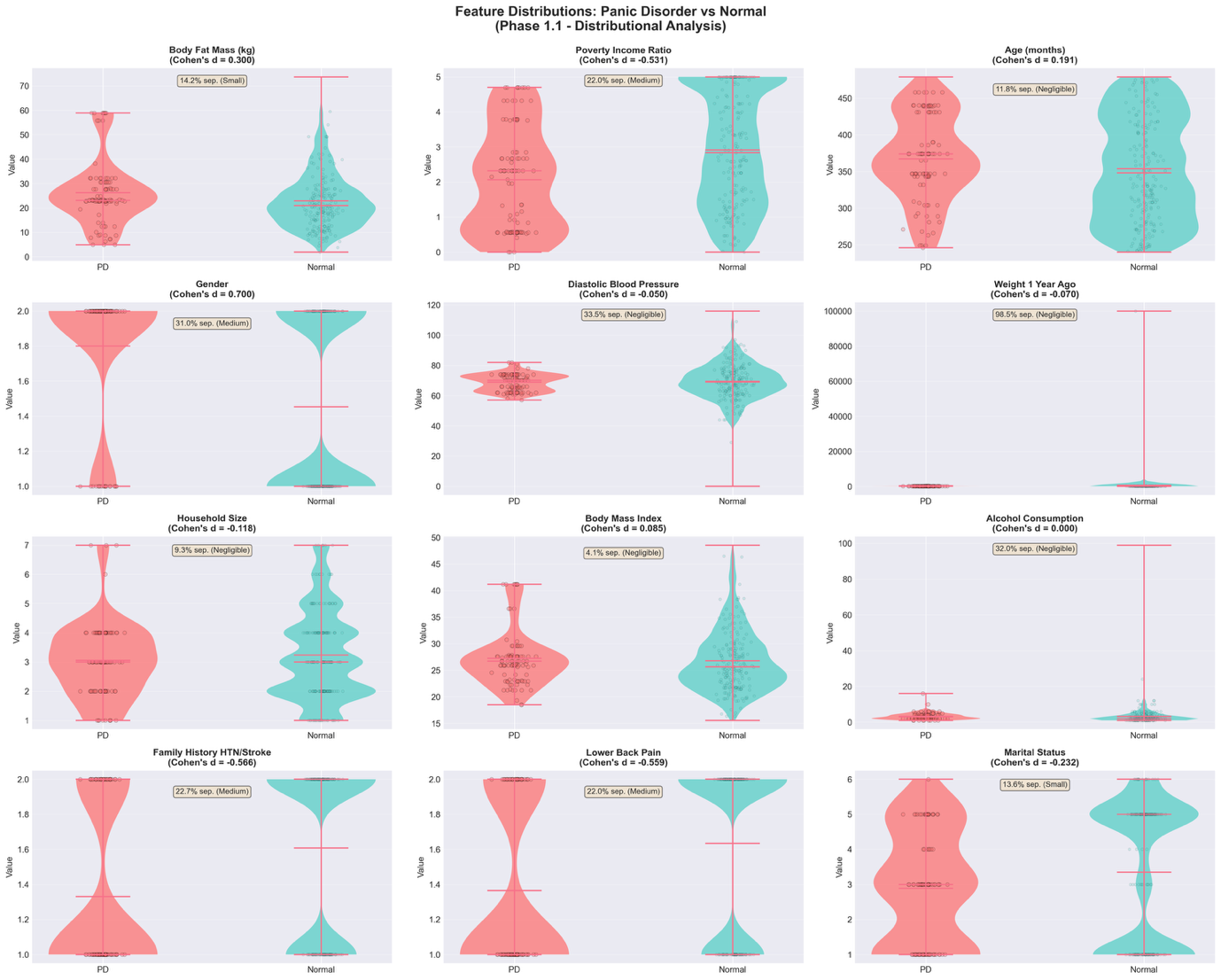
