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Dynamics of Antibody Responses to COVID-19 Vaccination in Senegalese Adults: A Multicentre Longitudinal Study

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Abstract

Background: The COVID-19 pandemic, caused by the SARS-CoV-2 virus, affected hundreds of millions of people worldwide and resulted in significant mortality. In Senegal, over 89,000 infections and nearly 2000 deaths were reported. The deployment of the Johnson & Johnson (adenoviral vector) and Sinopharm (inactivated virus) vaccines through the COVAX initiative and bilateral partnerships was crucial in mitigating the spread of the virus. However, little local data existed regarding their immunogenicity. This study aimed to evaluate the humoral immune response induced by the Johnson & Johnson and Sinopharm COVID-19 vaccines among Senegalese adults aged 18 years and older over a 12-month period. **Methods:** This longitudinal multicentre study was conducted between August 2022 and August 2023 with 375 adult volunteers. Plasma samples were collected and tested using the Q-Plex SARS-CoV-2 Human IgG (5-plex) kit to quantify antibodies targeting the S1, S2, and NP proteins of SARS-CoV-2. Follow-up visits were scheduled based on the vaccine received: Johnson & Johnson vaccine recipients had 7 time points (Day 0, Day 14, Day 28, Month 3, Month 6, Month 9, and Month 12), while Sinopharm vaccine recipients had 8 time points (Day 0, Day 14, Day 28(Day 0B), Day 14B, Day 28B, Month 6, Month 9, and Month 12). Analysis of antibody levels was stratified by vaccine type, age, sex, and period of sampling after vaccination. **Results:** Both vaccines elicited detectable antibody responses, albeit with disparate dynamics. Johnson & Johnson induced a stronger response

(S1: 490.66, S2: 1068.12, NP: 161.45) in young adults aged 18 - 30 years, while Sinopharm showed a better initial response (S1: 868.61, S2: 1608.58, NP: 310.88) in older individuals (46 - 70 years). However, antibody levels declined progressively in both groups over time (from S1: 465.99, S2: 1003, NP: 157.98 to S1: 210.01, S2: 466.88, NP: 141.39 and from S1: 451.36, S2: 1075.51, NP: 207.39 to S1: 446.74, S2: 631.09, NP: 142.59). Notably, women demonstrated more persistent antibody responses than men. Strong associations were observed between antibody positivity and sociodemographic factors such as household size, occupation, and formal educational level. **Conclusion:** This study confirms the immunogenicity of both Johnson & Johnson and Sinopharm vaccines in the Senegalese population, with appreciable levels of antibody production that gradually wane over time, supporting the need for booster doses to sustain long-term immunity. Differences in antibody responses by age, sex, and vaccine type highlight the role of individual and contextual factors. These findings underscore the importance of tailoring vaccination strategies and serological monitoring to local realities.

Keywords

COVID-19, Vaccination, Humoral Response, Johnson & Johnson, Sinopharm, Kinetics, Adult Cohort, Senegal, Longitudinal Study

1. Introduction

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which is responsible for the COVID-19 pandemic, has affected hundreds of millions of people and caused millions of deaths worldwide [1] [2]. As of August 13, 2024, Africa reported 874,036 confirmed cases and 18,498 deaths [3]. In Senegal, there were 89,053 infections and 1971 deaths [2]. To curb the spread of the virus, various measures were implemented globally, including physical distancing, masks-wearing, and the use of protective eyewear [4] [5]. These measures effectively reduced exposure risk and subsequently lowered the rate of new infections [6] [7]. Further reductions in infection rates were achieved with the introduction of vaccines less than a year after the WHO declared the pandemic [8] [9].

Various types of vaccines were developed, including inactivated virus vaccines, adenoviral vector vaccines, and messenger RNA (mRNA) vaccines [8]. In Senegal, vaccines such as Pfizer/BioNTech, AstraZeneca, Moderna, Sinopharm, and Johnson & Johnson (J&J) were administered. Regardless of the manufacturer or technology, these vaccines primarily targeted the Spike protein, which is located on the surface of the SARS-CoV-2 envelope. This protein facilitates binding to the cellular receptor ACE2 and subsequent entry into host cells [10] [11]. Several studies have demonstrated that antibodies directed against this protein provide some levels of protection against infection [12] [13]. Their effectiveness against ancestral strains ranges from 63% to 86%, while protection against severe forms of COVID-19 ranges from 73% to 95% [14]. However, vaccine efficacy can vary between populations due to genetic and environmental factors. Therefore, it is essential to include diverse populations in clinical trials and to assess the impact of geographical variations on immune responses to inform the future use of these vaccines [15] [16].

Like many resource-limited countries, Senegal received the majority of its vaccines through the COVAX initiative and bilateral partnerships. The Ministry of Health distributed these vaccines via the Expanded Programme on Immunisation (EPI), without any prior or subsequent evaluation of immunogenicity. In this context, we assessed the antibody response of participants who received Johnson & Johnson and Sinopharm vaccines over a 12-month period. Our aim was to determine the persistence of vaccine-induced humoral responses, evaluate the benefits of additional booster doses for the population, and analyse the impact of socio-demographic factors and community exposure on antibody production and persistence.

2. Materials and Method

2.1. Ethical Statement and Procedure

All study-related documents, including the study protocol, participant information sheet (PIS), informed consent form (ICF), and case report forms (CRF), were submitted to the Senegal National Health Research Ethics Committee (CNERS) under reference number 0000096/MSAS/CNERS/SP for expert review and ethical approval. The study received official ethical clearance from the committee prior to implementation.

2.2. Study Design and Recruitment of Participants

Participation in the study was voluntary, and participants had the option to withdraw at any time without justification or consequence. Written informed consent was obtained after participants received detailed information about the study objectives, procedures, potential risks, and benefits. This information was provided either through the Participant Information Sheet (PIS) for literate participants, or with the assistance of an independent witness who explained the study details in a language understandable to illiterate participants, to ensure optimal understanding of the study. Recruitment was conducted only from sites approved by the Ethics Committee among participants aged 18 years and older who willingly gave consent to participate in the study. Participants' preferences guided vaccine allocation, with each individual selecting the vaccine they received. Individuals showing COVID-19 symptoms or those who tested positive were excluded from the study. Follow-up visits were scheduled over 12 months, in accordance with the vaccination schedule specific to each vaccine, as detailed in **Table 1** below.

Table 1. Planning follow-up visits.

Vaccines	Monitoring (programme of visits)								Number of visiting points
Sinopharm	D0	D14	D28/D0B	D14B	D28B	M6	M9	M12	08
Jonhson	D0	D14	D28	M3		M6	M9	M12	07

This multicentre longitudinal study was conducted between 5 August 2022 and 9 August 2023, involving 375 volunteers aged 18 years and older, recruited from three health centres: Rufisque Health District, Diamniadio Health District and Philippe Maguilen Senghor Health District. Samples collected from participants were sent to IRESSEF (*Institut de Recherche en Santé*, *de Surveillance Épidémiologique et de Formation*) for analysis. Prior to vaccination, blood and nasopharyngeal samples were taken to establish baseline data (time 0). Of the participants, 331 received one dose of the Johnson & Johnson (J&J) vaccine (a viral vector vaccine), and 44 received two doses of Sinopharm vaccine (an inactivated virus vaccine), with specific follow-up depending on the vaccine administered. The study assessed the levels of antibodies directed against the Spike (anti-S1 and anti-S2) and the nucleocapsid (anti-NP) proteins, as well as the potential impact of barrier measures on the protection of the population.

