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Modelling Well-Being and Psychological Risk in Doctoral Education: An Integrated Latent Trait Approach

Donnarumma, A.; Guagliardi, O.; Di Stazio F.; Mazza E.; Tanelli M.; Paganoni A.M.

MOX, Dipartimento di Matematica
Politecnico di Milano, Via Bonardi 9 - 20133 Milano (Italy)

mox-dmat@polimi.it https://mox.polimi.it

Modelling Well-Being and Psychological Risk in Doctoral Education: An Integrated Latent Trait Approach

Alessandro Donnarumma[1], Oriana Guagliardi[2], Filomena Di Stazio[3], Elena Mazza[2,4], Mara Tanelli[2], Anna Maria Paganoni[1]

[1]MOX Laboratory, Department of Mathematics (DMAT), Politecnico di Milano, Milan, Italy.

[2]Department of Electronics, Information and Bioengineering (DEIB), Politecnico di Milano, Milan, Italy.

[3]Campus Life, Politecnico di Milano, Milan, Italy.

[4]Psychiatry Clinical Psychobiology, Division of Neuroscience, IRCCS Ospedale San Raffaele, Milan, Italy.

Correspondence: Alessandro Donnarumma, MOX Laboratory, Department of Mathematics (DMAT) Politecnico di Milano, Milan, Italy. E-mail: alessandro.donnarumma@polimi.it

Abstract

Doctoral education is increasingly recognized as a context in which psychological distress may emerge, shaped by academic demands, institutional environments and interpersonal dynamics. However, evidence on how these latent dimensions jointly configure doctoral well-being remains limited. This study investigates psychophysical well-being, psychological risk indicators and perceived discrimination among PhD candidates at a large public Italian university, using data from an anonymous voluntary questionnaire administered to doctoral researchers on well-being, academic stress, institutional conditions, social support and doctoral experience.

Latent constructs of psychological well-being were extracted using Item Response Theory models: among the tested specifications, the Four-Parameter Nested Logistic Regression Model (4PLnRM) provided the best empirical fit, capturing heterogeneity in item response patterns and improving representation of the latent trait structure. Results show that doctoral well-being is primarily driven by personal resources and perceived institutional quality, whereas social support has a comparatively limited association, challenging conventional assumptions regarding the protective role of peer networks in doctoral contexts.

With respect to perceived discrimination, a clear asymmetry emerges between vertical and horizontal dynamics. Supervisor-related ("hierarchical") discrimination is strongly associated with higher stress and poorer psychological outcomes, particularly among women and candidates considering program withdrawal, while peer-related ("horizontal") discrimination shows weak associations. Overall, findings indicate that doctoral mental health is more strongly associated with supervisory and institutional conditions than with informal support networks, suggesting that improving doctoral well-being may require structural interventions targeting supervisory relationships and institutional governance rather than relying exclusively on individual coping resources.

Keywords: Doctoral Education, Psychophysical Well-Being, Item Response Theory, Academic Discrimination, Attrition Risk, Supervisory Crisis

1. Introduction

1.1 Doctoral Well-Being as a Global Higher Education Challenge

Over the past decade, doctoral well-being has become a major concern for higher education systems worldwide. A growing body of evidence indicates that doctoral researchers experience substantially higher levels of psychological distress than both the general population and other highly educated groups (Levecque et al., 2017; Evans et al., 2018). Levecque et al. (2017) reported that approximately one-third of PhD candidates were at risk of developing a common psychiatric disorder, while Evans et al. (2018) found that graduate students were more than six times as likely as the general population to experience symptoms of anxiety and depression. Although prevalence estimates vary across national contexts, disciplinary settings and measurement strategies, subsequent research has consistently confirmed the elevated psychological vulnerability of doctoral researchers (Sverdlik et al., 2018; Satinsky et al., 2021).

1.2 Doctoral Socialization and Persistence

Doctoral well-being cannot be understood solely as the absence of psychological distress. Doctoral education is also a prolonged process of academic and professional socialization, through which candidates acquire disciplinary identities, research practices and professional norms while negotiating their place within scholarly communities (Weidman et al., 2001; Gardner, 2008). Supportive socialization may foster engagement, belonging and persistence, whereas fragmented or dysfunctional socialization can contribute to isolation, dissatisfaction and attrition (Lovitts, 2001; Golde, 2005). Recent research has therefore increasingly conceptualised doctoral persistence as a multidimensional process shaped by individual resources, supervisory relationships, departmental climate, academic identity formation and broader institutional conditions (Pyhältö et al., 2012; Cornér et al., 2017; Sverdlik et al., 2018). From this perspective, remaining in a doctoral programme is not merely a matter of personal motivation, but depends on whether the academic environment sustains candidates' engagement, legitimacy and sense of belonging over time.

1.3 Personal Resources and Doctoral Well-Being

Individual resources nevertheless remain central to doctoral trajectories. Psychological Capital theory emphasizes self-efficacy, resilience, optimism and hope as resources that support adaptation to demanding and uncertain environments (Bandura, 1997; Luthans et al., 2007). In doctoral education, these resources may buffer the effects of workload, academic setbacks and prolonged evaluation, while supporting persistence and engagement. However, their protective role should not be interpreted in purely individual terms. Personal resources are developed, sustained or depleted within relational and institutional contexts, including the quality of supervision, peer relationships and the broader organisational climate.

1.4 Supervisory Relationships, Relational Agency and Doctoral Well-Being

Among the contextual determinants of doctoral well-being, supervisory relationships occupy a particularly central position. Supervisors act not only as academic mentors, but also as evaluators, gatekeepers of progression and mediators of professional socialization (Lee, 2008). Their role may therefore shape doctoral candidates' psychological experiences, academic engagement, perceived legitimacy and decisions about persistence. The concept of relational agency offers a useful lens for interpreting these dynamics. Pyhältö and Keskinen (2012) suggest that doctoral well-being depends partly on whether candidates experience themselves as active contributors within meaningful scholarly communities. Intellectual autonomy, reciprocal recognition and constructive supervision may strengthen engagement and psychological flourishing; conversely, poor communication, asymmetrical power relations, discrimination and limited autonomy may undermine agency and intensify alienation, stress and emotional exhaustion (Cornér et al., 2017).

This relational perspective also highlights the need to distinguish between different sources of support and strain. Peer support is often described as protective against doctoral stress, yet the relative contribution of horizontal peer relationships and hierarchical supervisory relationships remains insufficiently disentangled. This distinction is especially important when considering perceived discrimination. Peer-related and supervisor-related discrimination may both damage well-being, but they are unlikely to operate through identical mechanisms. Because supervision involves evaluation, academic progression and access to future opportunities, supervisor-related discrimination may have particularly severe implications for psychological vulnerability and dropout intentions. Nevertheless, these mechanisms remain underexamined in doctoral well-being research (Cornér et al., 2017; Sverdlik et al., 2018). This gap motivates the present study's comparison of supervisor-related and peer-related forms of discrimination.

1.5 Methodological Limitations and the Present Study

Despite growing evidence on doctoral mental health, several theoretical and methodological gaps remain. First, the relative contribution of personal resources, institutional quality, supervisory relationships and social support is still insufficiently disentangled. Second, discrimination is often treated as a homogeneous experience, with limited attention to the potentially different consequences of hierarchical and peer-related forms. Third, much empirical work relies on aggregated sum scores from self-report questionnaires, implicitly treating psychological constructs as directly observable and uniformly measured. Doctoral well-being, however, is better understood as a latent and multidimensional phenomenon shaped by heterogeneous response patterns, varying sensitivities to stressors and interactions among individual, relational and institutional determinants (Embretson & Reise, 2000; Reise et al., 2005).