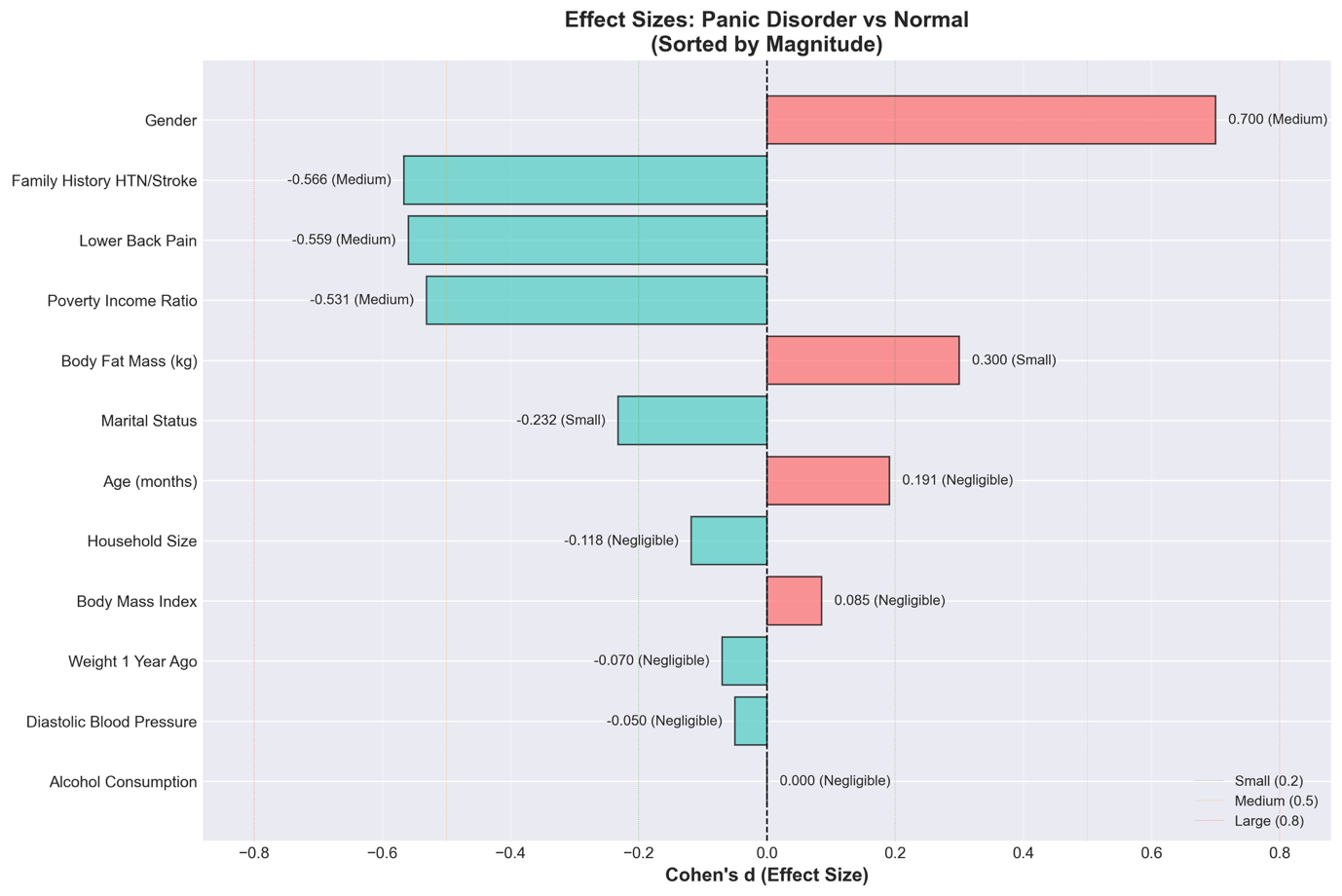
# SUPPLEMENTARY FIGURES (18)



