

Word count: 4500

Number of figures: 2

Number of tables: 3

**Meta-analysis of structural evidence for the Hierarchical Taxonomy of Psychopathology
(HiTOP) model**

Whitney R. Ringwald, M.S., M.S.W.¹

Miriam K. Forbes, Ph.D.²

Aidan G.C. Wright, Ph.D.¹

¹Department of Psychology, University of Pittsburgh

²Department of Psychology, Macquarie University

Corresponding author: Whitney R. Ringwald, Department of Psychology, University of Pittsburgh, 4305 Sennott Square, 210 S. Bouquet St., Pittsburgh, PA 15260. Email: wringwald@pitt.edu

Conflicts of interest: None.

Funding statement: This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Abstract

Background: The Hierarchical Taxonomy of Psychopathology (HiTOP) is a classification system that seeks to organize psychopathology using quantitative evidence—yet the current model was established by narrative review. This meta-analysis provides a quantitative synthesis of literature on transdiagnostic dimensions of psychopathology to evaluate the validity of the HiTOP framework. **Methods:** Published studies estimating factor-analytic models from *DSM* diagnoses were screened. A total of 120,596 participants from 35 studies assessing twenty-three *DSM* diagnoses were included in the meta-analytic models. Data were pooled into a meta-analytic correlation matrix using a random effects model. Exploratory factor analyses were conducted using the pooled correlation matrix. A hierarchical structure was estimated by extracting one to five factors representing levels of the HiTOP framework, then calculating congruence coefficients between factors at sequential levels. **Results:** Five transdiagnostic dimensions fit the *DSM* diagnoses well (comparative fit index [CFI] = .92, root mean square-error of approximation [RMSEA] = .07, and standardized root-mean-square residual [SRMR] = .03). Most diagnoses had factor loadings $> |.30|$ on the expected factors, and congruence coefficients between factors indicated a hierarchical structure consistent with the HiTOP framework. **Conclusions:** A model closely resembling the HiTOP framework fit the data well and placement of *DSM* diagnoses within transdiagnostic dimensions were largely confirmed, supporting it as valid structure for conceptualizing and organizing psychopathology. Results also suggest transdiagnostic research should 1) use traits, narrow symptoms, and dimensional measures of psychopathology instead of *DSM* diagnoses, 2) assess a broader array of constructs, and 3) increase focus on understudied pathologies.

A paradigm shift towards transdiagnostic dimensional approaches to classifying psychopathology has gained traction in recent years (Daggleish et al., 2020; Krueger et al., 2018). Much of this shift has been driven by a growing literature using factor-analytic methods to overcome shortcomings of traditional diagnostic systems (e.g., *DSM*) by identifying the empirical structure of mental disorders. Evidence from these studies have been synthesized based on a narrative review into the Hierarchical Taxonomy of Psychopathology (HiTOP) framework (Kotov et al., 2017). The HiTOP framework consists of five, hierarchically-organized levels. As shown in the top panel of Figure 1, at the lowest level of the hierarchy are narrow signs and symptoms which combine to reflect increasingly broad dimensions of psychopathology from syndromes/disorders (e.g., *DSM* diagnoses), to subfactors (e.g., fear, distress), to spectra (e.g., antagonism, detachment), and higher-order constructs encompassing features shared by most forms of psychopathology.

A hierarchical, dimensional classification system helps resolve issues of poor reliability (Regier et al., 2013), extensive overlap between diagnoses (Kessler et al., 2005), and problematic within-diagnosis heterogeneity (Galatzer-Levy & Bryant, 2013) that have slowed progress in clinical research and practice (Clark et al., 2017; Markon et al., 2011). Compared to *DSM* categories, HiTOP transdiagnostic dimensions better account for patterns of heritability (Lahey et al., 2017; Waszczuk et al., 2020), neurobiological processes (Barch, 2017; Parkes et al., 2020; Shanmugan et al., 2016), functional impairment (Waszczuk et al., 2017), the effects of environmental risk factors (Albott et al., 2018; Rodriguez-Seijas et al., 2015), and variation in treatment response (Barlow et al., 2017). Because of these promising findings, efforts to translate the HiTOP framework into real-world solutions by integrating it into clinical assessment and interventions are expanding (Conway et al., 2019; Hopwood et al., 2019; Ruggero et al., 2019).

