Mpox vaccination hesitancy, previous immunisation coverage, and vaccination readiness in the African region: a multinational survey

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eClinicalMedicine
2025;80: 103047
Published Online xxx
https://doi.org/10.1016/j.eclinm.2024.103047

Summary

Background Vaccination hesitancy poses a serious threat to mpox vaccination programs. Historically, vaccine uptake in the African region has been low, and this trend may impact future vaccination efforts. Our aim was to investigate the relationships between mpox vaccination hesitancy, immunisation coverage for other vaccines, and vaccination readiness among African adults.

Methods A multinational commercial web panel survey was conducted among 1832 African adults across six countries (Uganda, Nigeria, Morocco, Egypt, Kenya, and South Africa) from October 1 to October 10, 2024. Mpox vaccination hesitancy for themselves and children was defined as the reluctance to receive vaccines against mpox (if vaccines were available) for themselves and for children (if they had children). Vaccination readiness was assessed via the 7Cs model, which includes confidence, complacency, constraints, calculation, collective responsibility, compliance, and conspiracy. Weighted logistic regression models with the set of calibration sampling weights were used to estimate odds ratios (ORs) with 95% confidence intervals (95% CIs). The analysis explored the effects of immunisation coverage for other vaccines and vaccination readiness on hesitancy toward mpox vaccination, including mediation and joint relationships. DerSimonian-Laird random-effects meta-analyses were utilised to pool the results from six countries.

Findings The pooled weighted rate of mpox vaccination hesitancy among participants was 32.7% (95% CI: 25.4–40.0, I^2 = 91.5%, p < 0.0001) for themselves and 38.9% (95% CI 30.2–47.6, I^2 = 93.7%, p < 0.0001) for children. After adjusting for covariates, the absence of immunisation coverage for other vaccines independently increased the risk of mpox vaccination hesitancy for themselves and for children, with a pooled OR of 2.66 (95% CI 1.67–4.26, I^2 = 25.8%, p = 0.241) and a pooled OR of 2.16 (95% CI 1.42–3.30, I^2 = 0%, p = 0.471), respectively. The pooled mediation proportions of vaccination readiness for the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy were 15.85% (95% CI 0.64–31.06, I^2 = 60.9%, p = 0.703) and 52.53% (95% CI 20.93–84.14, I^2 = 0%, p = 0.988) for themselves and for children, respectively. The pooled weighted rate of mpox vaccination hesitancy was highest among individuals with low vaccination readiness and no history of other vaccinations, with a pooled weighted rate of 62.7% (95% CI 44.7–80.7, I^2 = 82.8%, p < 0.0001) for themselves and 76.3% (95% CI 66.9–85.7, I^2 = 40.6%, p = 0.135) for children. Compared with the reference group (high vaccination readiness and a history of other vaccinations), populations that reported low vaccination readiness and no history of other vaccinations exhibited the highest risk of mpox vaccination hesitancy for themselves (pooled OR 7.83, 95% CI 3.28–18.70, I^2 = 63.2%, p = 0.018) and for children (pooled OR 12.55, 95% CI 7.38–21.33, I^2 = 0%, p = 0.585), followed by populations that reported low vaccination readiness and a history of other vaccinations (pooled OR for themselves 2.69, 95% CI 1.70–4.26, I^2 = 66.7%, p = 0.01; pooled OR for children 4.97, 95% CI 3.66–6.74, I^2 = 19.6%, p = 0.286). However, populations that reported high vaccination readiness and no history of other vaccinations demonstrated a higher risk of mpox vaccination hesitancy for themselves (pooled OR 2.28 95% CI 1.05–4.94, I^2 = 0%, p = 0.608), but not for children.

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Interpretation Our findings indicate a significant level of hesitancy toward mpox vaccination in the African region. Individuals who have not previously received other vaccines are at a higher risk of refusing to vaccinate against mpox for themselves and for children. However, high vaccination readiness can help mitigate this risk. The study recommends that regions in Africa with low immunisation coverage should continue to enhance vaccination education and improve vaccination readiness to reduce hesitancy and promote the mpox vaccination program.

Funding This work was partly supported by the National Natural Science Foundation of China (grant numbers 72122001, 72474005).

Keywords: Mpox; Vaccination hesitancy; vaccination readiness; Immunisation coverage; Africa

Research in context

Evidence before this study

A rapid review was conducted via PubMed, Embase, Scopus, Web of Science, EBSCO, Wanfang Database, CNKI, and Sinomed to identify studies on the uptake of the mpox vaccine as of September 4, 2024. A comprehensive list of search terms, incorporating both MeSH and text words, was utilised (see Table S1). We found only four studies that reported mpox vaccination hesitancy before 2024 in one African country (two in Algeria and two in Ghana), indicating a lack of multinational studies on this topic. Vaccination is an effective method to prevent the spread of mpox. The World Health Organization (WHO) has been promoting the implementation of the mpox vaccination program in Africa. However, there are no studies reporting mpox vaccination hesitancy in children. Compared with other regions, the African region has consistently reported low vaccine uptake. Historically, vaccine uptake has been low in Africa, and this trend may influence future vaccinations, including the mpox vaccine. The relative impacts of immunisation coverage and vaccination readiness on mpox vaccination decisions are not well understood in the African region.

Added value of this study

Our findings revealed that the rates of mpox vaccination hesitancy among adults in the African region were higher than 30% for both themselves and children in 2024. Individuals who had never received other vaccines exhibited a 2.66-fold higher risk of mpox vaccination hesitancy for themselves and a 2.16-fold higher risk for children than those with immunisation coverage for other vaccines. Populations with low vaccination readiness and no history of other vaccinations demonstrated the highest risk of mpox vaccination hesitancy for both themselves (pooled OR [odds ratio] = 7.83) and children (pooled OR = 12.55) compared with populations that reported high vaccination readiness and a history of other vaccinations. Fortunately, increased vaccination readiness was related to a decrease in the risk of mpox vaccination hesitancy by 15.85% for themselves and 52.53% for children. Understanding these characteristics and relationships can assist governments in developing strategies to promote mpox vaccination, particularly for groups with generally lower vaccine uptake.

Implications of all the available evidence

Previous evidence has shown that the mpox vaccine uptake rate in Africa is 5.0%, which is significantly lower than that in other regions. Although the WHO has been promoting the mpox vaccination program in Africa, a substantial level of mpox vaccination hesitancy continues to hinder vaccine uptake, particularly among individuals who have never received other vaccines. Fortunately, a high level of vaccine readiness could improve this situation. This suggests that regions in Africa with low vaccine intake should continue to strengthen vaccination education and increase vaccination readiness to reduce mpox vaccination hesitancy and promote the mpox vaccination program.