**Supplementary Figure S1.** Individual Feature Distributions Across Groups. Violin plots of all 11 features stratified by PD status (PD n=115 red, Normal n=3,029 teal). Gender shows largest difference (d=0.700), followed by family history, pain, poverty. Physiological features show substantial overlap. Validates Table 2: individual features show modest-to-weak discrimination.

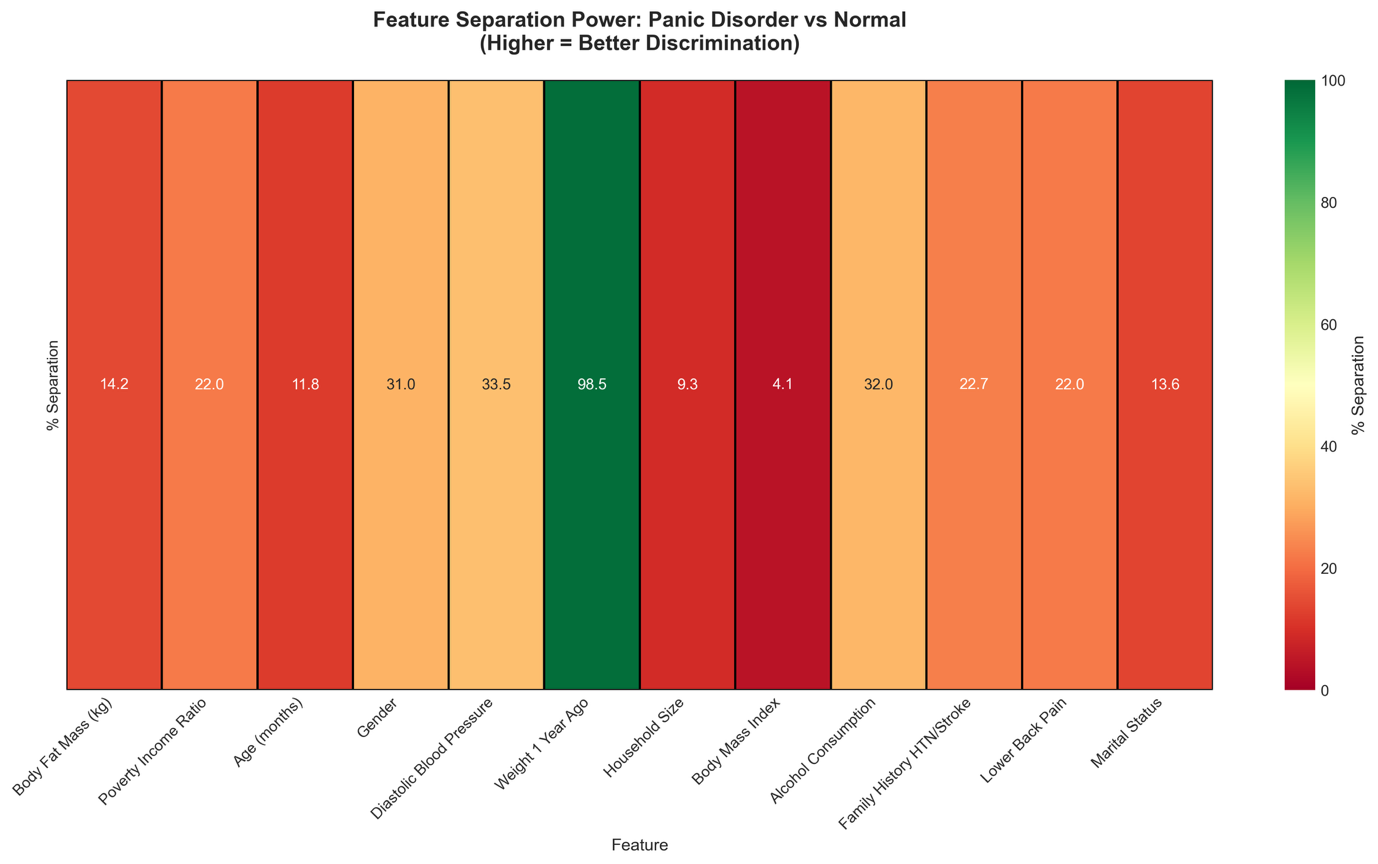
**Source:** phase1\_distributions/Figure1\_violin\_plots\_all\_features.png



**Supplementary Figure S2.** Feature Effect Sizes Ranked

Horizontal bar chart of Cohen's d effect sizes, ordered by magnitude. Gender highest (d=0.700), five features show negligible effects (|d|<0.2). Mean absolute effect: 0.284 (small). Color-coded by domain. NO feature achieves strong discrimination (d>0.8).