As the HiTOP framework becomes increasingly influential in how psychopathology is understood and treated, it is critical to ensure its principal objectives to “(a) integrate evidence generated by [the research on transdiagnostic dimensions of psychopathology] to date and (b) produce a system that reflects a synthesis of existing studies” (Kotov et al., 2017, p. 456) are fulfilled. The defining advantage of the HiTOP framework is its basis on quantitative evidence – yet the current model was established by a narrative review, not a direct quantitative meta-analysis. By indirectly comparing results from separate analyses—each of which only captures a subset of variables and typically focuses on only one level of the hierarchy—many parts of the model were inferred rather than empirically estimated. The only quantitative meta-analysis on psychopathology structure to date aligns with the relevant portions of the HiTOP framework that it covered, but it was published over a decade ago and included a very limited set of diagnoses (Krueger & Markon, 2006). There is also no statistical information about important characteristics of the model, such as the strength of associations between indicators and psychopathology dimensions (i.e., factor loadings). These gaps in what is known about the empirical structure threaten the model’s validity.

To produce a truly consensual model representing the current state of research on transdiagnostic dimensions, this meta-analysis provides a direct, quantitative synthesis of the literature by reanalyzing published samples in a single model. First, we tested the overall fit of the structure and the placement of *DSM* diagnoses in factor analytic models to compare with the HiTOP framework. Although the goal of the HiTOP framework is to eventually replace *DSM* constructs with empirically-derived and presumably transdiagnostic dimensions, understanding how these frameworks interface can promote communication. Our second aim was to enrich the

HiTOP framework with specific, meta-analytic parameter estimates. Finally, we aimed to present a road map for future investigations by identifying areas of the model in need of more research.

Methods

Eligibility criteria

All peer-reviewed, published factor-analytic studies estimating psychopathology dimensions from *DSM* diagnoses in adult samples were eligible for our meta-analysis. In addition to connecting research traditions, we chose to use *DSM* diagnostic indicators to maximize the number of studies eligible for inclusion and enable direct comparisons to the current HiTOP framework. Only studies in which diagnoses were assessed by structured or semi-structured interviews were eligible. Studies were included if diagnoses were operationalized as full syndrome (i.e., binary present or absent) or as ordinal symptom counts according to any version of the *DSM* criteria from the *DSM III-R* onwards. Studies were excluded if they used self-report measures of psychopathology or measures that did not assess *DSM* criteria. To ensure reliable correlation estimates, articles were also excluded that used samples smaller than 250 participants (Schönbrodt & Perugini, 2013).

Search criteria and study selection

To identify studies published before 2017, we screened references for the review paper that formed the basis of the current HiTOP model (Kotov et al., 2017). For studies on psychopathology structure published after the review paper (between January 1st, 2017 and July 1st, 2020), we searched PubMed and PsychINFO databases using the following keywords: (structure OR “structural model” OR “factor analysis” OR trait* OR dimension* OR spectra OR HiTOP OR “Hierarchical Taxonomy of Psychopathology” OR hierarchy) AND (psychopathology OR “mental disorder” OR “psychiatric disorder” OR transdiagnostic OR

“personality pathology” OR “maladaptive personality” OR “personality disorder”). Because some eligible studies were drawn from the same samples, the final screening stage involved selecting one study per sample. For each sample, we included the study that assessed the most diagnoses to maximize content coverage. In longitudinal studies that separately analyzed structures at different time points, we used data from the wave with the most diagnoses, or largest sample size for greater precision if the same diagnoses were assessed.

We obtained correlation matrices for diagnoses from each study included in the final meta-analyses. If correlations were not published, we requested this data from the study authors by email. If authors did not provide the correlations, another study from the same sample was included instead when possible; if there were no other published studies available from the sample, it was not included in the analysis.

Analyses

Coding and selection of diagnoses

To retain data on symptoms with low endorsement rates (e.g., psychosis), many studies combined criteria from different diagnoses to estimate their models. To account for variation in how diagnoses were operationalized across studies, and to avoid loss of data, we coded some diagnoses with sparse representation as a single indicator. Schizophrenia and composites of psychotic symptoms used in the studies (e.g., psychotic episodes, delusional disorder, schizoaffective disorder) were coded as psychotic disorders; anorexia, bulimia, and composites of eating disorder symptoms were coded as anorexia/bulimia; and bipolar I and II and manic episodes were coded as bipolar disorders. We considered most diagnoses as defined by different versions of the DSM to be isomorphic. For diagnoses that were combined or separated in different DSM versions, and were thus operationalized differently across studies, we coded them

as a single indicator. Specifically, we coded panic disorder with or without agoraphobia as panic disorder and drug or alcohol abuse and dependence as drug or alcohol use disorders. A complete list of how study diagnoses were coded for our analyses are in the supplementary materials. Each element in the combined correlation matrix needed to be drawn from at least one study, so any diagnoses without enough data available across studies to estimate a complete correlation matrix were excluded.