The collected data included socio-demographic information such as identity, gender, age, marital status, occupation, education level, ethnicity, and household composition, as well as vaccination status and COVID-19 exposure. During each visit, a survey assessed compliance with barrier measures. All this information was centralised in a database specific to each group studied.

2.3. Analytical Procedure

Nasopharyngeal and blood samples were taken before vaccination and at follow-up visits. Blood samples were processed either by Ficoll gradient to extract plasma and peripheral blood mononuclear cells (PBMC), or by centrifugation to isolate plasma. The PBMC were stored at −80˚C and then transferred to liquid nitrogen, while the plasma was aliquoted and stored at −80˚C. A portion was used for antibody testing with the Q-Plex SARS-CoV-2 Human IgG Quantitative kit, and the remainder was stored for subsequent immunological analysis.

2.4. Anti-SARS-CoV-2 Antibody Test

IgG antibodies to SARS-CoV-2 antigens (S1, S2, NP) were quantified in plasma using the Q-Plex SARS-CoV-2 Human IgG kit (5-plex), a specialised multiplex ELISA assay according to the manufacturer's instructions. Briefly, calibrators, controls and diluted samples were placed in sensitised wells, followed by successive incubations with detection antibodies and streptavidin, interspersed with washes to avoid non-specific binding. After substrate addition, the plates were analysed using the Quansys reader (Q-View Imager LS). A sample was considered reactive if it showed antibodies to S1, S2 proteins and the SARS-CoV-2 nucleoprotein (S1 cutoff value: 7.7 U/ml; S2 cutoff value: 30 U/ml; NP cutoff value: 25 U/ml).

2.5. Statistical Analysis

Data were entered into Microsoft Excel and subsequently imported into Stata for statistical analysis. Antibody responses to S1, S2, and NP were treated as dependent variables. A generalized estimating equations (GEE) model for repeated measures was applied to assess the association between antibody responses and explanatory variables, including occupation, education level, family size, mask use, symptomatic family history, and known exposure, across follow-up time points. The model was adjusted for baseline antibody titers and included vaccine type, follow-up time, and sociodemographic variables (age and sex) as covariates.

Due to the non-normal distribution of the data, non-parametric tests were used. The Mann-Whitney-Wilcoxon test was applied for comparisons between two groups, while the Kruskal-Wallis test was used for comparisons involving more than two groups. A p-value < 0.05 was considered statistically significant.

3. Results

3.1. Socio-Demographic Characteristics of Participants According to the Type of Vaccine Inoculated

A total of 375 participants aged between 18 and 70 years (median age of 20 years) were enrolled in the study, including 85 (22.6%) from Diamniadio, 280 (74.7%) from Rufisque and 10 (2.7%) from Philippe Magilen Senghor. Most of them (79.4%) were below 31 years. Men were in the slight majority (52.3%). Participants had varying levels of education, with the majority having secondary education (228, 68.9%). They also had a variety of occupations but were mostly students (224, 59.7%). They also belonged to different ethnic groups (Table 2).

Table 2. Socio-demographic characteristics of participants according to the type of vaccine inoculated.

Variables	Categories	J&J (n = 331)	Sinopharm (n = 44)	All (n = 375)
Site	Diamniadio	61 (18.4)	24 (54.5)	85 (22.6)
	Rufisque	262 (79.2)	18 (41.0)	280 (74.7)
	Philippe magilen Senghor	8 (2.4)	2 (4.5)	10 (2.7)
Age	Median (min - max)	20 (18 - 66)	29 (18 - 70)	20 (18 - 70)
	18 - 30	263 (79.4)	28 (63.6)	291 (77.6)
	31 - 45	50 (15.1)	14 (31.8)	64 (17.1)
	46 - 70	18 (5.5)	2 (4.5)	20 (5.3)
Gender	Male	174 (52.6)	22 (50)	196 (52.3)
	Female	157 (47.4)	22 (50)	179 (47.7)
Occupation	Pupils/Students	213 (64.3)	11 (25.0)	224 (59.7)
	Housewife	54 (16.3)	12 (27.3)	66 (17.6)
	Worker	25 (7.5)	7 (15.9)	32 (8.5)
	Commercial sector	25 (7.5)	9 (20.4)	34 (9.1)
	Medical profession	6 (2.0)	3 (6.8)	9 (2.4)
	Transport	4 (1.2)	1 (2.3)	5 (1.3)
	Unemployed	0 (0.0)	1 (2.3)	1 (0.3)
	Others	4 (1.2)	0 (0.0)	4 (1.1)

Continued

Education level	Elementary	76 (23.0)	22 (50)	98 (26.1)
	Secondary	228 (68.9)	13 (29.6)	241 (64.3)
	University	18 (5.4)	6 (13.6)	24 (6.4)
	No schooling	8 (2.4)	3 (6.8)	11 (2.9)
	Koranic school	1 (0.3)	0 (0.0)	1 (0.3)
Ethnic group	Wolof	86 (26.0)	25 (56.8)	111 (29.6)
	Serer	35 (10.6)	3 (6.9)	38 (10.1)
	Peulh	26 (7.8)	2 (4.5)	28 (7.5)
	Soce	11 (3.3)	2 (4.5)	13 (3.5)
	Diola	9 (2.7)	1 (2.3)	10 (2.7)
	Bambara	8 (2.4)	0 (0.0)	8 (2.1)
	Toucouleur	25 (7.6)	1 (2.3)	26 (6.9)
	Others	131 (39.6)	10 (22.7)	141 (37.6)

The data is presented as a number with proportion in bracket (%). The different variables have been broken down according to the different vaccines inoculated.