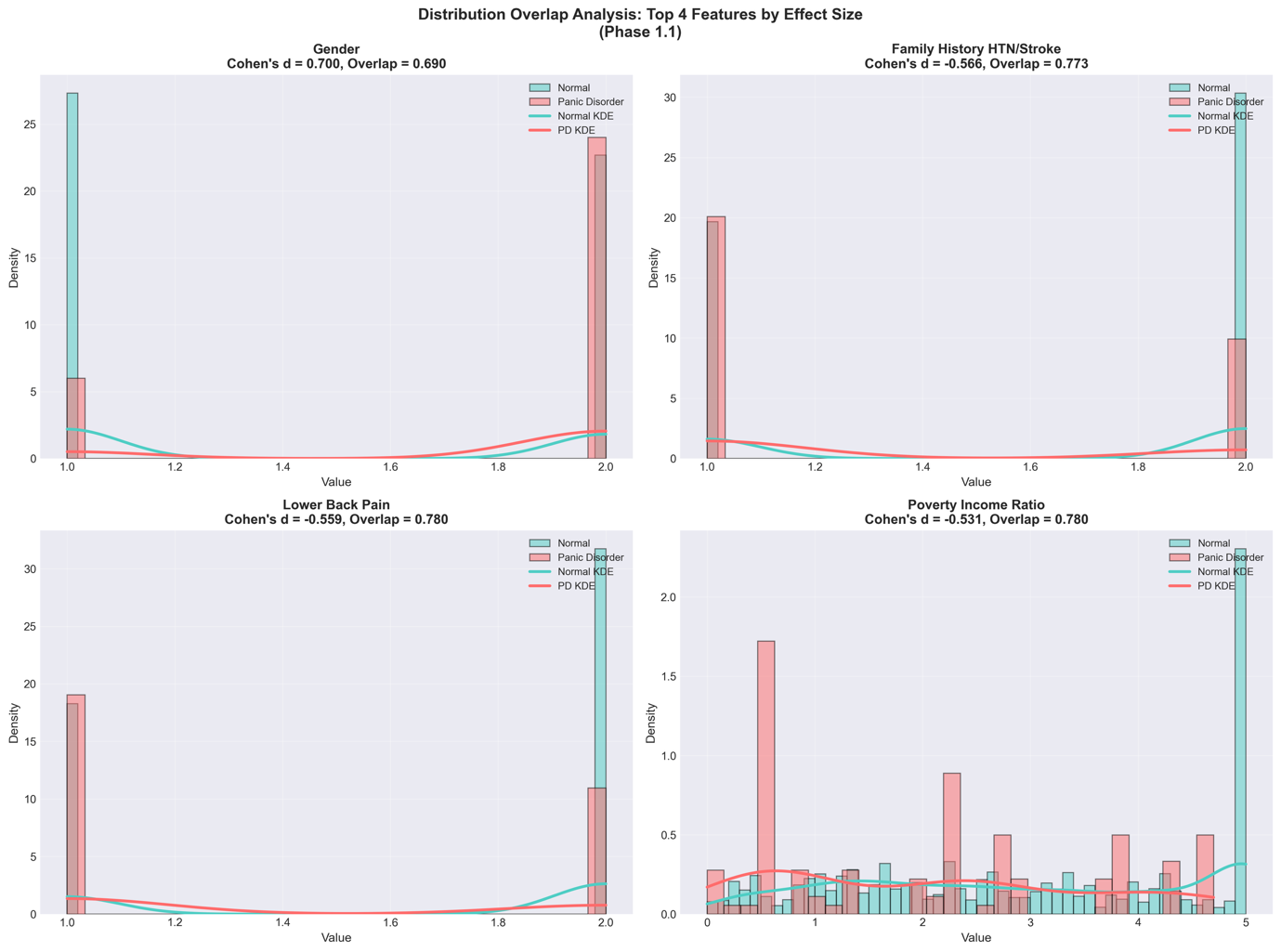
**Source:** phase1\_distributions/Figure2\_effect\_sizes\_ranked.png