Meta-analytic models

We meta-analytically estimated one to eleven factors representing the psychopathology dimensions above the syndrome/diagnosis level in the HiTOP framework. We used a two-stage procedure in which correlations between diagnoses were first pooled and then structural models were fit to the resulting pooled correlation matrix. The meta-analytic pooling of correlation matrices was performed in R (R core Team, 2018) using a univariate random effects approach (Hedges & Vevea, 1998; Markon et al., 2005). Heterogeneity was assessed using the Cochran Q test. Tau^2 (τ^2) was calculated to estimate between-study variance. Each correlation was independently estimated by taking the average correlation across studies that reported the effect, weighted for the study's sample size, and accounting for sampling variability. Thus, each meta-analytic correlation reflects an estimate of the population correlation, averaged across subpopulations.

In the second stage, we fit a series of structural models to the pooled correlation matrix using exploratory factor analysis (EFA) in Mplus (Muthén & Muthén, 2020) with robust maximum likelihood estimation.¹ Given the amount of variation in symptoms within diagnoses,

¹ Although the pooled correlation matrix was drawn from studies with polychoric correlations, which are typically analyzed using a least squares estimator to obtain more accurate *SE* estimates, we used maximum likelihood for two reasons. First, unweighted least squares estimation is the only option for EFA with summary data and it does not provide *SEs* or global fit, but maximum likelihood does. Second, we interpreted effect sizes (versus statistical significance) which are not expected to vary substantially with different estimators. Indeed, factor loadings differed by less than .02 in models using the least squares or maximum likelihood estimators (results in the supplement).

and to account for interstitial features (i.e., those that load on or reflect multiple higher-order dimensions), we used EFA to allow diagnoses to freely cross-load onto all factors. We used Geomin oblique rotation because it is advantageous for models with complex loading structures (Browne, 2001; McDonald, 2005), such as those expected for heterogeneous diagnostic indicators. Because each cell in the pooled correlation matrix had a different sample size, we used the harmonic mean of the per-correlation N to obtain parameter estimates for the structural model. The harmonic mean is often used in cases that a single value is needed to represent unequal samples because it balances the influence of especially high or low N s (Johnson et al., 2001). We evaluated the models based on factor interpretability and model fit. Because the χ^2 can be sensitive to ignorable sources of ill fit in large samples, we prioritized alternative fit indices. Model fit was assessed according to standard benchmarks (i.e., comparative fit index [CFI] $\geq .95$, root mean square-error of approximation [RMSEA] $\leq .06$, and standardized root-mean-square residual [SRMR] $\leq .08$; Hu & Bentler, 1999). For factor interpretation, we considered diagnoses with factor loadings $\geq |.30|$ to be a marker of the factor. We also considered the precision of factor loadings in our data (i.e., SE s) alongside the general parameter value threshold for interpreting the factors, but reiterate the caveat in footnote 1 that these SE s should be interpreted with caution.

After estimating the factors, we adapted Goldberg's method (Goldberg, 2006) to examine associations between psychopathology dimensions between sequential levels of the HiTOP framework. Typically, factor scores are correlated across levels with this method, but factor scores rely on individual-level data, which were unavailable for the pooled matrix. For our

However, we advise interpreting the SE s with caution for the above reasons.

analyses, we instead calculated the congruence coefficients (r_c) for factors across levels, which provided a comparable estimate of the cross-level associations between factors².

This modeling approach does not provide global model fit indices for a hierarchical model spanning the levels estimated here. Although the inability to test overall fit of the model is a limitation of the method, other methods of estimating a hierarchical structure were impractical for the present study. A confirmatory factor analytic approach would make it difficult to reflect heterogeneity in the diagnoses because it presumes a sparse factor loading matrix and requires the investigator to specify all loadings a priori, and exploratory structural equation modeling requires individual-level data. Thus, instead of testing overall fit, this model allowed us to evaluate the HiTOP framework conceptually via interpretation of factors at each level as well as their interrelationships. Following Loehlin and Goldberg's (2014) recommendation, we considered $|r_c| \geq .90$ between levels to indicate perpetuation of the same construct between levels of the hierarchy, and $.30 \leq |r_c| < .90$ to indicate a higher-order dimension splitting into more specific lower-order dimensions.

