



OPEN Vaccine hesitancy and decision regret among nurses in oncology settings in Italy: a cluster-based profile analysis

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Prior studies have examined decision regret and vaccine hesitancy using variable-centered approaches. However, little is known about the diversity of profiles within oncology settings where immunocompromised patients are at high risk. This study aimed to identify distinct clusters of vaccine-related attitudes among Italian nurses working in comprehensive cancer centers. A cross-sectional survey was conducted from June to September 2024, using validated instruments to assess decision regret and vaccine hesitancy (i.e., trust in vaccine efficacy, concerns about vaccine safety, and trust in health authorities and compliance). Data were collected from 241 RNs affiliated with the Italian Association of Cancer Nurses. A t-distributed Stochastic Neighbor Embedding (t-SNE) was used for dimensionality reduction before hierarchical clustering. Seven distinct profiles emerged, ranging from Confident Adherent (low regret, high trust, high compliance) to Resigned Skeptic (low trust, moderate concern, low compliance). Educational status and age significantly influenced cluster membership. Specific profiles displayed unexpected patterns (e.g., high trust with high regret, as in the Regretful Believer group), highlighting the complexity of vaccination attitudes. These findings underscore the importance of person-centered strategies for vaccine communication. Differentiated educational and institutional approaches may enhance trust and adherence among oncology nurses.

Keywords Vaccine hesitancy, Decision regret, Registered nurses, Oncology nursing, Cluster analysis, COVID-19 vaccination, Trust, Compliance, Concerns, Nursing education

Abbreviations

AIIAO	Associazione Italiana Infermieri di Area Oncologica
APC	Article Processing Charge
aVHS	Adult Vaccine Hesitancy Scale
COVID-19	Coronavirus Disease 2019
DRS	Decision Regret Scale
EU	European Union
EUSurvey	European Commission Survey Platform
HBM	Health Belief Model

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IRB	Institutional Review Board
IQR	Interquartile Range
MSN	Master of Science in Nursing
RN	Registered Nurse
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
t-SNE	t-distributed Stochastic Neighbor Embedding

Vaccine hesitancy remains a major challenge in global public health, threatening the success of vaccination campaigns and herd immunity efforts, particularly in high-stakes contexts such as the COVID-19 pandemic^{1–4}. While much attention has been paid to hesitancy among the general population, emerging evidence suggests that even healthcare professionals may exhibit variable levels of trust, concern, and compliance with vaccination protocols⁴. Understanding the psychological, educational, and contextual factors that influence these attitudes is essential for tailoring effective interventions within healthcare systems^{5,6}.

Registered Nurses (RNs) play a pivotal role in vaccination campaigns, not only as recipients of vaccines but also as frontline communicators who shape patient attitudes and behaviors⁷. This population's educational level and ongoing professional development may critically influence vaccine-related attitudes^{8,9}. RNs enrolled in advanced education programs, such as a Master of Science in Nursing (MSN), may exhibit different cognitive, emotional, and behavioral responses to vaccination compared to peers who are not currently engaged in academic programs^{10,11}. In this regard, educational exposure could enhance scientific literacy, reinforce trust in institutional guidance, and modulate concerns about vaccine safety, ultimately shaping decision-making patterns¹¹.

In Italy, comprehensive cancer centers represent highly specialized settings where vaccination is strongly emphasized both for the protection of immunocompromised patients and as a condition of workforce readiness¹². The vaccine-related behaviors of RNs in such settings may reflect a complex interplay of professional responsibility, institutional culture, and personal beliefs. Yet, to date, there is limited research focused specifically on Italian RNs working in oncology who differ by level of academic engagement¹³. Moreover, while prior studies have examined vaccine hesitancy and regret using variable-centered approaches, few have adopted a person-centered framework capable of identifying distinct psychological profiles¹⁴.

Decision regret, in particular, represents a salient yet underexplored dimension of post-vaccination experience^{14–19}. It reflects the emotional discomfort individuals may feel following their vaccination decision and has been shown to influence downstream behaviors such as adherence to booster schedules and compliance with future public health recommendations²⁰. When considered alongside trust in vaccine efficacy, concerns about vaccine safety, and willingness to comply with institutional guidance, decision regret offers a window into the motivational and cognitive landscape underpinning hesitancy²¹.

Notably, trust, concerns, and compliance are not isolated constructs. They represent core dimensions of vaccine hesitancy, capturing the extent to which individuals believe in the efficacy of vaccines, worry about their safety, and adhere to institutional recommendations²¹. Recent evidence from a national study involving Italian nursing students and RNs reported moderate to high levels of decision regret, with substantial variation in trust, concerns, and compliance¹⁴. Specifically, lower decision regret significantly predicted trust in vaccine efficacy ($R^2 = 31.3\%$), while fewer concerns about vaccine safety were also associated with lower regret ($R^2 = 26.9\%$). Compliance was modestly higher among RNs enrolled in a Master of Science in Nursing ($R^2 = 2.9\%$)¹⁴. Median values on a 5-point scale indicated high trust (1.5), moderate concerns (2.67), and intermediate compliance (2.0)¹⁴. A recent meta-analysis estimated COVID-19 vaccine hesitancy among Italian healthcare workers at 13.1% (95% CI: 6.9–20.9%), with rates declining from 18.2% before the campaign to 8.9% during the rollout²².

Despite growing interest in vaccine hesitancy among healthcare workers, distinct profiles of vaccine-related attitudes and experiences among RNs in comprehensive cancer centers have not been systematically identified^{23–26}. This gap limits the ability to design interventions that reflect the diversity of cognitive and behavioral orientations in these specialized clinical environments²⁷. A person-centered understanding of how decision regret, trust in efficacy, safety concerns, and compliance intersect is essential for advancing vaccine promotion strategies^{11,13}. For this reason, the aim of the present study is to identify distinct clusters of vaccine-related attitudes and experiences among Italian RNs working in comprehensive cancer centers, either enrolled in an MSN program or with no ongoing university education.

Materials and methods

Design

This study employed a cross-sectional, descriptive design²⁸. It was conducted to explore patterns of vaccine-related attitudes and behaviors among Italian RNs working in comprehensive cancer centers and affiliated with the Italian Cancer Nurses Association (AIIAO)¹³. Data were collected between June and September 2024 through an online survey²⁹. The study adhered to the ethical standards outlined in the Declaration of Helsinki and received approval from the Institutional Review Board of the University of Pavia (protocol number 4/CDS/2024, approved 18 March 2024) and the Institutional Review Board of AIIAO (protocol number CD/5/2024, approved 15 May 2024). This study adheres to the principles of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational research³⁰ and findings are reported accordingly.

Sample size and subjects

The required sample size was calculated using the formula for estimating a single population proportion³¹ assuming an anticipated vaccine hesitancy rate of 13.1% (based on recent meta-analytic evidence)²² a margin of error of 5%, and a 95% confidence level. This yielded a minimum sample size of 176 participants. To account for possible

non-response or incomplete data, a 25% attrition rate was considered³² resulting in a final target sample size of 240 participants.

Subjects were directly invited through institutional and professional contacts of the AIIAO, targeting RNs employed in comprehensive cancer centers across Italy. Inclusion criteria were being a currently practicing RN in a cancer care setting, affiliation with AIIAO, and either ongoing enrollment in an MSN program or no active university enrollment. Exclusion criteria included being a nursing student, holding an administrative role without clinical responsibilities, working outside oncology or non-cancer-focused services, or submitting an incomplete questionnaire.

Measurements

The electronic questionnaire collected information on sociodemographic and professional characteristics and measures related to vaccination attitudes and behaviors. Demographic variables included sex (female, male, prefer not to respond) and age. Participants also indicated their geographic location, categorized as Northern, Central, or Southern Italy, and their educational profile, defined as either RNs attending an MSN program or RNs with no ongoing university education.

Information on clinical practice settings was gathered with categories including critical care, medical care, surgical care, primary care, and outpatient services. Vaccination-related data included whether the participant had received the COVID-19 vaccine (yes/no) and the number of COVID-19 vaccine boosters received, categorized as: no boosters (i.e., unvaccinated), one booster, two boosters, or three boosters or more.