**Supplementary Figure S3.** Feature Separation Heatmap

Heatmap of percentage separation (non-overlapping area) for each feature. Gender shows maximum 31.0% separation. Most features show <20%. Mean separation: 19.4%. NO single feature achieves >32% separation.

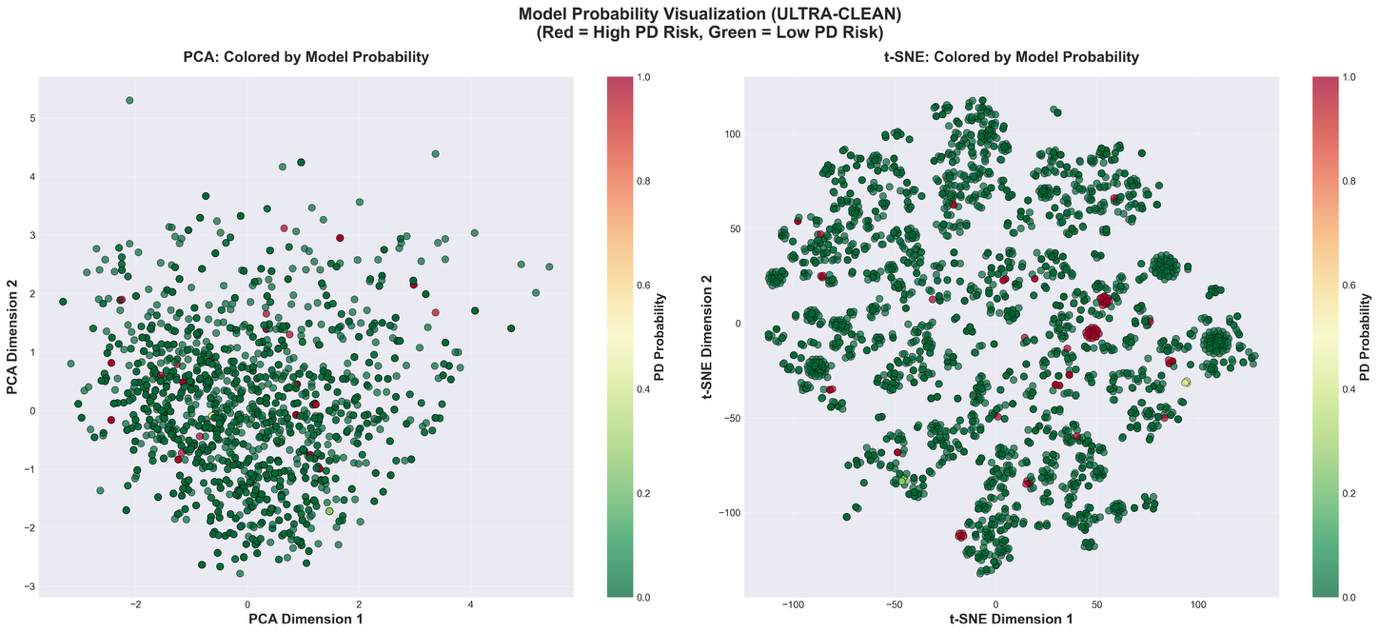
**Source:** phase1\_distributions/Figure3\_separation\_heatmap.png



**Supplementary Figure S4.** Distribution Overlaps for Top Four Features

Overlapping histograms for gender, family history, pain, poverty. Despite being 'top discriminators,' substantial overlap visible (70-80%). Gender shows clearest separation but still ~31% overlap.