Results

Correlation tables for each study included in the analysis are available on the Open Science Framework (https://osf.io/pqmtc/?view_only=521786c92eef4a8da6a70bdfbe42fae3).

Selection and inclusion of studies

As shown in Figure 2, 342 references from the previous HiTOP review and 3,734 articles identified through the database search were screened. A total of 86 studies representing 56 independent samples were eligible for inclusion.³ We were unable to obtain correlation matrices

² We compared congruence coefficients and factor score correlations in a sample with individual-level data and found the values differed by $< .10$, so we determined the indices can be used interchangeably for our purpose of estimating associations between factors.

³ Samples and studies do not correspond one to one because some studies analyzed multiple samples separately and some studies pooled multiple independent samples into a single structural analysis.

from 8 samples (11 articles); thus, after selecting a single study per sample according to our criteria, 48 samples from 35 articles ($N=120,596$) were included in the meta-analysis (study details are in Table 1).

Meta-analytic structural models

Meta-analytic correlation matrix

The pooled correlation matrix is shown in Table 2. Estimates of τ^2 and *SEs* for each meta-analytic correlation are in the supplement. Twenty-three diagnoses had adequate data to be included, encompassing nearly all of the syndrome-level constructs specified by the HiTOP framework. Exceptions were that there were no indicators for sexual problems or somatoform psychopathology. There were also not enough data to model disorders with childhood onset (e.g., attention deficit hyperactivity, separation anxiety, and intermittent explosive disorders). Table 2 shows the sample size assessed for each diagnosis and number of studies that contributed to each correlation. The total sample size for each diagnosis ranged from 9,510 to 115,944 and from 628 to 107,334 for each correlation. Major depression was assessed in the most studies ($k=30$) whereas avoidant, dependent, histrionic, and narcissistic personality disorders (PDs) were assessed in the fewest ($k=6$). The number of studies pooled to estimate each correlation in the matrix ranged from 1 to 26. A complete list of correlation sample sizes and studies per diagnosis are in the supplement.

Factor-analytic models

Only one to four factors could be extracted from the pooled correlation matrix using EFA. Models with five to eleven factors did not converge. The four-factor model was interpretable, but the model fit indices suggested it was a poor fit to the data ($CFI=.83$, $RMSEA=.09$, $SRMR=.05$). Convergence issues in these models were likely due to dependent PD

and bipolar disorder (i.e., identified Heywood cases). In models without dependent PD, a maximum of four factors could be extracted, but this model still had poor fit suggesting misspecification (CFI=.85, RMSEA=.08, SRMR=.04). Five and six-factor models with acceptable fit could be estimated after removing bipolar disorder, but including dependent PD. However, these models had some unexpected factor loadings that were difficult to interpret (e.g., dependent PD on an Antagonism factor; results in supplement). Removing both bipolar disorder and dependent PD from the models allowed up to six factors to be estimated, but the six-factor model included a factor marked by a single indicator with a negative residual variance indicating factor overextraction. The five-factor structure achieved acceptable model fit (CFI=.92, RMSEA=.07, SRMR=.03) and had more interpretable factors compared to the models including dependent PD. Most factor loading *SEs* rounded to .01 (full results in supplement). Thus, considering both model fit and interpretability, this model was selected as the final model.

In the final model, nearly all factor loadings were as expected based on the HiTOP framework's five-factor (spectra) level and could be interpreted as Internalizing, Detachment, Thought Disorder, Antagonism, and Disinhibition (bottom panel of Figure 1 shows loadings $\geq .30$; complete factor loadings in Table 3). Although the subfactor level of the HiTOP framework lies between the syndrome/diagnosis and spectrum level, we could not recover the subfactor structure due to having zero indicators for two of the subfactors (i.e., Sexual Problems, Mania) and only one indicator for two others (i.e., Eating Problems, Antisocial Behavior). Two results were inconsistent with the HiTOP framework. First, avoidant PD was expected to only load onto Detachment, but it had a primary loading on Internalizing and a secondary loading on Detachment. Second, social phobia was expected only to load onto Internalizing, but it had a marginal secondary loading on Detachment (i.e., the point estimate was just short of our pre-

determined threshold of $|\lambda|.30$], but the 95% confidence interval contained $.30$; $\lambda=.29$, $SE=0.015$, $CI:[.26,.32]$). Similarly, the point estimate for the loading of antisocial PD on Antagonism was also slightly below $.30$, but the threshold fell within the confidence interval so we considered antisocial PD to be a marker of Antagonism ($\lambda=.28$, $SE=0.013$, $CI:[.26,.30]$). Additionally, our model showed that obsessive-compulsive PD (OCPD), which is not yet specified in the HiTOP framework, loaded primarily on Antagonism and secondarily on Detachment.

