

# Supplementary material

## Study design, setting, and participants

This study was a cross-sectional survey among university students from 23 universities in Beijing, China, assessing their willingness to receive the HPV vaccine. In addition, Beijing has consistently been at the forefront of implementing public health policies and vaccination programs, thus supporting the execution of this study.

The decision to focus on university students as the target population for this study was based on their capacity for independent health decision-making and their considerable influence on peers and younger groups within social networks. Studying the vaccination willingness of university students provides insight into their attitudes toward vaccination and enables assessment of their role as key nodes in spreading health behaviors, particularly among younger populations. Furthermore, although the WHO recommends 9–14 years as the optimal age for HPV vaccination, research involving this age group is challenged by ethical and operational limitations. Therefore, university students were selected as a more feasible group, which guarantees successful implementation of the study and provides valuable data to support future investigation in younger populations.

This study was conducted from January 10 to February 10 of 2025, through a convenience sampling method. The HPV vaccination willingness rate among the students was 30%. Considering a potential 10% rate of invalid responses, the minimum required sample size was calculated to be 3,084 participants. The inclusion criteria were (1) age 16–25 years and (2) provision of informed consent. The exclusion criteria included (1) inability to comprehend the questionnaire, (2) presence of mental illness, and (3) inability to independently decide on vaccination. Data were collected through an online questionnaire. After application of the inclusion and exclusion criteria, a total of 6,244 participants were finally included in the analysis. Immediately after the completion of the cross-sectional survey, a momentary intervention was implemented for all participants to enhance their willingness to receive the HPV vaccine. The same set of questions was administered before and after the intervention, to repeatedly collect data on

participants' knowledge and attitudes toward HPV, and HPV vaccination willingness (**Figure S1**).

## Measures and intervention materials

The questionnaires used for the cross-sectional survey and momentary intervention were designed on the basis of the BeSD framework and comprised 5 sections: (1) demographic characteristics, including sex, age, parental educational background, place of origin, and monthly living expenses; (2) self-reported sexual history; (3) history of HPV vaccination; (4) knowledge and attitudes regarding HPV and the HPV vaccine; and (5) willingness to receive the HPV vaccine.

Knowledge regarding HPV and the HPV vaccine was assessed with 5 questions, and attitudes were evaluated with 6 questions before and after the momentary intervention. Correct answers or affirmative responses were assigned 1 point, whereas incorrect answers or responses of “I don't know” were assigned 0 points. The difference in knowledge scores before and after the intervention was calculated cumulatively. Attitudes were scored on a 3- or 5-point scale, with scores ranging from 1 to 5 (or 3), and higher scores indicating increasingly negative attitudes.

