



Longitudinal analysis of Covid-19 vaccine hesitancy and its determinants in Poland

Paweł Sowa^{1,A-F}✉, Łukasz Kiszkiel^{2,A-F}*, Maciej Alimowski^{2,A,C,E-F}, Piotr Paweł Laskowski^{2,A-B,E-F}, Łukasz Szczerciński^{3,4,A,F}, Anna Moniuszko-Malinowska^{5,E-F}, Andrzej Szpak^{6,E-F}, Karol Kamiński^{1,7,A-B,E-F}

¹ Department of Population Medicine and Lifestyle Diseases Prevention, Medical University, Białystok, Poland

² Society and Cognition Unit, University of Białystok, Poland

³ Department of Endocrinology, Diabetology and Internal Medicine, Medical University, Białystok, Poland

⁴ Clinical Research Centre, Medical University, Białystok, Poland

⁵ Department of Infectious Diseases and Neuroinfections, Medical University, Białystok, Poland

⁶ Department of Epidemiology and Biostatistics, Institute of Rural Health, Lublin, Poland

⁷ Department of Cardiology, University Hospital, Białystok, Poland

A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation,

D – Writing the article, E – Critical revision of the article, F – Final approval of the article

* Paweł Sowa and Łukasz Kiszkiel contributed equally to this work.

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Abstract

Introduction and Objective. Vaccine hesitancy is dynamic, with longitudinal evidence beyond two waves scarce. The aim of the study is to characterise, across a four-wave Polish panel (2021–2025), how stated vaccination intentions translate into actual vaccination, and to identify modifiable determinants of persistent non-vaccination versus delayed conversion.

Materials and Method. 4,205 wave records from 2,559 unique Polish adults (Rise or Fall [ROF] panel, 2021/2022/2024/2025) were harmonised. The analytical cohort (n=859, ≥2 waves) was classified into five trajectory classes: Baseline vaccinated, Early convert, Late convert, Persistent unvax willing (PuW), and Persistent unvax hesitant (PuH; reference). Predictors were identified by Multinomial logistic regression and discrete-time hazard models.

Results. By 2025, 83.4% of baseline-willing respondents were vaccinated vs. 38.9% of baseline-hesitant – a 44.5-percentage-point gap nearly identical to 2022 (45.7 pp). Persistent non-vaccination tracked higher fear of side-effects (hazard OR=0.63 per point; p<0.001) and conspiracy beliefs (OR=0.79; p<0.001); a Bachelor's degree raised the conversion hazard 2.6-fold (p<0.001). Low fear emerged as a strong predictor of Baseline vaccinated (OR=6.0) and Early convert (OR=3.0). PuW had the highest mean HLS-Q12 (3.04; omnibus p=0.040), with a borderline multinomial association (OR=1.56; p=0.077); HLS-Q12 robustly predicted lower vaccination hazard (OR=0.58; p=0.001).

Conclusions. Vaccine hesitancy in Poland is durable; the willing/hesitant behavioural gap persists. Post-rollout strategy should combine safety-centred dialogue targeting fear of side-effects with structural facilitators for the willing-but-unvaccinated subgroup.

Key words

Poland, longitudinal study, vaccine hesitancy, Covid-19, trajectory typology

INTRODUCTION AND OBJECTIVE

The World Health Organization (WHO) defines vaccine hesitancy as a motivational state of uncertainty or resistance towards vaccination [1, 2]. Conceptual frameworks such as the 5C and 7C models distinguish confidence, complacency, calculation, constraints, collective responsibility, compliance and convenience as antecedents of vaccination decisions [3, 4, 5]. Conspiracy beliefs, mistrust in science and information-environment factors are the most consistently replicated psychological predictors of refusal [6, 7], and sustained trust in the broader public-health system has been a central but unstable correlate of vaccine intent [8].

Poland has documented vaccine hesitancy and lower Covid-19 uptake than the European average: by October 2023, only 60.6% of Poles had received at least one dose vs. 75.6% in Europe [9]. A 2024 Lancet Regional Health Europe analysis

reported that Poland had one of Europe's highest excess-death tolls (+13.7%) over 2020–2023, and found vaccine coverage to be inversely associated with excess mortality [10]. Despite a sustained national communication campaign [11], and despite trust-targeted public communication efforts paralleled across other Central European contexts [12], the post-rollout vaccination gap has not been closed.

Most published evidence on Covid-19 hesitancy is cross-sectional, although hesitancy is dynamic [13, 14]. The 23-country Lazarus surveys documented a 5.2% rise in vaccine willingness in 2021–2022 [15]; the seven-country European panel by Sabat et al. showed hesitancy as the most unstable vaccine intention state (42% of ever-hesitant remained hesitant) [16]. A UK longitudinal study identified low fear of Covid-19 and negative attitudes as predictors of persistent hesitancy [17]. In Poland, Oleksy et al. tracked willingness across four waves around vaccine availability, and found conspiracy mentality and authoritarianism reduced willingness [18]. The original two-wave analysis of the Rise or Fall (ROF) panel [19] identified pre-rollout predictors of hesitancy; the present study extends the ROF panel to

✉ Address for correspondence: Paweł Sowa, Department of Population Medicine and Lifestyle Diseases Prevention, Medical University, Białystok, Poland
E-mail: pawel.sowa@umb.edu.pl

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four years of follow-up and shifts the focus from intention dynamics to behavioural trajectory typology.