Using the resulting EFA factors, we examined associations between psychopathology dimensions across levels of the hierarchy (associations shown in Figure 1; factor loadings in Table 3; model fit indices in the supplement). We focused on the higher-order structure (i.e., levels from the spectra and above) rather than all five levels of the HiTOP framework because our analyses did not include symptom-level indicators (the lowest level of the HiTOP framework), and we were unable to recover the subfactor level for reasons noted above. All diagnoses loaded $>.30$ onto a single higher-order factor, with borderline, paranoid, and schizotypal PDs as the strongest indicators. This general factor divided into Externalizing (marked most strongly by histrionic and narcissistic PD) and Internalizing (marked most strongly by social phobia and dysthymia) factors. At the third level, the Psychosis factor split off from Internalizing. At the fourth level, Externalizing divided into Antagonism and Disinhibition. Finally, at the five-factor level, Psychosis split into Thought Disorder and Detachment—the latter of which was also associated with Internalizing.

Moderators of between-study variance

We attempted to test study-level moderators of between-study variance by comparing factor-analytic models estimated in sample subgroups. We considered moderators that have been investigated in prior research including sample type (clinical or non-clinical), time frame of

assessment (current or lifetime diagnoses), use of binary versus symptom counts, and use of skip-outs in assessing diagnoses (Kotov et al., 2018). However, there was not enough data within any subgrouping of samples to estimate adequate five-factor models for comparison, so we were unable to assess these moderators.

Discussion

Our meta-analysis lends robust, quantitative evidence for the HiTOP framework. The meta-analytic structure represents a consensus among decades of empirical work from multiple countries, spanning diverse sample types, measurement instruments, and study designs. We found that a five-factor model resembling the HiTOP spectra fit the data well and the placement of *DSM* diagnoses were largely confirmed, showing the HiTOP framework is a reasonably accurate representation of research to date and supporting its validity for psychopathology classification.

In addition to providing evidence for the HiTOP framework's validity, our synthesis of the literature adds new insights into the structure and nature of transdiagnostic dimensions that could not be gleaned from the previous narrative review. In the current HiTOP framework, diagnoses are depicted as equivalent indicators of a given higher-order dimension, but we now quantify the strength of these associations with factor loadings. These parameters add greater precision to our interpretation of the HiTOP structure by indexing *how much* diagnoses reflect higher-order dimensions. As an example, we found that ~36% of the variance in panic disorder versus only ~10% in avoidant PD is accounted for by Internalizing, despite sharing fearful, avoidant clinical presentations. Comparing these numeric estimates of the relationship between observed features and psychopathology dimensions provides key information for deciding how to classify psychopathology moving forward. The factor loadings we found that were unexpected

based on the HiTOP model suggest several possible revisions and fresh directions for further inquiry. An especially novel finding, given that it is not yet included in the model, was that OCPD may be located in the Antagonism and Detachment spectra. This one meta-analytic parameter is not decisive, and more research is needed to explore the possibility—but recasting OCPD within the HiTOP framework would provide a way to rethink its core pathologies and leverage what is known about diagnoses with shared features (i.e., located in the same spectra) to open new avenues of research on this prevalent but understudied disorder (de Reus & Emmelkamp, 2012; Lenzenweger, 2008; Zimmerman et al., 2005).

HiTOP's higher-order structure fulfills the need for a phenotypic model that maps onto mounting evidence for non-specific genetic factors (Allegrini et al., 2020; Kendler, 2005; Pettersson et al., 2016), brain structure abnormalities (Romer et al., 2018; 2020), and pathophysiology (Elliott et al., 2018; Kebets et al., 2019) that cut across *DSM* categories. A practical obstacle to using the HiTOP framework for this purpose has been a lack of consensus evidence for the clinical presentation of higher-order dimensions (Levin-Aspenson et al., 2020), but our meta-analysis could help clarify these inconsistencies. For example, we found that personality pathologies (i.e., borderline, paranoid, and schizotypal) were among the strongest indicators for general psychopathology which adds to growing evidence that the cognitive, emotional, and behavioral dysregulation that distinguish these diagnoses in the *DSM* may actually be core, transdiagnostic symptoms. These findings align with theoretical (e.g., Carver et al., 2017; Gray & McNaughton, 2000; Spont, 1992) and empirical work (e.g., Gluschkoff et al., 2020; Oltmanns et al., 2018) and can serve as a springboard for research seeking to identify cross-cutting pathological features.