Conventional approaches may therefore obscure important forms of vulnerability, including latent heterogeneity across doctoral populations and non-linear associations between psychosocial factors and global well-being.

Against this background, the present study investigates doctoral well-being among PhD researchers at a large public Italian university through an integrated quantitative framework designed to capture both the multidimensional structure of psychological well-being and the complexity of its determinants. Rather than treating doctoral distress as a directly observable and homogeneous condition, the study conceptualizes well-being as a latent construct influenced by individual resources, supervisory and peer relationships, organisational climate and broader contextual stressors (Rasch, 1960; Wilson, 2005). Particular attention is devoted to the role of supervisory relationships and perceived discrimination, while also considering peer support and institutional quality.

The study addresses three main aims. First, it examines the latent structure of doctoral well-being and related psychosocial dimensions through psychometric modelling. Second, it investigates how personal, relational and institutional factors contribute to psychological vulnerability, severe mental-health-related symptoms and dropout-related intentions. Third, it explores whether distinct profiles of doctoral candidates can be identified, thereby accounting for heterogeneity that may be hidden by variable-centered approaches alone. To pursue these aims, the analysis combines item response theory, machine-learning classification, non-linear modelling and latent class/profile approaches within a unified empirical framework. This integration links measurement, prediction and interpretation, offering a more nuanced account of how doctoral well-being is shaped by the interplay between individual resources and the academic environment.

The remainder of the article presents the study context, questionnaire structure and analytical strategy, followed by the empirical results, discussion of the main findings, and concluding remarks on limitations and future research.

2. Methods

2.1 Study Context, Participants and Data Preprocessing

This study was conducted within an institutional initiative aimed at monitoring psychological well-being and academic experience among students and doctoral candidates at a large public Italian university. Data were collected through an anonymous and voluntary questionnaire developed within the university psychological support area, with the aim of investigating multiple dimensions of well-being, academic stress and perceived institutional climate. Participation was voluntary and anonymous, and respondents provided informed consent before completing the questionnaire. Data were analysed in aggregated form and no personally identifiable information was available to the researchers.

Although the broader survey involved the entire student body, the present study focuses exclusively on doctoral candidates, whose academic pathway is characterized by distinctive structural and psychological challenges. Accordingly, the original dataset was first restricted to PhD respondents only, excluding participants belonging to other student populations.

Before model estimation, the dataset underwent preprocessing to ensure consistency, reliability and interpretability across the subsequent analytical stages. Variables were inspected for coding consistency, admissible response ranges and missing values. Variables with more than 30% missing values were removed, and observations with missing values in the retained variables were excluded, resulting in a complete-case analytical dataset. Imputation was not applied because the analyses relied on observed response patterns across psychometric items, discrimination-related variables and subjective well-being indicators; imputing these responses would have required additional assumptions about the missing-data mechanism and could have altered response distributions, item category probabilities and latent profile structures.

Following data cleaning and preprocessing, the final analytical sample consisted of 637 PhD respondents and 172 variables. Among these, 84 psychometric items were measured on a 5-point Likert scale, while the remaining variables included socio-demographic characteristics, such as gender, nationality and age group, doctoral experience indicators, academic-related stressors and information regarding psychological symptoms and mental health history. Likert-type response formats are widely used in psychometric and educational research because they permit the measurement of latent attitudes and perceptions through ordered response categories (Joshi et al., 2015).

To ensure consistency across analyses, all psychometric questions were harmonised so that higher response values, namely 4 or 5 on the Likert scale, systematically indicated more favourable psychophysical conditions, stronger perceived resources or lower levels of stress, whereas lower scores, namely 1 or 2, reflected poorer well-being, weaker

perceived resources or higher stress. When necessary, negatively oriented items were reverse-coded to ensure a common interpretative direction across scales.

2.2 Measures and Questionnaire Structure

The questionnaire was developed by drawing on previous research on doctoral researchers' stress, mental well-being, and socio-psychological experiences within academic communities. In particular, the construction of the items was informed by Byrom et al. (2022), who examined predictors of stress and mental well-being among doctoral researchers, and by Stubb et al. (2011), whose work focused on PhD students' socio-psychological well-being, including the balance between inspiration, exhaustion, and the perceived quality of the scholarly community.

The primary domain, *general well-being and life satisfaction*, was conceptualised as the reference indicator of psychophysical well-being. Five additional domains captured factors potentially associated with doctoral stress and adaptation: *social resources*, *quality of the university environment*, *doctoral climate*, *personal resources* and *PhD workload*. Together, these domains covered perceived support, institutional inclusivity and safety, collegial climate, self-confidence in managing the doctoral pathway and the psychological burden of workload. This multidimensional structure aligns with latent trait perspectives in psychometric measurement (Embretson & Reise, 2000; Reise et al., 2005).

2.3 Item Response Theory (IRT) Framework

Psychological well-being is not directly observable and is therefore more appropriately conceptualised as a latent construct rather than as a simple aggregate of questionnaire responses. For this reason, Item Response Theory (IRT) was adopted to estimate the underlying dimensions of doctoral well-being while accounting for heterogeneity in item functioning and response behaviour (Embretson & Reise, 2000; de Ayala, 2009).

Formally, let X_{ij} denote the response of individual j to item i, let θ_j be a real-valued latent trait denoting the corresponding level of the underlying construct for respondent j, and let φ_i be the vector of item-specific parameters. For model identification, the latent trait distribution was assumed to follow a standard normal distribution: $\theta_j \sim N(0,1)$. IRT models specify the probability of observing a given response category k as a conditional function of the latent trait and item-specific parameters (Baker, 2001):

$$P(X_{ij} = k \mid \vartheta_j, \varphi_i) \tag{1}$$

Given the ordinal nature of the questionnaire items, four alternative polytomous IRT specifications were evaluated using the 29-item psychophysical well-being subscale (θ_{Score}): the Rating Scale Model (RSM), the Graded Response Model (GRM), the Generalized Partial Credit Model (GPCM), and the Four-Parameter Nested Logistic Regression Model (4PLnRM). These models differ in their flexibility in representing polytomous response processes.

Model estimation was performed using the *mirt* package for the R environment (Chalmers, 2012). To compare competing specifications, model selection combined traditional information criteria (AIC and BIC) with an empirical measure of explanatory power, namely the Proportion of Variance Explained (PropVar). This was computed as the ratio between explained and observed item variance.

Table 1. Polytomous IRT Model Fit Comparison

Model	log L	AIC	BIC	PropVar
RSM	-25,762.62	51,759.24	52,280.68	0.40
GRM	-24,470.65	49,231.30	49,877.53	0.38
GPCM	-19,261.09	38,752.17	39,264.70	0.61

Model	log L	AIC	BIC	PropVar
4PLnRM	-19,193.95	38,847.10	39,872.15	0.74

Among the evaluated models, the 4PLnRM achieved the highest explanatory power, accounting for 74% of the total observed variance in the psychophysical well-being scale. Although the GPCM achieved lower AIC and BIC values, the 4PLnRM explained a substantially larger proportion of observed variance. The 4PLnRM was therefore retained because its additional flexibility was theoretically relevant to the study aims and better captured response heterogeneity in the well-being scale.