Introduction

Mpox (formerly known as monkeypox) is a sporadic zoonosis caused by the monkeypox virus (MPXV). Prior to 2022, it occurred primarily in rural rainforest villages in western and central Africa.[1,2] Since the first mpox case was reported in the UK on May 7, 2022, the epidemic has spread to other continents outside Africa.[3] On July 23, 2022, the World Health Organization (WHO) director-general declared that the mpox epidemic constituted a public health emergency of international concern (PHEIC).[4] After the global mpox epidemic appeared to subside in 2023, the African region reported a significant increase in cases during the first half of 2024.[5] This rapidly escalating epidemic in Africa is one of the reasons for the renewed declaration of a PHEIC on August 14, 2024. The MPXV clade IIb is responsible for the ongoing multi-country outbreak from 2022 to 2024.[6] However, the emergence of a new offshoot of clade I, known as clade Ib, has complicated the global response to the outbreak. The current

outbreak in the Democratic Republic of the Congo (DRC) is attributed to clade Ib, which is associated with more severe disease than clade II, particularly among children.[7,8]

Vaccination is the most effective method for preventing infectious diseases. Several potential mpox vaccine candidates are currently under consideration, including LC16m8, ACAM2000, BNT166a, and BNT166c.[6] On September 13, 2024, the WHO approved an application for emergency authorisation for the use of Modified Vaccinia Ankara-Bavarian Nordic (MVA-BN). Additionally, since the most affected population includes children, the vaccine could also be administered to them. However, a meta-analysis revealed that the mpox vaccine uptake rate in the African region was only 5.0% in 2023, which was significantly lower than that reported in other regions.[9] Vaccination hesitancy poses a barrier to achieving vaccine popularisation, making it urgent to address mpox vaccination hesitancy to promote herd immunity and enhance public health emergency response capacity in Africa. Notably, only four studies reported on mpox vaccination hesitancy prior to 2024 in Algeria[10,11] and Ghana,[12,13] and there is a lack of recent multinational studies in the African region. Importantly, no research has investigated mpox vaccination hesitancy among vulnerable children. Given the generally low level of vaccine uptake, it is essential to understand the factors influencing mpox vaccination hesitancy and to identify strategies for improvement. There is no doubt that corresponding epidemiological data is vital for formulating more specific plans and policies regarding mpox vaccination.[14]

Vaccination coverage in Africa has been a critical public health issue. For instance, in 2023, only 34% (16/47) of countries in the WHO African Region achieved the target of 90% coverage for the diphtheria-tetanus-pertussis vaccine.[15] Low immunisation coverage has significant implications for public health, resulting in frequent outbreaks of diseases that could otherwise be prevented.[16,17] The introduction of new or underutilised vaccines in the African region is essential to prevent these outbreaks.[18] However, previous studies have reported that a lack of coronavirus disease 2019 (COVID-19) vaccination impedes mpox vaccine acceptance.[10,12] Low immunisation coverage may create a vicious cycle in which populations that have never been vaccinated may refuse to receive new vaccines owing to a lack of trust in vaccination programs. This, in turn, results in even lower immunisation coverage. Analysing the relationship between immunisation coverage and mpox vaccination hesitancy will be beneficial for identifying key populations that require more attention in mpox vaccination plans in regions with low immunisation coverage. In addition, vaccination readiness serves as a psychological and overarching term that encompasses the factors influencing the likelihood of receiving a vaccination.[19] Individual vaccination readiness may fluctuate based on interventions such as information campaigns and public debates.[19] Previous studies have documented its impact on the intention to receive vaccines.[20,21] Therefore, it is essential to investigate whether enhancing vaccination readiness can mitigate the effect of prior immunisation coverage on mpox vaccination hesitancy in regions with low immunisation coverage.

To address the risks posed by the new clade Ib strain, international organizations, including the WHO, the Vaccine Alliance, and other partners, have issued a tender to help secure mpox vaccines for the countries most affected. To provide evidence for the development of vaccination policies, this study aimed to investigate mpox vaccination hesitancy for themselves and children, as well as the relationships between the immunisation coverage for other vaccines, vaccination readiness, and mpox vaccination hesitancy among African adults across six countries.

Methods

Study design and participants

This multinational commercial web panel survey was conducted from October 1 to October 10, 2024, following the WHO's approval of an application for emergency authorisation for the use of MVA-BN. Participants aged 18 years and older were recruited through Dynata[22] across six African countries: Uganda, Nigeria, Morocco, Egypt, Kenya, and South Africa. We aimed to include all African countries with reported mpox cases on the basis of records from the WHO as of September 11, 2024.[5] Ultimately, we included the aforementioned six countries due to the limited scope of the Dynata platform in the African region. Owing to previous studies reporting significant gender differences in mpox vaccination hesitation rates in African countries,[12,13] we calculated the sample size according to gender strata using the *confidence intervals for one proportion* in PASS 15 software (NCSS, LLC). We set the mpox hesitation rate at 0.58 based on a meta-analysis in the African region,[9] with an allowable error of 0.15 times the mpox hesitation rate. The two-sided alpha was set at 0.05, resulting in a calculated sample size of 138. Considering that vaccination hesitation rates may vary between genders, we ultimately decided to recruit 150 participants from each gender in every country, resulting in a total of 300 participants per country. Those participants were then selected proportionally by age strata (18–44 years, 45–64 years, and ≥65 years) for each gender in every country, in accordance with population data in 2024 from the *World Population Prospects 2022*.[23] Dydata, a professional international commercial web panel survey platform, has a sampling database. In our

study, Dydata randomly sent emails to invite participants who met the gender and age criteria in each country on the basis of the sampling frame (Table S2). If informed consent was provided by the participants at the time of participation, the specific investigation was continued. The research was approved by the ethics committee of Peking University (IRB00001052). The research was performed in accordance with the Declaration of Helsinki.

Survey instrument

We translated an anonymized self-administered questionnaire (SAQ) into the official languages of each participating country as follows: Nigeria (English, Swahili), South Africa (English), Uganda (English), Kenya (English, Swahili), Morocco (French, Arabic), and Egypt (Arabic). The participants were free to choose one of the available languages in countries that offered two options. The questionnaire and its translations can be found in the supplementary document **Survey questionnaire**. This study gathered sociodemographic data and information related to mpox from the respondents, including age, gender, educational level, employment status, marital status, household income level, number of chronic diseases, self-assessed health status, sexual orientation, risky sexual behavior, MPXV infection status, MPXV infection status in children, mpox-related knowledge, mpox vaccination status, worries about stigma, and vaccination readiness.

To minimise the influence of varying cultural backgrounds, we employed a common 5-point Likert scale for participants to self-rate their household income level, health status, and worries about stigma. Risky sexual behavior was defined as any of the following behaviors: condomless sex, group sex, having more than 2 sexual partners, and attending a sex club/party/bathhouse. Six items were developed to assess mpox-related knowledge based on our previous studies.[24,25] These items covered sources of mpox infection, possible routes of transmission, susceptible populations, clinical symptoms, specific drugs, and preventive measures. To quantify mpox-related knowledge, each correct answer was awarded one point. The total score for mpox-related knowledge ranged from 0 to 23, with higher scores indicating better knowledge. The scores were categorised into three groups on the basis of quantiles: low mpox-related knowledge (0–3), moderate mpox-related knowledge (4–9), and high mpox-related knowledge (10–23).[25]

The term vaccination readiness as an umbrella concept for components that determine an individual's preparedness to receive a vaccine, is frequently employed to evaluate its impact on the intention to get vaccinated.[12,19,21] A total of 21 questions were developed based on the 7Cs model, which includes confidence, complacency, constraints, calculation, collective responsibility, compliance, and conspiracy.[26] Each dimension has a key point of measurement; for example, the key point for confidence is "trust". Specific details can be found in the published article.[19] We calculated the mean score and classified respondents into two groups (low and high) on the basis of the median scores.

There is no universal definition of vaccination coverage. According to the *Progress towards global immunization goals and implementation of the Immunization Agenda 2030* and the *Immunization Agenda 2030* from the WHO,[16,18] and the latest article,[17] vaccination coverage encompasses all vaccinations aimed at preventing the spread of infectious diseases. In our study, we aimed to explore the impact of immunisation coverage on mpox vaccination hesitancy. To achieve this goal, we assessed immunisation coverage for other vaccines (not including the mpox vaccine) by inquiring whether participants had received vaccinations for COVID-19, human papillomavirus (HPV), influenza, or other vaccines. Participants who had not received any of these vaccines (COVID-19, HPV, influenza, or other vaccines) were classified into the no immunisation coverage for other vaccines group.