The objective was aim of the study is to characterise the variability of Covid-19 vaccine hesitancy across four years of measurement in a Polish national panel, construct an empirical typology of longitudinal trajectories, and identify predictors of class membership and timing of first vaccination.

MATERIALS AND METHOD

Study design and sample. The present analyses draw on four waves of the Rise or Fall (ROF) longitudinal panel of the adult Polish population. Respondents were recruited from opinie.pl, a large Polish internet panel of approximately 100,000 active members, and each wave was stratified by gender, age, place of residence and province, using quotas derived from the Central Statistical Office (*Główny Urząd Statystyczny* – GUS). All waves were administered by computer-assisted web interviewing (CAWI) by IQS Group – a member of the Polish Association of Public Opinion and Marketing Research Firms – OFBOR, operating under ISO 20252 and the Polish Interviewer Quality Control Programme – PKJPA), and a stable respondent identifier linked panellists across waves. The four measurement waves were carried out: March 2021 (N=1,000), April 2022 (N=1,000), 2024 (N=1,093), and early 2025 (N=1,112). 2,559 unique respondents contributed at least one observation; 859 (33.6%) had ≥ 2 waves and constituted the analytical longitudinal cohort; 332 (13.0%) contributed all four waves (balanced panel).

Variable definitions. For participants recruited after the first wave, baseline age, education and place of residence were obtained from the corresponding survey items so that these characteristics were available in every wave; education was classified into three levels (basic vocational or lower; secondary or post-secondary; Bachelor's degree or higher). For the 2025 wave, vaccination status was defined as having received at least one dose, and vaccination attitude was classified as willing versus hesitant. Nineteen respondents with unclear age indication were excluded.

Trajectory classes. Five classes were defined: Baseline vaccinated (vaccinated at 2021), Early convert (vaccinated by 2022 after being unvaccinated in 2021), Late convert (vaccinated by 2024 or 2025, but not earlier), Persistent unvaccinated–willing (never vaccinated, last attitude willing), Persistent unvaccinated–hesitant (never vaccinated, last attitude hesitant). Respondents with <2 waves were excluded from class analyses.

Composite indices. Conspiracy Index (0–6) from ESS-based items recoded to agree=1/other=0 and summed. HLS-Q12 mean (1–4) on the HLS-EU scale where higher = greater self-reported difficulty using health information. Fear of side-effects (1–4, higher = more fear); low-fear binary = {1,2}. Fear of side-effects entered the multinomial model in this binary form and the discrete-time hazard model on its original 1–4 scale.

Statistical analysis. Analyses were conducted in R [20] using tidyverse, haven, nnet, broom and lme4 packages. Omnibus

tests used one-way ANOVA (continuous) or Pearson's χ^2 (categorical); pairwise *post-hoc* used Welch's t-tests / $2 \times 2 \chi^2$ with Bonferroni correction over 10 pairs. Three regression models were fitted: (i) multinomial logistic regression of trajectory class on baseline covariates with PuH as reference; (ii) discrete-time hazard model for first vaccination, with belief and demographic covariates fixed at their baseline (first-wave) values, restricting the risk set at each wave to those still unvaccinated; (iii) cumulative-incidence summaries by baseline attitude.

The study was approved by the Bioethical Committee of the Medical University of Białystok (approval no. APK.002.346.2020); written informed consent was obtained from all participants.

RESULTS

Sample description and panel structure. From a total of 2,559 unique respondents, 1,700 (66.4%) contributed a single wave (predominantly late recruits in 2024 and 2025), 404 (15.8%) two waves, 123 (4.8%) three, and 332 (13.0%) all four. The analytical longitudinal cohort (≥ 2 waves) comprised 859 individuals, larger than the original two-wave ROF retention cohort [19] and with twice the observation window. Within the analytical cohort, Early convert was the most frequent trajectory (n=512, 59.6%), followed by Persistent unvaccinated–willing (PuW, n=132, 15.4%), Persistent unvaccinated–hesitant (PuH, n=107, 12.5%), Baseline vaccinated (n=68, 7.9%) and Late convert (n=40, 4.7%) (Tab. 1).

Demographic differences. Statistically significant class differences were detected for age (omnibus $p<0.001$), age group ($p<0.001$), education ($p<0.001$), place of residence ($p=0.003$), Conspiracy Index ($p<0.001$), Fear of side-effects ($p<0.001$) and HLS-Q12 mean ($p=0.040$). Gender did not differ ($p=0.233$). Baseline vaccinated and Early converts were the oldest classes (means 55.4 and 54.1 years); Late converts and Persistent classes were younger (mean 45.5–47.0 years). Baseline vaccinated had a striking concentration of higher education (63.2% Bachelor's+) compared with 32.8% of Early converts and 14.4–20.6% of the remaining classes. Conspiracy and Fear of side-effects rose monotonically from BV (1.24 and 2.26) through Early/Late convert to the two Persistent classes (2.83–2.93 Conspiracy; 3.32–3.47 Fear), with seven of ten pairwise Fear contrasts surviving Bonferroni correction.