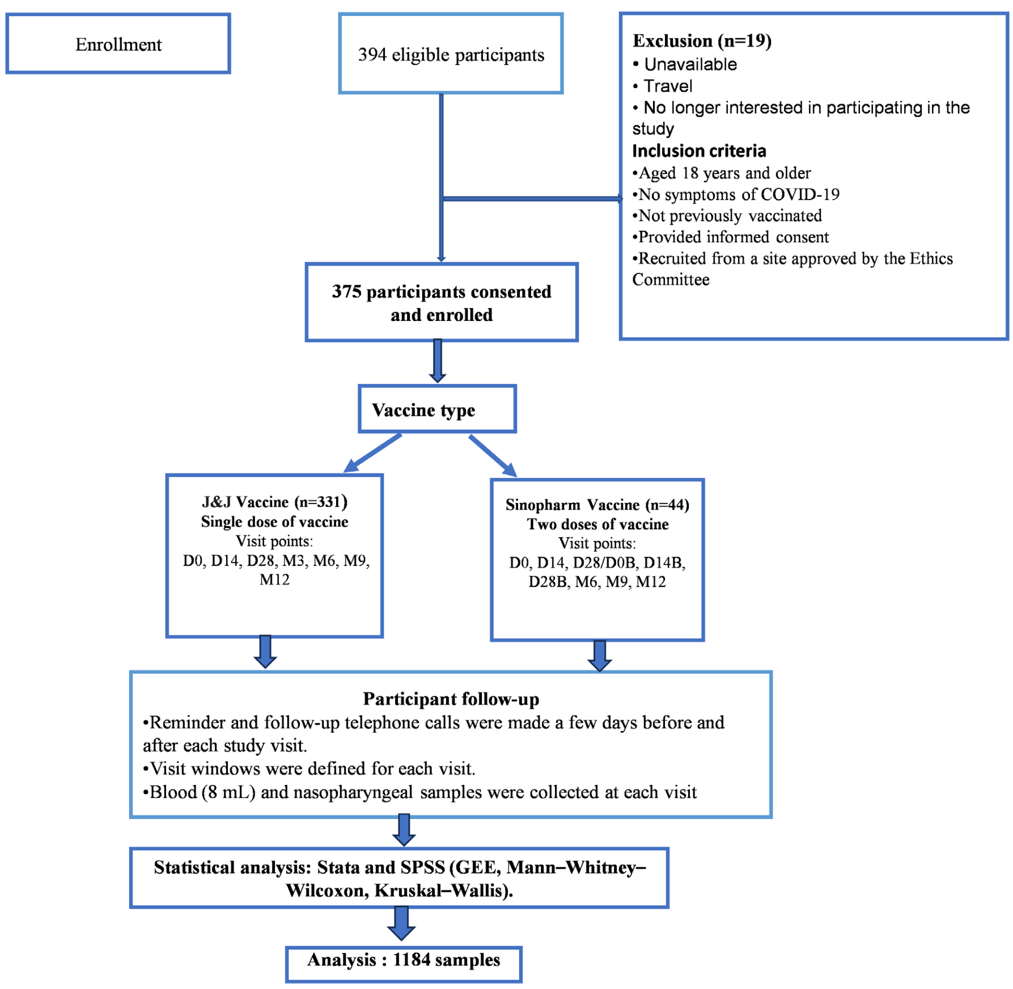


Figure 1. Study flow chart.

3.2. Evolution of the Study

Out of 394 eligible subjects, a total of 375 participants were enrolled in the study. Most participants (331; 88.3%) received the Johnson and Johnson (J&J) vaccine while the remaining 44 (11.73%) received the Sinopharm vaccine. Follow-up visits were scheduled according to the vaccine received. Participants who received the J&J vaccine had seven visit points: D0, D14, D 28, Month 3, Month 6, Month 9, Month 12, and those who received the Sinopharm vaccine had eight time points: D0, D14, D28 /D0B, D14B, D28B, Month 6, Month 9, Month 12 (**Figure 1**).

3.3. Association between Socio-Demographic Characteristics and Antibody Positivity

Several significant associations between certain socio-demographic and behavioural variables and anti-SARS-CoV-2 antibody positivity (S1, S2 and NP) were observed during follow-ups. Anti-S1 antibody positivity was independently associated with household of more than 16 people, being housewife, working in the commercial sector, and being a secondary school student. A significant association between anti-S2 antibodies and the commercial sector was also observed. Finally, anti-NP antibody positivity was frequent among Koranic school pupils (**Table 3**).

Table 3. Factors associated with anti-SARS-CoV-2 antibody positivity, including variable coefficients, associated p-values and confidence intervals.

Variables	Categories	S1			S2			NP		
		Coefficient*	p-value	CI** (95%)	Coefficient	p-value	CI (95%)	Coefficient	p-value	CI (95%)
Occupation	Pupils/students	0			0			0		
	Housewife	−238.9	**0.017**	[−435.2 - 42.5]	−252.8	0.162	[−607.0 - 101.3]	−10.2	0.776	[−80.5 - 60.1]
	Worker	−109.9	0.236	[−291.4 - 71.7]	−303.4	0.071	[−632.6 - 25.7]	−15.0	0.653	[−80.4 - 50.4]
	Commercial sector	−227.0	**0.027**	[−428.8 - 25.3]	−479.8	**0.009**	[−841.9 - 11.8]	−0.1	0.997	[−71.1 - 70.8]
	Medical profession	−102.4	0.485	[−389.5 - 184.7]	−188.6	0.473	[−703.4 - 326.3]	−64.6	0.199	[−163.0 - 33.9]
	Transport	−44.2	0.811	[−405.5 - 317.2]	−402.6	0.223	[−1050.3 - 245.0]	−29.0	0.645	[−152.5 - 94.5]
	Unemployed	−275.2	0.441	[−975.8 - 425.4]	−637.8	0.318	[−1889.5 - 613.9]	−181.6	0.139	[−422.1 - 58.9]
	Others	−397.7	0.076	[−836.3 - 40.9]	−481.7	0.224	[−1258.6 - 295.2]	−8.0	0.921	[−165.6 - 149.7]
Education level	Elementary	0			0			0		
	Secondary	215.7	**0.013**	[45.6 - 385.7]	274.3	0.079	[−31.5 - 580.0]	28.9	0.351	[−31.8 - 89.5]
	University	−185.9	0.195	[−467.2 - 95.5]	−416.6	0.105	[−919.9 - 86.7]	20.4	0.685	[−78.1 - 118.9]

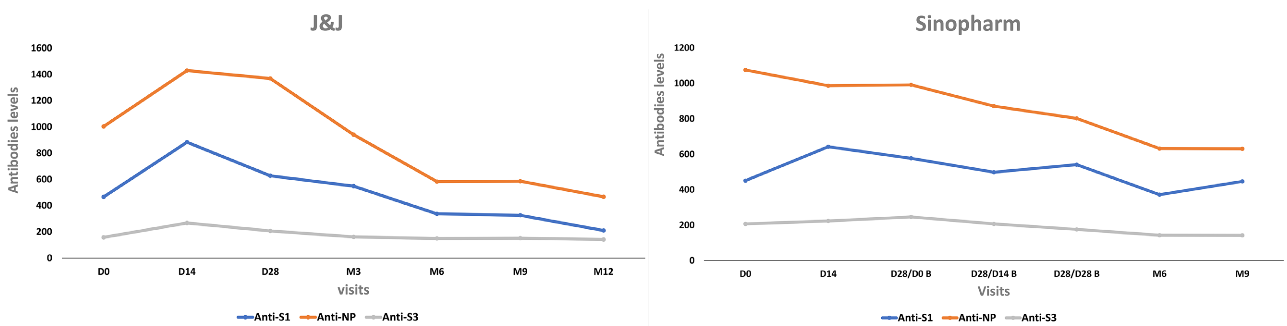
Continued

	No schooling	−122.1	0.385	[−397.5 - 153.3]	8.3	0.974	[−484.8 - 501.4]	79.2	0.108	[−17.3 - 175.7]
	Koranic school	79.2	0.735	[−379.9 - 538.2]	117.8	0.778	[−699.3 - 934.9]	242.1	**0.002**	[91.5 - 392.8]
Family size	[1 - 5]	0			0			0		
	[6 - 10]	−75.9	0.138	[−176.2 - 24.5]	−108.4	0.215	[−279.8 - 63.0]	−8.2	0.618	[−40.4 - 24.0]
	[11 - 15]	−157.3	0.071	[−328.3 - 13.7]	−14.2	0.925	[−308.6 - 280.2]	17.8	0.534	[−38.3 - 73.9]
	>16	−248.2	**0.006**	[−426.2 - 70.2]	−106.9	0.496	[−414.9 - 201.0]	−31.8	0.288	[−90.4 - 26.8]

*Coefficient = 0: reference; Coefficient > 0: increase in the level of antibodies compared with the reference. Coefficient of <0: decrease in antibody level compared to the reference. **CI: confidence interval at 95%.

3.4. Evaluation of Anti-S1, Anti-S2, and Anti-NP Antibodies Responses According to Vaccine Type and Visit Time Points

The median levels of anti-S1, anti-S2 and anti-NP antibodies in participants who received the J&J vaccine were respectively 465.9900 IU/ml, 1003.0000 IU/ml, 157.9800 IU/ml at baseline (D0), which increased sharply, peaking at 883.0700 IU/ml, 1429.1500 IU/ml, 267.4850 IU/ml at D14. These were followed by slight drop of anti-S2 and anti-Np levels to 1369.025 IU/ml and 206.68 IU/ml respectively while the level of anti-S1 sharply dropped to 627.295 IU/ml on D28. While the level of anti-S2 sharply fell to 582.98 IU/ml before levelling off and reaching 466.885 IU/ml at M12, the levels of anti-S1 and anti-Np respectively declined gradually over time to 210.01 IU/ml and 141.39 IU/ml at M12 (Figure 2(A)).