The Four-Parameter Nested Logistic Regression Model (4PLnRM) extends the conventional 4PL framework by combining a logistic component for the key response category with a nested nominal component for the remaining response options. In the present study, the highest response category of the 5-point Likert scale ($k^*=5$) was defined as the key category, corresponding to the most favourable psychophysical condition. The probability of endorsing this category is modelled as:

$$P(X_{ij} = k^* \,|\vartheta_j) = \; c_i + (d_i - c_i)/(1 + exp^{-1}\{a_i(\vartheta_j - b_i)\}) \tag{2}$$

where a_i denotes item discrimination, b_i item difficulty, c_i the lower asymptote, d_i the upper asymptote, and θ_j the latent trait of respondent j. Conditional on not selecting the key category, the remaining response categories (k = 1,2,3,4) are modelled through a nested nominal structure. This formulation allows respondents with high levels of latent well-being to retain a non-zero probability of selecting categories lower than 5, thereby accommodating heterogeneous response processes, item-specific nuances and subjective interpretations of response labels: unlike conventional ordinal IRT models, the 4PLnRM does not rely exclusively on ordered category thresholds, providing greater flexibility in representing complex response behaviour.

2.4 Predictive Modelling of Psychological Vulnerability

To complement psychometric estimation with predictive and explanatory analyses, a second analytical stage investigated the extent to which latent dimensions of doctoral well-being were associated with severe psychological vulnerability and overall psychophysical well-being. Given the potential complexity and non-linearity of psychosocial mechanisms underlying doctoral distress, both ML classification algorithms and semi-parametric regression approaches were employed.

2.4.1 Classification of Severe Psychological Risk

To investigate whether latent dimensions of doctoral well-being were predictive of severe psychological vulnerability, supervised ML classifiers were employed to identify doctoral candidates at higher psychological risk. The outcome variable was a binary indicator of severe psychological symptoms, defined by the presence of at least one among panic attacks, self-harm ideation or suicidal thoughts reported during the previous twelve months. This outcome aimed to distinguish respondents experiencing severe manifestations of psychological distress from those reporting less critical conditions.

Predictors included both latent trait estimates derived from the IRT framework and relevant contextual variables describing doctoral experience and socio-demographic characteristics. Specifically, latent dimensions related to social resources, institutional climate, workload, personal resources and doctoral environment were included alongside variables concerning gender, nationality, intention to discontinue the doctoral programme and economic affordability.

Two complementary tree-based ML algorithms were implemented: Random Forest (RF) and Extreme Gradient Boosting (XGBoost). These methods were selected because of their ability to model complex interactions and non-linear relationships without imposing restrictive parametric assumptions.

These models were employed not merely for prediction accuracy, but primarily to identify the relative importance of the IRT-extracted latent features in explaining severe psychological vulnerability among doctoral researchers, in order

to assess the practical relevance of the proposed IRT measurement strategy. Model performance was evaluated through cross-validated classification metrics, including accuracy, precision, recall and area under the receiver operating characteristic curve (AUC). Given the partially imbalanced nature of psychological risk outcomes, multiple evaluation metrics were retained to avoid misleading interpretations based solely on predictive accuracy.

2.4.2 Generalized Additive Model (GAM)

To investigate potentially non-linear relationships between overall psychophysical well-being and its underlying latent dimensions, a Generalized Additive Model (GAM) was estimated (Wood, 2017).

GAMs were used because relationships between psychological well-being and contextual stressors may involve thresholds, diminishing returns or asymmetric effects that are not captured by linear specifications.

In the present analysis, thin-plate regression splines were employed to flexibly estimate the relationship between latent dimensions of doctoral experience and global psychophysical well-being while avoiding excessive parametric assumptions regarding functional form (Wood, 2017). The degree of smoothness was estimated automatically through penalized likelihood procedures implemented in the mgcv package for the R environment (Wood, 2011). Given the approximately Gaussian distribution of the dependent variable, the GAM was specified using a Gaussian response distribution with an identity link. Formally, the model takes the form:

$$\vartheta_{Score_i} = \beta_0 + \sum_{j=1}^{5} s(\vartheta_{j_i}) + \varepsilon_i \ , \ \ \varepsilon_i \sim N(0, \sigma^2) \tag{3}$$

where θ_1 = personal resources, θ_2 = quality of the university environment, θ_3 = workload, θ_4 = doctoral climate, θ_5 = social resources and $s(\cdot)$ denotes the smooth non-linear function estimated via penalized splines.

2.5 Relational and Institutional Determinants of Doctoral Distress

A final analytical stage focused on relational and institutional determinants of doctoral distress, with particular attention to perceived discrimination and supervisory relationships. Because discrimination may emerge through heterogeneous configurations of experiences and institutional contexts, complementary person-centered and inferential approaches were combined.

To investigate patterns of perceived discrimination across doctoral programmes, additional analyses were conducted using questionnaire items not included in the IRT framework. These analyses used non-Likert questionnaire items to distinguish the type of discriminatory or aggressive experience reported and the perceived source of responsibility.

In our sample, 29.3% of respondents report having experienced or witnessed at least one discriminatory episode or aggressive/unwanted behaviour within the academic environment; however, to ensure coherence and significance of the analyses, only respondents who explicitly reported personally experiencing such episodes were subsequently considered as the positive class for inferential modelling.

2.5.1 Latent Class Analysis of Discrimination Profiles

To investigate heterogeneity in perceived discrimination experiences, Latent Class Analysis (LCA) was conducted on categorical indicators of discriminatory, aggressive or inappropriate behaviours. LCA was used to identify unobserved subgroups of PhD students sharing similar response patterns, with model selection based on Log-Likelihood, AIC, BIC and substantive interpretability, while avoiding solutions driven by very small or poorly distinguishable classes (McCutcheon, 1987).

2.5.2 Group Differences in Psychological Vulnerability (ANOVA)

A one-way ANOVA was conducted to compare the IRT-extracted θ_{Score} across four discrimination groups: *supervisors/tutors only, peers only, both* and *none*. We remark that lower θ_{Score} values correspond to higher perceived stress and poorer psychophysical well-being. Model assumptions were inspected, and homogeneity of variance was supported by Levene's test ($p=0.68$). Following a significant omnibus test, Tukey's HSD was used for pairwise

comparisons while controlling for family-wise error inflation.

2.5.3 Logistic Generalized Linear Model (GLM) of Supervisor-Related Discrimination

Finally, a logistic Generalized Linear Model (GLM) was estimated to identify predictors of perceived supervisor-related discrimination. The binary outcome indicated whether a respondent reported discrimination involving supervisors or faculty members. Predictors included gender, intention to modify or abandon the doctoral programme, age group and international student status.

Before retaining the final GLM specification, a preliminary mixed-effects model including a PhD course-level random intercept was estimated to assess whether supervisor-related discrimination varied substantially across doctoral programmes. The resulting Variance Partition Ratio was very low (VPR = 2.1%), indicating that only a small proportion of the variability was attributable to programme-level differences. Accordingly, and to avoid unnecessary model complexity, the final inferential model was specified as a more parsimonious logistic GLM without random effects.