Cumulative vaccination dynamics. Among the 470 respondents willing at the 2021 baseline, cumulative vaccination rose from 78.1% by 2022 to 79.1% by 2024 and 83.4% by 2025 (+5.3 pp over three years). Among the 185 respondents hesitant at baseline, the trajectory was 32.4% $\rightarrow$ 37.3% $\rightarrow$ 38.9% (+6.5 pp). The willing/hesitant gap at the end of follow-up (44.5 pp in 2025) was almost identical to the 2022 gap (45.7 pp), demonstrating that the bulk of behavioural divergence was established during the primary rollout year (Fig. 1–2).

Predictors of trajectory class. The multinomial model on n=859 (Tab. 2; Fig. 3) revealed four patterns. (i) A monotonic Conspiracy gradient: each one-point increase reduced odds of Baseline vaccinated (OR=0.74; $p=0.001$), Early convert

Table 1. Study group characteristics by longitudinal trajectory class

Variable	BV (n=68)	EC (n=512)	LC (n=40)	PuW (n=132)	PuH (n=107)	Overall p
Age, years (mean ± SD)	55.4 ± 17.1	54.1 ± 14.8	45.5 ± 14.8	46.2 ± 14.6	47.0 ± 15.7	<0.001***
Conspiracy Index, 0–6	1.24 ± 1.77	1.57 ± 1.89	1.73 ± 1.93	2.83 ± 2.11	2.93 ± 1.97	<0.001***
HLS-Q12 mean, 1–4	2.91 ± 0.61	2.90 ± 0.52	2.77 ± 0.48	3.04 ± 0.47	2.92 ± 0.59	0.040*
Fear of side effects, 1–4	2.26 ± 1.00	2.70 ± 1.01	2.92 ± 0.94	3.32 ± 0.86	3.47 ± 0.85	<0.001***
Sex: Female, n (%)	34 (50.0%)	258 (50.4%)	19 (47.5%)	80 (60.6%)	51 (47.7%)	0.233
Edu: Bachelor's+, n (%)	43 (63.2%)	168 (32.8%)	7 (17.5%)	19 (14.4%)	22 (20.6%)	<0.001***
Edu: Secondary, n (%)	14 (20.6%)	206 (40.2%)	22 (55.0%)	48 (36.4%)	37 (34.6%)	
Edu: Basic voc./lower, n (%)	11 (16.2%)	138 (27.0%)	11 (27.5%)	65 (49.2%)	48 (44.9%)	
Place: Rural, n (%)	13 (19.1%)	128 (25.0%)	8 (20.0%)	27 (20.5%)	31 (29.0%)	0.003**
Place: City <20k	16 (23.5%)	153 (29.9%)	16 (40.0%)	61 (46.2%)	42 (39.3%)	
Place: City 20–100k	10 (14.7%)	51 (10.0%)	7 (17.5%)	10 (7.6%)	12 (11.2%)	
Place: ≥100k	29 (42.7%)	180 (35.2%)	9 (22.5%)	34 (25.8%)	22 (20.6%)	
Age group 18–35, n (%)	12 (17.6%)	69 (13.5%)	12 (30.0%)	35 (26.5%)	32 (29.9%)	<0.001***
Age group 36–64, n (%)	29 (42.6%)	271 (52.9%)	20 (50.0%)	82 (62.1%)	54 (50.5%)	
Age group ≥65, n (%)	27 (39.7%)	172 (33.6%)	8 (20.0%)	15 (11.4%)	21 (19.6%)	

BV = Baseline vaccinated; EC = Early convert; LC = Late convert; PuW = Persistent unvax willing; PuH = Persistent unvax hesitant. Continuous variables: mean ± SD. Categorical: n (% of class). Overall p tests whether ANY of the five trajectory classes differ for the ENTIRE variable (one-way ANOVA for continuous; Pearson's χ^2 on the full contingency table across all listed levels for categorical) – NOT for the individual category shown in that row; for multi-level categoricals (Education, Place, Age group) the overall p is shown only in the first row of the block, and the empty cells in subsequent rows of the same block reflect the same overall test. Bonferroni-corrected pairwise post-hoc comparisons across the 10 class pairs are provided in Supplementary Table S1a–h. *p<0.05; **p<0.01; ***p<0.001

Table 2. Multinomial logistic regression: predictors of longitudinal trajectory class (reference: Persistent unvaccinated hesitant; n=859). Selected significant estimates