(A) (B)

Figure 2. Cinetic of anti-S1, anti-S2, and anti-NP antibodies responses according to vaccine type and visit time points.

Among participants vaccinated with the Sinopharm vaccine (Figure 2(B)), the median level of anti-S2 was surprisingly the highest at baseline with 1075.515 IU/ml which declined to 986.85 IU/ml at D14 followed by a slight rise to 991.6 IU/ml before falling all the way to 632.31 IU/ml at M6 and 631.095 IU/ml at M9. The level of anti-S1 at baseline(D0) was 4551.365 IU/ml which increases slightly to 223.84 IU/ml at D14 to peak at 246 at D28 before declining gradually to 142.59

IU/ml at M9. Contrarily, baseline level of anti-S1 which was 451.364 IU/ml rose sharply to peak at 642.57 IU/ml on D14 before gradually declining through 557 IU/ml on day 28 to 498.935 IU/ml on D42/D14B) before a slight rise to 541.39 IU/ml on D56/D28B, declined to 372.13 on M6 before rising to 446.74 IU/ml on M9.

3.5. Influence of Gender (Sex) on Antibody Response before and after Vaccination

After anti-body levels of anti-S1, anti-S2 and anti-Np antibodies after for participants vaccinated with the J&J vaccine is summarised below (Table 4). The median level of anti-S1 antibodies at day 0 among female participants was significantly ($p = 0.026$) lower (450.18 IU/ml) compared to that among the male participants (494.37 IU/ml). The difference became even more pronounced ($p < 0.001$) 14 days after vaccination with females having 691.93 IU/ml compared to the 1728.80 IU/ml recorded for the males. The levels of anti-S2 antibodies among female and male participants at baseline were comparable ($p = 0.096$). However, on the 14th day after vaccination, the levels among male participants (1830.53 IU/ml) had increased significantly ($p < 0.001$) compared to levels among females (1304.22 IU/ml). subsequently the levels decreased gradually through day 28, month 3 until month 12 among both sexes albeit no significant difference was observed. Like anti-S1 antibodies levels, the level of anti-NP antibodies at day 0 was 154.04 IU/ml in female participants, which was significantly lower ($p = 0.029$) compared to the 163.48 IU/ml in men. At day 14, the levels increased to 255.36 IU/ml in women and 306.59 IU/ml in men, but no differences were observed between the two sexes ($p = 0.083$). Thereafter, the levels decreased progressively until 9 months when a surprised increase in levels was observed in both groups with no difference between the groups ($p = 1$). This happenstance was followed by gradual decrease in levels until month 12 as shown in Figure 3.

Table 4. Antibody response between male and female participants vaccinated with Johnson & Johnson vaccine.

Sampling period	Antibodies	Female				male				p-value
		N	Median	Q1	Q3	N	Median	Q1	Q3	
D0	S1	157	450.18	306.78	555.03	174	494.36	342.91	619.44	0.026
D14	S1	133	691.93	533.74	1721.47	155	1728.80	649.38	2481.90	p < 0.001
D28	S1	132	632.33	487.55	900.87	148	627.29	483.75	980.76	0.830
M3	S1	46	548.19	502.88	689.53	25	533.65	373.78	709.84	0.348
M6	S1	9	350.24	279.81	515.63	8	321.73	250.75	419.24	0.481
M9	S1	6	414.45	218.96	551.76	2	321.80	320.78		0.643
M12	S1	1	179.87	179.87	179.87	1	240.15	240.15	240.15	1.000
D0	S2	157	973.25	614.41	1229.34	174	1046.61	663.85	1447.09	0.096
D14	S2	133	1304.22	983.50	2099.71	155	1830.53	1231.2900	3547.50	0.001
D28	S2	132	1331.60	1153.21	1489.79	148	1426.84	1140.01	1541.04	0.331
M3	S2	46	997.72	681.01	1196.30	25	677.36	467.65	1228.81	0.329

Continued

M6	S2	9	738.86	372.80	1381.16	8	543.06	357.55	656.62	0.236
M9	S2	6	873.27	509.47	1242.97	2	419.41	259.97		0.286
M12	S2	1	716.16	716.16	716.16	1	217.61	217.61	217.61	1.000
D0	NP	157	154.04	105.40	218.17	174	163.48	133.88	260.54	0.029
D14	NP	133	255.36	120.02	384.00	155	306.59	141.95	567.80	0.083
D28	NP	132	204.21	141.35	338.75	148	209.75	139.57	323.25	0.916
M3	NP	46	165.41	116.82	356.75	25	155.80	126.76	292.29	0.904
M6	NP	9	155.17	120.41	200.75	8	142.31	136.42	169.87	0.541
M9	NP	6	266.42	107.11	470.60	2	151.86	145.23		1.000
M12	NP	1	154.80	154.80	154.80	1	127.98	127.98	127.98	1.000

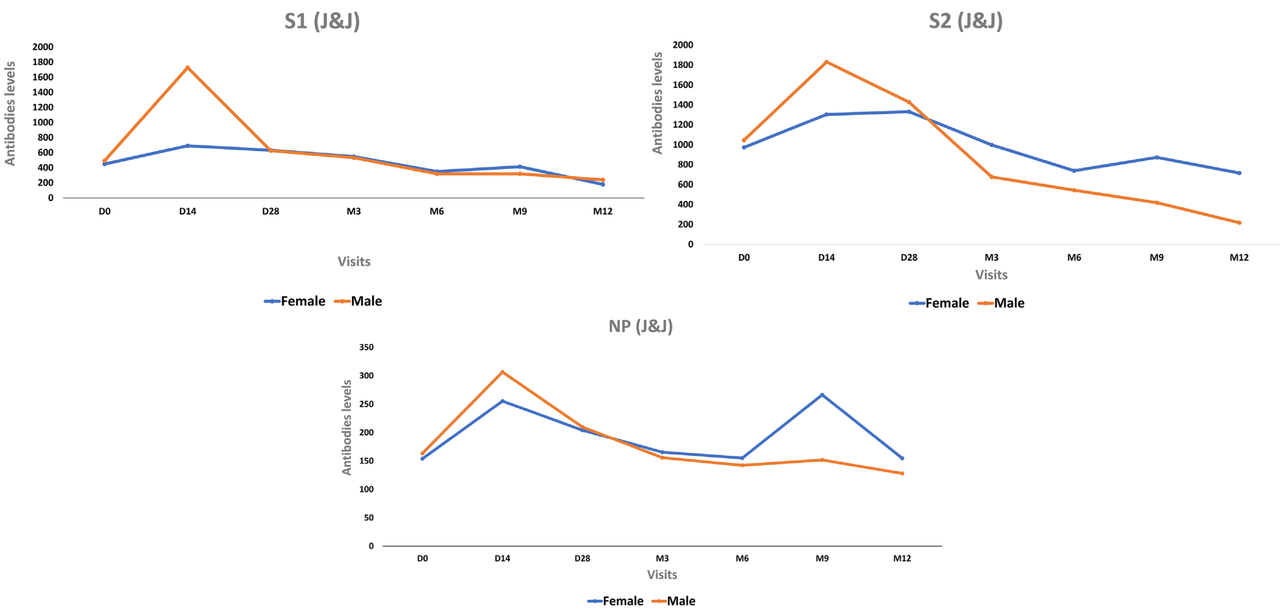


Figure 3. Evolution of Anti-S1, S2 and NP antibodies response in participants vaccinated with Johnson & Johnson as a function of gender and visits.