Our results on the higher-order structure may also provide a framework to better conceptualize evolving research on shared and specific risk pathways for psychosis. Recent work suggests affective/distress and negative symptoms differentially predict the transition to psychotic disorder (Binbay et al., 2012; Zavos et al., 2014), which could be due to influences at different levels of the hierarchy—specifically, increased risk associated with affective/distress symptoms (Legge et al., 2019) may reflect the influence of the superordinate Internalizing dimension whereas risk associated with negative symptoms may relate to specific factors in the subordinate Detachment dimension. More refined conceptualization enabled by the HiTOP framework could eventually improve prognostic accuracy and lead to more targeted treatment.

Although our meta-analysis adds more certainty to many aspects of the HiTOP model, the fact that some constructs could not be included reveals areas of relative uncertainty that can inform ongoing research. Our analyses underscore how operationalizing psychopathology as meeting full *DSM* criteria means that less is known about diagnoses with lower base rates like psychotic disorders, eating disorders, and some of the PDs. Measuring these pathologies dimensionally would help address these gaps in the literature because it would allow for modeling subthreshold manifestations that occur at higher rates in the general population.

There are also forms of psychopathology observed in clinical practice but lack coverage in the *DSM*. For instance, interpersonal dependency can be a clinical problem, but dependent PD is one of the only diagnoses that captures such warm, submissive symptoms (e.g., difficulty disagreeing with others due to fear of losing support) (Zimmermann & Wright, 2017). Underrepresentation of this pathology in *DSM* constructs, along with the heterogeneity of dependent PD criteria, may be why we could not appropriately model the diagnosis—it includes some criteria that correlate strongly with other diagnoses and some criteria that are not similar to

any other diagnoses. The HiTOP framework can easily incorporate pathologies like dependency with research using non-*DSM* measures that have better coverage of the construct (e.g., Simms et al., 2011) to produce a more comprehensive model than the *DSM*.

At the same time, some constructs have good coverage in the *DSM* but are rarely assessed in psychopathology research. The lack of research on some diagnoses meant we were either unable to evaluate their placement in the structure (e.g., somatoform symptoms, sexual problems), or their meta-analytic correlations were drawn from fewer samples (e.g., psychosis) which by definition makes those estimates less precise. It is difficult to know how variability in the precision of meta-analytic correlations may have impacted our results given the number of parameters in the models, but the dearth of studies on PDs is one likely reason we were unable to include bipolar disorders. Only two studies assessed bipolar disorders along with the PDs comprising Antagonism, meaning there is little data on how bipolar disorders relate to an entire spectrum and thus its placement in the overall structure is uncertain.

Limitations

Several limitations of our study should be acknowledged. Our results indicate a prevailing limitation of the factor-analytic literature, which is that many studies use *DSM* constructs that are often unreliable, highly overlapping, and heterogenous. HiTOP aims to improve upon these constructs, so using them as the units of analysis acts as a barrier to uncovering the natural structure of psychopathology. It is reasonable to speculate that the structures derived from *DSM* diagnoses will differ from those using narrower, more homogenous constructs. Despite this limitation, modeling with *DSM* diagnoses still provides useful information about psychopathology structure because much of the heterogeneity in content is captured by cross-loadings across factors. Furthermore, the few studies that have estimated a

comprehensive hierarchical model from narrow symptoms have found structures that are remarkably similar to what we found (e.g., Forbes et al., 2021), suggesting that models using *DSM* diagnoses do not necessarily produce fundamentally different results. Using *DSM* diagnoses in our analyses also served practical purposes. For example, as previously noted, using *DSM* diagnoses facilitates communication with clinicians and researchers who are primarily familiar with these constructs. Because much of the research underlying the HiTOP framework was based on DSM diagnoses, using these same constructs as indicators also allowed for direct comparisons between our meta-analytic models and HiTOP. And finally, pooling data across studies requires that the indicators are close to equivalent, so the widely-used, standardized *DSM* criteria maximized the number of samples we could include.