To assess cognitive and emotional reactions to vaccination decisions, the Italian version of the Decision Regret Scale (DRS) was administered¹⁴. The DRS is a validated five-item instrument scored on a 5-point Likert scale, with items 2 and 4 reverse-coded. Higher scores indicate lower levels of decision regret, and the final score is expressed as the average of all items.

Vaccine hesitancy was further evaluated using the Italian version of the Adult Vaccine Hesitancy Scale (aVHS), which includes three distinct subscales³³: (1) Trust in Vaccine Efficacy and Benefits, (2) Concerns about Vaccine Safety, and (3) Trust in Health Authorities and Compliance. Each subscale consists of multiple items rated on a 5-point Likert scale, with specific items reverse-coded as per validated scoring protocols. For each subscale, higher scores reflect more favorable attitudes: greater trust, fewer concerns, and stronger compliance, respectively.

Procedure

Data collection was conducted through an online survey between June and September 2024. In designing this population-based study, we anticipated achieving a response rate of approximately 50%, a benchmark consistent with current literature on survey-based research methodologies. To meet the final sample size target, we invited approximately 480 potentially eligible participants across the national territory, encompassing Northern, Central, and Southern Italy. Participant contact information was obtained through a random selection from the official mailing list of the AIIAO.

Before launching the survey, research team members were trained on survey research's ethical and methodological considerations. Additionally, strategies for maximizing response rates while ensuring data integrity were discussed. A pilot test involving five volunteer respondents was carried out to detect and resolve any issues related to survey design, question clarity, or technical usability.

The survey was administered using the EUSurvey platform, which enabled 24/7 accessibility and user flexibility³⁴. Advanced platform features were employed to minimize the risk of duplicate entries, including IP address tracking.

Upon receiving the survey invitation, potential participants were presented with an introductory information sheet outlining the study's purpose, procedures, and ethical safeguards. Before beginning the survey, participants were required to provide informed consent through an electronic signature. This consent process ensured that participants understood their role, the voluntary nature of their involvement, and their rights regarding data privacy and withdrawal from the study.

Data analysis

All analyses were conducted in R version 4.5.0 (R Core Team, 2025). The dataset had no missing values, as all survey items relevant to this study were configured as mandatory in the online questionnaire, preventing incomplete submissions. Data were screened for missing values, outliers, and inconsistencies before analysis using frequency tables and distributional checks. Descriptive statistics were computed and reported according to the nature and distribution of each variable. Categorical variables were summarized using frequencies and percentages, while continuous or ordinal variables, including the DRS and the aVHS subscales (Trust, Concerns, and Compliance), were described using medians and interquartile ranges (IQR) due to non-normal distributions.

To reduce data dimensionality and facilitate the identification of latent profiles, a t-distributed stochastic neighbor embedding (t-SNE) unsupervised machine learning algorithm was applied using the Orange Data Mining Toolbox, version 3.38.1 for Microsoft Windows³⁵. A t-distributed stochastic neighbor embedding (t-SNE) was performed on the following variables after a standardizing procedure: age, number of vaccine boosters, DRS score, and the three subscale scores of the aVHS (Trust, Concerns, and Compliance). The algorithm was configured with a perplexity of 30, a learning rate of 200, and an Euclidean distance metric, yielding two stochastic components (tSNE_x and tSNE_y)^{36,37}. The perplexity was chosen to balance preservation of local and global structures, consistent with recommended values (5–50) for datasets of this size ($n \approx 240$), while the learning rate optimized convergence stability and minimized crowding effects. Sensitivity analyses varying perplexity from 10 to 50 and learning rate from 100 to 500 yielded qualitatively similar embeddings, with Adjusted Rand Index (ARI) values > 0.90 compared to the original configuration, supporting robustness.

A hierarchical cluster analysis using Ward's D2 method was then performed on the tSNE components³⁸. This agglomerative approach was selected for its ability to minimize within-cluster variance and generate interpretable dendrograms³⁹. Compared to partitioning methods (e.g., k-means), hierarchical clustering does not require prior specification of the number of clusters and offers a more flexible framework for identifying nested structures in complex datasets, particularly suitable for exploratory profiling of a heterogeneous population like nurses³⁹.

The optimal number of clusters was informed by both theoretical hypotheses derived from previous clustering studies in similar nursing populations and empirical evidence from the silhouette width index^{25,26}. Multiple models were explored to assess goodness-of-fit and maximize interpretability. The solution with seven clusters ($k=7$) was selected based on its overall silhouette coefficient and conceptual coherence⁴⁰.

Cluster stability and adequacy of the achieved sample size were evaluated through empirical testing. Subsampling without replacement was performed at $n=160, 200$, and 240 (300 iterations each), and perturbation testing was conducted by adding Gaussian noise to the t-SNE coordinates (5% and 10% of the empirical SD per axis). Agreement with the original labels was quantified using the ARI and mean silhouette. Subsampling yielded ARI means of 0.884 (95% CI: 0.699–1.000) at $n=160$, 0.925 (95% CI: 0.761–1.000) at $n=200$, and 0.989 (95% CI: 0.909–1.000) at $n=240$, with mean silhouettes ~ 0.55 . Perturbation tests produced ARI means of 0.913 (95% CI: 0.752–1.000) with 5% noise and 0.829 (95% CI: 0.632–0.967) with 10% noise. Additional bootstrapping with 80% random samples (1,000 iterations) confirmed high stability, with median ARI ≥ 0.85 across all conditions, indicating that the achieved sample size was sufficient to recover the observed cluster structure with high robustness. To evaluate the stability of the seven-cluster solution, we used a bootstrap-based resampling procedure (1,000 iterations, 80% of the sample without replacement) and re-applied hierarchical clustering (Ward's method) to the resampled data. Agreement between the original and bootstrap-derived cluster labels was quantified using Cohen's κ , which is appropriate for categorical classifications such as cluster assignments. Clusters were first aligned using the Hungarian algorithm to account for label permutation before computing κ ⁴¹. We report the mean κ , standard deviation, and 95% percentile-based confidence intervals as measures of classification stability.

The identified cluster structure was then visualized using a scatterplot of the tSNE_x and tSNE_y components, with each cluster represented by a unique color drawn from the Paired palette in R⁴². The same color scheme was applied to a dendrogram illustrating the hierarchical structure of the clusters⁴³.

Once the clusters were defined, the demographic and psychological characteristics of respondents within each cluster were examined and compared across groups. Chi-square tests were used to compare categorical variables, including sex, geographic location, educational profile, clinical setting, and COVID-19 vaccination status. Fisher's exact test was used in cases of small cell counts (i.e., COVID-19 vaccination status). For continuous variables such as age, DRS, Trust, Concerns, and Compliance scores, comparisons were made using the Kruskal–Wallis test, followed by Dunn's post-hoc pairwise comparisons with Holm correction to identify specific between-cluster differences. Effect sizes were computed for all between-cluster comparisons to aid interpretation: Cramér's V for categorical variables, with benchmarks of 0.10, 0.30, and 0.50 indicating small, medium, and large effects, respectively, and η^2 (eta-squared) for continuous variables, with benchmarks of 0.01 (small), 0.06 (medium), and 0.14 (large). These core vaccine-related scores were also visualized across clusters using boxplots with jittered data points, colored consistently using the cluster palette⁴². A Bonferroni correction was applied to correct for multiple comparisons and reduce the risk of Type I error⁴⁴. With 11 pairwise comparisons per variable, statistical significance was set at $p < 0.005$.

Results

Sample characteristics

As shown in Table 1, of the approximately 480 eligible nurses invited, 241 completed the survey, yielding a response rate of $\sim 50\%$. The majority were female (68.0%), with a median age of 28 years (IQR = 24.00–40.00). Most respondents were located in Northern Italy (57.7%), followed by Central Italy (22.0%) and Southern Italy (20.3%). Slightly more than half (52.3%) were RNs attending an MSN program, while 47.7% reported no ongoing university education.