From the summary of antibody levels of anti-S1, anti-S2 and anti-Np among male and female participants vaccinated with the Sinopharm vaccine (Table 5), the baseline (D0) levels of anti-S1 Ab was comparable (p = 0.7960) between the females (427.96 IU/ml) and males (488.99 IU/ml). Notwithstanding the higher level of the antibody among females (716.00 IU/ml) 2 weeks after vaccination compared to the 535.88 IU/ml among males, there was no significant difference between the two groups (p = 0.174). Thereafter, a gradual decrease in levels was observed among the females up to month 9 whereas the males saw a mild increase in levels on day 28 (544.10 IU/ml) before gradual decline to month 9. Nevertheless, no significant differences were observed between the two sexes throughout the period. Similarly, although anti-S2 antibodies were relatively high among male participants during the earlier visits but relatively lower during the latter visits compared to female participants, no significant differences were observed between the two groups throughout the study. Additionally, we did not see any difference in anti-Np levels between the two groups irrespective of the sampling period as shown in Figure 4.

Table 5. Anti-S1, S2 and NP antibodies response in participants vaccinated with Sinopharm as a function of gender and visits.

Sampling period	Antibodies	Female				Male				p-value
		N	Median	Q1	Q3	N	Median	Q1	Q3	
D0	S1	22	427.96	353.82	589.90	22	488.98	241.95	586.98	0.796
D14	S1	18	716.00	413.13	1233.27	21	535.88	367.23	727.36	0.174
D28/D0B	S1	13	583.08	358.40	811.23	18	544.10	382.27	721.36	0.737
D42/D14B	S1	11	504.16	443.57	620.34	15	449.50	299.41	526.59	0.164
D56/D28B	S1	12	561.20	389.85	1210.94	13	367.16	282.89	595.72	0.110
M6	S1	5	435.55	301.48	521.41	8	364.30	286.16	485.04	0.435
M9	S1	2	415.51	228.77		6	446.74	300.31	526.87	1.000
D0	S2	22	1040.28	472.74	1431.48	22	1099.68	539.78	1278.42	0.833
D14	S2	18	951.28	565.12	3044.93	21	986.85	679.39	1310.04	0.770
D28/D0B	S2	13	1084.80	689.97	1243.45	18	853.40	570.11	1251.54	0.395
D42/D14B	S2	11	942.72	784.93	1112.76	15	823.40	659.45	1117.87	0.384
D56/D28B	S2	12	894.83	550.25	1646.68	13	661.86	474.08	1179.56	0.347
M6	S2	5	1050.27	623.09	1166.51	8	499.90	344.34	649.31	0.065
M9	S2	2	1008.65	603.10		6	611.94	524.28	863.26	0.429
D0	NP	22	191.04	90.10	279.42	22	207.39	140.80	258.16	0.639
D14	NP	18	195.97	147.66	348.36	21	244.24	201.16	380.61	0.426
D28/D0B	NP	13	231.32	141.02	401.86	18	278.96	161.66	517.23	0.395
D42/D14B	NP	11	208.42	190.60	356.94	15	206.07	130.00	362.02	0.646
D56/D28B	NP	12	158.76	88.48	270.43	13	176.45	142.66	244.30	0.728
M6	NP	5	394.98	128.63	415.54	8	137.87	119.64	182.31	0.284
M9	NP	2	311.82	140.22		6	142.28	113.40	230.63	0.429

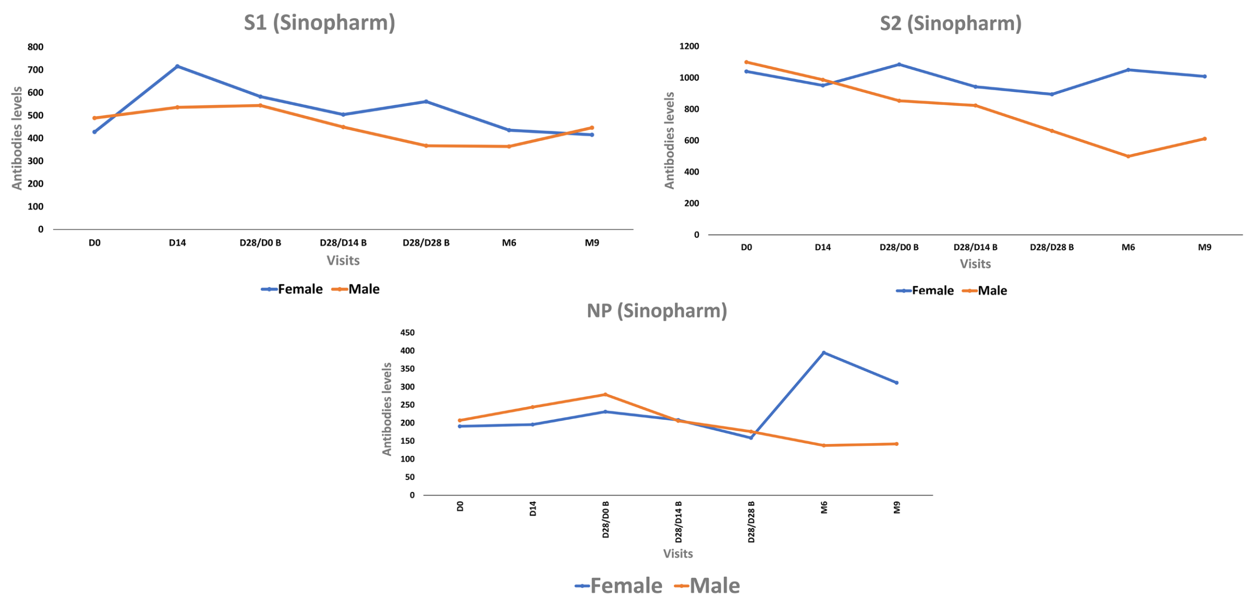


Figure 4. Evolution of Anti-S1, S2 and NP antibodies response in participants vaccinated with Sinopharm as a function of gender and visits.

3.6. Influence of Age on Antibody Response after Vaccination

The levels of anti-S1, anti-S2 and anti-Np antibodies among different age groups of participants are compared at different sampling periods below (Table 6). We observed relatively higher levels of anti-S1 Ab among participants of age 18 - 30 years throughout the visits, but levels were significantly higher at baseline ($p < 0.001$), day 14 ($p < 0.001$) and month 6 ($p = 0.049$) compared to the other two age groups. Similar observation was made for anti-S2 antibodies, with participants of age 18 - 30 years having relatively high levels of anti-S2 antibodies throughout the visits with significant higher levels at D0, D14 and month 6. A single exception was at month 6, where anti-S2 antibody levels were higher ($p = 0.017$) among participants of 46 - 70 age group compared to age group 18 - 35 and those above 70 years. Again, the levels of anti-Np antibody were relatively higher among participants of age 18 - 30 years with significant levels ($p < 0.001$) observed during baseline(D0) and day 14 compared to age groups 31 - 45 years and those above 45 years as shown in Figure 5.

Table 6. Antibody levels of participants of different age groups vaccinated with the J&J vaccine.