There were also a number of questions we were unable address with our study that will be necessary for validating the HiTOP framework. Due to the sparseness of data, we could not test competing placements of diagnoses, the fit of provisional dimensions (e.g., somatoform), or moderators of the structure. Thus, additional research is needed to investigate questions such as whether bipolar disorders reflect internalizing and/or thought disorder spectra, as well as the extent to which severity of psychopathology in a sample impacts the overall structure and what this could mean for a literature that has largely relied on low pathology, epidemiological samples. A unique strength of the HiTOP framework is the explicit commitment to ongoing revisions based on new data, so we see our study as just one piece of a broader, iterative validation process.

Conclusion

Our meta-analysis adds quantitative validation of the HiTOP framework, enhances it with concrete information about its parameters, and clarifies an agenda for transdiagnostic research

moving forward. Based on these results, we recommend that researchers interested in a quantitatively-based approach to studying psychopathology should (1) use more homogenous, empirically defined constructs like traits, narrow symptoms, and dimensional measures of psychopathology instead of *DSM* diagnoses, (2) assess a broader array of constructs, and (3) increase focus on areas of relative uncertainty in the model including somatoform symptoms, sexual problems, psychosis, eating pathology, personality pathology, and bipolar disorders. The HiTOP system will continue to evolve as research accumulates, but our study shows that a hierarchical, dimensional model has the empirical foundation needed to potentially transform how psychopathology is conceptualized, diagnosed, and treated.

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Table 1. Participant characteristics and study details for samples included in the meta-analysis

Study	N	Sample country	DSM version	Instrument	Time frame	Diagnosis measure	Skip -outs	Sample description
Baek et al., 2019	307	Korea	IV	Diagnostic Interview for Genetic Studies, SCID	lifetime	binary	Y	Patients diagnosed with bipolar disorder recruited from inpatient hospitals.
Caspi et al., 2014	1,000	New Zealand	IV	DIS	12-month	counts	N	Birth cohort.
Chamberlain et al., 2018	576	United States	IV	DSM-IV symptom tick-list for obsessive-compulsive disorder, MINI	current	binary and counts	Y	Community members recruited using media advertisements.
Class et al., 2019	499	United States	5	Young adult version of the Diagnostic Interview for Children	12-month	counts	Y	Subsample selected for psychopathology scores drawn from a representative twin sample of Tennessee metropolitan areas.
Conway & Brown, 2018	4,928	United States	IV	Anxiety Disorders Interview Schedule	lifetime and current ⁴	binary	Y	Outpatients recruited from a community-based treatment center.
Conway et al., 2018	705	Australia	IV	KSADS, SCID	lifetime	binary	Y	Subsample of offspring oversampled for having mothers endorsing elevated depression symptoms drawn from a birth cohort study. ⁵
de Jonge et al., 2018	15,499	Brazil, Colombia, Colombia-Medellin, Mexico, Murcia, Ireland, Peru, Poland, Romania	IV	CIDI	lifetime	binary	N	Nationally representative samples.
Farmer et al., 2013	816	United States	III-R/IV	KSADS, SCID	lifetime	binary	Y	Stratified follow-up sample of participants with or without lifetime diagnostic history drawn from a randomly selected sample of community youth.

⁴ We used the correlation matrix for lifetime diagnoses in our main analysis, but using the correlation matrix for current diagnosis did not result in any substantive difference in the meta-analytic structure.

⁵ Conway et al., 2018 and Starr et al., 2014 estimated the structures for offspring and mothers, respectively, from the same sample.