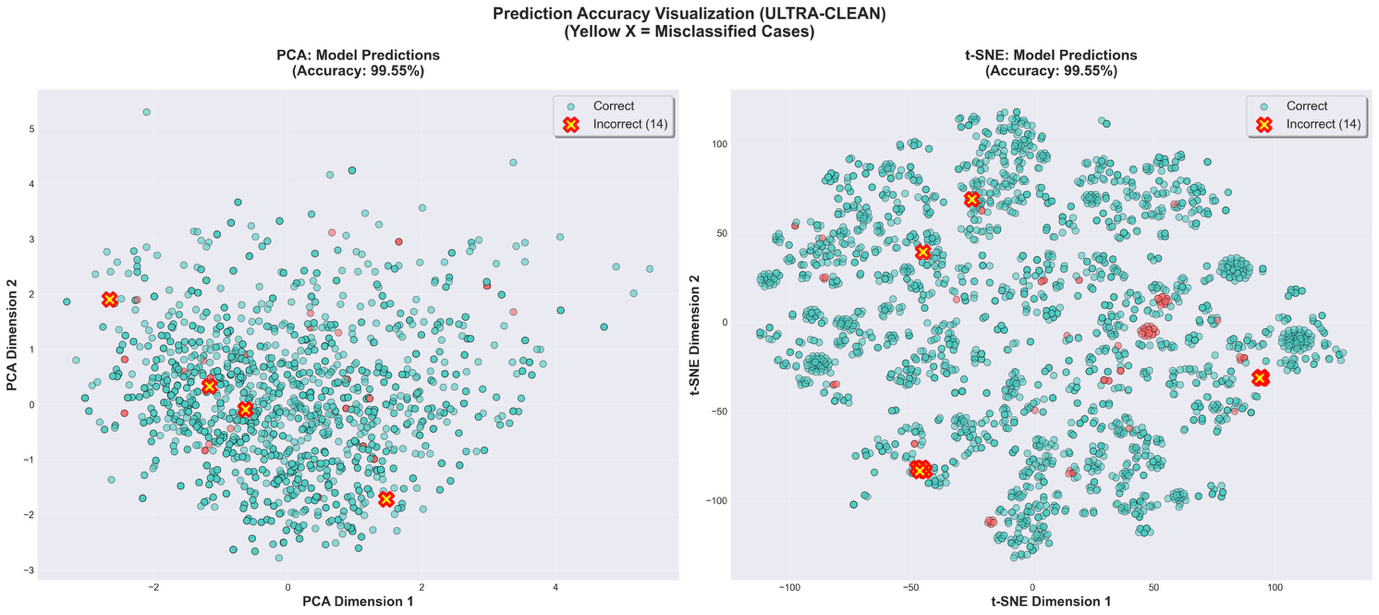
**Source:** phase1\_distributions/Figure4\_distribution\_overlaps\_top4.png



**Supplementary Figure S5.** UMAP Colored by Model Predicted Probability

UMAP with gradient coloring by predicted PD probability (blue=0% to red=100%). Color gradient reveals underlying structure not visible in 2D projection. Most PD cases in red regions, normals in blue.