Sampling period	antibodies	18 - 30 years				31 - 45 years				46 - 70 years				p-value
		N	Median	Q1	Q3	N	Median	Q1	Q3	N	Median	Q1	Q3	
D0	S1	263	490.66	381.17	609.81	50	331.77	267.87	467.08	18	339.99	255.16	460.95	p < 0.001
D14	S1	232	1463.52	643.32	2378.40	37	549.34	471.79	808.45	19	453.14	403.48	738.93	p < 0.001
D28	S1	226	594.78	475.18	956.67	37	680.38	548.70	906.69	17	732.33	501.34	1132.96	0.287
M3	S1	39	547.65	444.89	803.44	22	545.69	506.76	661.38	10	548.32	456.31	689.53	0.961
M6	S1	12	413.45	308.20	477.81	4	279.81	242.81	336.45	1	175.11	175.11	175.11	0.049
M9	S1	5	499.36	293.45	556.78	3	320.78	83.63						0.250
M12	S1	1	179.87	179.87	179.87	1	240.15	240.15	240.15					
D0	S2	263	1068.12	796.48	1432.47	50	652.79	452.98	972.27	18	608.21	447.97	982.42	p < 0.001
D14	S2	232	1684.30	1209.40	3427.75	37	1215.15	996.72	1432.53	19	993.31	812.82	1949.38	p < 0.001
D28	S2	226	1409.97	1159.88	1537.52	37	1259.12	1023.61	1460.66	17	1315.50	1086.41	1505.74	0.184
M3	S2	39	892.98	531.79	1119.01	22	1004.57	519.45	1234.97	10	1103.15	689.57	1257.36	0.469
M6	S2	12	638.79	528.16	779.72	4	282.17	176.91	416.21	1	738.86	738.86	738.86	0.017
M9	S2	5	1153.33	550.71	1286.40	3	470.17	259.97						0.143
M12	S2	1	716.16	716.16	716.16	1	217.61	217.61	217.61					
D0	NP	263	161.45	131.56	244.61	50	155.87	99.32	214.82	18	117.21	57.27	157.21	p < 0.001
D14	NP	232	283.89	139.72	546.98	37	241.97	127.35	373.12	19	147.27	116.76	268.47	p < 0.001
D28	NP	226	204.44	140.17	327.60	37	259.04	153.13	383.86	17	168.66	98.28	321.89	0.257
M3	NP	39	160.96	125.88	341.36	22	178.30	119.25	333.30	10	148.96	112.78	405.25	0.993
M6	NP	12	169.26	136.60	197.86	4	122.25	74.48	150.81	1	149.68	149.68	149.68	0.151
M9	NP	5	400.57	145.38	499.01	3	108.95	101.59						0.071
M12	NP	1	154.80	154.80	154.80	1	127.98	127.98	127.98					

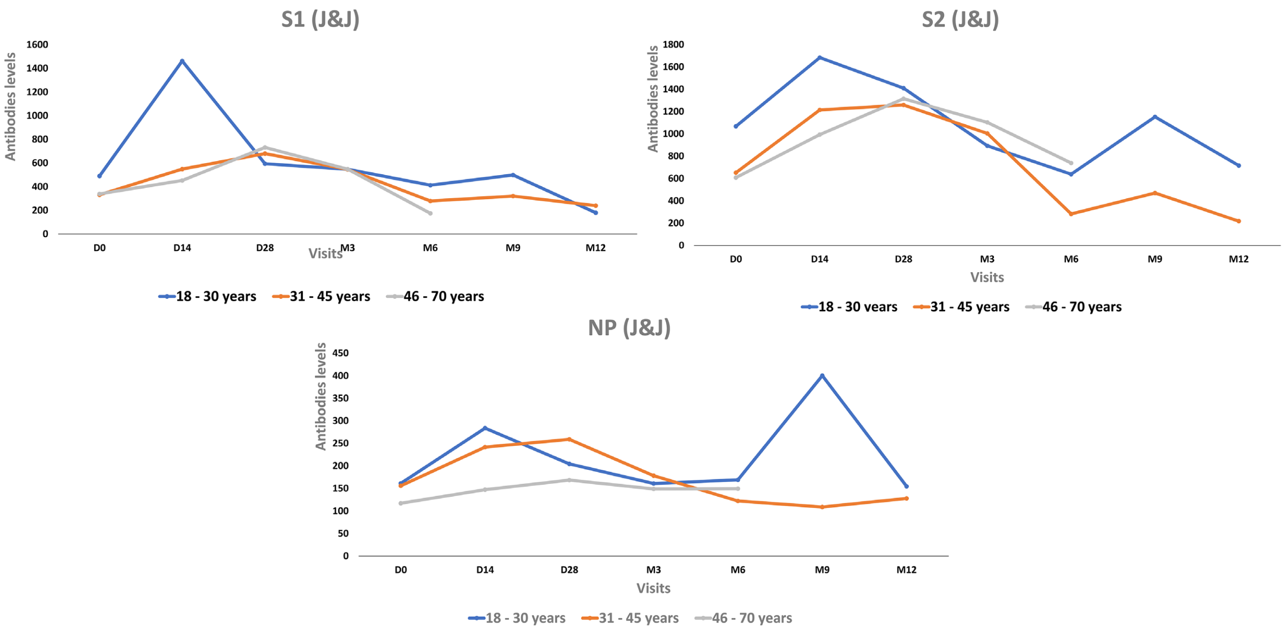


Figure 5. Evolution of Anti-S1, S2 and NP antibodies response in participants vaccinated with Johnson & Johnson according to age groups and visits.

Table 7 below shows the levels of anti-S1, anti-S2 and anti-Np antibodies observed among participants of the three age groups. Although anti-S1 antibody levels were relatively higher among the 46 - 70 age group throughout the study, no significant difference was seen when compared to the other age groups at any point in time ($p > 0.05$). The 46 - 70-year age group similarly had relatively higher levels of anti-S2 antibody at all time points but we observed significant difference in levels compared to the other groups at baseline ($p = 0.047$) and on day 14 ($p = 0.039$). Similar to the level of anti-S1 antibodies, no significant difference in level of anti-Np was recorded between the age groups despite the levels being relatively higher among age groups 46 - 70 years during early phase of the study as shown in Figure 6.

Table 7. Antibody levels of participants of different age groups vaccinated with the Sinopharm vaccine.

Sampling period	Antibodies	18 - 30 years				31 - 45 years				46 - 70 years				p-value
		N	Median	Q1	Q3	N	Median	Q1	Q3	N	Median	Q1	Q3	
D0	S1	28	488.98	310.91	580.15	14	398.16	352.68	477.91	2	868.60	682.59		0.069
D14	S1	24	693.04	466.36	925.64	13	447.10	320.16	976.00	2	1317.82	604.25		0.446
D28/D0B	S1	20	575.88	300.51	750.01	10	564.82	441.40	597.91	1	965.00	965.00	965.00	0.348
D42/D14B	S1	15	406.07	299.41	530.52	10	503.89	482.49	713.33	1	526.59	526.59	526.59	0.227
D56/D28B	S1	14	365.40	292.59	576.35	10	796.37	468.34	1557.70	1	551.18	551.18	551.18	0.121
M6	S1	7	369.42	280.89	435.55	5	372.13	266.41	521.41	1	694.99	694.99	694.99	0.241
M9	S1	6	496.32	391.69	568.96	2	243.03	228.77						0.071
D0	S2	28	1099.68	567.64	1286.64	14	777.49	398.14	1226.91	2	1608.58	1495.77		0.047
D14	S2	24	1108.19	674.79	2625.38	13	716.48	481.57	925.65	2	1831.13	1368.76		0.039
D28/D0B	S2	20	933.32	607.39	1269.20	10	962.33	679.53	1153.72	1	1321.06	1321.06	1321.06	0.468