Among the 61 participants who reported their current work setting, the most common areas were surgical care (23.7%), primary care (23.2%), and medical care (19.5%). Fewer respondents reported working in outpatient services (21.6%) or critical care (12.0%). Almost all participants (97.1%) reported receiving the COVID-19 vaccine. Regarding booster doses, 63.1% had received three boosters or more, 29.5% had received two boosters, 2.9% were unvaccinated, and 4.6% had received only one booster.

The DRS score had a median of 2.0 (IQR = 1.6–3.0). Regarding vaccine hesitancy dimensions, the median score for Trust in Vaccine Efficacy and Benefits was 1.75 (IQR = 1.0–2.0), Concerns about Vaccine Safety was 2.67 (IQR = 2.0–3.0), and Trust in Health Authorities and Compliance was 2.0 (IQR = 1.3–2.3).

t-SNE representation

Figure 1 displays the two-dimensional t-SNE projection of the sample. In the upper panel, nurses are color-coded according to their educational profile: those attending an MSN program and those with no ongoing university education. The distribution appears balanced, with no clear concentration of one profile in specific regions of the t-SNE space.

In the lower panel, the same projection is shown after applying hierarchical clustering, with each data point colored according to its cluster assignment ($k=7$). The resulting clusters appear well-separated across the t-SNE dimensions, supporting the interpretability of the seven-cluster solution. The visual dispersion suggests meaningful differentiation in vaccine-related attitudes and experiences among participants, confirming the suitability of the clustering structure.

		N	%
Sex			
	Females	164	68.0
	Males	77	32.0
Age			
	Years; 95% CI: 26.9–30.5; (median; IQR)	28.00	24.00–40.00
Location			
	Northern Italy	139	57.7
	Central Italy	53	22.0
	Southern Italy	49	20.3
Profile			
	RNs attending an MSN	126	52.3
	RNs with no ongoing university education	115	47.7
Work settings (<i>n</i> = 61 workers)			
	Critical care	29	12.0
	Medical care	47	19.5
	Surgical care	57	23.7
	Primary care	56	23.2
	Outpatient services	52	21.6
COVID-19 vaccine*			
	Yes	237	97.1
Number of COVID-19 Vaccine Boosters			
	No boosters (unvaccinated respondents)	7	2.9
	One booster	11	4.6
	Two boosters	71	29.5
	Three or more boosters	152	63.1
Decision Regret Scale			
	Score; 95% CI: 1.85–2.17; (median; IQR)	2.0	1.6–3.0
Adult Vaccine Hesitancy Scale			
	Score of Trust in Vaccine Efficacy and Benefits; 95% CI: 1.59–1.83; (median; IQR)	1.75	1.0–2.0
	Score of Concerns about Vaccine Safety; 95% CI: 2.70–2.92; (median; IQR)	2.67	2.0–3.0
	Score of Trust in Health Authorities and Compliance; 95% CI: 1.97–2.21; (median; IQR)	2.0	1.3–2.3

Table 1. Sample characteristics (*N* = 241).

Hierarchical clustering: selecting the number of clusters

As shown in Fig. 2 (top panel), the silhouette width increased steadily from 5 to 7 clusters, reaching a maximum at *k* = 7 (mean silhouette = 0.547), after which it declined. This pattern suggests that the 7-cluster solution provided the best balance between cohesion within clusters and separation between them.

Further support for the 7-cluster solution is shown in the bottom panel of Fig. 2, which presents the average silhouette width for each of the seven clusters. The internal consistency of the cluster solution was acceptable, with clusters 5 and 6 showing the highest silhouette values, indicating strong internal cohesion, while clusters 1 and 3 exhibited lower silhouette widths, suggesting less homogeneity. These results confirmed the interpretability and quality of the final 7-cluster structure used in subsequent analyses.

Hierarchical clustering: defining distinct profiles

Following the identification of the optimal number of clusters (*k* = 7), a hierarchical clustering solution using Ward's method was applied to the t-SNE-derived components. The resulting dendrogram (Fig. 3) visually represents the clustering structure and confirms an acceptable level of separation across the seven clusters, with average silhouette widths ranging from 0.329 (Cluster 1) to 0.894 (Cluster 5). Cluster sizes ranged from 13 to 68 participants: Cluster 1, *n* = 21 (8.7%); Cluster 2, *n* = 48 (19.9%); Cluster 3, *n* = 46 (19.1%); Cluster 4, *n* = 68 (28.2%); Cluster 5, *n* = 13 (5.4%); Cluster 6, *n* = 26 (10.8%); and Cluster 7, *n* = 19 (7.9%). Stability was further assessed through subsampling (bootstrapping with 80% random samples, 1,000 iterations) and perturbation testing (Gaussian noise with mean 0, SD 0.05 applied to the embedding before reclustering). Both methods demonstrated high agreement with the original solution (subsampling: ARI = 0.989, 95% CI: 0.909–1.000; perturbation: ARI = 0.913, 95% CI: 0.752–1.000), with median ARI values of 0.89 and 0.87, respectively, and mean silhouette widths consistently around 0.55. These results support the robustness and reproducibility of the identified profiles. In addition, a bootstrap-based agreement analysis yielded a mean Cohen's κ of 0.788 (SD = 0.092; 95% CI: 0.599–0.918), indicating substantial reproducibility of the cluster assignments across resamples.