Outcome class	Predictor	OR	95% CI	p-value
Baseline vaccinated	Age (per year)	1.03	1.00–1.05	0.024*
Baseline vaccinated	Education: Bachelor's+	6.71	2.72–16.58	<0.001***
Baseline vaccinated	Low fear of side effects	6.01	2.76–13.07	<0.001***
Baseline vaccinated	Conspiracy Index	0.74	0.61–0.88	0.001**
Baseline vaccinated	HLS-Q12 mean	0.51	0.27–0.97	0.038*
Early convert	Age (per year)	1.02	1.01–1.04	0.002**
Early convert	Education: Bachelor's+	1.91	1.05–3.47	0.033*
Early convert	Low fear of side effects	3.00	1.64–5.48	<0.001***
Early convert	Conspiracy Index	0.77	0.69–0.85	<0.001***
Late convert	Education: Secondary	2.83	1.18–6.78	0.019*
Late convert	Place: City >100k	5.83	1.10–31.05	0.039*
Late convert	Conspiracy Index	0.76	0.62–0.92	0.005**
Persistent unvax willing	HLS-Q12 mean	1.56	0.95–2.57	0.077

Model adjusts for age, gender, education, place, fear (binary), Conspiracy Index and HLS-Q12. *p<0.05; **p<0.01; ***p<0.001

(OR=0.77; p<0.001) and Late convert (OR=0.76; p=0.005) vs. PuH. (ii) Low fear of side-effects emerged as a strong predictor of vaccinated trajectories: Baseline vaccinated OR=6.01 (95% CI 2.76–13.07; p<0.001); Early convert OR=3.00 (1.64–5.48; p<0.001). (iii) A Bachelor's degree increased odds of Baseline vaccination 6.7-fold (2.72–16.58; p<0.001) and Early conversion 1.9-fold (1.05–3.47; p=0.033); for Late convert, secondary education was the strongest signal (OR=2.83, 1.18–6.78; p=0.019). (iv) HLS-Q12 protected against Baseline vaccination membership (OR=0.51; p=0.038) and showed a borderline elevation for the PuW 'willing non-actor' class (OR=1.56, 95% CI 0.95–2.57; p=0.077) – a marginal multinomial result that nonetheless mirrors the descriptive elevation of PuW's HLS-Q12 mean and the robust HLS-Q12 effect in the hazard model below.

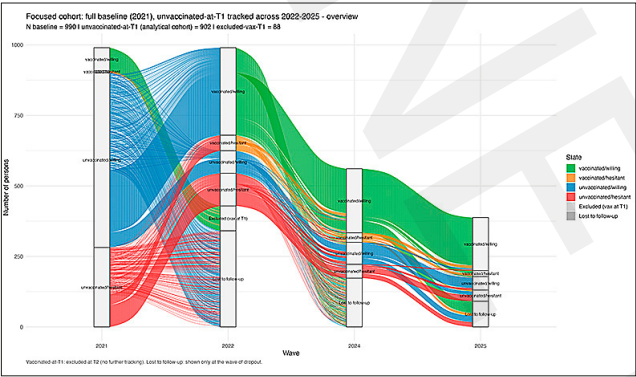


Figure 1. Focused-cohort alluvial visualisation of vaccination/attitude trajectories across four waves (ROF 2021, 2022, 2024, 2025). At T1 (2021), the full cohort is displayed across four states (vaccination × attitude); at T2–T4, only respondents unvaccinated at T1 are tracked. ‘Excluded (vax at T1)’ and ‘Lost to follow-up’ appear as one-time transitions

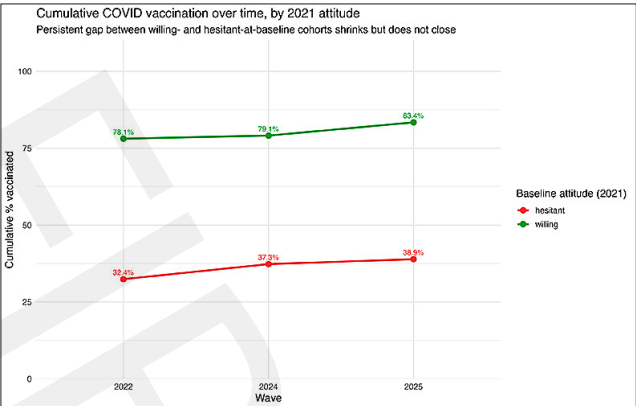


Figure 2. Cumulative proportion vaccinated for Covid-19 across the four follow-up waves, stratified by baseline (2021) attitude. The persistent 40–45 percentage-point gap between willing and hesitant baseline cohorts narrows by less than two percentage points over three post-rollout years

Table 3. Discrete-time hazard model for first Covid-19 vaccination. Sample: 860 person-periods, 405 events; singletons excluded.