Continued

D42/D14B	S2	15	823.40	659.45	1075.32	10	924.29	769.240	1146.52	1	1399.47	1399.47	1399.47	0.181
D56/D28B	S2	14	733.20	498.00	1176.95	10	770.82	375.45	1554.88	1	2791.36	2791.36	2791.36	0.381
M6	S2	7	512.66	463.47	654.98	5	713.86	418.48	1166.51	1	1286.27	1286.27	1286.27	0.146
M9	S2	6	686.26	558.45	1338.10	2	541.01	478.92						0.286
D0	NP	28	207.60	152.31	259.48	14	152.26	88.22	246.26	2	310.87	285.22		0.082
D14	NP	24	237.28	198.84	330.63	13	185.40	116.45	357.56	2	619.36	401.65		0.079
D28/D0B	NP	20	252.16	143.30	501.39	10	235.07	144.83	483.18	1	424.26	424.26	424.26	0.717
D42/D14B	NP	15	208.42	143.80	355.47	10	273.63	163.05	374.56	1	179.24	179.24	179.24	0.685
D56/D28B	NP	14	153.42	133.19	203.27	10	212.13	82.13	428.09	1	177.80	177.80	177.80	0.745
M6	NP	7	143.47	130.38	208.39	5	130.12	121.61	401.31	1	167.08	167.08	167.08	0.895
M9	NP	6	165.48	132.43	394.23	2	127.22	114.23						0.429

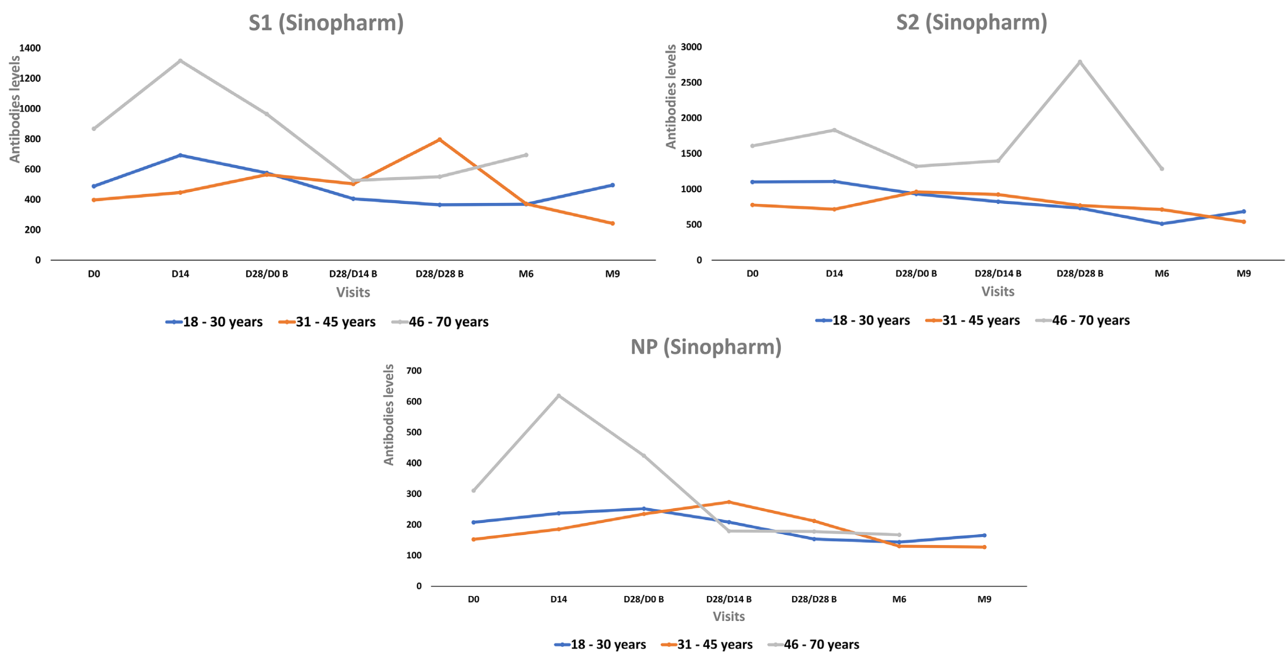


Figure 6. Evolution of Anti-S1, S2 and NP antibodies response in participants vaccinated with Sinopharm according to age groups and visits.

4. Discussion

This study focused on monitoring the long-term humoral response to SARS-CoV-2 vaccination by periodic measurement of the levels of targeted anti-bodies to spike protein antigens (S1, S2) and nucleocapsid antigen (Np) for 12 months. It also explored the influence of socio-demographic factors and community-level exposure on these immune responses.

The observed associations between socio-demographic factors and antibody profiles reflect the different exposure patterns and specific characteristics of the administered vaccines. Participants received either two doses of an inactivated whole-virus vaccine (Sinopharm) or one dose of an adenoviral vector vaccine

(J&J). Sinopharm can induce antibodies against the Spike protein (S1/S2) and the nucleoprotein (NP) due to its whole-virus composition [17], whereas the Johnson & Johnson vaccine only expresses the Spike protein and does not induce anti-NP antibodies [18].

The association between anti-S1 seropositivity and households with more than 16 members confirms the role of overcrowding in facilitating intra-household transmission, whereby close and prolonged contact increases viral circulation [19] [20]. Similarly, commercial workers and students are exposed to repeated interpersonal interactions in high-density environments, which may explain the higher S1/S2 positivity observed in these groups [21] [22]. In contrast, the higher anti-NP positivity in Koranic school pupils probably reflects natural infection, as NP antibodies are markers of previous viral replication rather than Spike-only vaccination [23].

On Day 0, prior to any injection, several participants already exhibited high levels of antibodies despite no prior vaccination, suggesting previous natural exposure to SARS-CoV-2. This situation is consistent with the epidemiological context in Senegal during 2022-2023, which was marked by widespread viral circulation and a population largely already immunized, either through natural infection or repeated exposure to the virus. Such pre-existing immunity, well documented in high-transmission settings [24], can enhance vaccine-induced responses through a "booster-like" effect [25]. This could explain the rapid and elevated antibody levels observed shortly after vaccination. However, some variability in immune responses was noted, likely influenced by individual factors such as age, sex, and prior exposure. This study helps to address the gap in immunological data on COVID-19 in African populations and highlights the importance of assessing pre-existing immunity prior to vaccination.

The J&J vaccine (Ad26.COV2. S) initially induced a robust humoral response, with significantly high concentrations of anti-S1 and anti-S2 antibodies observed on days 14 and 28 post-vaccination. These results confirm the efficacy of this single-dose vaccine in generating a rapid immune response, as previously reported in several clinical studies [26]. However, this response progressively diminishes over time, with a notable decline in antibody levels at six and nine months. This decline aligns with findings from other cohorts, where the persistence of antibodies after vaccination with Ad26.COV2.S was lower than that observed with mRNA vaccines [27]. The declining levels of antibodies may be explained by the non-replicating nature of the viral vector platforms, which relies solely on the Spike protein and tends to elicit a strong but transient antibody response. The emergence of viral variants and the absence of additional antigens may also contribute to a less durable immune response [28] [29]. Nevertheless, the observed decline in antibody levels may reflect the natural course of the immune response [30], as well as the vaccine's tendency to induce a predominantly cellular immune response and the generation of memory T and B cells rather than sustained antibody production [31]. These findings are in line with the study by Self *et al.* [32], which reported that anti-Spike and anti-RBD IgG levels were significantly lower in individuals vaccinated with Johnson & Johnson compared to those who received Moderna or Pfizer-BioNTech vaccines. Overall, these results highlight the importance of monitoring the duration of vaccine-induced immunity and adapting immunization strategies accordingly, particularly through the administration of homologous or heterologous booster doses. Our findings support the use of booster doses to maintain long-term antibody protection, particularly in areas with high viral circulation or among at-risk individuals.