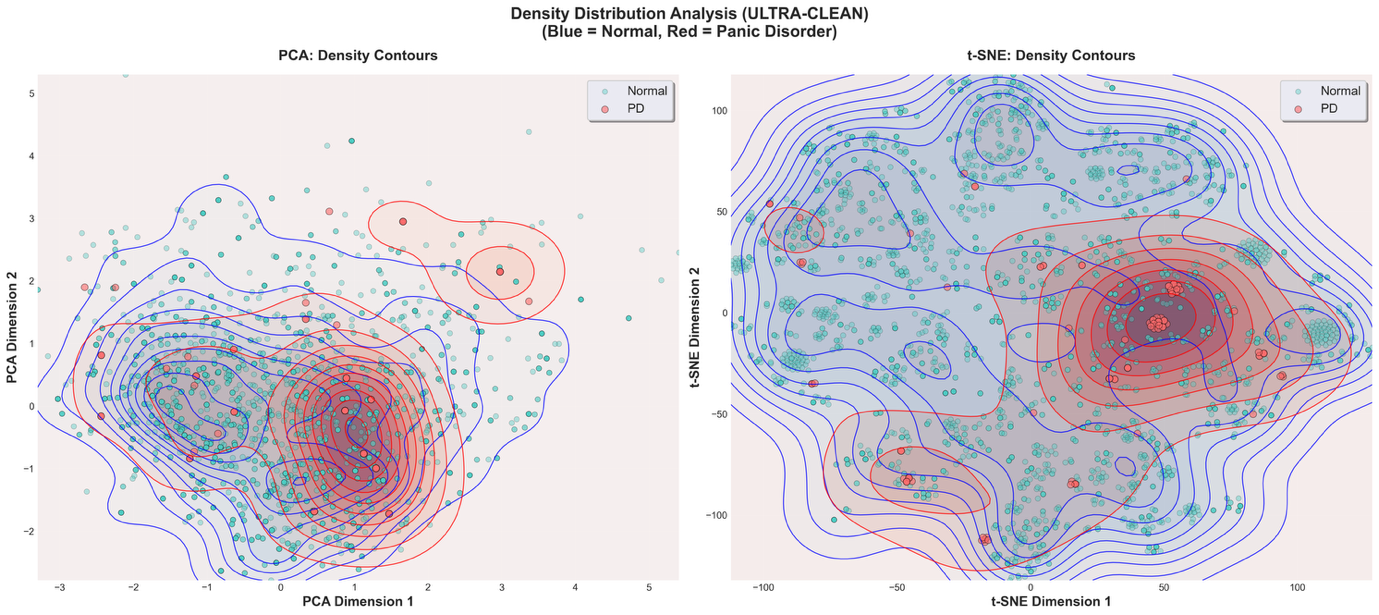
**Source:** phase1\_2\_visualization\_ULTRA\_CLEAN/Figure2\_probability\_colored\_ULTRA\_CLEAN.png



**Supplementary Figure S6.** UMAP Showing Correct vs Incorrect Predictions

UMAP with incorrect predictions marked with yellow 'X' (n=3 total: 1 FP, 2 FN). Errors do NOT cluster, suggesting complex multidimensional patterns rather than systematic 2D boundary issues.

**Source:** phase1\_2\_visualization\_ULTRA\_CLEAN/Figure3\_prediction\_accuracy\_ULTRA\_CLEAN.png



**Supplementary Figure S7.** Density Contours in UMAP Space

UMAP with kernel density contours for PD (red) and Normal (blue). Contours partially overlap: ~40% of 2D space contains both groups. Consistent with moderate Silhouette scores.

**Source:** phase1\_2\_visualization\_ULTRA\_CLEAN/Figure4\_density\_contours\_ULTRA\_CLEAN.png

A diagram of a network

AI-generated content may be incorrect.

**Supplementary Figure S8.** Complete Interpretable Decision Tree Structure

Full decision tree (max\_depth=5, 6 leaves) with branching structure. Root splits on PIR ≤ 4.71. Tree's primary failure visible: most participants classified as PD, creating 464 false positives. Uses only 4 of 11 features.

**Source:** phase2\_1\_decision\_tree\_ULTRA\_CLEAN/Figure1\_decision\_tree\_full.png

A graph with red and blue squares

AI-generated content may be incorrect.

**Supplementary Figure S9.** Decision Tree Feature Importance Comparison

Bar chart comparing decision tree vs gradient boosting importance. Tree uses only 4 features with extreme concentration (PIR 88.2%), ignoring 7 features (0%). Gradient boosting distributes across all 11 (max 16.1%).

**Source:** phase2\_1\_decision\_tree\_ULTRA\_CLEAN/Figure2\_feature\_importance\_tree.png

A group of graphs with red and blue dots

AI-generated content may be incorrect.

**Supplementary Figure S10.** SHAP Feature Importance Bar Chart

Horizontal bar chart of mean absolute SHAP values. Alternative to beeswarm (Figure 2). Body fat and poverty tied at 16.1%. No dominant feature (max<17%), balanced distribution. Color-coded by domain.

