SSA countries plan to include malaria vaccination in their national EPI											34	4.28
Malaria vaccination intention for children if offered as part of EPI												
Very likely											519	65.28
Quite likely											193	24.28
Quite unlikely											31	3.90
Very unlikely											7	0.88
Do not know											45	5.66

\*Three participants who had not been available for the survey in wave 1 of data collection (N=1012) were surveyed in the subsequent waves. EPI, Expanded Programme on Immunization; SSA countries, sub-Saharan African countries.

**Table 2** Longitudinal patterns of COVID-19 vaccine intention and associated vaccine intention/uptake in the six different waves of data collection (N=1015)

Longitudinal patterns of COVID-19 intention	Vaccine intention and uptake						Participants with the same COVID-19 pattern as the other household surveyed member (%)
	Wave 1* (N=1012)	Wave 2 (N=995)	Wave 3 (N=941)	Wave 4 (N=927)	Wave 5 (N=840)	Wave 6 (N=795)	
Continuously strong COVID-19 vaccine intention (N=354; 34.88%)							58.76
Vaccinated against COVID-19	NA	NA	NA	33.86%	59.20%	59.66%	
Very likely	83.62%	80.69%	62.65%	36.68%	17.06%	10.00%	
Quite likely/unlikely	12.99%	16.43%	22.53%	15.36%	10.03%	11.38%	
Very unlikely	2.54%	2.02%	12.96%	12.23%	11.71%	18.62%	
Did not know	0.85%	0.86%	1.85%	1.88%	2.01%	0.34%	
Increasingly strong COVID-19 vaccine intention (N=339; 33.40%)							49.56
Vaccinated against COVID-19	NA	NA	NA	12.17%	36.90%	43.08%	
Very likely	5.93%	8.26%	16.13%	10.20%	8.49%	4.35%	
Quite likely/unlikely	81.60%	77.68%	48.39%	48.03%	21.77%	17.00%	
Very unlikely	8.31%	4.59%	27.74%	21.71%	26.94%	32.41%	
Did not know	4.15%	9.48%	7.74%	7.89%	5.90%	3.16%	
Increasingly less strong COVID-19 vaccine intention (N=322; 31.72%)							46.58
Vaccinated against COVID-19	NA	NA	NA	1.32%	1.48%	0.40%	
Very likely	54.21%	43.93%	12.38%	8.55%	1.48%	0.00%	
Quite likely/unlikely	35.51%	47.04%	47.23%	53.29%	47.41%	27.78%	
Very unlikely	8.10%	4.67%	37.13%	29.93%	38.52%	68.25%	
Did not know	2.18%	4.36%	3.26%	6.91%	11.11%	3.57%	

The latent class mixed model handles missing data on the dependent variable under the hypothesis of missingness at random. Not having been surveyed in at least one wave did not significantly impact cluster allocation (p=0.079). The three-class classification (Integrated Classification Likelihood (ICL)=7001.7) had mean posterior probabilities of 86%, 76% and 87%, respectively. For comparison purposes, the two- and four-class solutions were associated with ICL=6955.1 and ICL=7112.9, respectively.  
\*Three participants who were not available for the survey in wave 1 (N=1012) were surveyed in the subsequent waves.

to malaria vaccination intention for children (wave 6), 4.28% of the participants reported that they were aware that some Western SSA countries had planned to add malaria vaccination to their national EPI. Almost all participants reported they would be very likely (65.28%) or quite likely (24.28%) to have their children vaccinated against malaria if a vaccine were offered free of charge.

**Longitudinal patterns of COVID-19 vaccine intention**

As a result of LCMM, a three-class solution was selected as it provided the best compromise between parsimony, model fit and interpretability (table 2, online supplemental figure S.1). Solutions with four or more classes either included very small clusters or failed to converge. The mean posterior probabilities of class membership were 0.86, 0.77 and 0.83 for clusters 1, 2 and 3, respectively, indicating reasonably good separation between clusters. Dropout rates were 18.08%, 25.37% and 21.74% in clusters 1, 2 and 3, respectively. There was no

significant association between dropout and latent class membership, both in unadjusted analyses (p=0.066) and after adjustment for baseline characteristics (p=0.162). Considering that 22.04% of the 558 survey households were polygamous (table 1), a sensitivity analysis restricted to monogamous households was also conducted. As a result, 97.69% of participants were found to remain in the same cluster, suggesting that vaccine intention/uptake over time did not significantly differ depending on whether households were monogamous or polygamous.