The primary outcomes were mpox vaccination hesitancy for themselves and for children. Participants without children were also expected to respond to the question regarding their intention to vaccinate children against mpox, assuming they had children. This hesitancy was defined as the proportion of participants who responded "no" when asked whether they would be willing to receive vaccines against mpox (if vaccines were available) for themselves and for children (if they had children).[24]

Data analysis

The baseline characteristics of the study population were described as the means ± standard deviations (SDs) for the continuous variables or percentages for the categorical variables. The calibration sampling weights (Table S3) were calculated via the formula $calibration\ sampling\ weights = \frac{number\ of\ population_{each\ gender-age\ strata}}{number\ of\ particpants_{each\ gender-age\ strata}}$, which the population size in 2024 was from the *World Population Prospects 2022*.[23] A weighted Chi-square test with the set of calibration sampling weights was employed in the univariate analysis via the *survey* package. The weighted rate of mpox vaccination hesitancy, along with 95% confidence intervals (95% CIs), was computed via the *survey* package.

Weighted logistic regression models with the set of calibration sampling weights were employed to estimate odds ratios (ORs) with 95% CIs, incorporating adjustments for potential covariates via the *survey* package. To assess the robustness of the results, we developed three models that adjusted for different covariates. Model 1 was a univariate model. Model 2 was adjusted for age, gender, educational level,

employment status, marital status, household income level, living with children, number of chronic diseases, self-assessed health status, sexual orientation, risky sexual behavior, MPXV infection status, MPXV infection status in children, mpox-related knowledge, mpox vaccination, and worries about stigma. On the basis of model 2, we further adjusted for vaccination readiness in model 3.

To understand interactions of immunisation coverage with vaccine readiness on mpox vaccination hesitancy. We quantified the additive and multiplicative interactions by adding a product term between immunisation coverage for other vaccines (no vs yes) and vaccination readiness (high vs low) in our model.[27,28] The interaction on the additive scale was measured using the relative excess risk due to interaction (RERI) along with the corresponding 95% CI.[29] We utilised the *mediation* package to conduct causal mediation analysis and to calculate the proportions mediated by vaccination readiness.[30] To quantify the joint effects, we categorised participants into four groups based on their immunisation coverage for other vaccines (no vs yes) and vaccination readiness (high vs low). We subsequently estimated the ORs with 95% CIs for mpox vaccination hesitancy across different groups compared with the reference group (high vaccination readiness and a history of other vaccinations). Additionally, we performed subgroup analyses to investigate the variability in the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy among different subpopulations. To mitigate the impact of the varying degrees of the mpox epidemic across different countries on the overall results, we also conducted regression analyses at the national level and DerSimonian-Laird random-effects meta-analyses[31] to calculate the pooled results.

To test the robustness of our results, we conducted three sensitivity analyses. First, to provide evidence for the promotion of new vaccination programs, we excluded the mpox vaccination status from the immunisation coverage metric because our primary focus was to explore the impact of prior infectious disease vaccinations on the willingness to receive a new vaccine (the mpox vaccine was authorised for emergency use by the WHO in September 2024). Consequently, we included mpox vaccination status as a covariate and adjusted for it in our model. After accounting for mpox vaccination status in the immunisation coverage, participants who had not received any vaccine (mpox, COVID-19, HPV, influenza, or other vaccines) were classified into the no immunisation coverage for any vaccine group. Additionally, associating COVID-19, HPV, and influenza vaccinations is to be cautious, as they do not represent the same context. Therefore, we performed supplementary regression analyses for immunisation coverage for any vaccine, COVID-19 vaccination, HPV vaccination, and influenza vaccination separately. Second, we examined the mediating role of vaccination readiness to provide evidence for vaccination programs in public health practice, given the operability and changeability of vaccination readiness. To ensure more similar variables in practical applications, we supplemented our analysis by investigating the mediating effects of mpox-related knowledge and worries about stigma on the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy. Finally, because covariates, including MPXV infection status, MPXV infection status in children, and Mpox vaccination, varied across countries with differing epidemic levels, which may affect our results, we removed these items and included epidemic level as a covariate in our regression models. According to the mpox cases reported by the WHO as of September 11, 2024, we classified epidemic levels into three groups: mpox affected group level 1 (Nigeria, 916 cases; South Africa, 29 cases), mpox affected group level 2 (Uganda, 10 cases; Morocco, 5 cases), and mpox affected group level 3 (Kenya, 4 cases; Egypt, 3 cases).

All analyses were conducted via R version 4.4.1. A two-sided p-value of less than 0.05 was considered statistically significant.

Role of the funding source

The funder had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had access to all the data in the study and had final responsibility for the decision to submit the manuscript for publication.

Results

The response rates varied from 52.5% to 60.6% across the six countries (Table S4). Table 1 presents the baseline characteristics of the participants. Among the 1832 participants (38.0 ± 2.1 years), more than half had attained a tertiary education or higher (61.7%).

The weighted rates of mpox vaccination hesitancy among the six countries ranged from 21.9% (95% CI 17.5–26.9) to 47.1% (95% CI 41.5–52.8) for themselves and from 23.2% (95% CI 18.8–28.4) to 52.1% (95% CI 46.4–57.7) for children (both $p < 0.0001$) (Table 1). Overall, the weighted rate of mpox vaccination hesitancy among participants regarding themselves was 28.7% (95% CI 21.1–37.8), and the rate for children was 33.8% (95% CI 21.9–48.3). Participants with lower educational levels, those who were unemployed, single, had a lower household income level, lived without children, practiced safe sexual behavior, were uninfected with the MPXV, and had no children exhibited higher rates of mpox vaccination hesitancy for both themselves and for children (all $p < 0.05$). Additionally, older participants, those with more chronic diseases, and individuals who