Predictor	OR	95% CI	p-value
Wave 2022 (reference)	ref.	-	-
Wave 2024 (vs. 2022)	0.073	0.04–0.13	<0.001***
Wave 2025 (vs. 2022)	0.097	0.06–0.16	<0.001***
Age at baseline (per year)	1.023	1.012–1.035	<0.001***
Sex: Male (vs. Female)	1.11	0.78–1.59	0.551
Education: Secondary	2.10	1.42–3.13	<0.001***
Education: Bachelor's+	2.60	1.63–4.18	<0.001***
Fear of side effects (per unit)	0.63	0.51–0.77	<0.001***
Conspiracy Index (per unit)	0.79	0.73–0.87	<0.001***
HLS-Q12 mean (per unit)	0.58	0.42–0.81	0.001**

Reference categories: Wave 2022; Education = Basic vocational or lower; Sex = Female; Place = Rural.
*p<0.05; **p<0.01; ***p<0.001

Timing of first vaccination. The discrete-time hazard model (Tab. 3; n=860 person-periods, 405 events) confirmed that conversion concentrated in 2022: relative to the 2022 reference, the hazard was OR=0.07 (95% CI 0.04–0.13; p<0.001) in 2024 and OR=0.10 (0.06–0.16; p<0.001) in 2025. Among demographic predictors, a Bachelor's degree raised the per-wave conversion hazard 2.6-fold (1.63–4.18; p<0.001) and secondary education 2.1-fold (1.42–3.13; p<0.001). Among modifiable beliefs, fear of side-effects (OR=0.63 per unit; p<0.001) and conspiracy (OR=0.79; p<0.001) each reduced the conversion hazard, as did greater HLS-Q12 difficulty (OR=0.58 per unit; p=0.001).

Detailed pairwise *post-hoc* matrices (Suppl. Tab. S1a–h) and a STROBE-style flow of the analytical cohort (Suppl. Fig. S1) are provided as online supplementary materials.

DISCUSSION

Despite four years of communication efforts and unrestricted vaccine availability, the divergence between baseline vaccine intentions and actual vaccination behaviour did not narrow appreciably. The willing/hesitant gap of 45.7 percentage points at the end of the primary rollout year (2022) had only narrowed to 44.5 percentage points by 2025. That a substantial hesitant segment persists across four years is consistent with the pooled COVID-19 vaccine-hesitancy prevalence of approximately 32% synthesised across 78 meta-analyses in a 2024 umbrella review [29]; durable hesitancy thus appears to be a stable cross-national phenomenon rather than a Polish idiosyncrasy. The pattern suggests that the early-rollout window – the months in which vaccines first became publicly available – was disproportionately associated with subsequent longitudinal trajectories, and that later communication and policy measures coincided with much smaller incremental gains in coverage.

The five-class longitudinal typology surfaces two analytically distinct subgroups that the two-wave ROF design [19] could not see. Late converts (4.7% of cohort) were younger and lower-educated, with intermediate Conspiracy and Fear scores; their decision likely reflects slow ideological drift combined with structural exposure (workplace requirements, primary-care contacts) rather than acute persuasion. The