Formally, let Y_i be the binary outcome indicating whether respondent i reported supervisor-related discrimination. The model takes the form:

$$logit(P(Y_i = 1)) = \beta_0 + \sum_{k=1}^{p} \beta_k X_{ki} , \quad (4)$$

where β_0 is the intercept, X_{ki} are the individual-level predictors and β_k are the corresponding fixed-effect coefficients.

3. Results

3.1. Descriptive and Exploratory Analysis

The cleaned dataset comprised 637 doctoral candidates. Descriptive analyses indicated substantial psychological and institutional vulnerability within the sample. Overall, 40.7% of respondents reported an intention to modify their research programme or discontinue the doctoral pathway, while 31.9% reported insufficient economic resources to sustain their research under satisfactory conditions. Severe psychological manifestations were also frequent: 24% of respondents reported at least one among panic attacks, self-harm ideation or suicidal thoughts during the previous twelve months. These descriptive patterns provide the empirical background for the subsequent latent trait, predictive and relational analyses.

3.2. Latent Trait Estimation and IRT Model Selection

As shown in Table 1, the Four-Parameter Nested Logistic Regression Model (4PLnRM) accounted for the largest share of observed variance in the psychophysical well-being scale. Although the GPCM achieved lower AIC and BIC values, the 4PLnRM explained a substantially higher proportion of variance (74% vs. 61%) and was therefore retained because it better captured response heterogeneity relevant to the study aims.

This result suggests that doctoral well-being is not fully represented by more restrictive ordinal latent trait models or by simple aggregate scores. The 4PLnRM was the only specification tested that did not impose a strictly ordered-threshold structure on all response categories, allowing for the possibility that respondents interpreted adjacent Likert categories in more heterogeneous and context-dependent ways. This does not imply that ordinal assumptions are inappropriate but indicates that additional flexibility is useful for modelling self-reported well-being in this sample. The 4PLnRM was therefore used to estimate latent traits across the six core subdomains.

Table 2 shows that the model explained a substantial proportion of variance across all latent dimensions, with particularly high values for personal resources and social resources.

Table 2. 4PLnRM Explanatory Power Across Subdomains

Sub-Dataset / Latent Dimension	Proportion of Variance Explained
Perceived General Well-being (θ_{Score})	0.740
Personal Resources ($\theta_{Personal\ Resources}$)	0.965
Social Resources ($\theta_{Social\ Resources}$)	0.909
Workload ($\theta_{Workload}$)	0.796
Doctoral Climate ($\theta_{Doctoral\ Climate}$)	0.736
Quality of University Environment ($\theta_{Uni\ Quality}$)	0.689

As an additional diagnostic check, Shapiro-Wilk tests did not reject normality for any estimated θ distribution; the 4PLnRM-extracted features were therefore treated as approximately normally distributed standardized latent measures in subsequent analyses.

The Test Information Function for the primary well-being construct, θ_{Score}, displayed a bimodal pattern, with peaks around $\theta \approx -1.5$ and $\theta \approx 2$. The instrument therefore provided the greatest precision both for candidates experiencing moderate-to-high stress and for those reporting high levels of psychological well-being.

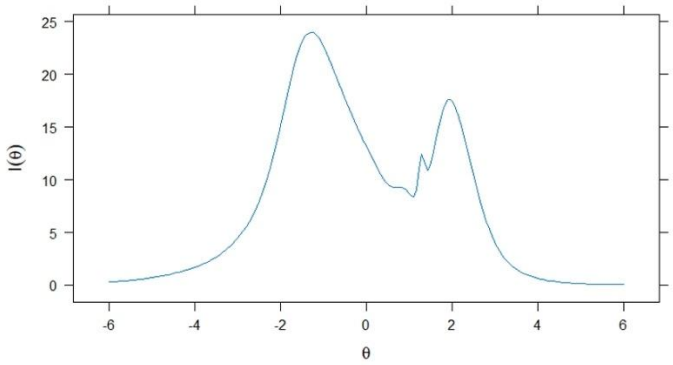

Fig. 1. Test Information Function (TIF) of the 4PLnRM model

3.3. Predictive Classification of High-Risk Candidates

Random Forest and XGBoost classifiers were trained to assess whether the IRT-estimated latent traits predicted severe psychological risk, defined as the presence of panic attacks, self-harm ideation or suicidal thoughts. As reported in Table 3, both models showed strong discriminative performance, with identical AUC values of 0.893. Random Forest achieved slightly higher overall accuracy and specificity, whereas XGBoost achieved higher sensitivity.

These results indicate that severe psychological vulnerability was associated with identifiable psychosocial configurations rather than being randomly distributed across the doctoral population. The strong performance obtained using latent trait estimates also supports the practical relevance of the IRT framework: the extracted dimensions captured meaningful aspects of doctoral functioning, not merely statistical variation. Feature importance analyses further showed that latent dimensions related to personal resources, workload, institutional quality and doctoral climate were among the most influential predictors, outperforming traditional socio-demographic variables such as age, sex and nationality.

Table 3. Machine Learning Classification Performance Metrics

Metric	Random Forest	XGBoost
AUC	0.893	0.893
Accuracy	0.842	0.821
Recall (Sensitivity)	0.644	0.711
Specificity	0.903	0.855
Precision	0.674	0.604
F_1 Score	0.659	0.653