Characteristics	n (%)	Vaccination hesitancy for themselves (n, weighted rate and its 95% CI)	p value	Vaccination hesitancy for children (n, weighted rate and its 95% CI)	p value
Overall	1823	599, 28.7 (21.1–37.8)		711, 33.8 (21.9–48.3)	
Country			<0.0001		<0.0001
Egypt	302 (16.57)	66, 21.9 (17.5–26.9)		103, 34.1 (29.0–39.7)	
Morocco	303 (16.62)	143, 47.1 (41.5–52.8)		158, 52.1 (46.4–57.7)	
Kenya	307 (16.84)	105, 34.0 (28.9–39.5)		102, 33.3 (28.2–38.8)	
South Africa	304 (16.67)	99, 32.5 (27.5–38.0)		141, 46.2 (40.6–51.8)	
Uganda	305 (16.73)	113, 37.1 (31.8–42.7)		137, 44.9 (39.3–50.5)	
Nigeria	302 (16.57)	73, 24.2 (19.6–29.4)		70, 23.2 (18.8–28.4)	
Age group (years)			0.259		0.004
18~44	1267 (69.5)	396, 27.3 (20.7–35.1)		422, 28.8 (18.6–41.8)	
45~64	425 (23.3)	159, 33.0 (21.1–47.6)		199, 40.9 (27.4–56.0)	
65 and above	131 (7.2)	44, 29.0 (16.0–46.6)		90, 62.5 (33.3–84.8)	
Gender			0.069		0.168
Male	888 (48.7)	271, 26.9 (19.8–35.5)		326, 31.8 (18.7–48.5)	
Female	935 (51.3)	328, 30.4 (22.0–40.5)		385, 35.8 (24.6–48.8)	
Educational level			0.012		0.036
Secondary education and below	316 (17.3)	110, 35.2 (26.7–44.8)		161, 50.0 (31.0–69.1)	
Pre-university course	383 (21.0)	156, 39.4 (32.6–46.7)		165, 39.9 (24.6–57.6)	
Tertiary education	1124 (61.7)	333, 24.8 (17.7–33.7)		385, 29.2 (19.3–41.5)	
Employment			0.001		0.004
Employed	938 (51.5)	260, 22.9 (15.3–32.9)		298, 27.5 (19.6–37.1)	
Unemployed	254 (13.9)	111, 39.6 (26.2–54.8)		147, 54.8 (34.9–73.2)	
Others	631 (34.6)	228, 34.6 (30.0–39.5)		266, 37.4 (23.9–53.2)	
Marital status			0.024		0.002
Single/others	749 (41.1)	292, 34.3 (24.7–45.4)		357, 44.6 (32.8–57.1)	
Married	1074 (58.9)	307, 25.3 (18.7–33.3)		354, 27.3 (15.5–43.3)	
Income level			0.002		0.001
Low	305 (16.7)	131, 41.0 (29.2–54.0)		156, 46.3 (28.5–65.1)	
Average	1187 (65.1)	400, 30.1 (22.6–38.8)		469, 35.2 (22.8–49.9)	
High	331 (18.2)	68, 17.6 (11.9–25.4)		86, 22.7 (16.6–30.2)	
Living with children			0.019		<0.001
No	688 (37.7)	261, 37.2 (32.5–42.1)		397, 53.8 (40.3–66.8)	
Yes	1135 (62.3)	338, 24.2 (15.6–35.6)		314, 23.2 (14.4–35.2)	
Number of chronic diseases			0.570		<0.001
0	1205 (66.1)	406, 29.5 (21.7–38.6)		450, 32.7 (21.9–45.8)	
1	440 (24.1)	137, 27.4 (20.2–36.0)		170, 32.8 (20.7–47.6)	
2 or above	178 (9.8)	56, 26.9 (14.5–44.5)		91, 45.1 (29.6–61.5)	
Self-assessed health status			0.057		0.001
Poor	111 (6.1)	53, 43.3 (26.7–61.5)		76, 63.9 (40.7–82.0)	
General	366 (20.1)	123, 30.0 (18.4–44.8)		182, 46.4 (28.6–65.1)	
Good	1346 (73.8)	423, 27.7 (21.5–34.7)		453, 29.7 (21.4–39.5)	
Sexual orientation			0.1		0.099
Heterosexual	1245 (68.3)	389, 27.1 (19.1–36.8)		488, 34.5 (23.7–47.2)	
Bisexual	194 (10.6)	60, 25.7 (15.7–39.2)		62, 24.9 (13.5–41.3)	
Others	384 (21.1)	150, 35.8 (25.8–47.2)		161, 37.1 (20.7–57.1)	
Risky sexual behavior			0.031		0.003
No	1301 (71.4)	459, 31.7 (23.8–40.8)		569, 38.6 (26.8–51.9)	
Yes	522 (28.6)	140, 21.8 (13.5–33.2)		142, 22.8 (12.7–37.6)	
MPXV infection status			<0.001		0.001
No	1659 (91.0)	581, 31.7 (24.8–39.4)		669, 35.6 (23.5–49.8)	
Yes	164 (9.0)	18, 7.8 (4.0–14.9)		42, 21.7 (15.1–30.2)	

(Table 1 continues on next page)

Characteristics	n (%)	Vaccination hesitancy for themselves (n, weighted rate and its 95% CI)	p value	Vaccination hesitancy for children (n, weighted rate and its 95% CI)	p value
(Continued from previous page)					
MPXV infection status in children			0.041		<0.001
No children	370 (20.3)	129, 33.0 (27.9–38.6)		204, 50.7 (30.5–70.6)	
Infection	104 (5.7)	19, 15.2 (8.2–26.5)		15, 13.1 (5.4–28.7)	
No infection	1349 (74.0)	451, 29.0 (20.3–39.5)		492, 31.6 (21.3–44.0)	
Mpox-related knowledge			0.169		0.429
Low	518 (28.4)	218, 36.8 (21.7–55.0)		224, 38.2 (25.6–52.7)	
Medium	786 (43.1)	228, 25.5 (19.2–32.9)		313, 33.1 (17.8–53.1)	
High	519 (28.5)	153, 25.9 (16.3–38.6)		174, 30.7 (20.8–42.7)	
Mpox vaccination			0.001		0.05
No	1718 (94.2)	587, 30.4 (23.1–38.9)		688, 35.2 (23.4–49.1)	
Yes	105 (5.8)	12, 10.2 (5.9–17.1)		23, 18.9 (8.1–38.0)	
Worries about stigma			0.256		0.689
Low	829 (45.5)	264, 28.3 (20.8–37.3)		336, 34.9 (22.6–49.5)	
Medium	496 (27.2)	175, 30.9 (21.9–41.6)		201, 34.2 (18.4–54.6)	
High	498 (27.3)	160, 27.2 (19.3–36.7)		174, 31.7 (23.3–41.6)	
Vaccination readiness			0.001		<0.001
Low	893 (49.0)	393, 39.4 (27.8–52.3)		525, 54.0 (42.7–65.0)	
High	930 (51.0)	206, 19.8 (15.3–25.2)		186, 16.9 (11.1–24.9)	

95% CI, 95% confidence interval; MPXV, monkeypox virus.

Table 1: **Population characteristics by mpox vaccination hesitancy for themselves and children in the African region.**

reported a lower self-assessed health status reported higher rates of mpox vaccination hesitancy for children (all $p < 0.05$) but not for themselves (Table 1).

The pooled weighted rates of mpox vaccination hesitancy among participants for themselves (32.7%, 95% CI 25.4–40.0, I^2 = 91.5%, $p < 0.0001$) and for children (38.9%, 95% CI 30.2–47.6, I^2 = 93.7%, $p < 0.0001$) were both higher than 30% (Table S5). The weighted rates of mpox vaccination hesitancy for themselves and for children among participants who had never been vaccinated against other diseases were higher than those with immunisation coverage for other vaccines across the six countries (all $p < 0.05$). After adjusting for covariates, the absence of immunisation coverage for other vaccines independently increased the risk of mpox vaccination hesitancy for themselves and for children, with a pooled OR of 2.66 (95% CI 1.67–4.26, I^2 = 25.8%, p = 0.241) and a pooled OR of 2.16 (95% CI 1.42–3.30, I^2 = 0%, p = 0.471), respectively. The pooled results of the interactions revealed that there were no significant multiplicative and additive interactions between immunisation coverage for other vaccines and vaccination readiness (Table 2). The pooled mediation proportions of vaccination readiness for the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy were 15.85% (95% CI 0.64–31.06, I^2 = 60.9%, p = 0.703) and 52.53% (95% CI 20.93–84.14, I^2 = 0%, p = 0.988) for themselves and for children, respectively (Table 2). Table S6 illustrates the joint relationships between immunisation coverage for other vaccines and vaccination readiness with the risk of mpox vaccination hesitancy for themselves and for children across six countries. The pooled weighted rates of mpox vaccination hesitancy for themselves (62.7%, 95% CI 44.7–80.7, I^2 = 82.8%, $p < 0.0001$) and for children (76.3%, 95% CI 66.9–85.7, I^2 = 40.6%, p = 0.135) were both highest among individuals with low vaccination readiness and no history of other vaccinations. Compared with the reference group (high vaccination readiness and a history of other vaccinations), populations that reported low vaccination readiness and no history of other vaccinations exhibited the highest risk of mpox vaccination hesitancy for themselves (pooled OR 7.83, 95% CI 3.28–18.70, I^2 = 63.2%, p = 0.018) and for children (pooled OR 12.55, 95% CI 7.38–21.33, I^2 = 0%, p = 0.585). However, populations that reported high vaccination readiness and no history of other vaccinations demonstrated a 2.28-fold (95% CI 1.05–4.94, I^2 = 0%, p = 0.608) higher risk of mpox vaccination hesitancy for themselves but not for children. Additionally, populations that reported low vaccination readiness and a history of other vaccinations had a higher risk of mpox vaccination hesitancy, both for themselves (pooled OR 2.69, 95% CI 1.70–4.26, I^2 = 66.7%, p = 0.01) and for children (pooled OR 4.97, 95% CI 3.66–6.74, I^2 = 19.6%, p = 0.286).