The first cluster (34.88% of participants, N=354; table 2) comprised individuals with a pattern of continuously strong vaccine intention, although slightly decreasing over time (online supplemental figure S.1). Of these, 59.66% were vaccinated against COVID-19 (wave 6; table 2). Individuals in this cluster were more likely to have a similar pattern to the other surveyed

members in their household (58.76% vs 47.81% in the rest of the study sample;  $p=0.001$ ). Overall, 31.92% of participants in this cluster reported the same vaccine intention in five and six consecutive time points (9.04% and 22.88%, respectively). Among the 68.36% of those who declared they would be 'very likely' to get vaccinated in waves 1 and 2, 30.58% indicated vaccine hesitancy/refusal in wave 3 (ie, shortly after the launch of the Senegalese COVID-19 vaccination campaign in February 2021). However, vaccine uptake in this subgroup did not significantly differ from that of the rest of the cluster (45.95% vs 49.64%;  $p=0.572$ ).

The second cluster (33.40%,  $N=339$ ; [table 2](#)) comprised individuals with increasingly strong COVID-19 vaccine intention over time; at wave 6, 43.08% had been vaccinated. In this cluster, 6.49% of individuals reported stable vaccine intention in five or six consecutive waves. Among the 62.24% of individuals who reported vaccine hesitancy in waves 1 and 2, 20.38% reported very strong vaccine intention in wave 3 (65.12% COVID-19 vaccine uptake at wave 6 vs 27.36% in the rest of the cluster,  $p<0.001$ ).

The third cluster (31.72%,  $N=322$ ; [table 2](#)) comprised individuals sharing a pattern of increasingly less strong vaccine intention; only three of these participants reported they were vaccinated at wave 6. In this cluster, 3.73% of individuals reported stable vaccine intention in five or six consecutive waves of data collection. Among the 27.02% of individuals who reported very strong vaccine intention in waves 1 and 2, 77.01% declared vaccine hesitancy or refusal in wave 3.

#### Time-invariant and time-varying covariates of the longitudinal patterns of COVID-19 vaccine intention

The pattern of continuously strong COVID-19 vaccine intention was more likely to be detected in participants aged 60 and over (OR 1.53, 95% CI 1.15 to 2.06;  $p=0.004$ ), and in those participants who understood, at the time of the launch of the Senegalese vaccination campaign, that COVID-19 vaccines aim to prevent severe forms of the disease (OR 1.60, 95% CI 1.22 to 2.10;  $p=0.001$ ; [table 3](#)). It was less likely to be detected in participants living relatively far from health posts (OR 0.66, 95% CI 0.48 to 0.91;  $p=0.011$ ), and in those with a low risk perception score before vaccines became available (OR 0.54, 95% CI 0.39 to 0.75;  $p<0.001$ ; [table 3](#)). Concerning the pattern of increasingly strong vaccine intention, it was less likely to be detected in participants with formal education (OR 0.62, 95% CI 0.45 to 0.87;  $p=0.005$ ), those with a higher self-perceived health status (OR 0.61, 95% CI 0.44 to 0.84;  $p=0.003$ ) and in those with a high level of trust in health authorities at baseline (OR 0.68, 95% CI 0.49 to 0.94;  $p=0.020$ ; [table 3](#)). It was more likely to be detected in participants with a low risk perception score when no vaccine was available (OR 1.98, 95% CI 1.46 to 2.67;  $p<0.001$ ). Finally, being 60 years old and over (OR 0.59, 95% CI 0.43 to 0.81;  $p=0.001$ ), living far from health posts (OR 1.37, 95% CI 1.01 to 1.86;  $p=0.045$ ), reporting good understanding of the aim of the COVID-19 vaccine

(OR 0.59, 95% CI 0.44 to 0.77;  $p<0.001$ ) at baseline and declaring a high level of trust in health authorities at baseline (OR 1.73, 95% CI 1.30 to 2.30;  $p<0.001$ ) were all factors associated with the pattern of increasingly less strong vaccine intention over time ([table 3](#)). A summary of factors associated with the three longitudinal patterns of COVID-19 vaccine intention is provided in a forest plot (online supplemental figure S.2).