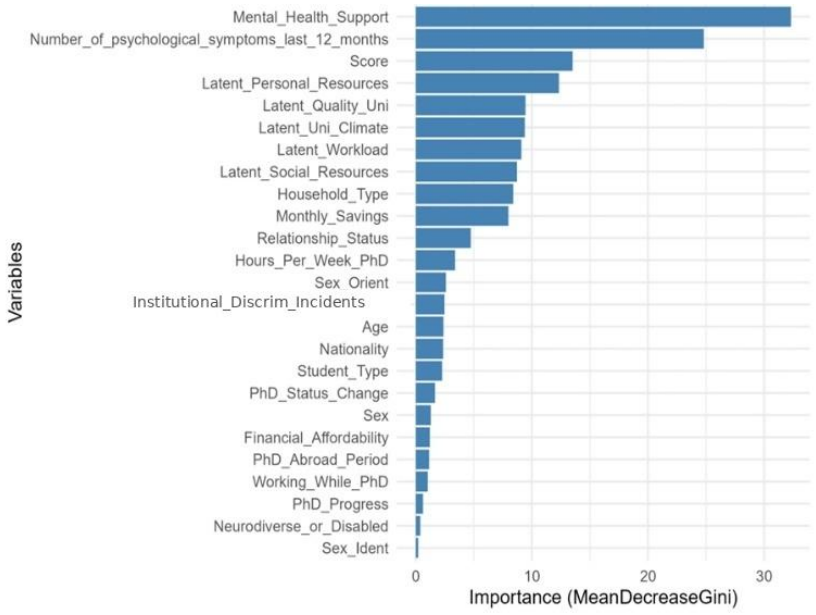

Fig. 2a. Random Forest feature importance plot for severe psychological symptoms

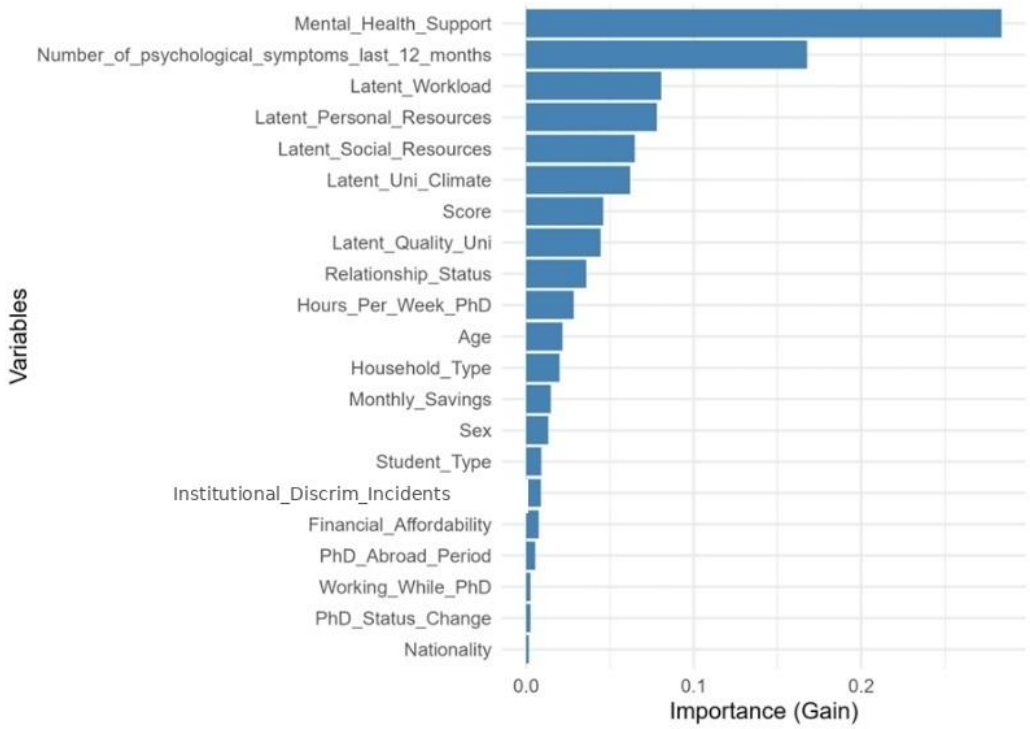

Fig. 2b. XGBoost Feature importance plot for severe psychological symptoms

3.4. Non-linear Determinants of Well-being (GAM)

The GAM analyses revealed that doctoral well-being is not governed by simple linear mechanisms. Instead, several latent dimensions exhibited threshold effects, asymmetric associations and diminishing returns, suggesting that improvements in well-being emerge through complex interactions between individual and contextual resources.

A nested model comparison verified that the non-linear GAM specification significantly outperformed a standard linear regression model ($F(12.7, 618.3) = 4.58$, $p < 0.001$), reducing residual variance and increasing the adjusted R^2 to 0.671. Cross-validation confirmed the robustness of the model (CV-$R^2 \approx 0.65$, RMSE = 0.576, MAE = 0.451).

Table 4. GAM Smooth Terms Quantitative Summary

Latent Predictor (θ)	Effective Degrees of Freedom (edf)	F-statistic	p-value
Personal Resources ($\theta_{\text{Personal Resources}}$)	3.88	66.32	< 0.0001***
Workload (θ_{Workload})	4.83	16.34	< 0.0001***
Doctoral Climate ($\theta_{\text{Doctoral Climate}}$)	3.43	7.17	1.04×10^{-5}***
Quality of University ($\theta_{\text{Quality of university}}$)	4.55	6.32	5.85×10^{-6}***

Latent Predictor (θ)	Effective Degrees of Freedom (edf)	F-statistic	p-value
Social Resources ($\theta_{Social\ Resources}$)	1.00	9.40	0.0023**

Partial effect plots (see Figures 3-7) suggested asymmetric and non-linear patterns in well-being dynamics:

Personal resources ($\theta_{Personal\ Resources}$): displayed a steep, monotonic positive relationship, acting as the strongest predictor of high well-being. This pattern aligns with broader evidence emphasizing self-efficacy, resilience and psychological capital as key determinants of psychological functioning in demanding academic environments (Bandura, 1997; Luthans et al., 2007).

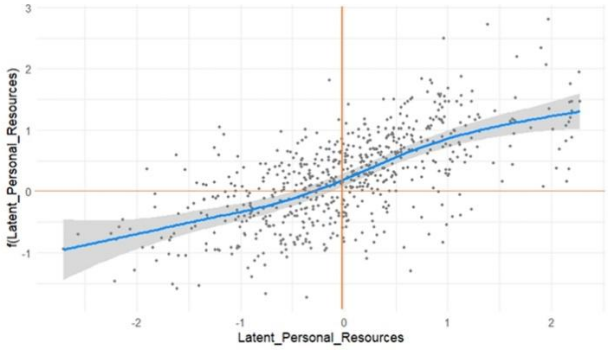

Fig. 3. Partial effect of $\theta_{Personal\ Resources}$ on the overall latent well-being

Quality of the university environment ($\theta_{Quality\ of\ university}$): a similarly increasing trend is observed, although slightly smoother than personal resources; this suggests that positive perceptions of the broader academic environment also enhance well-being scores

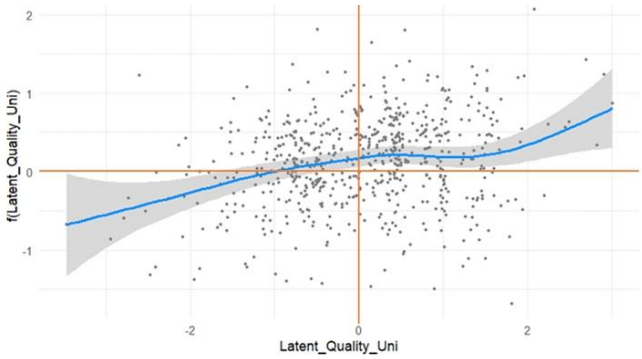

Fig. 4. Partial effect of $\theta_{Quality\ of\ university}$ on the overall latent well-being

Workload ($\theta_{Workload}$): The association between workload and well-being was markedly non-linear. Candidates

experiencing highly stressful workloads exhibited persistently low well-being scores, suggesting that modest reductions in workload may be insufficient to produce immediate psychological benefits. Conversely, well-being improved more rapidly once workload became perceived as manageable, indicating the existence of a potential threshold beyond which academic demands cease to function as major stressors.

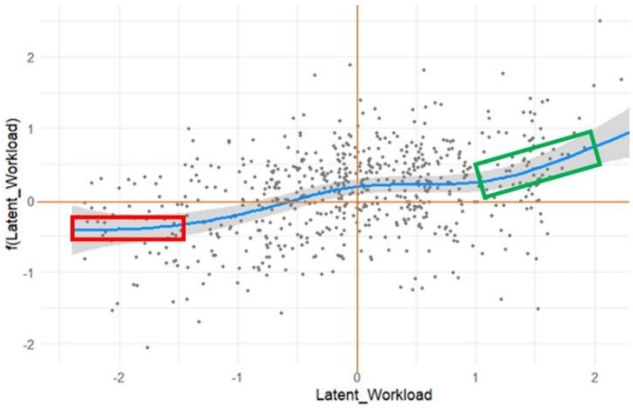

Fig. 5. Partial effect of $\theta_{Workload}$ on the overall latent well-being

Doctoral Climate ($\theta_{Doctoral\ Climate}$): Interestingly, average levels of collegiality were associated with minimal changes in well-being. Substantial psychological benefits emerged only within highly collaborative environments, suggesting that merely reducing interpersonal conflict may be insufficient; rather, genuinely supportive doctoral communities may be required before measurable well-being gains become evident.