## Intervention material

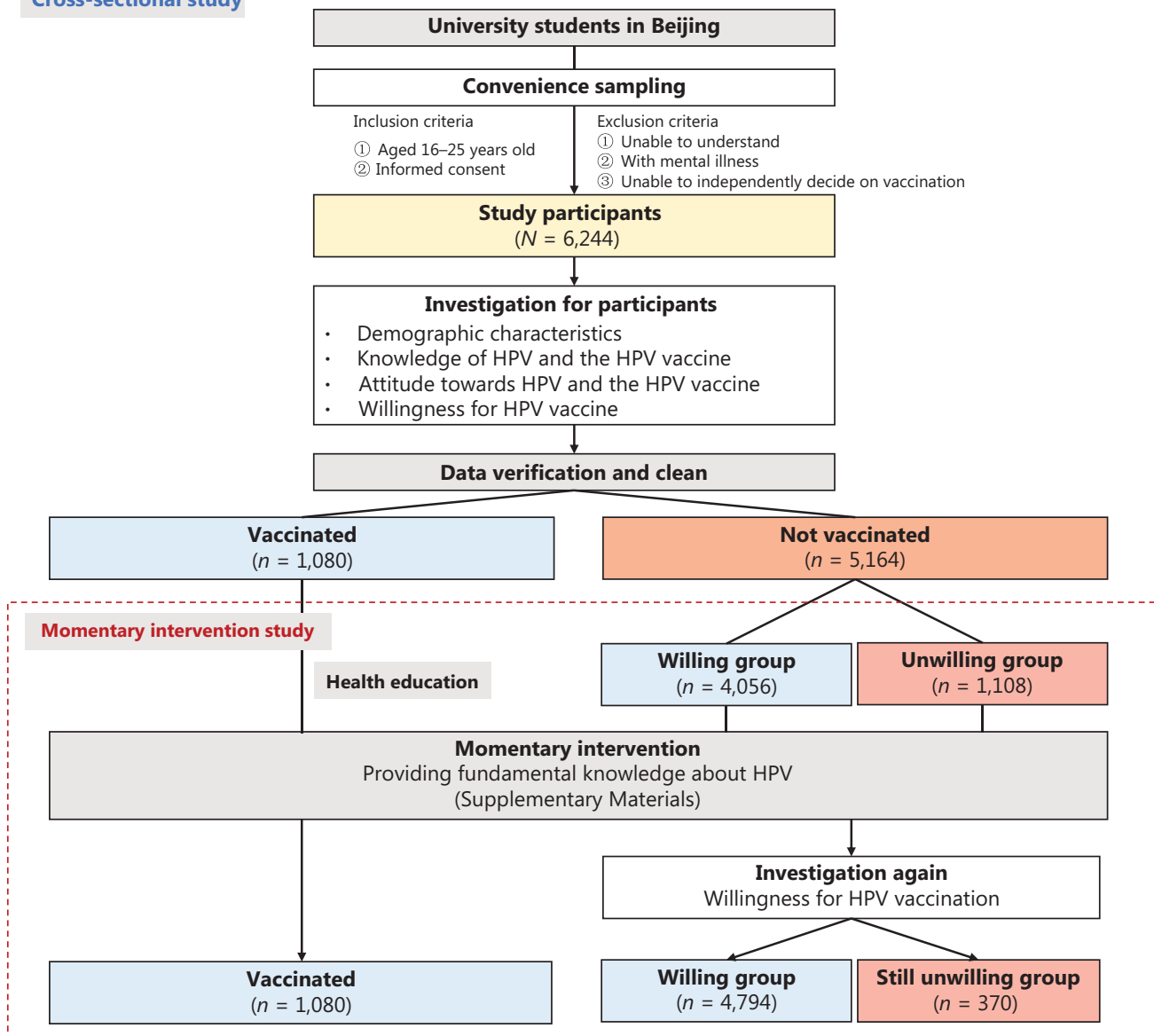
After group discussions and expert consultations, a 5-min intervention video was produced, incorporating materials from the Chinese Center for Disease Control and Prevention (CDC) and WHO on HPV and cervical cancer. The video focused primarily on providing fundamental knowledge regarding HPV, including the risks associated with HPV infection, modes of transmission, methods for preventing HPV infection, an introduction to HPV vaccines, and the benefits of receiving HPV vaccination. The video content underwent 2 rounds of review by experts in the HPV vaccine field, public health communication, and cultural adaptation, to ensure the inclusion of appropriate visuals, language style, and cultural sensitivity. These reviews were aimed at enhancing both the scientific accuracy and the cultural appropriateness of the intervention. In December 2024, 2 rounds of pilot testing were conducted in a total of 40 participants, and the results from these tests were not included in the formal data collection.

## Statistical analysis

Continuous variables are described with means and standard deviations, whereas categorical variables are expressed as frequencies and proportions. Group comparisons of respondent characteristics associated with willingness to receive the HPV vaccine were assessed with the  $\chi^2$  test for categorical variables and the t-test for continuous variables. Pre-post changes in knowledge and attitude variables, measured on the same individuals, were evaluated with the McNemar test for binary outcomes and the Stuart–Maxwell test for multcategory outcomes. Univariate and multivariate logistic regression models were applied to explore the relationships

among individual characteristics, behavioral and social drivers, and HPV vaccination willingness. Variables significantly associated with unwillingness or hesitancy to vaccinate ( $P < 0.05$  in univariate analysis) were included in the multivariate logistic regression model, and odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Logistic regression was also performed to examine changes in vaccination willingness before and after the intervention, and to further analyze the differential effects of the intervention across subgroups. A  $P$ -value of  $<0.05$  was considered statistically significant. A Sankey diagram was constructed to visualize changes in vaccination willingness after the intervention. Statistical analyses and visualizations were performed in R version 4.2.1 (R Foundation, Vienna, Austria).