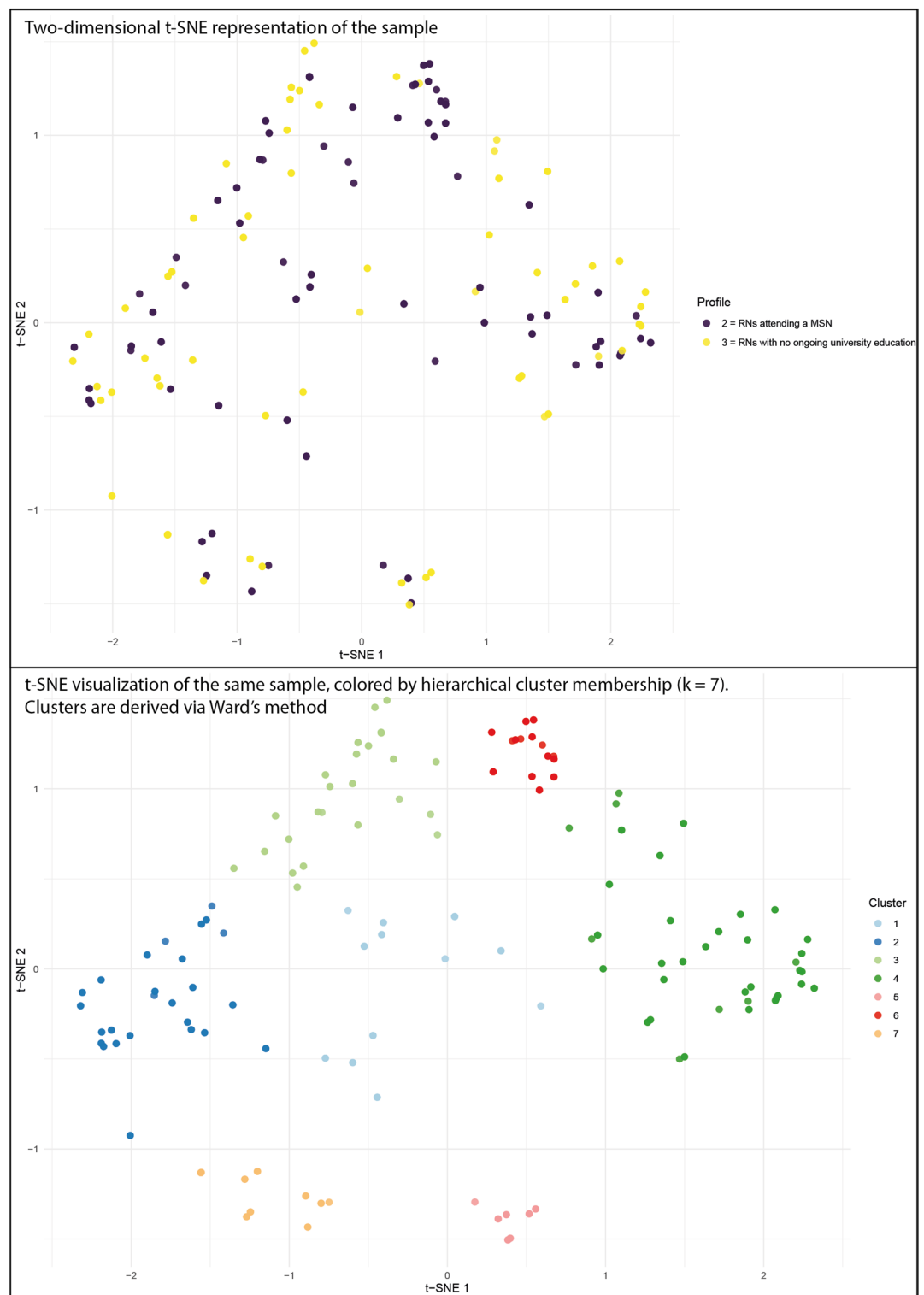


Fig. 1. Two-dimensional t-SNE plot showing the distribution of study participants based on age, vaccine-related attitudes, and behaviors. Each point represents one participant. In the upper panel, colors indicate professional profile: RNs attending an MSN program (purple) and RNs with no ongoing university education (yellow). In the lower panel, colors represent the seven clusters identified through hierarchical clustering (Ward's method). The t-SNE components provide a low-dimensional representation of the original variables (Decision Regret Scale and Adult Vaccine Hesitancy subscales: Trust, Concerns, and Compliance), preserving the data structure to support pattern recognition and clustering.]

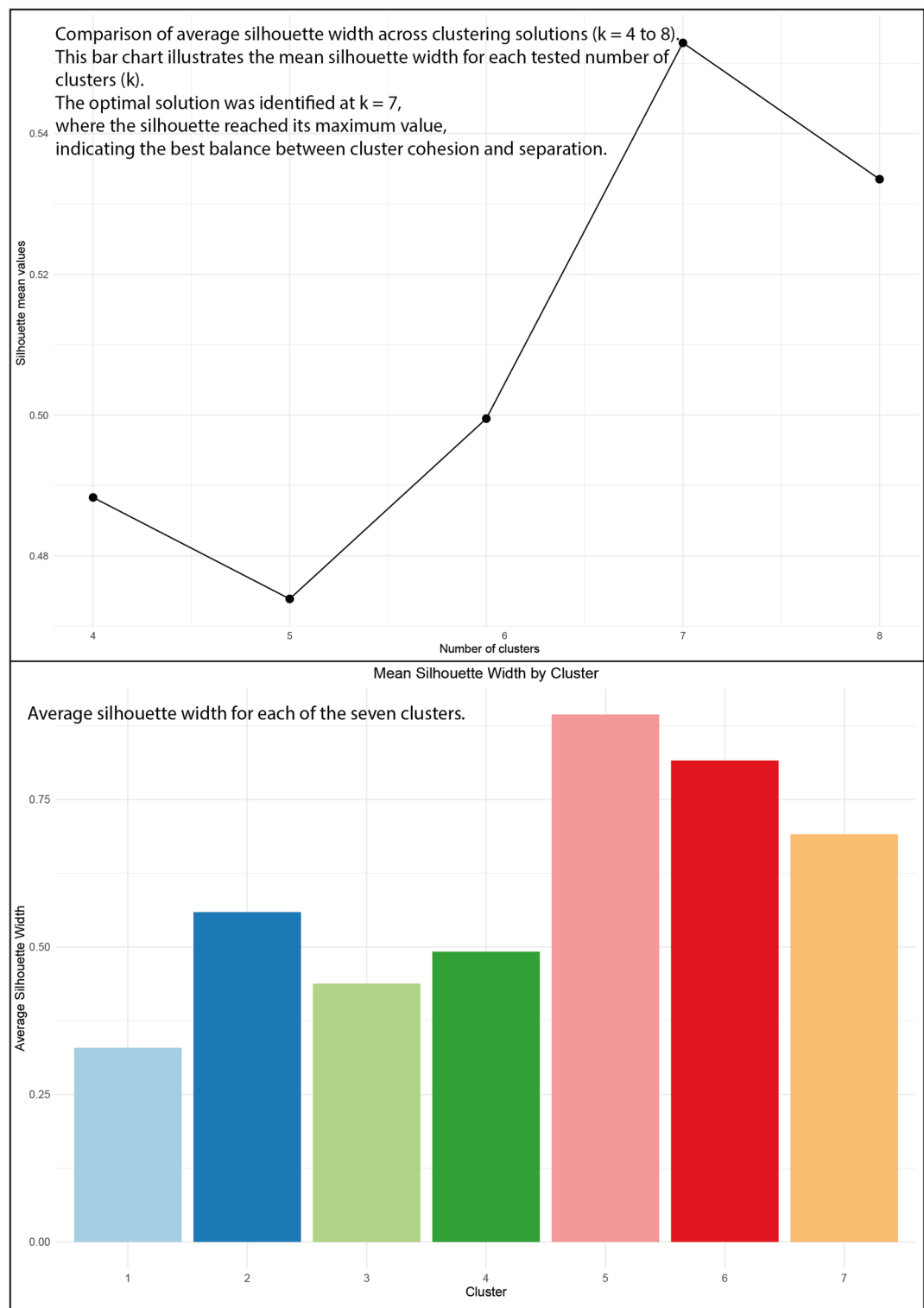


Fig. 2. Average silhouette widths. Top panel: Comparison of average silhouette widths across hierarchical clustering solutions ranging from 4 to 8 clusters (k). The highest silhouette value was reached at $k = 7$, suggesting this as the optimal number of clusters. Bottom panel: Average silhouette width for each cluster within the 7-cluster solution, reflecting internal consistency of each group. Clusters 5 and 6 displayed the highest cohesion.]