With regard to the time-varying factors likely to explain variations in vaccine intention within patterns, trust in health authorities over time was found to be significantly associated with the continuously strong vaccine intention pattern ( $\beta=1.88$ , 95% CI 1.34 to 2.42;  $p<0.001$ ; [table 3](#)). Moreover, risk perception was slightly, although significantly, associated with the increasingly less strong vaccine intention pattern over time ( $\beta=0.07$ , 95% CI 0.02 to 0.12;  $p=0.003$ ), while both risk perception ( $\beta=0.06$ , 95% CI 0.02 to 0.10;  $p=0.006$ ) and trust in authorities over time ( $\beta=0.60$ , 95% CI 0.43 to 0.77;  $p<0.001$ ) were explanatory of the increasingly strong vaccine intention pattern. Finally, better self-perceived health status over time was positively associated with all three patterns ( $\beta=0.13$ ,  $p=0.008$ ,  $\beta=0.23$ ,  $p<0.001$  and  $\beta=0.25$ ,  $p<0.001$ , respectively; [table 3](#)).

#### Malaria vaccine intention for children

At wave 6, 65.28% of the study participants reported they would be very likely to have their children vaccinated against malaria if it were offered as part of the EPI ([table 4](#)). No significant difference was detected between heads of households and spouses (63.47% and 67.23%, respectively;  $p=0.223$ ). Participants with children under 2 years old were more likely to report strong vaccine intention (very high likelihood to get children vaccinated in 74.31% of participants vs 63.85% in the rest of the study sample;  $p=0.033$ ). Direct comparisons showed that participants vaccinated against COVID-19 were more likely to report strong malaria vaccine intention (74.56% vs 60.16%;  $p<0.001$ ). When taking the three temporal patterns of COVID-19 vaccine intention into account, a decreasing gradient in strong malaria vaccine intention was detected, from continuously strong to increasingly strong to increasingly less strong intention over time (75.86%, 63.64% and 54.76%, respectively;  $p<0.001$ ). Moreover, 32.96% of all the participants had a similar malaria vaccine intention and a similar temporal COVID-19 vaccine intention pattern as the other person surveyed in their household. Furthermore, household members who both had continuously strong COVID-19 vaccine intention over the six waves were more likely to have strong malaria vaccination intention for their children (40.00% vs 28.52% in the rest of the study sample;  $p=0.001$ ).

#### DISCUSSION

The present study confirmed the positive attitudes to malaria vaccination for children among different general

**Table 3** Factors associated with the longitudinal patterns of COVID-19 vaccine intention (N=1015)

	Longitudinal patterns of COVID-19 intention								
	Continuously strong COVID-19 vaccine intention (N=354; 34.88%)		Increasingly strong COVID-19 vaccine intention (N=339; 33.40%)		Increasingly less strong COVID-19 vaccine intention (N=322; 31.72%)				
	%	aOR (95% CI)*	P value	%	aOR (95% CI)*	P value	%	aOR (95% CI)*	P value
<b>Time-invariant covariates</b>									
Age≥60years old (ref.<60)	32.49	1.53 (1.15 to 2.06)	0.004	30.68	NS	22.05	0.59 (0.43 to 0.81)	0.001	
Primary education or higher (ref. no formal education)	32.20	1.50 (1.12 to 2.02)	0.007	20.06	0.62 (0.45 to 0.87)	24.84	NS	0.005	
Farmer (ref. other occupation)	62.71	†		53.10	†	62.73	NS		
Self-perceived health status>Q3 (ref.<Q3)	30.79	NS		18.88	0.61 (0.44 to 0.84)	29.81	NS	0.003	
Distance from health post>Q3 (ref.<Q3)	19.21	0.66 (0.48 to 0.91)	0.011	27.14	NS	28.88	1.37 (1.01 to 1.86)	0.045	
COVID-19 risk perception score<Q1 (ref.>Q1)	17.80	0.54 (0.39 to 0.75)	<0.001	35.40	1.98 (1.46 to 2.67)	21.74	NS	<0.001	
High/very high level of trust in government's ability to address the outbreak (ref. low/very low)	59.04	NS		52.21	0.68 (0.49 to 0.94)	66.15	1.73 (1.30 to 2.30)	<0.001	
Agreed that COVID-19 vaccines aim to prevent severe forms of the disease (ref. No)	64.69	1.60 (1.22 to 2.10)	0.001	55.16	NS	50.62	0.59 (0.44 to 0.77)	<0.001	
<b>Time-varying covariates</b>	%‡	β (95% CI)§	P value	%‡	β (95% CI)§#	P value	%‡	β (95% CI)§	P value
COVID-19 risk perception score—mean (SD)	4.01 (2.31)	0.00 (−0.05 to 0.06)	0.907	3.72 (2.31)	0.06 (0.02 to 0.10)	0.006	4.04 (2.26)	0.07 (0.02 to 0.12)	0.003
Self-perceived health status—mean (SD)	8.39 (1.62)	0.13 (0.03 to 0.23)	0.008	7.59 (2.07)	0.23 (0.15 to 0.32)	<0.001	8.34 (1.85)	0.25 (0.14 to 0.36)	<0.001
High/very high level of trust in government's ability to address the outbreak (ref. low/very low)	62.39	1.88 (1.34 to 2.42)	<0.001	55.72	0.60 (0.43 to 0.77)	<0.001	66.54	−0.13 (−0.40 to 0.14)	0.347