Cross-sectional study

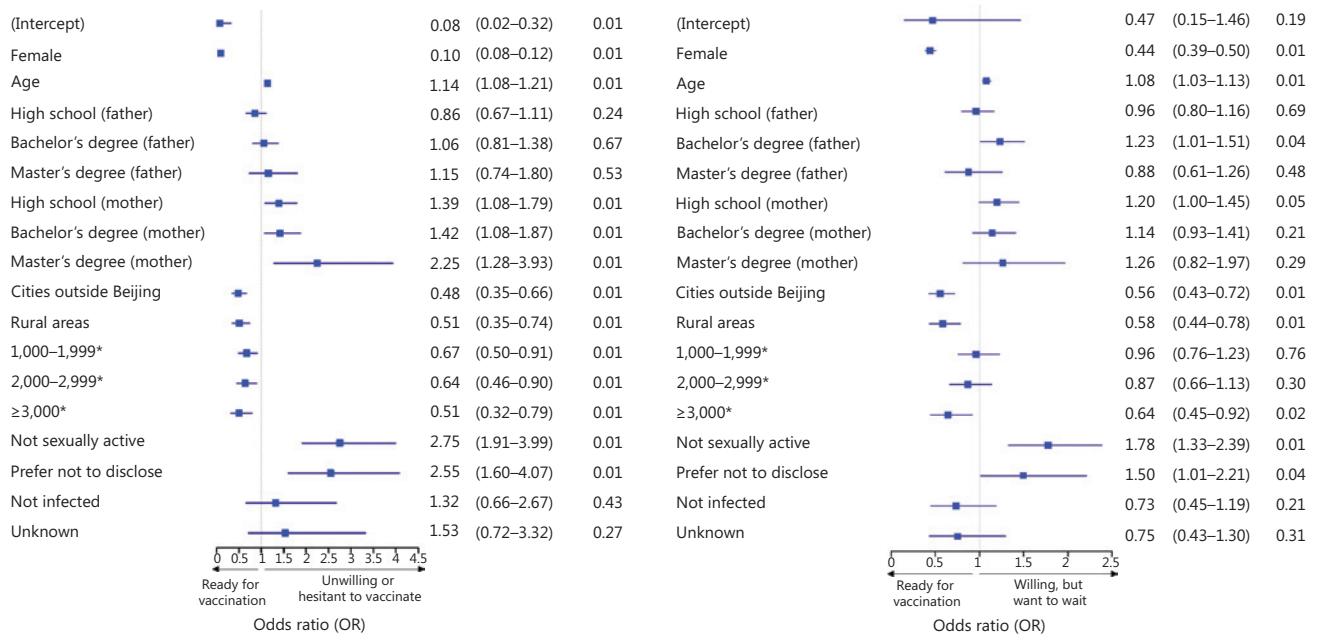


**Figure S1** Flow diagram of study conduct. **Part I: Cross-sectional study.** The study recruited university students from Beijing through convenience sampling ( $n = 6,244$ ). Participants' demographic characteristics, knowledge of HPV and the HPV vaccine, attitudes towards HPV and the HPV vaccine, and willingness to receive the HPV vaccine were assessed. The participants were categorized into 2 groups: those who had been vaccinated ( $n = 1,080$ ) and those who had not ( $n = 5,164$ ). **Part II: Momentary intervention study.** To ensure fairness in access to knowledge, all participants were exposed to a 5-min educational video intervention on HPV. After the intervention, the participants were reassessed on their willingness to receive the HPV vaccine, as well as their knowledge and attitudes. In the unvaccinated group, participants were categorized after the intervention into those willing to vaccinate ( $n = 4,794$ ) and those unwilling to vaccinate ( $n = 370$ ). HPV, human papillomavirus.

**Table S1** HPV vaccine types and satisfaction

Variable	n (%)
Type of vaccine	
Bivalent	159 (14.72)
Quadrivalent	60 (5.56)
Nonavalent	861 (79.72)
Reminder for subsequent HPV doses after the first dose	
Yes	911 (84.35)
No	169 (15.65)
HPV vaccine service satisfaction*	
Mean (SD)	4.44 (0.62)

\*Satisfaction rating (0–5 scale, 5 = very satisfied).