At the overall level, the weighted rates of mpox vaccination hesitancy for themselves and for children

	Multiplicative interaction, OR (95% CI)	Additive interaction, relative excess risk due to interaction (95% CI)	Mediation proportion, % (95% CI), p value
Mpox vaccination hesitancy for themselves			
Egypt	1.54 (0.12–19.89)	−0.18 (−3.27 to 0.99)	41.66 (−920.90 to 1499.00), 0.780
Morocco	0.23 (0.01–6.31)	−0.51 (−18.11 to 7.33)	84.39 (37.87–242.00), 0.020
Kenya	0.16 (0.01–2.06)	29.24 (−11.82 to 61.11)	11.30 (−2.42 to 43.00), 0.120
South Africa	0.63 (0.08–4.82)	−0.46 (−4.01 to 1.58)	77.66 (36.36–270.00), <0.0001
Uganda	0.06 (0.01–0.78)	84.41 (−4.05 to 155.47)	14.73 (2.42–45.00), 0.040
Nigeria	7.66 (1.35–43.57)	0.03 (−2.09 to 0.68)	33.69 (−512.07 to 207.00), 0.420
Random-effects model	0.60 (0.13–2.74)	−0.07 (−1.68 to 1.55)	15.85 (0.64–31.06)
Heterogeneity	I^2 = 60.9%, p = 0.025	I^2 = 27.6%, p = 0.228	I^2 = 60.9%, p = 0.703
Mpox vaccination hesitancy for children			
Egypt	3.98 (0.48–33.23)	−0.73 (−4.38 to 0.47)	75.17 (32.34–284.00), 0.020
Morocco	0.66 (0.02–24.44)	−5.30 (−85.90 to 4.68)	54.91 (28.91–136.00), 0.020
Kenya	2.19 (0.23–20.84)	−1.72 (−8.90 to 0.43)	43.47 (10.96–108.00), <0.0001
South Africa	0.10 (0.01–1.54)	6.86 (−3.98 to 26.69)	63.83 (25.70–203.00), 0.020
Uganda[a]	0.00 (0.00–0.00)	13709024.14 (10230963.13–18369459.96)	59.26 (−3398.62 to 1362.00), 0.420
Nigeria	0.14 (0.01–1.88)	2.35 (−9.00 to 8.73)	56.65 (−25.42 to 302.00), 0.060
Random-effects model	0.70 (0.15–3.28)	−0.63 (−2.70 to 1.44)	52.53 (20.93–84.14)
Heterogeneity	I^2 = 42.3%, p = 0.140	I^2 = 0%, p = 0.808	I^2 = 0%, p = 0.988

Notes: All the models were adjusted for age, gender, educational level, employment status, marital status, household income level, living with children, number of chronic diseases, self-assessed health status, sexual orientation, risky sexual behavior, monkeypox virus (MPXV) infection status, MPXV infection status in children, mpox-related knowledge, mpox vaccination, worries about stigma, and vaccination readiness. [a]Due to the wide 95% confidence interval (95% CI), meta-analysis did not include these three estimates of this country. Odds ratio (OR) for the product term between the immunisation coverage for other vaccines (no vs yes) and vaccination readiness (high vs low) was used to evaluate multiplicative interaction and its 95% CI which did not include 1 meant a statistically significant multiplicative interaction. The relative excess risk due to interaction (RERI) between the immunisation coverage for other vaccinations (no vs yes) and vaccination readiness (high vs low) was used to evaluate additive interaction. The 95% CI of RERI were more than zero, which meant that the combined effect is synergistic, if less than zero, there is antagonism.[27,29] 95% CI, 95% confidence interval; MPXV, monkeypox virus; OR, odds ratio.

Table 2: **The interactions and mediations of immunisation coverage for other vaccines and vaccination readiness with the risk of mpox vaccination hesitancy for themselves and children across six countries.**

among participants who had never been vaccinated for other vaccines were also significantly higher than those with immunisation coverage for other vaccines (both p < 0.001) (Table S7). After adjusting for covariates, participants who had never been vaccinated for other vaccines were found to have a 1.65-fold (95% CI 1.35–2.02) higher risk of mpox vaccination hesitancy for themselves, and a 1.74-fold (95% CI 1.39–2.18) higher risk of mpox vaccination hesitancy for children than those with immunisation coverage for other vaccines. In subgroup analyses (Tables S8–S9), the negative impact of not being vaccinated with other vaccines on mpox vaccination hesitancy for themselves was more pronounced among females, individuals with a low household income level, and those practicing safe sexual behavior (all p for interactions<0.05) (Fig. 1 and Table S8). The results of the interactions (Table S7) and mediation proportions (Figure S1) were relatively stable at the overall level. The were no significant mediating effects of mpox-related knowledge (Figure S2) and worries about stigma (Figure S3) on the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy. Fig. 2 illustrates the stable joint relationships between immunisation coverage for other vaccines and vaccination readiness with the risk of mpox vaccination hesitancy for themselves and for children at the overall level. The weighted rates of mpox vaccination hesitancy for themselves (49.2%, 95% CI 28.3–70.5) and for children (70.4%, 95% CI 61.2–78.2) were both highest among those with low vaccination readiness and no history of other vaccinations (both p < 0.0001). Compared with the reference group (high vaccination readiness and a history of other vaccinations), populations that reported low vaccination readiness and no history of other vaccinations still exhibited the highest risk of mpox vaccination hesitancy for themselves (OR 3.17, 95% CI 1.71–5.88) and for children (OR 10.47, 95% CI 8.41–13.04). In sensitivity analyses, after considering mpox vaccination status into the immunisation coverage, participants who had never been vaccinated exhibited a 1.93-fold (95% CI 1.70–2.21) increased risk of mpox vaccination hesitancy for themselves and a 1.61-fold (95% CI 1.16–2.24) increased risk of mpox vaccination hesitancy for children, compared with those with immunisation coverage (Table S10). The negative impacts of no immunisation coverage of the influenza vaccine were more pronounced than that of the COVID-19 vaccine, while immunisation coverage of the HPV vaccine and mpox vaccine did not influence mpox vaccination hesitancy. The joint relationships of

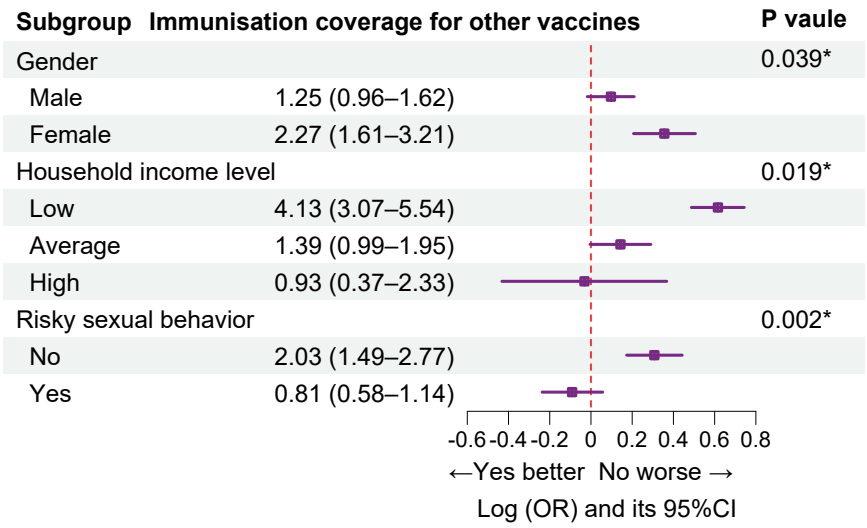

Fig. 1: **Subgroup analysis of the relationships between immunisation coverage for other vaccines and mpox vaccination hesitancy for themselves at the overall level**. All models were adjusted for age, gender, educational level, employment status, marital status, household income level, living with children, number of chronic diseases, self-assessed health status, sexual orientation, risky sexual behavior, monkeypox virus (MPXV) infection status, MPXV infection status in children, mpox-related knowledge, mpox vaccination, worries about stigma, and vaccination readiness. 95% CI, 95% confidence interval; MPXV, monkeypox virus; OR, odds ratio.