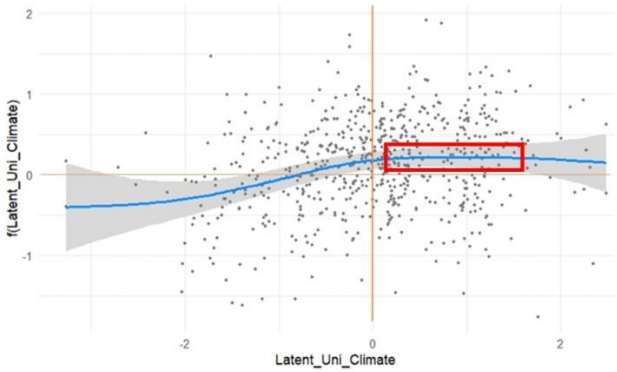

Fig. 6. Partial effect of $\theta_{Doctoral\ Climate}$ on the overall latent well-being

Social Resources ($\theta_{Social\ Resources}$): Behaved strictly linearly (edf = 1) with a remarkably flat slope, indicating that external social networks (family, friends) exert a marginal practical impact on academic well-being relative to structural and internal factors.

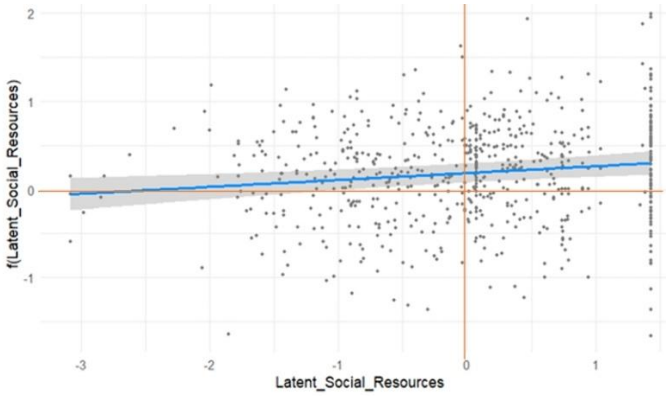

Fig. 7. Partial effect of $\theta_{\text{Social Resources}}$ on the overall latent well-being

3.5. Typologies of Perceived Discrimination: Latent Class Analysis

A total of 29.3% of respondents reported having experienced or witnessed at least one discriminatory or aggressive episode within the academic environment. However, the distribution of these experiences was far from homogeneous. Rather than representing a single phenomenon affecting all doctoral candidates in a similar way, discrimination appeared to emerge through distinct configurations involving different perpetrators, demographic characteristics and academic outcomes. To investigate this heterogeneity, a Latent Class Analysis (LCA) was performed. Based on statistical fit indices and substantive interpretability, a three-class solution was retained (AIC = 9350.71, BIC = 9605.24, Entropy = 0.613). Solutions ranging from two to four classes were evaluated; the three-class solution provided the best balance between statistical fit, entropy and cluster interpretability. The resulting classes suggested both a gradient of institutional vulnerability and qualitative differences in the relational source of that vulnerability, ranging from relatively protected profiles with minimal exposure to discrimination to highly vulnerable profiles characterized by frequent hierarchical conflicts and elevated attrition intentions. This pattern suggests that discriminatory experiences are not randomly distributed across the doctoral population but tend to cluster within distinct psychosocial configurations.

Table 5 reports the conditional response probabilities for the principal indicators across the three latent profiles.

Table 5. Conditional Response Probabilities for Key Indicators Across Latent Classes

Variable	Class 1 (40.1%)	Class 2 (11.8%)	Class 3 (48.1%)
Discrimination Perpetrator			
None	0.808	0.275	0.944
Only Students	0.106	0.122	0.039
Only Lecturers	0.052	0.320	0.008
Both Students & Lecturers	0.034	0.283	0.009
Aggressive Behaviour Perpetrator			
None	0.979	0.544	0.975
Only Lecturers / Both	0.000	0.388	0.026

Variable	Class 1 (40.1%)	Class 2 (11.8%)	Class 3 (48.1%)
Demographic & Academic Markers			
Female Gender	0.439	0.582	0.319
International Student	0.371	0.196	0.001
Non-Heterosexual Orientation	0.222	0.166	0.038
Learning/Physical Disability (DSA)	0.000	0.116	0.025
Age Over 28	0.426	0.446	0.098
Intention to Drop Out	0.353	0.880	0.310

The latent class solution does not appear to reflect a simple continuum of discrimination severity. Rather, it reveals two qualitatively distinct pathways of institutional vulnerability.

Class 1 (40.1%) was characterized mainly by peer-related discrimination and included comparatively high proportions of international students and sexual minorities. Although members of this class reported exposure to discriminatory experiences involving fellow doctoral candidates, their intention to modify or abandon the programme remained relatively moderate. Class 2 (11.8%) displayed a markedly different profile: discriminatory experiences were more frequently attributed to supervisors and faculty members and were often accompanied by aggressive or disrespectful behaviours. This group included higher proportions of women and students reporting disabilities and showed an exceptionally high prevalence of programme modification or withdrawal intentions (88%). Class 3 (48.1%) represented a comparatively protected profile, with low levels of discrimination and lower attrition intentions.

Taken together, these profiles suggest that the critical distinction is not simply whether discrimination occurs, but whether it is embedded in horizontal or hierarchical relationships. Peer-related discrimination appears more closely linked to minority status and social integration, whereas supervisor-related discrimination coincides with a broader pattern of institutional vulnerability and academic disengagement.

3.6. Impact of Discrimination Sources on Well-being (ANOVA)

To evaluate the inferential impact of the source of discrimination on the continuous latent trait of psychophysical well-being (θ_{Score}), a One-Way ANOVA was performed across four groups defined by the perpetrator: *Supervisors Only, Peers Only, Both, and None*.

The ANOVA confirmed a highly significant group effect ($F(3, 633) = 13.16$, $p < 0.001$). Post-hoc pairwise comparisons using Tukey's Honestly Significant Difference (HSD) test identified specific directional gaps.

Candidates facing discrimination exclusively from supervisors experienced significantly lower well-being (higher stress) than those reporting no discrimination ($\Delta = -0.629$, $p < 0.001$) and those experiencing peer-only discrimination ($\Delta = -0.471$, $p = 0.046$).

Experiencing discrimination from both supervisors and peers induced the highest stress levels, differing significantly from the no-discrimination group ($\Delta = -0.684$, $p < 0.001$) and the peer-only group ($\Delta = -0.526$, $p = 0.05$).

The difference between the *supervisors-only* group and the *both* group was statistically negligible ($\Delta = -0.056$, $p = 0.999$), demonstrating that the addition of peer conflict does not exacerbate the severe psychological damage already inflicted by hierarchical distress.

Crucially, the contrast between peer-only discrimination and the no-discrimination baseline was not statistically significant ($\Delta = -0.158$, $p = 0.678$).