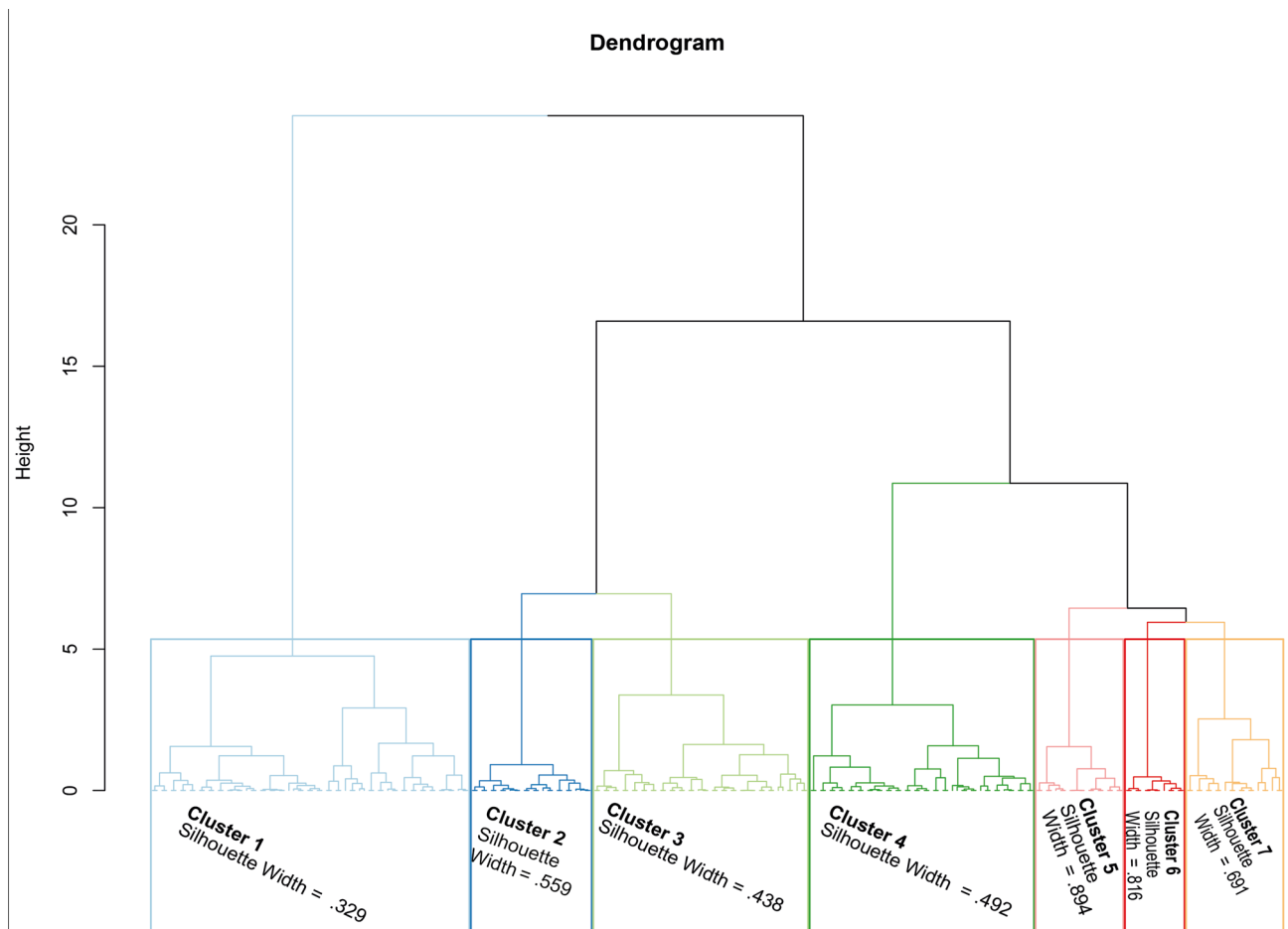


Fig. 3. Dendrogram of hierarchical clustering solution ($k=7$) with Ward's method. Rectangles indicate the seven-cluster solution, each color-coded according to the palette used in subsequent figures. Silhouette widths are displayed for each cluster, representing within-cluster cohesion and between-cluster separation. Clusters vary in both size and silhouette quality, with Cluster 5 showing the highest internal consistency (silhouette=0.894) and Cluster 1 the lowest (silhouette=0.329).]

Demographic characteristics and educational profiles between clusters

Table 2 summarizes the demographic and educational profiles across the seven clusters. No significant differences were found for sex (Cramer's $V=0.16$, $p=0.417$), with women comprising the majority in all clusters. However, age varied significantly ($\eta^2=0.069$, $p<0.001$), with Cluster 4 including the oldest respondents (median = 34.00) and Cluster 6 the youngest (median = 24.00). The geographic distribution showed no significant differences (Cramer's $V=0.17$, $p=0.268$), although Northern Italy was most represented overall. The educational profile significantly differed between clusters (Cramer's $V=0.28$, $p=0.004$), with Clusters 1 and 6 showing the highest proportions of RNs enrolled in MSN programs, and Clusters 2 and 5 showing a higher proportion of RNs without ongoing education. Among those reporting work settings ($n=61$), no significant differences were observed (Cramer's $V=0.16$, $p=0.363$), with surgical and outpatient care being the most common. Vaccination status and number of boosters differed significantly across clusters (Cramer's $V=0.29$, $p=0.003$; Cramer's $V=0.24$, $p<0.001$, respectively). Clusters 5 and 6 had the highest rates of respondents with three or more boosters, while Cluster 3 had the highest proportion of unvaccinated or minimally vaccinated individuals.

DRS, trust, concerns, and compliance scores between clusters

Figure 4 displays the distribution across the seven identified clusters of DRS and aVHS subscale scores, namely: Trust in Vaccine Efficacy, Concerns about Vaccine Safety, and Compliance with Recommendations. Figure S1, Figure S2, Figure S3, and Figure S4 describe the relationship maps between clusters and scores.

Statistically significant differences were observed across clusters for all four variables ($p<0.001$ for each, Kruskal–Wallis test). Cluster 5 exhibited the highest levels of decision regret and safety concerns, coupled with moderate trust and lower compliance. Conversely, Cluster 4 showed the lowest levels of regret and trust, indicating a detached or indifferent profile. Cluster 3 reported the lowest safety concerns and highest compliance, paired with low regret, characterizing a confident, guideline-aligned profile. Clusters 2 and 7 shared similar patterns of elevated regret and concerns but differed in compliance levels, with Cluster 7 showing higher adherence to recommendations. Cluster 6 stood out for extremely low trust and compliance, despite moderate regret.

	Cluster 1 (N=21)		Cluster 2 (N=48)		Cluster 3 (N=46)		Cluster 4 (N=68)		Cluster 5 (N=13)		Cluster 6 (N=26)		Cluster 7 (N=19)		Effect size	P
	N	%	N	%	N	%	N	%	N	%	N	%	N	%		
Sex																
	15	71.4	37	77.1	28	60.9	46	67.6	7	53.8	20	76.9	11	57.9		
Females															0.16	
Males	6	28.6	11	22.9	18	39.1	22	32.4	6	46.2	6	23.1	8	42.1		0.417
Age																
	27.00	24.00–38.00	29.00	24.25–40.00	28.50	25.00–40.00	34.00	25.25–40.00	31.00	25.00–47.00	24.00	24.00–28.00	28.00	24.00–33.00	0.069	<0.001
Years (median; IQR)																
Location																
	16	76.2	25	52.1	20	43.5	44	64.7	8	61.5	17	65.4	9	47.4		
Northern Italy																
Central Italy	3	14.3	13	27.1	15	32.6	11	16.2	1	7.7	6	23.1	4	21.1	0.17	0.268
Southern Italy	2	9.5	10	20.8	11	23.9	13	19.1	4	30.8	3	11.5	6	31.6		
Profile																
	14	66.7	22	45.8	22	47.8	31	45.6	5	38.5	23	88.5	9	47.4	0.28	0.004
RNs attending an MSN																
RNs with no ongoing university education	7	33.3	26	54.2	24	52.2	37	54.4	8	61.5	3	11.5	10	52.6		
Work settings (n=61 workers)																
	1	4.8	8	16.7	5	10.9	9	13.2	1	7.7	2	7.7	3	15.8		
Critical care																
Medical care	4	19	11	22.9	7	15.2	12	17.6	0	0	5	19.2	8	42.1		
Surgical care	7	33.3	10	20.8	11	23.9	17	25	4	30.8	4	15.4	4	21.1	0.16	0.363
Primary care	5	23.8	10	20.8	17	37	12	17.6	4	30.8	6	23.1	2	10.5		
Outpatient services	4	19	9	18.8	6	13	18	26.5	4	30.8	9	34.6	2	10.5		
COVID-19 vaccine*																
	21	100	42	87.5	45	97.8	68	100	13	100	26	100	19	100	0.29	0.003
Yes																
Number of COVID-19 Vaccine Boosters																
	0	0	6	12.5	1	2.2	0	0	0	0	0	0	0	0		
No boosters (unvaccinated respondents)																
One booster	0	0	5	10.4	0	0	1	1.5	0	0	3	11.5	2	10.5	0.24	<0.001
Two boosters	10	47.6	21	43.8	6	13	16	23.5	2	15.4	7	26.9	9	47.4		
Three or more boosters	11	52.4	16	33.3	39	84.6	51	75	11	84.6	16	61.5	8	42.1		

Table 2. Demographic characteristics and educational profiles between clusters. The significance threshold for all between-cluster comparisons was adjusted using the Bonferroni correction to account for multiple testing. The corrected alpha level was set at $p < 0.005$. Statistically significant p-values are shown in bold. Effect sizes are reported as Cramér's V for categorical variables and η^2 for continuous variables, with benchmarks of 0.10/0.30/0.50 (small/medium/large) for Cramér's V and 0.01/0.06/0.14 (small/medium/large) for η^2 .