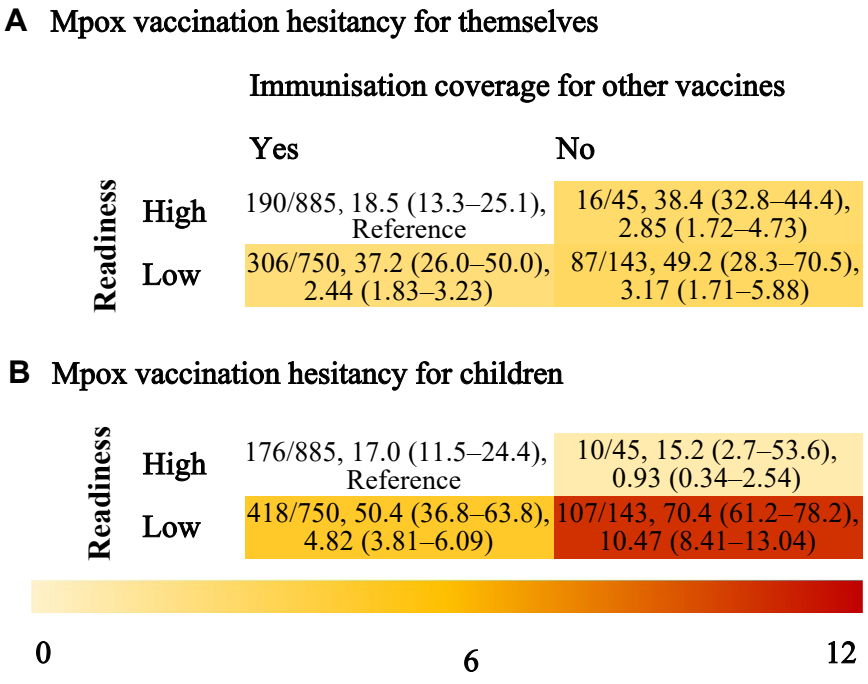

Fig. 2: **Joint relationships of the immunisation coverage for other vaccines and vaccination readiness with the risk of mpox vaccination hesitancy at the overall level**. A. Mpox vaccination hesitancy for themselves. B. Mpox vaccination hesitancy for children. Each cell represents the number of participants who reported hesitancy toward mpox vaccination, as well as the number of participants who reported each combination of immunisation coverage for other vaccines and vaccination readiness, followed by the weighted rate of mpox vaccination hesitancy and its 95% confidence interval (95% CI) and the odds ratio and its 95% CI. Both p values for Chi-square test were <0.001. All the models were adjusted for age, gender, educational level, employment, marital status, household income level, living with children, number of chronic diseases, self-assessed health status, sexual orientation, risky sexual behavior, monkeypox virus (MPXV) infection status, MPXV infection status in children, mpox-related knowledge, mpox vaccination, worries about stigma, and vaccination readiness. 95% CI, 95% confidence interval; MPXV, monkeypox virus.

the immunisation coverage for any vaccine and vaccination readiness with the risk of mpox vaccination hesitancy, as well as the mediating results, remained stable (Table S11, Figure S4). The results adjusted the epidemic level in the regression models were stable (Tables S12–S13). Compared with the other groups, the participants who had never been vaccinated in group level 1 (Nigeria and South Africa) exhibited the smallest odds ratio (OR 1.70, 95% CI 1.46–1.98) of mpox vaccination hesitancy for themselves (p for interaction <0.05) (Table S14).

Discussion

To the best of our knowledge, this multinational study offers insights into mpox vaccination hesitancy for themselves and children, as well as its relationship with prior vaccination experiences in the African region. The pooled weighted rates of mpox vaccination hesitancy were 32.7% for themselves and 38.9% for children. Individuals who had never received other vaccines demonstrated a higher risk of mpox vaccination hesitancy for both themselves and children. Fortunately, increased vaccination readiness could mitigate the negative impact of a lack of vaccination experience on mpox vaccination hesitancy.

As of October 6, 2024, a total of 9939 laboratory-confirmed cases, including 55 deaths, have been reported to the WHO.[5] Among these cases, more than 75% (7535/9939, with 32 deaths) originated from the African region.[5] To prevent a mpox epidemic and reduce mortality among children, the WHO approved an application for emergency authorisation for the use of MVA-BN on September 13, 2024.[6] However, vaccination hesitancy continues to impede the promotion of vaccination programs. In 2023, Sulaiman et al. reported that, compared with other regions, the African region had the lowest mpox vaccine acceptance rate of 41.9%.[9] In our study, we reported that the rate of mpox vaccination hesitancy was 32.7%, which was lower than 58.1%.[9] People may be increasingly willing to get vaccinated because of concerns about the heightened risk of infection stemming from the recent mpox epidemic. No studies have reported the rate of mpox vaccination hesitancy for children in the African region. However, children are the most affected population in this area due to the high mortality rate.[7,8] Promoting childhood vaccination is a key concern in the mpox vaccination program. Our findings indicate that the rate of mpox vaccination hesitancy for children is more than one in three, which is slightly higher than that of the general population. These findings suggest that additional efforts are necessary to promote mpox vaccination in children.

Previous experiences with vaccinations have influenced the acceptance of vaccines for other infectious diseases, including the current epidemic of mpox. Some studies have reported a correlation between COVID-19 vaccination status or influenza vaccination status and mpox vaccine acceptance in Japan, the USA, and other countries.[10,12,32,33] The WHO reported that, in 2023, there were 14.5 million children globally who missed any vaccinations-so-called zero-dose children, especially in African countries.[34] Therefore, investigating the relationship between immunisation coverage for other vaccines and mpox vaccination hesitancy in the African region is essential to provide evidence for future studies, such as modelling studies. Our findings indicate that individuals who have never been vaccinated against other diseases are at a higher risk of mpox vaccination hesitancy for themselves and for children. This result serves as a significant warning, as immunisation coverage in the African region is lower than other regions, suggesting that there may be substantial obstacles to implementing mpox vaccination in Africa, even if the vaccine is available. Furthermore, we found that in countries with a higher epidemic level (Nigeria and South Africa), the harmful effect of low immunisation coverage was lower than that in countries with lower epidemic levels. This result suggests that in low-epidemic areas, more work should be done earlier to reduce the impact of low immunisation coverage on mpox vaccination hesitation to avoid worsening the epidemic. How can we mitigate this risk? Our findings further suggest that enhancing vaccination readiness could alleviate this risk associated with low immunisation coverage. The pooled mediation proportion of vaccination readiness for mpox vaccination hesitancy was nearly 16% for themselves and 50% for children. Therefore, in addition to addressing critical issues such as the cost of the vaccine and its availability in the most affected regions of Africa,[8] other factors, including health education in vaccine programs, should be strengthened in populations with low immunisation coverage to promote mpox vaccine uptake.