\*Adjusted ORs (aORs) with 95% CIs. ORs are reported only for time-invariant covariates from the class-membership model (multivariable logistic regression).

†The occupation variable (farmer) was excluded from the multivariable model due to high collinearity (p<0.001) with the education variable (primary education or higher).

‡Percentages are shown for categorical variables; means with SD are shown for continuous variables.

§β coefficients with 95% CIs. These coefficients reflect changes in the longitudinal pattern over time.

NS, variable not retained in the final multivariable model following stepwise selection.

**Table 4** Attitudes to malaria vaccination for children depending on the longitudinal patterns of COVID-19 vaccine intention (wave 6, N=795)

	Longitudinal patterns of COVID-19 vaccine intention							
	Continuously strong COVID-19 vaccine intention (N=290; 36.48%)		Increasingly strong COVID-19 vaccine intention (N=253; 31.82%)		Increasingly less strong COVID-19 vaccine intention (N=252; 31.70%)		All (N=795)	
	N	%	N	%	N	%	N	%
Very strong malaria vaccine intention for children if offered as part of EPI	220	75.86	161	63.64	138	54.76	519	65.28
Heads of households	127	75.15	84	60.00	74	52.86	285	63.47
Spouses (in charge of managing household for polygamous couples)	93	76.86	77	68.14	64	57.14	234	67.63
With children under 2 years old	33	84.62	25	69.44	23	67.65	81	74.31
Vaccinated against COVID-19	132	76.30	78	71.56	1	100.00	211	74.56
Household member with the same malaria vaccination intention	172	39.27	138	31.51	128	29.22	438	100.00
Household member with the same pattern of COVID-19 vaccination intention	164	56.55	126	49.80	124	49.21	414	52.08
Sharing the same malaria vaccination intention	116	40.00	78	30.83	68	26.98	262	32.96

EPI, Expanded Programme on Immunization.

populations.<sup>34 35</sup> These positive attitudes were in line with the high childhood vaccination coverage in Senegal.<sup>36</sup> The study also showed that attitudes to malaria vaccination were consistent with the temporal dynamics of COVID-19 vaccine intention and uptake rates. More specifically, a small percentage of participants with an increasingly less strong vaccine intention over time were vaccinated, while 60% of those with a continuously strong vaccine intention were vaccinated. In addition, our study confirmed and reinforced the importance of COVID-19 risk perception<sup>37 38</sup> and trust in health authorities<sup>38 39</sup> as key factors contributing to explaining temporal patterns of COVID-19 vaccine intention.<sup>22</sup> Fluctuations over time in these factors were also associated with changes in vaccine intention in patterns.

The consistency found between attitudes to malaria vaccination and the temporal patterns of COVID-19 vaccine intention does not call into question the vaccine-specific determinants of hesitancy, especially given that COVID-19 vaccines were developed in response to a rapid emerging worldwide outbreak, whereas malaria vaccines target an endemic infectious disease with a high burden of deaths in young children. However, it is possible that this consistency was related to the role played by the participants' sociodemographic factors.