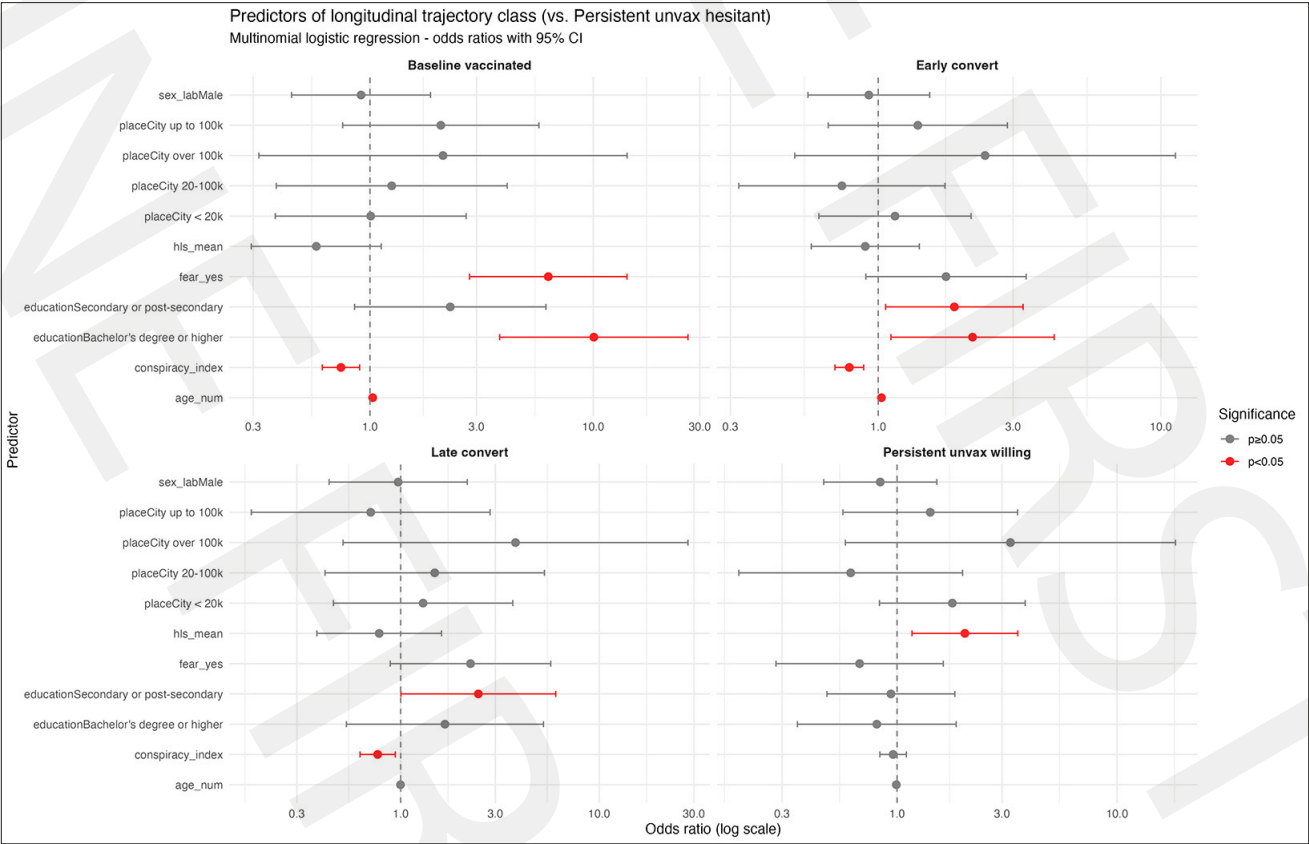


Figure 3. Forest plot of multinomial logistic regression estimates: odds ratios (95% CI) for predictors of each longitudinal trajectory class versus the reference class (Persistent unvaccinated, hesitant; n=859). Red: p<0.05; grey: p≥0.05

hazard model confirms late conversion is a real channel of post-rollout uptake but at substantially lower per-wave hazard than the 2022 rollout.

The Persistent unvaccinated–willing class (PuW, 15.4% of cohort) – ‘willing non-actors’ – is the most striking class. Their Conspiracy Index (2.83) and Fear scores (3.32) are statistically indistinguishable from Persistent hesitant respondents, yet they remain unvaccinated through four years of follow-up. In the present analysis, the adjusted multinomial association between HLS-Q12 and PuW is borderline ($OR=1.56$; $p=0.077$); the central evidence shifts to the descriptive Table 1 pattern (PuW has the highest mean HLS-Q12 score, 3.04; omnibus $p=0.040$) combined with the robust HLS-Q12 effect in the hazard model ($OR=0.58$ per unit; $p=0.001$). This converging exploratory signal is conceptually analogous to the ‘Willing but Obstructed’ profile recently described by Dai et al. in a Chinese latent profile analysis of zoster vaccine hesitancy [21], to the role of constraints in the 7C model of Lièvre et al. [4], and to qualitatively documented structural barriers among US African American/Black and Latine frontline essential workers [22] and Arabic-speaking Australian communities [23]: respondents who would in principle accept a vaccine but report difficulty navigating the health-information environment may not convert intention into action. It must be stressed, however, that the variables available cannot directly establish why PuW respondents remained unvaccinated, and this class is almost certainly heterogeneous. Beyond genuine difficulty navigating the health-information environment, it may encompass individuals who mask firm anti-vaccination views behind reported access problems, as well as respondents with limited autonomy over their own health decisions who depend on influential family members or their local community. Consistent with this last interpretation, PuW showed the highest proportion of women, a predominantly middle-aged profile, relatively low educational attainment and frequent residence in smaller towns. Disentangling these mechanisms lies beyond the scope of the present variables and is an important direction for future research.

The obtained results extend prior longitudinal vaccine-hesitancy studies. The Sabat et al. seven-country European panel documented intention instability (only 42% of ever-hesitant respondents remained hesitant) [16]; the presented Polish data confirm this instability but show that it does not translate into a closing of the cumulative behavioural gap. The Phillips et al. UK study [17] identified low fear of Covid-19 and negative attitudes as predictors of persistent hesitancy; the current presented results highlight the inverse – low fear of side-effects, a modifiable belief, was the strongest discriminator of vaccinated trajectories ($OR=6.01$ for Baseline vaccinated, $OR=3.00$ for Early convert in the multinomial; $OR=0.63$ per unit in the hazard model). The Oleksy et al. Polish four-wave study [18] showed conspiracy mentality predicted reduced willingness around vaccine availability; the results of the current study extend this from intention to behaviour over four years.

In the Polish-specific literature, Raciborski et al. used factor analysis to identify three dimensions of vaccination attitudes among Polish adults aged 15–39 – general trust in vaccination, vaccine safety concerns, and trust in fake medical news combined with Covid-19 denial – producing six homogeneous groups closely related to the trajectory typology of the current study [24]. The qualitative Polish study by Młodziński et al. documented health denialism as

a discrete cognitive style systematically associated with Covid-19 vaccine refusal [25], complementing the quantitative Conspiracy/Fear gradient observed in the currently presented cohort. The earlier Polish infodemiology study by Chlabicz et al. documented the volume and tone of Covid-19 medical misinformation circulating on the Polish web during the pandemic [26], providing a plausible environmental substrate for the persistent hesitant cluster.