Notably, low immunisation coverage cannot be addressed solely at the individual public level by improving vaccine readiness and reducing vaccination hesitation. The *Immunization Agenda 2030* highlights that factors such as subnational inequity, cross-border population movements, demographic shifts, climate change, natural disasters, conflict, political instability, outbreaks, and vaccine supply issues all influence immunisation coverage.[16] Furthermore, the COVID-19 pandemic in 2020 and 2021 resulted in setbacks across multiple immunisation indicators due to significant disruptions in supply chains and essential service delivery, overwhelmed health systems, and burned-out health workers.[18] Globally, recovery has been least pronounced in the African region.[18] In this region, the number of zero-dose children rose from 7.64 million in 2021 to 7.78 million in 2022—a 25% increase since the baseline year of 2019.[18] Challenges to immunisation coverage in Africa stem from various levels: at the health

system level (limited human resources and inadequate infrastructure), at the medical worker/caretaker level (lack of knowledge about immunisation, distrust in vaccines and immunisation programs, financial deprivation, etc.), and other factors (migration and language barrier).[35] Consequently, if immunisation coverage for multiple antigens continues to fall short of the recommended benchmarks for herd immunity across countries, frequent outbreaks of vaccine-preventable diseases will lead to increased morbidity and mortality for both individual countries and the entire African region.[16,18,36] Addressing low immunisation coverage in Africa requires a multifaceted strategy that includes raising public awareness, improving infrastructure, optimising vaccine supply chain management, and strengthening international cooperation and support. Among these, collaborative investments in research and development and equitable access to new vaccines are the most critical components of the solution.[16] The WHO has sought to cultivate local expertise and enable African manufacturers to produce vaccines locally, thereby promoting self-reliance and resilience against health emergencies. At the individual level, our results indicate that under conditions of low immunisation coverage, the risk of mpox vaccination hesitancy increases, leading to a further decline in immunisation coverage. However, enhancing the population's vaccine readiness presents an opportunity to break this vicious cycle.

In our study, we found that socioeconomic and sexual factors influenced hesitancy toward mpox vaccination. Populations with lower educational levels, those who were unemployed, unmarried individuals, those with lower household income levels, and individuals without children all exhibited higher rates of vaccination hesitancy. Braimah et al.[14] similarly found that unmarried individuals in Ghana were more likely to refuse the mpox vaccine. However, this study reported that populations with lower incomes and those who were unemployed were more likely to accept vaccination.[14] In fact, the relationship between socioeconomic factors and mpox vaccination hesitancy in the African region is inconsistent. For example, some studies in African countries did not report differences in mpox vaccination hesitancy by marital status,[10,12] educational level,[11,12] and income.[12] The reasons behind these inconsistent results may be influenced by the survey period and the characteristics of the survey population (health workers, students, men who have sex with men, etc.). Populations with higher educational levels and those who are employed may refuse vaccination because they take precautions and perceive a lower risk of infection. However, they may also choose to be vaccinated due to exposure to the virus in certain workplaces, such as laboratories or hospitals.[14] In the future, a combination of quantitative and qualitative exploration of how socioeconomic factors influence behaviors toward vaccination will be beneficial. Additionally, our study found that populations who reported safe sexual behavior exhibited higher rates of hesitancy, which may be attributed to a lower perceived risk of infection.

Our study provides the latest data on mpox vaccination hesitancy in the African region. Specifically, data on mpox vaccination hesitancy for children, particularly in the context of higher mortality rates, is critical for future vaccine resource allocation. For example, this information can help adjust public health strategies by addressing associated factors and planning educational campaigns with targeted messaging for specific populations on the basis of the latest data regarding important demographic characteristics (lower educational levels, unemployment, lower income, etc.). Furthermore, by examining the relationship between mpox vaccination hesitancy and immunisation coverage for other vaccines, this study highlights that need for vaccination programs to involve long-term, continuous, and holistic efforts rather than short-term, intermittent initiatives focused solely on individual diseases. This understanding is crucial for policymakers to grasp the importance of the term "immunisation coverage". In addition, our study assessed the impact of vaccination readiness on the relationship between mpox vaccination hesitancy and immunisation coverage for other vaccines. This finding underscores that in areas with low immunisation coverage, enhancing vaccination readiness, such as building the population's trust in vaccination programs, should be prioritized to reduce the risk of hesitancy.

The strength of this article lies in its multinational scope and its status as the first study to report on mpox vaccination hesitancy for children in the African region following the WHO declaration of a renewed PHEIC on August 14, 2024. The results of this study will be beneficial for enhancing and practically implementing mpox vaccination programs. However, our study has several limitations. First, we relied on self-reported information, which introduced call bias. Additionally, some data, including household income, health status, and worries about stigma, were gathered through self-rating questions. Future research should incorporate more accurate and objective assessments across different cultural contexts. Second, our survey was a commercial web panel survey, which is unlikely to be representative of the general population. In addition, although we attempted to recruit participants via a gender-age stratified design, selection bias remained due to the constraints of the online survey. Most participants had higher educational levels, which may have influenced their willingness to accept the mpox vaccination. As a result, the rate of mpox vaccination hesitancy in our study may be underestimated, as they were more likely to accept the mpox vaccine. In addition, since the response rate ranged from 50% to 60% in our study, the representativeness of the sample may be compromised. We speculate that individuals who chose

to complete the questionnaire might be more attentive to mpox and more willing to receive the mpox vaccine, which may contribute to the underestimated rate of mpox vaccination hesitancy. Finally, we should acknowledge that the mpox epidemic situation in each country may influence attitudes toward vaccination. Therefore, caution is warranted when interpreting the overall results. Nevertheless, we also analyzed the results by country, and these findings were relatively stable across the six countries included in our study. Additionally, while we tried to include all African countries, the platform was only able to investigate the aforementioned six countries. Importantly, these results, including attitudes toward vaccination, mpox infection status, and mpox vaccination, varied to some extent between these countries due to different mpox epidemic levels. Consequently, these findings should be generalised to Africa as a whole with caution.

In conclusion, our findings indicate a significant level of hesitancy toward mpox vaccination in the African region. Individuals who have not previously received other vaccines are at a higher risk of refusing to vaccinate against mpox for themselves and for children. However, high vaccination readiness can help mitigate this risk. This study suggests that regions in Africa with low immunisation coverage should continue to enhance vaccination education and improve vaccination readiness to reduce mpox vaccination hesitancy and promote the mpox vaccination program.

Contributors

JL, MD, JD, ML, WL, and BN conceptualised and designed the study, JL, MD, JD, and WY did data acquisition and data curation, MD did formal analysis, visualization and writing–original draft, JD, ML, WL, BN, and JL did writing-reviewing and editing. MD and JD accessed and verified the data. All the authors have seen and approved the submitted version of this manuscript.

Data sharing statement

Data are obtained according to corresponding author permission.

Declaration of interests

We declare no competing interests.

Acknowledgements

This work was partly supported by the National Natural Science Foundation of China (grant numbers 72122001, 72474005, 72334004). The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report. We appreciate the works in language translations of questionnaire by Dynata.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2024.103047.