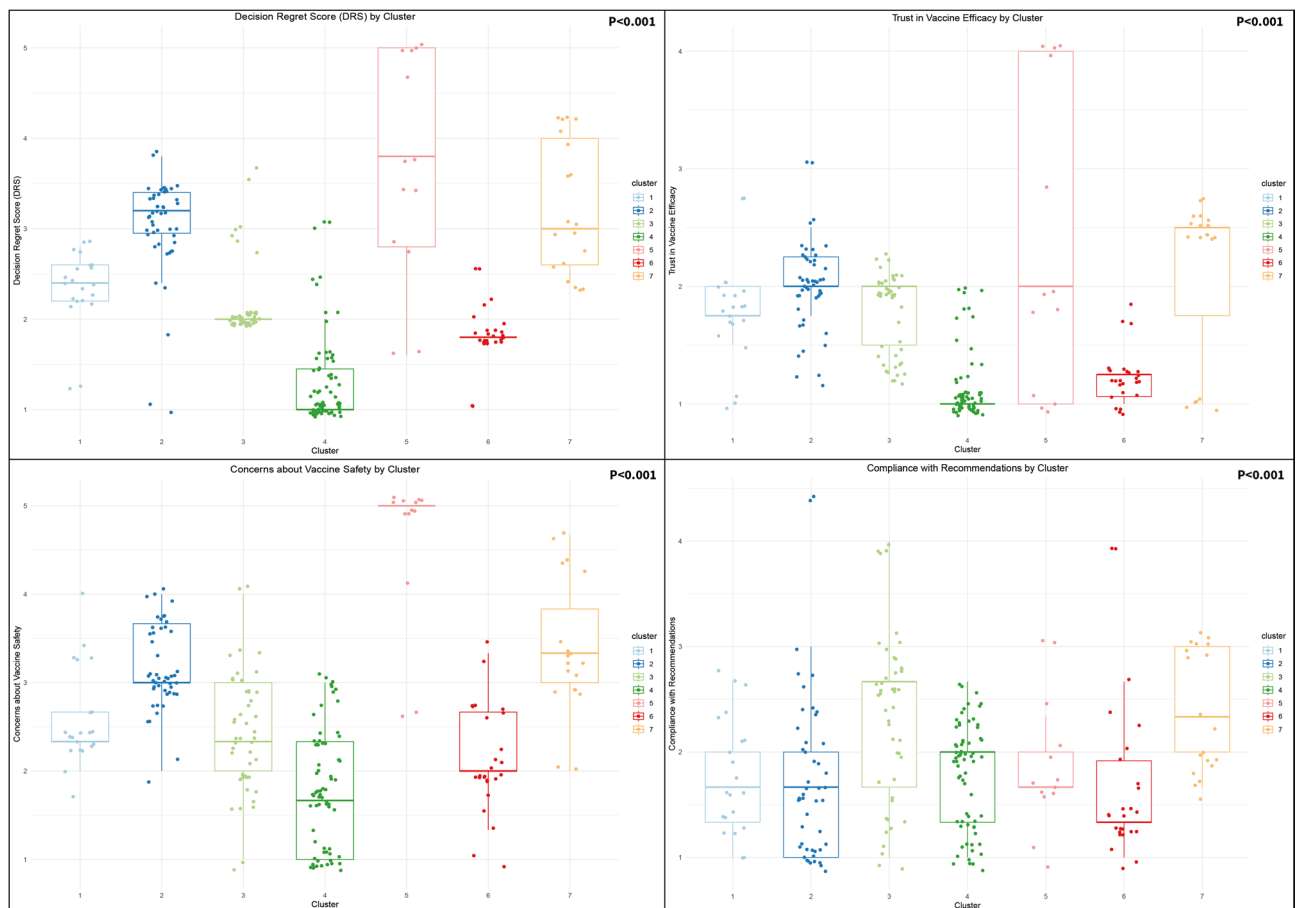


Fig. 4. Distribution of vaccine-related scores across the seven clusters. Each panel represents one dimension: (top left) Decision Regret Scale (DRS), (top right) Trust in Vaccine Efficacy, (bottom left) Concerns about Vaccine Safety, and (bottom right) Compliance with Health Recommendations. Colored jittered points correspond to individual scores. All comparisons between clusters were statistically significant (Kruskal–Wallis test, $p < 0.001$). Bonferroni correction was applied for pairwise comparisons (adjusted $\alpha = 0.005$).]

Post-hoc pairwise comparisons were conducted using Dunn's test with Holm correction (adjusted $\alpha = 0.005$) to further clarify these differences. For Decision Regret, multiple contrasts reached significance, notably between Cluster 4 and all other clusters ($p_{\text{adj}} < 0.001$), as well as between Clusters 3 and 5 ($p_{\text{adj}} = 0.0008$) and Clusters 5 and 6 ($p_{\text{adj}} = 0.0032$). For Trust in Vaccine Efficacy, Clusters 4 and 6 consistently differed from the majority of other clusters, with the strongest contrasts observed against Clusters 1, 2, and 3 (all $p_{\text{adj}} < 0.001$). In Concerns about Vaccine Safety, Cluster 5 showed significantly higher concern scores than Clusters 1, 3, and 4 (all $p_{\text{adj}} \leq 0.0001$), while Clusters 2 and 6 also differed markedly from most other clusters. Finally, for Compliance with Recommendations, significant contrasts emerged between Clusters 2 and 3 ($p_{\text{adj}} = 0.002$), Clusters 3 and 4 ($p_{\text{adj}} = 0.0009$), and Clusters 6 and 7 ($p_{\text{adj}} = 0.0034$). These results highlight distinct inter-cluster contrasts in attitudinal, emotional, and behavioral dimensions, reinforcing the heterogeneity of the identified profiles.

Discussion

This study aimed to identify distinct profiles of vaccine-related attitudes among Italian RNs working in comprehensive cancer centers, with specific attention to their educational engagement, namely, whether they were enrolled in an MSN program or not pursuing university education. Using a person-centered analytic approach, we applied unsupervised clustering techniques to a set of four core indicators^{45,46}: decision regret, trust in vaccine efficacy, concerns about vaccine safety, and compliance with institutional guidance. These indicators represent established dimensions of vaccine hesitancy, yet are rarely explored collectively through data-driven typologies within professional nursing populations^{23–26}. Our sample's demographic profile (68% female; median age 28 years) broadly aligns with national nursing workforce data, which indicates that 77.3% of nurses in Italy are female⁴⁷. The younger age of our participants compared to the national average (45 years) likely reflects the concentration of oncology nurses in specialist cancer centers and the inclusion of Master of Science in Nursing students. While this enhances the relevance of our findings for highly specialized oncology settings, it also suggests that caution is warranted in extrapolating to older or more generalist nursing populations.

The analysis revealed seven empirically derived clusters, each characterized by a unique configuration of cognitive, emotional, and behavioral orientations toward vaccination. These profiles ranged from “Confident

Adherent” RNs who demonstrated high trust, low regret, and high compliance, to more ambivalent or paradoxical patterns such as those observed in the “Regretful Believer” or “Resigned Skeptic” groups. This typology underscores the diversity of vaccine-related experiences even within a relatively homogeneous occupational cohort^{48–51}.

A key innovation of this study lies in its integration of machine learning–based dimensionality reduction (t-SNE) and hierarchical clustering to classify RNs based on multi-dimensional attitudinal data^{36,37,39}. This approach enabled the emergence of meaningful subgroups that transcend simple demographic categories and provide a nuanced understanding of hesitancy in a population united by professional identity but differentiated by educational and experiential variables. The seven clusters identified in this study reflect diverse and nuanced (sometimes counterintuitive) patterns of vaccine-related attitudes and behaviors among RNs. Interpreting these profiles through the lens of existing literature and behavioral theory reveals important insights into the interplay between cognitive appraisal, emotional response, and compliance behavior^{48,52–55}.