Living far from a health post was a significant determinant of the pattern of increasingly less strong COVID-19 vaccine intention over time; this barrier to access to healthcare services may not only explain less positive attitudes to malaria vaccination for children in our study, but

it could also play a role in decreases in malaria vaccine uptake of the four-dose schedule.<sup>40</sup> With regard to the pattern of increasingly strong COVID-19 vaccine intention over time, less educated participants and those with poorer self-perceived health status were overrepresented. Given the greater need for information on vaccines for these two profiles,<sup>41</sup> the possibility that these participants may have needed more time before being able to express strong vaccination intention<sup>42</sup> could explain the progressive acceleration of strong COVID-19 vaccine intention/uptake. Further investigations could assess whether this pattern of increasingly strong vaccine intention could apply to malaria vaccination in children and measure the extent to which increasing public awareness of the benefits of malaria vaccination (less frequent and severe malaria) could positively impact vaccine intention and adherence to the four-dose schedule.<sup>43</sup>

Finally, participants with a pattern of continuously strong COVID-19 vaccine intention were more likely than others to have a similar COVID-19 vaccination pattern as the other surveyed members of their household and similar strong positive attitudes to malaria vaccination for children. These strong positive attitudes can be seen as reflecting the desired response from institutional information on health risks and benefits from getting vaccinated. However, the possibility of social desirability bias cannot be excluded, whereby participants may have provided answers they believed to be most socially acceptable and desirable.<sup>44</sup> Further investigations at the household level could provide a

better understanding of convergent/divergent views on vaccine intention within households, and their impact on vaccine uptake.

Furthermore, our study confirmed previous findings that attitudes to malaria vaccination for children do not differ between genders.<sup>45</sup> In households where both surveyed members had strong positive attitudes to malaria vaccination for their children, this could translate into a higher likelihood of their completing the four-dose schedule.<sup>40</sup> With regard to COVID-19, our study also confirmed previous findings that vaccine intention was a significant predictor of vaccine uptake,<sup>17 18 37 38 46</sup> that fluctuations in risk perception were related to fluctuations in COVID-19 incidence over the pandemic,<sup>47</sup> and that stable vaccine intention over time was more likely to occur in individuals with strong intention to get vaccinated.<sup>18 38</sup> In addition, our study confirmed that older individuals,<sup>37–39</sup> those with a higher educational level<sup>37 38 46 48</sup> and those with a greater understanding of the purpose of COVID-19 vaccines,<sup>46</sup> were all less likely to switch over time from having strong vaccine intention to being vaccine hesitant. Finally, our study confirmed that vaccine-hesitant individuals with a poor self-perceived health status were less likely to develop strong vaccine intention over time.<sup>18</sup>

This study has limitations. First, given that risk perception and trust in authorities at an early stage of the pandemic were significant factors in explaining patterns of COVID-19 vaccine intention over time, our data analysis could have benefited from starting data collection before the first cases were detected in Western sub-Saharan Africa. A second limitation of the study relates to the difference between the 35.60% COVID-19 vaccine uptake rate that was reported in our study and the 15.20% national Senegalese uptake rate. Although the differences in the methods of calculating vaccine uptake rates at a national level (relative to the Senegalese population that was aged 24 on average in 2024<sup>49</sup>)<sup>15</sup> and in our study (relative to rural households whose heads of households and their spouses were 49 years old on average) could explain most of the difference in uptake rates, we could not assess the extent to which the COVID-19 vaccine uptake rate in our study was similar to those in other rural areas in Senegal. In addition to higher vaccine uptake in rural areas in SSA,<sup>20</sup> COVID-19 vaccine uptake in our study may have been overestimated due to social desirability bias. Another reason for higher uptake rates could relate to the local involvement of the *Badienou Gokh* (community health workers) in promoting vaccination.<sup>50</sup> A third limitation was that the study did not include assessing the participants' attitudes to malaria vaccination for children depending on their use of long-lasting insecticidal nets. Similarly, another limitation was that the study did not include an assessment of the impact of external events that may have influenced COVID-19 vaccine intention/uptake during the study period (eg, government campaigns, media coverage of the COVID-19 vaccination).

To conclude, further investigation would be necessary to assess the generalisability of using individual dynamics of COVID-19 vaccination as a reference for studying attitudes to newly offered vaccines. As regards malaria vaccination intention and the real-world dynamics of uptake of the four scheduled vaccine doses, targeting of parents who need incentives to address barriers to compliance could be improved by accounting for their dynamics of COVID-19 vaccination.

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