The intervention directions outlined below are interpretive hypotheses suggested by the observed typology, rather than effects established by our data. Three operationally distinguishable groups may inform differentiated public-health responses: (a) Late converts, in whom structural exposure drives eventual uptake on a multi-year timescale and who benefit from low-intensity sustained communication; (b) the PuW ‘willing non-actor’ cluster, for whom structural facilitators (appointment outreach, mobile vaccination units, workplace vaccination) could be explored as candidate strategies whose effectiveness would need to be tested directly, since the presented observational design could not establish that they would raise uptake; and (c) the Persistent hesitant cluster, characterised by high Conspiracy and Fear scores, for whom interventions would likely need to address ideological and trust components. Prebunking (inoculation) messaging [6] and reflective interventions targeting vaccine conspiracy beliefs [27] are potentially relevant, but the reflective-intervention effect reported in [27] was moderated by intellectual humility rather than being uniform; therefore, these are presented as directions for future intervention research rather than as strategies recommended on the basis of the present findings. More broadly, because willing non-actors may include people whose decisions are shaped by influential hesitant relatives or community figures, structural facilitators alone might be insufficient unless combined with engagement of local opinion leaders and of the persistently hesitant individuals who voice strong negative views.

CONCLUSIONS

Vaccine hesitancy in Poland is dynamic but ultimately durable: the willing/hesitant gap in cumulative vaccination established during the primary rollout year (45.7 pp in 2022) narrowed only marginally to 44.5 pp by 2025. Three modifiable determinants – fear of vaccine side-effects, conspiracy beliefs and education – robustly predicted both trajectory class membership and the timing of first vaccination. Two distinct subgroups emerged from the four-wave typology: Late converts (younger, lower-educated, intermediate beliefs) and Persistent unvaccinated, willing (the ‘willing non-actor’ cluster). In the post-rollout period, public-health communication combining safety-centred dialogue targeting fear of side effects with structural facilitators (workplace vaccination, appointment outreach, mobile units) for the willing-but-unvaccinated subgroup is a plausible direction, although its effectiveness remains to be evaluated and does not follow directly from our observational findings. Multi-wave trajectory typology coupled with discrete-time hazard modelling provides a template for monitoring future vaccination campaigns beyond a single pathogen, and may be relevant to other preventive vaccinations where stated intention chronically diverges from actual uptake – including HPV vaccination, for which an intention-behaviour gap

of comparable structure has recently been documented in Chinese female college students [28].

Limitations of the study. First, reliance on self-reported data introduces social-desirability bias. Second, 66.4% of unique respondents contributed fewer than two waves and were excluded from trajectory analyses; the analytical cohort may differ systematically from the general population, although the quota structure partially mitigates this. A formal comparison of retained (≥ 2 waves) versus excluded single-wave respondents showed that the analytical cohort was older and better educated (education $p < 0.001$) and reported modestly higher conspiracy and health-information-difficulty scores (standardised differences ≤ 0.25); crucially, baseline vaccine attitude (willing vs hesitant) and gender did not differ ($p = 0.18$ and $p = 0.52$), indicating that the central willing/hesitant contrast is unlikely to be a retention artefact. Residual selection on unmeasured factors cannot be excluded.

Third, attitude was not measured in 2022 and was carried forward from 2021; in addition, the wording of the 2025 attitude item differed from earlier waves (emphasising support for mandatory vaccination), which may affect strict comparability of the willing/hesitant classification at the final wave. Fourth, the 2025 vaccination status was operationalised from the self-reported number of doses received; this was cross-validated against dose-schedule skip-logic. Fifth, the adjusted multinomial association of HLS-Q12 with the PuW class was borderline ($p = 0.077$); the main supporting evidence for the ‘willing non-actor’ framing comes from the omnibus descriptive pattern ($p = 0.040$) and the hazard model ($p = 0.001$) rather than the adjusted multinomial alone. Sixth, the place-of-residence omnibus was significant but no pairwise survived Bonferroni correction, indicating a diffuse rather than concentrated effect. Seventh, several trajectory classes were small (Late convert $n = 40$, Baseline vaccinated $n = 68$), so a number of multinomial estimates carry wide confidence intervals and should be regarded as imprecise. Findings are based on a Polish panel and may have limited generalisability to other contexts.

Ethics. The study was approved by the Bioethical Committee of the Medical University of Białystok (approval no. APK.002.346.2020). Informed consent was obtained from all participants.