Cluster 3, which is the Confident Adherent group, exhibited low regret, high trust in vaccine efficacy, low concern about safety, and high compliance. This configuration aligns with prior findings that associate advanced education with greater vaccine acceptance and institutional trust^{56–59}. The majority of respondents in this cluster were either MSN students or RNs with strong engagement in institutional practice, suggesting that educational exposure may enhance perceived vaccine benefit and reduce hesitation⁶⁰. This profile resonates with the “Confidence” component of the 3 C model of vaccine hesitancy^{61,62} as well as with the Health Belief Model (HBM) concept of perceived benefit^{63,64}.

In contrast, Cluster 5 (Regretful Believer) presented a striking paradox: very high regret and concern coexisting with high trust in vaccine efficacy. Despite their confidence in the science, these RNs reported lower compliance, suggesting that emotional dissonance or post-vaccination distress may inhibit future adherence⁶⁵. This cluster may reflect the effects of mistrust in healthcare authorities, while keeping trust in science and vaccines^{66,67}. Such a distinction highlights how trust is not a monolithic construct: individuals may differentiate between scientific evidence, institutional actors, and political mandates. Prior research has shown that when institutional trust erodes, due to policy inconsistencies, lack of transparency, or coercive measures, individuals may still value scientific innovation but disengage from implementation frameworks⁶⁸. In this sense, Cluster 5 embodies a form of “disenchanted compliance,” in which cognitive alignment with vaccine efficacy is overridden by institutional fatigue or emotional withdrawal⁶⁹. From a behavioral theory perspective, this paradox is consistent with cognitive dissonance theory, whereby individuals experience psychological discomfort when their actions (e.g., compliance with vaccination mandates) conflict with emotional or moral evaluations of the process⁷⁰. Similar profiles have been described in studies of “vaccine regret,” where negative emotional responses to vaccination, whether due to perceived side effects, ethical concerns, or contextual pressures, lead to reduced future compliance despite maintained confidence in the vaccine’s scientific validity^{71,72}. This pattern underscores that trust in efficacy alone is insufficient to sustain adherence if negative affect and contextual mistrust remain unaddressed.

Cluster 6, labeled Resigned Skeptic, exhibited moderate regret but extremely low trust and compliance, paired with moderate concern. Notably, this group was predominantly composed of MSN students. While this finding may seem counterintuitive, it aligns with prior studies showing that heightened critical appraisal skills during postgraduate education may, in some cases, elicit increased skepticism due to perceived mismatch between policy, strategies, and personal values^{73,74}. This suggests that education alone does not uniformly enhance vaccine confidence; rather, its impact may vary depending on how individuals internalize curricular content, interpret peer norms, and respond to institutional messaging.

Cluster 2 (High Concern Hesitant) was notable for its moderate-to-high levels of regret and concern, low trust, and low compliance. This group bore the closest resemblance to the prototypical vaccine-hesitant profile identified in prior variable-centered studies^{75,76}. Yet, the clustering method allowed this group to be distinguished from others with similar surface characteristics but divergent underlying patterns. For example, Cluster 7, the Obligated Adherent, shared high concern and regret but maintained high trust and compliance, indicating that behavioral adherence can coexist with unresolved doubts, particularly among nurses with a strong sense of professional responsibility.

Cluster 1, labeled Passive Trust, showed moderate regret, low trust, low concern, and low compliance. This emotionally neutral, disengaged pattern may reflect complacency or a perception of low personal risk, aligning with the “Complacency” construct of the 3 C model⁵⁹. In contrast, Cluster 4 (Detached Skeptic) combined very low regret and trust with moderate concern and compliance. This group appeared cognitively and emotionally detached from the vaccination discourse, suggesting a form of passive disengagement rather than active resistance^{65,77}.

Age and education appeared to modulate these patterns slightly. Clusters with the highest booster uptake and compliance (e.g., Clusters 3 and 5) tended to include older participants, while younger nurses (especially in Cluster 6) reported lower compliance and trust. Educational status was similarly influential: while MSN attendance was associated with profiles showing high engagement (Cluster 3), it also appeared in clusters marked by mistrust (Cluster 6), reinforcing the idea that education shapes, but does not determine, vaccine attitudes⁷⁸.

The identification of seven distinct vaccine-related profiles among RNs underscores the need for tailored communication strategies that move beyond generic vaccine promotion^{79–87}. Public health messaging and institutional education should be differentiated according to each profile’s cognitive, emotional, and behavioral characteristics, addressing regret in some groups, rebuilding trust in others, or enhancing clarity around safety and efficacy where concerns prevail. In this context, advanced nursing education plays a pivotal role^{10,17}. MSN programs help foster critical appraisal skills and deepen understanding of public health rationales, which may enhance vaccine acceptance when institutional narratives are perceived as credible and ethically sound. However, as observed in this study, education could also lead to skepticism if professional values clash with

Cluster	n	Label		Profile Description
1	21	Passive Trust	☹️	Mid-level DRS (moderate regret), low trust, low safety concerns (i.e., more concern), and low compliance. Emotionally neutral but behaviorally passive.
2	48	High Concern Hesitant	☹️ ?	Low DRS (high regret), low trust, high safety concern, low compliance. Hesitant and emotionally unsettled, with significant regret and doubt.
3	46	Confident Adherent	✅	High DRS (low regret), high trust, few concerns, and high compliance. A rational, confident profile aligned with vaccine guidance.
4	68	Detached Skeptic	🗑️	Very high DRS (very low regret), very low trust, moderate concerns, moderate compliance. Disconnected but not emotionally reactive.
5	13	Regretful Believer	☹️ 🤝	Very low DRS (high regret), high trust, very few concerns, low compliance. Paradoxical: believes in the vaccine but regrets getting it and disengages.
6	26	Resigned Skeptic	❌	Moderate DRS (some regret), very low trust, moderate concerns, low compliance. Emotionally detached and skeptical toward institutions.
7	19	Obligated Adherent	☹️ ✍️	Mid-to-low DRS (some regret), high trust, fewer concerns, and high compliance. Accepting guidance but not fully at peace with the decision.

Note: Each profile combines cognitive (trust in vaccine efficacy, concerns about safety), emotional (decision regret), and behavioral (compliance with recommendations) dimensions to create a distinct “attitudinal fingerprint.” Icons indicate the predominant emotional tone.

Fig. 5. Cluster-based fingerprinting of vaccine-related attitudes. Each cluster is labeled with a descriptive title, corresponding iconography, and a narrative summary with interpretative emerging profiles. The figure illustrates the diversity of cognitive, emotional, and behavioral orientations toward COVID-19 vaccination among Italian RNs working in comprehensive cancer centers.]

policy implementation. Finally, vaccine-related behaviors carry heightened implications in oncology care settings, where RNs serve immunocompromised patients. Nurses’ adherence to vaccination schedules is crucial to protecting vulnerable populations and reinforcing institutional norms and safety culture. Tailoring interventions to specific attitudinal profiles may strengthen nurses’ roles as informed, trusted communicators in high-stakes clinical environments.

Our results are consistent with recent international research that has applied clustering approaches to examine vaccine attitudes among healthcare workers. For example, McCready et al. identified five clusters among UK nurses, including “Wholehearted Acceptors” and “Skeptical Hesitants,” which parallel our Confident Adherent and High Concern Hesitant profiles²⁵. Similarly, Erfani et al. reported four patterns among Iranian nurses, noting the coexistence of high trust and high regret in one subgroup, a paradox closely mirroring our Regretful Believer cluster²⁶. The present study extends these patterns by identifying seven distinct profiles within Italian oncology nurses, revealing more nuanced and sometimes unexpected combinations of trust, regret, and compliance (e.g., the Regretful Believer), which were not captured in the simpler two- to four-group solutions of prior work. Notably, another recent study⁸⁸ also reported mixed-profile clusters where trust in vaccine science coexisted with low institutional trust, aligning with our observation that trust is multidimensional and differentially directed toward science versus policy actors. The greater granularity of our typology likely reflects the use of multiple psychometrically robust scales and a machine-learning clustering approach, underscoring the value of fine-grained segmentation for tailoring communication strategies to specific cognitive-emotional profiles.