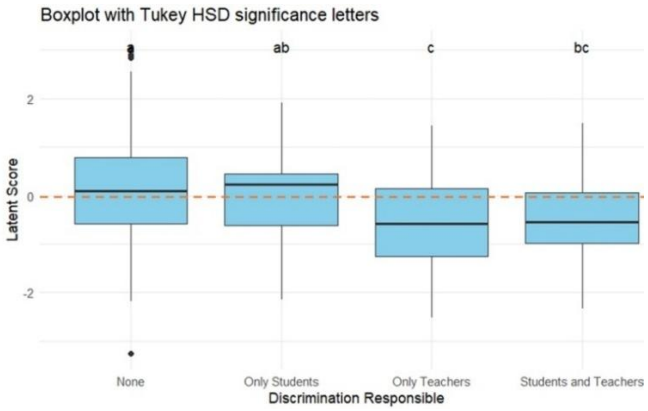

Fig. 8. Distribution of θ_{Score} across groups.

Groups sharing the same letter are not significantly different, whereas groups with different letters differ significantly according to Tukey's HSD post-hoc test

These findings indicate a marked asymmetry between horizontal and hierarchical discrimination. Peer-related discrimination was not significantly associated with lower θScore, whereas supervisor-related discrimination was consistently associated with poorer psychophysical well-being. Although the cross-sectional design prevents causal inference, the magnitude and consistency of these differences point to the psychological relevance of power asymmetries in doctoral supervisory relationships.

3.7. Predictors of Supervisor-Related Discrimination (Logistic GLM)

The logistic GLM further clarified the correlates of supervisor-related discrimination. A preliminary mixed-effects specification including a PhD course-level random intercept produced a very low Variance Partition Ratio (VPR = 2.1%), indicating limited programme-level variability; the final model therefore focused on individual-level predictors.

Table 6. Logistic GLM Summary for Supervisor-Related Discrimination

Fixed Effects	Estimate (β)	SE	OR	p-value
Intercept	-2.409	0.308	0.090	< 0.001***
Female Gender	0.579	0.209	1.784	0.0056**
Intention to Drop Out (Yes)	1.117	0.186	3.056	< 0.001***
Age Over 28	0.200	0.183	1.221	0.2744
International Student Status	0.141	0.227	1.151	0.5345

As shown in Table 6, intention to modify or abandon the doctoral programme was the strongest correlate of supervisor-related discrimination. Candidates reporting attrition intentions had approximately three times the odds of reporting

discriminatory behaviours by supervisors compared with those intending to continue (OR = 3.06, $p < 0.001$). Gender also emerged as significant: female doctoral candidates had higher odds of reporting supervisor-related discrimination than male candidates (OR = 1.78, $p = 0.0056$). By contrast, neither age nor international student status reached statistical significance.

Overall, the GLM results reinforce the patterns observed in the LCA and ANOVA. Supervisor-related discrimination was associated with markers of academic vulnerability, particularly attrition intentions and female gender, while the low VPR suggests that these experiences were not concentrated within a small number of doctoral programmes. Rather, they appear to reflect broader relational and institutional dynamics within the doctoral environment.

4. Discussion

The present study examined doctoral well-being through an integrated framework combining latent trait modelling, machine-learning classification, non-linear regression and person-centred analyses. Based on data from 637 doctoral researchers, the findings portray doctoral well-being as a multidimensional, latent and heterogeneous condition shaped by personal resources, institutional quality and relational experiences. Consistent with international evidence, doctoral education emerges as a demanding environment associated with substantial psychological vulnerability (Levecque et al., 2017; Evans et al., 2018; Satinsky et al., 2021); however, the present results also indicate that such vulnerability is poorly represented by aggregate questionnaire scores alone and is better approached through models able to capture latent structure, response heterogeneity and non-linear associations.

4.1 Doctoral Well-Being as a Multidimensional Construct

A first contribution concerns the psychometric representation of doctoral well-being. The superior performance of the 4PLnRM indicates substantial response heterogeneity, supporting latent trait perspectives according to which individuals with similar levels of underlying psychological functioning may nevertheless display different response patterns (Embretson & Reise, 2000; Reise & Waller, 2009). This is substantively important because, among the models tested, the 4PLnRM was the only specification that did not impose a strictly ordinal structure on all response categories. Although the questionnaire used Likert-type items, the model comparison suggests that respondents may not always interpret adjacent categories as uniform successive steps along a single continuum; categories such as “agree” and “strongly agree” may sometimes reflect different interpretations of the item content rather than merely increasing intensity of the same latent trait.

This interpretation should remain cautious. The results do not imply that doctoral well-being is non-ordinal in itself, nor that Likert scales are inappropriate, but they do suggest a more complex response process than additive scores or strictly ordinal IRT models can capture. Substantively, this supports a view of well-being as emerging from interacting personal, relational and institutional conditions, rather than as a simple linear movement from distress to flourishing. The bimodal Test Information Function further indicates that the instrument is informative at both vulnerable and resilient ends of the continuum, a property that may support future institutional monitoring, provided that such monitoring is used to understand support needs rather than to classify candidates reductively.

4.2 Personal Resources and Institutional Quality

The Generalized Additive Model identified personal resources and perceived institutional quality as the strongest correlates of doctoral well-being. The association with personal resources is consistent with research on self-efficacy, resilience and psychological capital, which emphasizes perceived competence and adaptive capacity in demanding environments (Bandura, 1997; Luthans et al., 2007). Doctoral candidates who feel able to manage uncertainty, setbacks and performance pressure may be better positioned to sustain engagement; however, because the data are cross-sectional and self-reported, candidates with higher well-being may also evaluate their own resources more favorably, or both variables may reflect a broader sense of academic confidence and control.

This point is important because an excessive emphasis on personal resources may unintentionally individualize doctoral distress, framing vulnerability as a deficit of resilience rather than as the outcome of demanding academic structures. The present findings instead suggest that personal resources matter, but mainly within environments that make those resources usable. A similar caution applies to institutional quality. Perceptions of fairness, transparency and organisational support were positively associated with well-being, in line with research linking supportive doctoral

environments to satisfaction and persistence (Gardner, 2008; Sverdlik et al., 2018), but the direction of this association cannot be established here. What the results support is therefore an interactionist interpretation: doctoral well-being is unlikely to depend exclusively on personal resilience or institutional provision, but on their alignment. Personal resources may be most protective when embedded in supportive environments, while institutional support may be less effective when candidates feel unable to exercise control over their doctoral trajectory.

4.3 The Limited Role of Social Resources

The comparatively modest contribution of social resources was unexpected, but it should not be read as evidence that family and friendship networks are unimportant. Rather, it suggests that general emotional support may be less directly connected to doctoral-specific stressors than supervision, departmental integration and scholarly belonging, a pattern also noted in previous doctoral education research (Pyhältö et al., 2012; Cornér et al., 2017; Sverdlik et al., 2018). Friends and relatives may help alleviate emotional burden, but they often lack the institutional knowledge and positional authority needed to address supervisory conflict, publication pressure, funding uncertainty or unclear career prospects. The issue, then, is not whether social support matters, but whether support is academically situated enough to modify the conditions generating distress. Peer-support initiatives and community-building activities remain valuable, but they are unlikely to be sufficient if they leave unchanged the structural and supervisory arrangements through which doctoral stress is produced.

4.4 Hierarchical and Horizontal Discrimination: The Role of Power Asymmetries

One of the clearest findings concerns the asymmetry between hierarchical and horizontal discrimination. Across Latent Class Analysis, ANOVA and the Generalized Linear Model, the critical distinction was not simply whether discrimination occurred, but where power was located. Peer-related discrimination was associated with negative experiences, yet not systematically with markedly poorer well-being or stronger attrition intentions; supervisor-related discrimination, by contrast, was consistently associated with lower psychophysical well-being, greater psychological vulnerability and a substantially stronger intention to modify or abandon the doctoral programmes.