The administration of the first dose of the Sinopharm vaccine led to a slight increase in anti-S1 and anti-NP SARS-CoV-2 antibody levels, while a slight decrease was observed in anti-S2 antibody levels. These findings suggest a modest humoral response induced by the initial dose, with a preferential specificity directed toward the S1 subunit of the Spike protein, which contains the receptor-binding domain (RBD) a major target of neutralizing immunity [33]. The increase in anti-NP antibodies can be attributed to the nature of the Sinopharm vaccine (BBIBP-CorV), which is an inactivated whole-virus vaccine containing all structural viral proteins, including the nucleoprotein (NP). This is consistent with the findings of an earlier study [18], and contrasts with mRNA or viral vector vaccines, which solely express the Spike protein. The observed decrease in anti-S2 antibodies may be due to the intrinsically lower immunogenicity of the S2 subunit compared to S1 [34] suggesting that S2 may be less exposed making it a less dominant target for humoral responses. Additionally, this limited response may reflect a transient redistribution of immune resources, awaiting amplification following the second dose. However, contrary to expectations, no significant booster effect was observed following the administration of the second dose of the vaccine. This could be because the first dose may have induced an immune response that approached the maximal level, thereby limiting further enhancement by the second dose, as previously suggested [32] [33] or that the second dose was administered too early, or that the antibody measurements were taken before the immune system had completed its full response to the first dose making the increase in antibody levels not yet apparent. This is consistent with an earlier report which highlighted the importance of optimizing the interval between doses [35]. It is also possible that the second dose only targeted enhancing antibody affinity through affinity maturation rather than increase the overall quantity [36] [37]. Finally, individual variability must be considered. Factors such as age, sex, general health status, and comorbidities can significantly influence the magnitude and quality of the immune response as previously described [38] [39].

Our study revealed a sex-specific dynamic in the immune response induced by vaccination irrespective of the target antibodies as depicted by the higher levels of anti-S1, anti-S2 and anti-Np antibodies in the early phases of the study among men. However, this trend reversed over time: women gradually developed higher antibody titres and demonstrated greater antibody persistence for both vaccines assessed. This pattern remained consistent throughout the follow-up period in agreement with previous reports of women mounting more durable and protective immune response compared to men [40] [41]. This enhanced immunity in females was largely attributed to the influence of sex hormones particularly oestrogens and the presence of immunoregulatory genes on the X chromosome [41]-[43]. In contrast, men tend to exhibit a more intense but transient immune response, often accompanied by heightened inflammation. This phenomenon has also been described by Takahashi *et al.* (2020), who reported sex-based differences in immune responses to SARS-CoV-2, which helped to explain some of the observed disparities in clinical outcomes [44]. Several studies have shown that various immune cells, such as B lymphocytes, express oestrogen receptors that are regulated by circulating oestrogen levels [45] [46]. Moreover, oestrogen has been shown to promote immunoglobulin production, while testosterone may exert an inhibitory effect [47].

Moreso, this study revealed that the levels of anti-S1, anti-S2, and anti-NP antibodies vary depending on the type of vaccine administered and the age group. Overall, the J&J vaccine elicited a stronger immune response in younger individuals, particularly those aged 18 to 30 years, throughout the follow-up period which contrasts the stronger immune response elicited by the Sinopharm vaccine among participants between 46 to 70 years of age particularly at the early stages of the study. This observation may be explained by the higher immunological reactivity of younger adults, who generally exhibit better B and T cell functionality with faster and more effective humoral response. This agree with the report that age is a critical determinant of vaccine immunogenicity, with older individuals often showing a diminished response due to immunosenescence [48] [49]. Furthermore, the J&J vaccine, being a viral vector-based platform, may stimulate a stronger initial response in younger individuals whose naïve immune systems are more responsive to this type of vaccine as highlighted in the findings from an earlier study on the immunogenicity and efficacy of the Ad26.COV2. S vaccine [50]. Notwithstanding, the lost to follow-up among participants of age above 46 years leading to incomplete data on long-term effect of the Sinopharm vaccine, the earlier response observed agrees with an earlier report from a study which observed higher average antibody titres in individuals aged 45 and above [51]. Conversely, these results contrast with the conclusions of another study which documented a decline in antibody levels with increasing age among Sinopharm vaccine recipients [52] [53]. Potential explanation for this observation could be that the presence of pre-existing immune memory, due to prior exposure to related coronaviruses, could enhance the initial response in older subjects. Additionally, external factors such as stress, fatigue, and nutrition which tend to be more stable in older adults, may also play a favourable role in modulating the immune response [42] [43]. Nevertheless, further investigations are needed to better understand the actual underlying mechanisms. Notwithstanding, these results underscore the importance of adopting an age-specific approach when evaluating vaccine immunogenicity which may help inform tailored vaccination strategies, particularly regarding booster administration in older populations.

5. Strengths and Limitations of the Study

A major strength of this study is the extended follow-up period, combined with multiple data collection points, enabling a detailed assessment of immune response dynamics over time. The immune response was then analysed according to several key variables, including gender, age and vaccine type. This multidimensional approach explored many factors that could influence immunogenicity. The study also assessed the impact of sociodemographic characteristics and exposure at community level, providing valuable insights into individual and contextual determinants of immune response. This study is limited by the small Sinopharm cohort (n = 44) compared with Johnson & Johnson (n = 331), along with uneven distribution of certain variables, particularly age and sex, and gradual loss to follow-up, may have reduced the statistical power of subgroup analyses and contributed to variability in the results. A more thorough assessment of participants' overall health status and environmental factors would have been necessary to better understand the observed disparities. Additionally, the analysis focused solely on the humoral response, measured by antibody levels, without evaluating the cellular response (T lymphocytes and their subpopulations), which is crucial for comprehensive immunity. Another important limitation is the absence of antibody neutralization assays, which would have provided valuable complementary data to support the conclusions drawn from ELISA results. Another limitation of this study is the absence of baseline PCR and serological testing, which limited the confirmation of prior SARS-CoV-2 infection among participants. Despite these constraints, this study offers significant insights into vaccine-induced immune responses and paves the way for further in-depth research.

6. Conclusion

This study evaluated the humoral response induced by the Johnson & Johnson and Sinopharm vaccines in Senegalese adults aged 18 and older. The results confirm the immunogenicity of both vaccines, showing a robust antibody response that gradually declines over time, highlighting the importance of booster doses to maintain long-term immunity. Variations were observed according to age, sex, and vaccine type, emphasizing the influence of individual and contextual factors, some of which warrant further investigation. Finally, this study underscores the need to tailor vaccination strategies, protective measures, and serological monitoring to local realities. Prioritizing the most vulnerable groups while reinforcing effective prevention practices is essential.

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Author Contributions

FBNM, DJW, TND designed the project.

FBNM, ND, DJW, NKK, ALS, NDD, MSG, and JKB, NAL performed the experimental analyses.

BFNM, ND, OD, AM and IDO analysed the data and prepared the figures & tables.

FBNM, ND and IDO wrote and reviewed the manuscript.

DJW, TND, SOM supervised the overall study.

All authors have read and approved the final submitted version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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