Although data collection was completed between June and September 2024, the interpretation of these findings should be viewed in light of the evolving COVID-19 landscape. Changes in national vaccination policies, the introduction of updated booster formulations, shifting public health priorities, and reduced pandemic salience in public discourse may all influence the stability of the profiles described in this study^{89,90}. While core psychological constructs such as trust, regret, and compliance are likely to remain relevant, the magnitude and distribution of these attitudes may shift over time as contextual cues, institutional messaging, and personal risk perceptions change. Longitudinal monitoring of these clusters could clarify whether they represent enduring orientations toward vaccination or transient responses to a specific phase of the pandemic.

Emerging fingerprints

Summarizing the combination of Decision Regret, Trust in Vaccine Efficacy, Concerns about Vaccine Safety, and Compliance with Recommendations revealed seven distinct clusters, each reflecting a unique psychological and behavioral orientation toward COVID-19 vaccination (Fig. 5). These clusters represent diverse patterns of engagement, ranging from emotionally neutral and behaviorally passive to rationally confident or emotionally conflicted.

Cluster 1 Passive Trust was characterized by mid-level decision regret, low trust, high concern, and low compliance, suggestive of emotional detachment and behavioral passivity. Cluster 2 High Concern Hesitant combined high regret, low trust, high concern, and low compliance, representing an emotionally unsettled group marked by significant doubt. Cluster 3 Confident Adherent exhibited low regret, high trust, low concern, and high compliance, aligning with a rational and health-guided decision-making process. Cluster 4 Detached Skeptic showed very low regret, very low trust, moderate concern, and moderate compliance, suggesting cognitive disengagement despite partial behavioral adherence. Cluster 5 Regretful Believer presented a paradoxical profile of very high regret, high trust, very low concern, and low compliance. These participants appeared to believe in the vaccine’s efficacy but withdrew from adherence, possibly due to unresolved emotional distress. Cluster 6 Resigned Skeptic demonstrated moderate regret, very low trust, moderate concern, and low compliance,

indicative of emotional detachment and skepticism toward institutions. Cluster 7 Obligated Adherent combined some degree of regret with high trust, low concern, and high compliance, suggesting compliance driven more by a sense of duty than by internal conviction.

Strengths and limitations

This study presents several strengths that enhance its methodological and practical relevance. First, it introduces a novel cluster-based approach that moves beyond variable-centered analyses, enabling the identification of behaviorally distinct profiles of vaccine attitudes among RNs. Using a real-world clinical population (i.e., RNs working in comprehensive cancer centers), this study adds ecological validity to the findings, particularly in a high-stakes care context where vaccination adherence is crucial^{91,92}. Moreover, the study is grounded in robust psychometric instruments, which capture a nuanced spectrum of cognitive and emotional dimensions underpinning vaccine behavior.

Nevertheless, several limitations should be acknowledged. The cross-sectional design prevents causal inference and limits the ability to assess changes in vaccine attitudes over time. Data were based on self-reported measures, which may be subject to recall bias and social desirability effects. Although the sample included RNs from various Italian regions, generalizability is constrained by its focus on oncology nurses affiliated with a national professional association. Members of AIIAO may differ from the broader oncology nursing workforce in their level of professional engagement, and the non-random recruitment strategy via association mailing lists may have attracted individuals with stronger views or higher engagement. Our sample's demographic profile (68% female; median age 28 years) broadly aligns with national nursing workforce data, which indicate that 77.3% of nurses in Italy are female, although the younger age compared to the national average (45 years) reflects the concentration of oncology nurses in specialist cancer centers and the inclusion of MSN students. The response rate was approximately 50%, consistent with comparable surveys of healthcare professionals. Yet, non-response bias cannot be excluded, as participants may differ systematically from non-respondents in vaccine-related attitudes and behaviors. While the t-SNE parameters were justified and sensitivity-tested across a broad range, their stochastic nature may still yield minor local variations in the embedding. However, the overall cluster structure remained stable. Finally, one cluster was relatively small ($n = 13$), warranting cautious interpretation of its estimates despite the strong overall stability observed in subsampling and perturbation analyses.

Future research should employ longitudinal designs to monitor the evolution of vaccine-related attitudes and behaviours among RNs, clarifying potential causal pathways between educational status, attitudinal dimensions, and actual vaccination behaviours. Broader and more representative sampling frames, extending beyond oncology settings, would improve the generalisability of the profiles identified. At the same time, the integration of objective indicators of vaccine uptake, such as institutional immunisation records, would mitigate self-report bias and strengthen the robustness of the evidence base.

Practical implications

The seven profiles identified in this study highlight the necessity of moving beyond uniform vaccine promotion strategies toward approaches that are tailored to the specific cognitive, emotional, and behavioral configurations of each group. For nurses exhibiting patterns of passive trust, interventions may need to focus on overcoming behavioral inertia through streamlined processes and subtle prompts that encourage uptake without requiring high cognitive effort. Those displaying high concern and hesitancy are likely to benefit from transparent, safety-focused communication delivered by credible peers, accompanied by structured opportunities to address specific fears and uncertainties. In contrast, confident adherents, characterized by high trust and compliance, represent a valuable institutional resource and could be strategically engaged as peer champions to amplify positive norms. Detached skeptics, whose disengagement is both cognitive and emotional, may respond more effectively to personalized, motivational interviewing approaches that explore underlying barriers while reinforcing professional responsibility. The paradoxical profile of the regretful believer suggests the need for interventions that address emotional dissonance following vaccination, including supportive forums to process adverse experiences and to reconcile trust in science with dissatisfaction toward institutional processes. Resigned skeptics, particularly those encountered in postgraduate educational settings, may require targeted curricular and dialogue-based strategies that openly acknowledge and address tensions between personal values, critical appraisal, and policy mandates. Finally, obligated adherents, whose compliance is driven more by professional duty than by intrinsic conviction, might be supported through targeted, evidence-based communication aimed at consolidating trust and preventing disengagement over time. Collectively, aligning communication, education, and institutional engagement strategies with the attitudinal fingerprints of each profile has the potential to strengthen vaccine adherence, safeguard immunocompromised patients in oncology settings, and reinforce a sustainable culture of safety.

Conclusions

This study identified seven distinct profiles of vaccine-related attitudes among Italian RNs working in comprehensive cancer centers, highlighting the complex interplay between decision regret, trust, concerns, and compliance. The findings underscore the need for tailored communication and education strategies that take into account cognitive and emotional diversity within the nursing workforce. A person-centered approach may enhance vaccine confidence and adherence, particularly in high-risk clinical settings where nurses play a pivotal role in safeguarding patient and institutional safety.

Data availability

The data that support the findings of this study are available from AIIO (Associazione Italiana Infermieri di Area Oncologica), but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are, however, available from the authors upon reasonable request and with permission of AIIO by contacting Rosario Caruso (rosario.caruso@unimi.it).

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Conceptualization, R.C., P.M.P., Si.C., and S.B.; Methodology, R.C., A.S.B., A.M., C.A., M.G., and A.P.; Software, R.C.; Validation, R.C., A.S.B., P.M.P., and Si.C.; Formal analysis, R.C.; Investigation, all authors; Resources, A.M.; Data curation, R.C. and S.B.; Writing – original draft preparation, A.S.B. and R.C.; Writing – review and editing, R.C., C.A., M.A.A., S.B., Se.C., G.C., G.Cr., M.D., M.G., A.P., A.M., and Si.C.; Visualization, R.C.; Supervision, R.C., C.A., A.M., and Si.C.; Project administration, A.M. All authors have read and agreed to the published version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

This study was carried out in accordance with relevant guidelines and regulations according to the Declaration of Helsinki. Ethical approval for the study was obtained from the IRB of the University of Pavia (protocol number 4/CDS/2024, approved 18 March 2024) and the IRB of AIIAO (protocol number CD/5/2024, approved 15 May 2024). Ethical considerations for the study included obtaining electronically signed informed consent, preserving anonymity and confidentiality of participants, the voluntary nature of participation and the right to withdraw from the study at any time.

Consent for publication

Not applicable.

Additional information

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