**Figure S2** Forest plot of factors influencing HPV vaccination willingness. Ready for vaccination vs. unwilling or hesitant to vaccinate (A). This panel presents the factors influencing HPV vaccination willingness, by comparing participants who were ready for vaccination with those who were unwilling or hesitant to vaccinate. The analysis included demographic factors (such as age, sex, and parental education level), geographical location (urban vs. rural areas, cities outside Beijing), and sexual activity status. The ORs and 95% CIs for each factor are shown, and statistical significance is indicated by P-values. Ready for vaccination vs. willing but want to wait (B). This panel compares participants who were ready for vaccination with those who were willing but wanted to wait. Similar factors were analyzed, and the results are presented with the associated ORs and CIs. \*Results with statistical significance.

**Table S2** Factors influencing attitudes toward HPV vaccination, on the basis of the BeSD framework

	Ready for vaccination		Willing but want to wait		Unwilling or hesitant to vaccinate	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Thinking and feeling						
Confidence in vaccine importance	0.92 (0.85, 0.99)	0.03	0.97 (0.88, 1.07)	0.54	1.08 (0.95, 1.23)	0.25
Confidence in vaccine benefits	1.14 (1.02, 1.28)	0.02	1.16 (1.00, 1.33)	0.03	1.26 (1.05, 1.51)	0.01
Confidence in vaccine safety	1.07 (0.82, 1.39)	0.62	1.26 (0.94, 1.68)	0.13	2.30 (1.62, 3.29)	< 0.01
Confidence in health workers	0.72 (0.62, 0.85)	< 0.01	1.11 (0.91, 1.34)	0.30	1.18 (0.93, 1.49)	0.19
Social processes						
Health workers' recommendation	1.48 (1.35, 1.62)	< 0.01	1.90 (1.70, 2.13)	< 0.01	1.94 (1.65, 2.30)	< 0.01
Peer norms	1.71 (1.57, 1.86)	< 0.01	2.10 (1.88, 2.35)	< 0.01	2.18 (1.86, 2.58)	< 0.01
Family's attitude	1.12 (0.97, 1.29)	0.11	3.77 (3.20, 4.46)	< 0.01	6.38 (5.20, 7.89)	< 0.01
Practical issues						
Vaccine accessibility	3.67 (3.06, 4.42)	< 0.01	3.95 (3.20, 4.88)	< 0.01	5.22 (3.91, 7.00)	< 0.01
Convenience of vaccination	1.03 (0.85, 1.25)	0.75	1.35 (1.07, 1.71)	0.01	1.67 (1.19, 2.36)	< 0.01
Self-paid vaccination	1.91 (1.61, 2.28)	< 0.01	1.99 (1.62, 2.45)	< 0.01	1.74 (1.32, 2.29)	< 0.01

\*Reference group: HPV-vaccinated study participants ( $n = 1,086$ ).

**Table S3** Objective factors influencing willingness change before and after intervention\*

	Decline or no change in vaccination willingness	P
Pre-post knowledge score difference	0.86 (0.80, 0.92)	< 0.01
Physician's recommendation		
Yes	Ref	
No	0.98 (0.77, 1.24)	0.88
Peer vaccination status		
Less than half	Ref	
More than half	0.96 (0.68, 1.34)	0.81
Family attitude		
Opposed	Ref	
Neutral	0.49 (0.22, 1.01)	0.06
Supportive	0.32 (0.14, 0.65)	< 0.01
Vaccine accessibility		
High	Ref	
Low	0.97 (0.81, 1.17)	0.78
Vaccination site convenience		
Yes	Ref	
No	1.04 (0.86, 1.25)	0.69
Vaccine price affordability		
Fully affordable	Ref	
Mostly affordable	1.68 (1.13, 2.54)	0.01
Unaffordable	1.79 (1.19, 2.73)	< 0.01

\*Reference group: increased willingness to vaccinate.

**Table S4** Variance inflation factors (VIF) and tolerance values for independent variables in the multivariate logistic regression model

Variable	VIF	Tolerance
2,001–3,000	4.20	0.238
1,001–2,000	4.15	0.241
≥ 3,001	4.06	0.247
Bachelor's degree/associate's degree (mother)	3.11	0.322
Bachelor's degree/associate's degree (father)	3.06	0.327
High school/technical school (mother)	2.15	0.466
High school/technical school (father)	2.07	0.484
Master's degree or above (father)	1.99	0.503
Master's degree or above (mother)	1.58	0.632

Maximum VIF = 4.20. No variable pairs had  $|r| \geq 0.70$ .