The person-centred results made this distinction especially visible. One latent profile was mainly characterized by peer-related discrimination affecting international students and sexual minorities, whereas a more vulnerable profile was dominated by supervisor-related discrimination and aggressive behaviours involving faculty members; strikingly, nearly 88% of candidates in this profile reported intentions to modify or leave their doctoral pathway. ANOVA showed significantly lower well-being among candidates reporting supervisor-related discrimination than among both comparison groups, while logistic regression confirmed its strong association with dropout-related intentions.

These findings suggest that hierarchical and horizontal discrimination should not be treated as equivalent manifestations of the same phenomenon. Peer-related discrimination may primarily damage social integration and interpersonal climate, whereas supervisor-related discrimination can threaten academic progression, professional identity and perceived future opportunities. This interpretation is consistent with the central role of supervision in doctoral education, where supervisors act as mentors, evaluators, gatekeepers of resources and mediators of professional development (Lee, 2008), and with the notion of relational agency, since discrimination within the supervisory relationship may undermine candidates' sense of being legitimate and valued participants in the research community (Pyhältö & Keskinen, 2012). Although causal conclusions cannot be drawn, the convergence of evidence across methods suggests that supervisor-related discrimination represents a particularly consequential form of institutional vulnerability rather than merely an interpersonal difficulty.

4.5 Gendered Vulnerability and the "Leaky Pipeline Phenomenon"

A further finding concerns the greater exposure of female doctoral candidates to supervisor-related discrimination. Both the Latent Class Analysis and the GLM indicated that women were disproportionately represented among the most vulnerable profiles and had higher odds of reporting discriminatory experiences involving supervisors, even after accounting for age, international status and doctoral programme characteristics. This pattern resonates with the leaky pipeline phenomenon, namely the progressive underrepresentation of women across academic career stages despite their strong participation at earlier educational levels (Blickenstaff, 2005; Shaw & Stanton, 2012). While this process is shaped by multiple mechanisms, including implicit bias, gender stereotyping, unequal mentoring and work-life

constraints, supervisory relationships remain a crucial site through which academic belonging, recognition and retention are negotiated (Moss-Racusin et al., 2012; Van den Brink & Benschop, 2014).

The study does not observe long-term academic trajectories and therefore cannot determine whether these experiences translate into later career exit. Its contribution is more specific: it identifies the doctoral stage as a relational context in which gendered vulnerability may already be structured through unequal supervisory experiences. In this sense, the association between female gender, hierarchical discrimination and attrition intentions points to a possible mechanism through which gender inequalities may be reproduced before formal academic careers have even begun. Improving doctoral well-being therefore requires not only general mental-health interventions, but also gender-sensitive supervisory practices, transparent reporting mechanisms and safeguards against power asymmetries.

4.6 Methodological Contributions

Methodologically, the study shows the value of integrating psychometric, predictive and person-centred approaches. Item Response Theory estimated well-being and doctoral experience as latent dimensions rather than aggregate scores; machine-learning models assessed the predictive relevance of these dimensions for severe psychological vulnerability; Generalized Additive Models captured non-linear patterns missed by conventional linear models; and Latent Class Analysis, together with logistic regression, revealed heterogeneity in discrimination experiences and their association with individual characteristics. This pipeline offers a richer representation of doctoral well-being than single-method designs and illustrates how higher education research can connect measurement, prediction and interpretation without reducing complex psychosocial phenomena to either purely individual traits or purely institutional effects.

4.7 Policy Implications

The findings point to several implications for institutional practice, although intervention effectiveness remains to be evaluated empirically. Universities should treat supervisory quality, transparency and accountability as central components of doctoral well-being, using supervisory committees, co-supervision models or independent advisory channels to reduce excessive dependence on a single supervisor. Institutional quality should also be understood as part of the well-being infrastructure of doctoral education, supported by fair procedures, inclusive climates and accessible services rather than delegated to individual resilience. The gendered pattern of vulnerability further calls for gender-sensitive supervisory training, clear anti-discrimination procedures and confidential reporting mechanisms capable of addressing power asymmetries within academic relationships.

Finally, the predictive performance obtained from models incorporating latent well-being dimensions suggests that psychometric monitoring may provide useful institutional information when implemented ethically, voluntarily and with strong safeguards for privacy and confidentiality. However, monitoring should not become a substitute for institutional responsibility. Well-being surveys may identify risk, but they cannot by themselves resolve the supervisory and organisational conditions that produce it. Overall, the study supports a shift from individual-centred accounts of doctoral mental health toward institutional approaches that address the personal, relational and organisational conditions through which doctoral well-being is produced.

5. Conclusion

This study examined doctoral well-being, psychological vulnerability and attrition intentions through an integrated framework combining 4PLnRM psychometric modelling, GAM, LCA and GLM. Rather than treating doctoral distress as a set of individual symptoms, the analysis shows how well-being is shaped by the alignment between personal resources, institutional conditions and relational experiences. Its central contribution is therefore both substantive and methodological: doctoral well-being is poorly captured by aggregate questionnaire scores or by explanations centred only on resilience, and is better understood as a latent, heterogeneous and context-dependent phenomenon.

Across the analytical pipeline, the 4PLnRM highlighted response heterogeneity, the GAM revealed non-linear associations, and the LCA/GLM showed that vulnerability is structured by relational power. In particular, supervisor-related discrimination was more consistently associated with poorer well-being and attrition intentions than peer-related discrimination, while the low programme-level variance (VPR = 2.1%) suggests that these patterns may reflect broader institutional and relational vulnerabilities rather than isolated programme-level problems.

5.1 Limitations and Future Directions

Several limitations should be acknowledged. The cross-sectional design prevents causal claims about the relationships among well-being, supervisory experiences and attrition intentions, even when associations were consistent across analytical approaches. The reliance on self-report measures may also introduce common-method variance, response-style effects and perceptual bias; this is especially relevant for discrimination, which should be interpreted here as perceived institutional experience rather than independently verified misconduct. In addition, voluntary participation may have produced self-selection bias, as candidates with particularly positive or negative experiences may have been more inclined to respond. Finally, although the sample was large and heterogeneous, data came from a single institution, limiting generalizability across national systems, disciplinary cultures and organisational contexts.

Future research should therefore adopt longitudinal and multi-institutional designs, integrating perceived well-being with objective or administrative indicators such as time-to-degree, supervisory meeting frequency, publication activity, formal complaints and actual dropout behaviour. Such evidence would help clarify whether the profiles identified here remain stable across contexts and whether supervisor-related discrimination functions as an early mechanism of disengagement from academic careers.

5.2 Concluding Remarks

The broader implication of this study is that doctoral well-being cannot be delegated to individual coping alone. Severe distress and attrition intentions are not merely personal vulnerabilities to be managed through resilience training, but signals of how doctoral environments distribute recognition, support, uncertainty and power. Institutions seeking to improve doctoral mental health should therefore address the relational and organisational conditions of doctoral training, including supervisory accountability, confidential reporting mechanisms, gender-sensitive practices and more collaborative research cultures.

Ultimately, doctoral well-being should be understood as an emergent property of the academic environment in which doctoral work is carried out. Supporting it requires not only helping candidates endure doctoral education, but also reshaping the conditions under which doctoral education becomes psychologically sustainable.

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