References

1 Mukinda VB, Mwema G, Kilundu M, Heymann DL, Khan AS, Esposito JJ. Re-Emergence of human monkeypox in Zaire in 1996. Monkeypox epidemiologic working group. *Lancet*. 1997;349 (9063):1449–1450. https://doi.org/10.1016/s0140-6736(05)63725-7.
2 Rezza G. Emergence of human monkeypox in west Africa. *Lancet Infect Dis*. 2019;19(8):797–799. https://doi.org/10.1016/S1473-3099(19)30281-6.
3 Du M, Sun H, Zhang S, et al. Global epidemiological features of human monkeypox cases and their associations with social-economic level and international travel arrivals: a systematic review and ecological study. *Int J Public Health*. 2023;68:1605426. https://doi.org/10.3389/ijph.2023.1605426.
4 World Health Organization. Second meeting of the international health regulations (2005) (IHR) emergency committee regarding the multi-country outbreak of monkeypox. https://www.who.int/news/item/23-07-2022-second-meeting-of-the-international-health-regulations-(2005)-(ihr)-emergency-committee-regarding-the-multi-country-outbreak-of-monkeypox. Accessed November 20, 2024.
5 World Health Organization. 2022-24 mpox (monkeypox) outbreak: global trends. https://worldhealthorg.shinyapps.io/mpx_global/#1_Overview; 2024. Accessed September 11, and October 6, 2024.
6 World Health Organization. Mpox global strategic preparedness and response plan. https://www.who.int/publications/m/item/mpox-global-strategic-preparedness-and-response-plan. Accessed November 20, 2023.
7 Vakaniaki EH, Kacita C, Kinganda-Lusamaki E, et al. Sustained human outbreak of a new MPXV clade I lineage in eastern Democratic Republic of the Congo. *Nat Med*. 2024;30(10): 2791–2795. https://doi.org/10.1038/s41591-024-03130-3.
8 Du M, Liu M, Niu B, Liu J. The global alarm bell is ringing due to the threat of potential severe cases and deaths caused by clade I of monkeypox virus. *Lancet Infect Dis*. 2024;24(10):e616–e617. https://doi.org/10.1016/S1473-3099(24)00530-9.
9 Sulaiman SK, Isma'il Tsiga-Ahmed F, Musa MS, Makama BT, Sulaiman AK, Abdulaziz TB. Global prevalence and correlates of mpox vaccine acceptance and uptake: a systematic review and meta-analysis. *Commun Med*. 2024;4(1):136. https://doi.org/10.1038/s43856-024-00564-1.
10 Lounis M, Bencherit D, Abdelhadi S. Knowledge and awareness of Algerian healthcare workers about human monkeypox and their attitude toward its vaccination: an online cross-sectional survey. *Vacunas*. 2023;24(2):122–127. https://doi.org/10.1016/j.vacun.2022.11.003.
11 Lounis M, Hamimes A, Dahmani A. Assessment of monkeypox (MPOX) knowledge and vaccination intention among health and life sciences students in Algeria: a cross-sectional study. *Infect Dis Rep*. 2024;16(2):170–180. https://doi.org/10.3390/idr16020013.
12 Ghazy RM, Yazbek S, Gebreal A, et al. Monkeypox vaccine acceptance among Ghanaians: a call for action. *Vaccines*. 2023;11(2):240. https://doi.org/10.3390/vaccines11020240.
13 Braimah JA, Achore M, Dery F, Ayanore MA, Bisung E, Kuuire V. Do self-rated health and previous vaccine uptake influence the willingness to accept MPOX vaccine during a public health emergency of concern? A cross-sectional study. *PLOS Glob Public Health*. 2024;4(8):e0003564. https://doi.org/10.1371/journal.pgph.0003564.
14 Wang L, Gao GF. More mpox data are needed to better respond to the public health emergency of international concern. *Lancet*. 2024;404(10461):1399–1400. https://doi.org/10.1016/S0140-6736(24)02070-1.
15 World Health Organization. WHO/UNICEF estimates of national immunization coverage. https://www.who.int/teams/immunization-vaccines-and-biologicals/immunization-analysis-and-insights/global-monitoring/immunization-coverage/who-unicef-estimates-of-national-immunization-coverage; 2024. Accessed November 20, 2024.
16 World Health Organization. Immunization Agenda 2030. https://www.who.int/docs/default-source/immunization/strategy/ia2030/ia2030-document-en.pdf. Accessed November 20, 2024.
17 Liu S, Durantini MR, Calabrese C, Sanchez F, Albarracin D. A systematic review and meta-analysis of strategies to promote vaccination uptake. *Nat Hum Behav*. 2024;8(9):1689–1705. https://doi.org/10.1038/s41562-024-01940-6.
18 World Health Organization. Progress towards global immunization goals and implementation of the Immunization Agenda 2030. https://apps.who.int/gb/ebwha/pdf_files/EB154/B154_9-en.pdf. Accessed November 20, 2024.
19 Geiger M, Rees F, Lilleholt L, et al. Measuring the 7Cs of vaccination readiness. *Eur J Psychol Assess*. 2022;38(4):261–269. https://doi.org/10.1027/1015-5759/a000663.
20 Oeser P, Grune J, Dedow J, Herrmann WJ. The 5 C model and Mpox vaccination behavior in Germany: a cross-sectional survey. *BMC Public Health*. 2024;24(1):1039. https://doi.org/10.1186/s12889-024-18489-8.
21 Ghazy RM, Okeh DU, Sallam M, et al. Psychological antecedents of healthcare workers towards monkeypox vaccination in Nigeria.

Vaccines. 2022;10(12):2151. https://doi.org/10.3390/vaccines10122151.
22 L Lazarus JV, Ratzan SC, Palayew A, et al. A global survey of potential acceptance of a COVID-19 vaccine. *Nat Med*. 2021;27(2):225–228. https://doi.org/10.1038/s41591-020-1124-9.
23 United Nations, Department of Economic and Social Affairs, Population Division. Probabilistic population projections based on the World population Prospects 2022. http://population.un.org/wpp/; 2022. Accessed September 12, 2024.
24 Zheng M, Qin C, Qian X, et al. Knowledge and vaccination acceptance toward the human monkeypox among men who have sex with men in China. *Front Public Health*. 2022;10:997637. https://doi.org/10.3389/fpubh.2022.997637.
25 Du M, Zheng M, Liu J, et al. The prevalence of mpox and its association with sexual behavior among Chinese men who have sex with men in early August 2023. *J Med Virol*. 2023;95(12):e29320. https://doi.org/10.1002/jmv.29320.
26 Rees F, Geiger M, Lilleholt L, et al. Measuring parents' readiness to vaccinate themselves and their children against COVID-19. *Vaccine*. 2022;40(28):3825–3834. https://doi.org/10.1016/j.vaccine.2022.04.091.
27 Zhang YB, Chen C, Pan XF, et al. Associations of healthy lifestyle and socioeconomic status with mortality and incident cardiovascular disease: two prospective cohort studies. *BMJ*. 2021;373:n604. https://doi.org/10.1136/bmj.n604.
28 Du M, Zhu L, Liu M, Liu J. Mutual associations of healthy behaviours and socioeconomic status with respiratory diseases mortality: a large prospective cohort study. *Nutrients*. 2023;15(8):1872. https://doi.org/10.3390/nu15081872.
29 Hosmer DW, Lemeshow S. Confidence interval estimation of interaction. *Epidemiology*. 1992;3(5):452–456. https://doi.org/10.1097/00001648-199209000-00012.
30 Tingley D, Yamamoto T, Hirose K, Keele L, Imai K. Mediation: R package for causal mediation analysis. *J Stat Soft*. 2014;59(5):1–38.
31 DerSimonian R, Laird N. Meta-analysis in clinical trials revisited. *Contemp Clin Trials*. 2015;45(Pt A):139–145. https://doi.org/10.1016/j.cct.2015.09.002.
32 Hori D, Kaneda Y, Ozaki A, Tabuchi T. Sexual orientation was associated with intention to be vaccinated with a smallpox vaccine against mpox: a cross-sectional preliminary survey in Japan. *Vaccine*. 2023;41(27):3954–3959. https://doi.org/10.1016/j.vaccine.2023.05.050.
33 Bates BR, Grijalva MJ. Knowledge, attitudes, and practices towards monkeypox during the 2022 outbreak: an online cross-sectional survey among clinicians in Ohio, USA. *J Infect Public Health*. 2022;15(12):1459–1465. https://doi.org/10.1016/j.jiph.2022.11.004.
34 World Health Organization. Immunization coverage. https://www.who.int/news-room/fact-sheets/detail/immunization-coverage. Accessed November 20, 2024.
35 Bangura JB, Xiao S, Qiu D, Ouyang F, Chen L. Barriers to childhood immunization in sub-Saharan Africa: a systematic review. *BMC Public Health*. 2020;20(1):1108. https://doi.org/10.1186/s12889-020-09169-4.
36 Adamu AA, Ndiaye S, Jalo RI, et al. Enhancing vaccine delivery in Africa with implementation science. *Discover Public Health*. 2024;21(1):190. https://doi.org/10.1186/s12982-024-00321-8.