**Source:** phase2\_2\_SHAP\_ULTRA\_CLEAN/Figure2\_SHAP\_importance\_bar.png

A graph with red and blue dots

AI-generated content may be incorrect.

**Supplementary Figure S11.** SHAP Dependence Plots for Top Four Features

Four-panel scatter plots: SHAP value vs feature value for body fat, poverty, age, BMI. Non-linear patterns visible. Vertical spread quantifies interaction effects—same value produces different SHAP depending on other features.

**Source:** phase2\_2\_SHAP\_ULTRA\_CLEAN/Figure3\_SHAP\_dependence\_top4.png

A screenshot of a graph

AI-generated content may be incorrect.

**Supplementary Figure S12.** Detailed Visualization of Top Three Interactions

Three scatter plots for top 3 interactions: Body fat × Age (1.047), PIR × BMI (1.016), Age × BP (0.807). Visual demonstration of synergy: effects AMPLIFY in combination, not additive.

**Source:** phase2\_2\_SHAP\_ULTRA\_CLEAN/Figure5\_SHAP\_top3\_interactions.png

A graph of a bar chart

AI-generated content may be incorrect.

**Supplementary Figure S13.** SHAP Waterfall Examples for Individual Predictions

Waterfall plots for three cases: True Positive PD, True Negative Normal, False Negative. Shows feature-by-feature contributions starting from base value. Provides individual-level interpretability.

**Source:** phase2\_2\_SHAP\_ULTRA\_CLEAN/Figure6\_SHAP\_waterfall\_examples.png

A collage of graphs

AI-generated content may be incorrect.

A comparison of blue and green bars

AI-generated content may be incorrect.

**Supplementary Figure S14.** SHAP Value Distributions: PD vs Normal Comparison

Side-by-side violin plots comparing SHAP distributions between PD (red) and Normal (teal). Body fat shows largest difference: PD +1.915, Normal -3.019. Visual representation of Table 4 class-stratified analysis.

**Source:** phase2\_2\_SHAP\_ULTRA\_CLEAN/Figure7\_SHAP\_PD\_vs\_Normal\_comparison.png

A graph of a bar graph

AI-generated content may be incorrect.

**Supplementary Figure S15.** Poverty-Income Ratio Distributions by Group

Overlapping histograms of PIR for PD (mean 2.06±1.47) vs Normal (2.91±1.61). PD shifted leftward with 25.8% in extreme poverty vs 6.5% Normal. Despite shift, substantial overlap (>75%).

**Source:** poverty\_paradox\_investigation/Figure1\_poverty\_distributions.png

A graph of a curve

AI-generated content may be incorrect.

**Supplementary Figure S16.** PD Prevalence Across Poverty Quartiles

Bar chart of prevalence by quartile: Q1 6.42%, Q2 4.08%, Q3 2.92%, Q4 1.16%. Monotonic decrease, 5.5-fold difference. Error bars show 95% CI. Chi-square trend significant (p<0.001).

**Source:** poverty\_paradox\_investigation/Figure2\_quartile\_analysis.png

A red and green chart

AI-generated content may be incorrect.

**Supplementary Figure S17.** Feature Correlations with Poverty-Income Ratio

Horizontal bar chart of Pearson correlations between PIR and all features. Age strongest positive (+0.20), explaining Simpson's Paradox. Household size, marital status, alcohol negative. Body composition negative (BMI -0.14, fat -0.08).

**Source:** poverty\_paradox\_investigation/Figure3\_poverty\_correlations.png

A graph showing different colored bars

AI-generated content may be incorrect.

**Supplementary Figure S18.** Phenotypic Differences Among PD Cases by SES

Grouped bars comparing low-PIR vs high-PIR PD subgroups. Wealthier PD: older (+31.5 months, p=0.009), more body fat (+7.1 kg, p=0.012), more pain (+31.6%, p=0.001). Suggests PD heterogeneity by SES.

**Source:** poverty\_paradox\_investigation/Figure4\_pd\_subgroup\_differences.png