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REFERENCES

- MacDonald NE. Vaccine hesitancy: Definition, scope and determinants. *Vaccine*. 2015;33(34):4161–4.
- World Health Organization. Understanding the behavioural and social drivers of vaccine uptake – WHO position paper, May 2022. *Wkly Epidemiol Rec*. 2022;97:209–24.
- Betsch C, Schmid P, Heinemeier D, et al. Beyond confidence: Development of a measure assessing the 5C psychological antecedents of vaccination. *PLoS ONE*. 2018;13(12):e0208601
- Lièvre G, Sicsic J, Galmiche S, et al. Are the 7C psychological antecedents associated with COVID-19 vaccine behaviours beyond intentions? *Vaccine*. 2024;42(14):3288–99.
- Oudin Doglioni D, Gagneux-Brunon A, Gauchet A, et al. Psychometric validation of a 7C-model of antecedents of vaccine acceptance among healthcare workers, parents and adolescents in France. *Sci Rep*. 2023;13(1):19895.
- Kisa A, Kisa S. Health conspiracy theories: a scoping review of drivers, impacts, and countermeasures. *Int J Equity Health*. 2025;24(1):93.
- Simione L, Vagni M, Maiorano T, et al. Paranoia affected COVID-19 vaccine refusal by increasing beliefs in conspiracy theories and mistrust of science. *Front Psychol*. 2025;16:1718763.
- Larson HJ, Clarke RM, Jarrett C, et al. Measuring trust in vaccination: A systematic review. *Hum Vaccin Immunother*. 2018;14(7):1599–1609.
- Ministerstwo Zdrowia. Raport szczepień przeciwko COVID-19 w Polsce. Available at: <https://www.gov.pl/web/szczepimysie/raport-szczepien-przeciwko-covid-19> (accessed 24 Oct 2023).
- Pizzato M, Gerli AG, La Vecchia C, et al. Impact of COVID-19 on total excess mortality and geographic disparities in Europe, 2020–2023. *Lancet Reg Health Eur*. 2024;44:100996.
- Wróblewski M, Bartnicki M, Stankowska J, et al. Sukces czy porażka? Społeczna ewaluacja Narodowego Programu Szczepień przeciwko COVID-19. Warszawa: Łukasiewicz-ORGMA SZ; 2022.
- Schernhammer E, Weitzer J, Laubichler MD, et al. Correlates of COVID-19 vaccine hesitancy in Austria: trust and the government. *J Public Health*. 2022;44(1):e106–16.
- Loomba S, De Figueiredo A, Piatek SJ, et al. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nat Hum Behav*. 2021;5(3):337–48.
- Lazarus JV, Wyka K, White TM, et al. Revisiting COVID-19 vaccine hesitancy around the world using data from 23 countries in 2021. *Nat Commun*. 2022;13(1):3801.
- Lazarus JV, Wyka K, White TM, et al. A survey of COVID-19 vaccine acceptance across 23 countries in 2022. *Nat Med*. 2023;29(2):366–75.
- Sabat I, Neumann-Böhme S, Barros PP, et al. Vaccine hesitancy comes in waves: Longitudinal evidence on willingness to vaccinate against COVID-19 from seven European countries. *Vaccine*. 2023;41(36):5304–12.
- Phillips R, Gillespie D, Hallingberg B, et al. Perceived threat of COVID-19, attitudes towards vaccination, and vaccine hesitancy: A prospective longitudinal study in the UK. *Br J Health Psychol*. 2022;27(4):1354–81.
- Oleksy T, Wnuk A, Gambin M, et al. Barriers and facilitators of willingness to vaccinate against COVID-19: A four-wave longitudinal study. *Pers Individ Dif*. 2022;190:111524.
- Sowa P, Kiszkiel Ł, Laskowski PP, et al. COVID-19 Vaccine Hesitancy in Poland – Multifactorial Impact Trajectories. *Vaccines*. 2021;9(8):876.
- R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation; 2024.
- Dai J, Xie Y, Wang Y, et al. Profiles of Hesitancy Toward the Herpes Zoster Vaccine Among Older Adults in China: A Latent Profile Analysis. *Vaccines*. 2026;14(4):331.
- Gwadz M, Robinson JA, Serrano FGB, et al. Perspectives on COVID-19 Vaccination Among Unvaccinated and Under-Vaccinated African American/Black and Latine Frontline Essential Workers: A Qualitative Exploration. *AIDS Behav*. 2025;29(8):2461–82.
- Vasiliadis S, Cook J, Nissan K, et al. Vaccine misinformation among Arabic-speakers in Australia and the audience and appetite for a game-based intervention. *Vaccine*. 2025;62:127599.
- Raciborski F, Tomaszewska A, Rakocy K, et al. The multidimensional nature of attitudes towards preventive vaccinations – a cross-sectional survey among Poles aged 15–39 years. *Int J Occup Med Environ Health*. 2023;36(2):214–28.
- Młodziński I, Zwierczyk U, Rzepecka E, et al. Manifestation of Health Denialism in Attitudes toward COVID-19 Vaccination: A Qualitative Study. *Vaccines*. 2023;11(12):1822.
- Chlabicz M, Nabożny A, Koszelew J, et al. Medical Misinformation in Polish on the World Wide Web During the COVID-19 Pandemic Period: Infodemiology Study. *J Med Internet Res*. 2024;26:e48130.
- Bayrak F, Kayatepe E, Özman N, et al. Can reflection mitigate COVID-19 vaccine conspiracy beliefs and hesitancy? *Psychol Health*. 2025;1–32.
- Yang L, Xing C, Yu X, et al. Coverage of HPV Vaccination and Influencing Factors Among Female College Students in Northern China. *Vaccines*. 2025;13(6):598.
- Rahbeni TA, Satapathy P, Itumalla R, et al. COVID-19 Vaccine Hesitancy: Umbrella Review of Systematic Reviews and Meta-Analysis. *JMIR Public Health Surveill*. 2024;10:e54769.