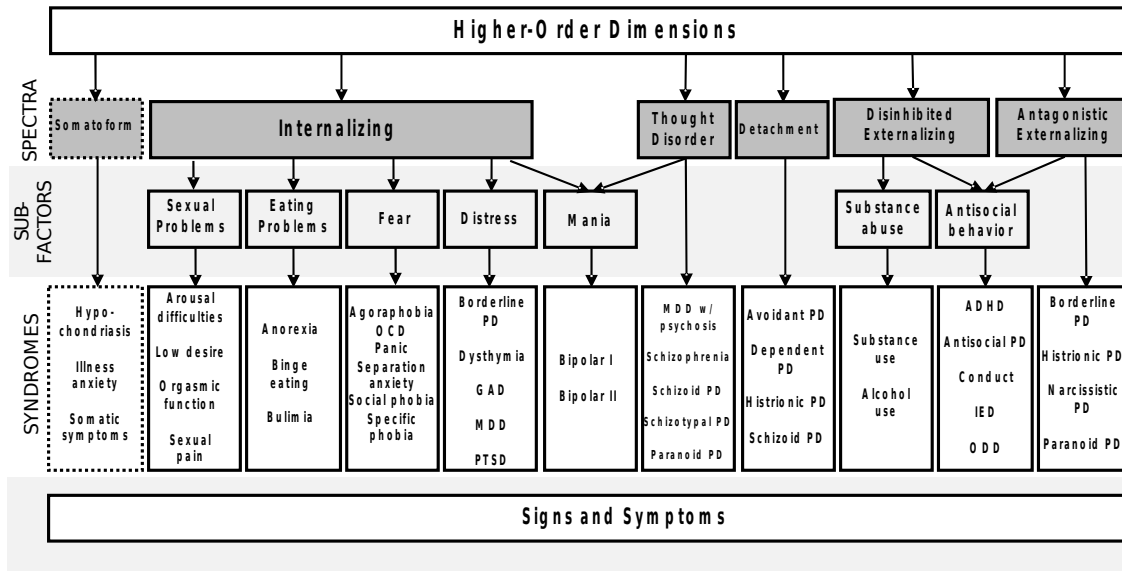
Study	N	Sample country	DSM version	Instrument	Time frame	Diagnosis measure	Skip -outs	Sample description
Fergussen et al., 2006	953	United States	IV	CIDI	lifetime	counts	Y	Birth cohort.
Finn et al., 2009	477	United States	IV	Semi-Structured Assessment for the Genetics of Alcoholism	lifetime	counts	Y	Community members recruited through advertisements in local newspapers.
Forbes et al., 2017	2,900	United States	IV	SCID	lifetime	binary	N	Patients recruited from an outpatient treatment center.
Friedman et al., 2020	765	United States	IV	CIDI, DIS	lifetime	counts	Y	Twin birth cohort.
Friedman et al., 2020	1,784	United States	IV	CIDI, DIS	lifetime	counts	Y	Twin birth cohort.
Girard et al., 2017	825	United States	III-R/IV	SCID, SIDP, LEAD	lifetime	binary	N	Five samples including outpatients and community members.
Hicks et al., 2013	7,665	United States	III-R	CIDI, SCID	lifetime	counts	Y	Two samples drawn from family design studies; a twin sample and nontwin biological/adoptive offspring sample.
Ignatyev et al., 2019	427	Chile	IV	MINI, SCID	current	binary	Y	Participants randomly selected at intake from prison facilities.
Keyes et al., 2013	34,653	United States	IV	Alcohol Use Disorder and Associated Disabilities Interview Schedule	lifetime	binary	N	Representative sample of US population.
Kotov et al., 2011	469	United States	III-R	SCID	lifetime	binary	Y	Cohort with first-admission psychosis recruited from inpatient units.
Kotov et al., 2015	385	United States	IV	IMAS	1 month	counts	Y	Undergraduate students.
Kotov et al., 2015	288	United States	IV	IMAS	1 month	counts	Y	Patients recruited from outpatient treatment centers.
Levin-Aspenson et al., 2019	7,459	United States	III-R	CIDI	lifetime	binary	Y	Representative sample of US population.
Marek et al., 2020	1,311	United States	IV	Semi-structured diagnostic interview	current	binary	N	Patients receiving bariatric surgery.
Marek et al., 2020	1,494	United States	IV	Semi-structured diagnostic interview	current	binary	N	Patients from chronic pain treatment program.
McDonald et al., 2019	480	United States	IV	SCID-Research Version	lifetime	binary	Y	Participants recruited from community and screened for a history of substance use and/or criminal behavior.
Miller et al., 2008	1,325	United States	III-R	SCID	lifetime	binary	Y	Male military veterans receiving health services at the Veterans Affairs Department.
Oltmanns et al., 2018	1,630	United States	IV	SIDP	current	binary	N	Representative sample of St. Louis.

Study	N	Sample country	DSM version	Instrument	Time frame	Diagnosis measure	Skip -outs	Sample description
Romer et al., 2018	1,358	United States	IV	MINI	lifetime	counts	Y	Undergraduate students.
Røysamb et al., 2011	2,794	Norway	IV	CIDI, SIDP	lifetime	binary/counts	N	Twin birth cohort.
Russotti et al., 2018	384	United States	IV	DIS	12-month	counts	Y	Economically-disadvantaged participants recruited based on child abuse/neglect reports through the Department of Human Services.
Slade & Watson, 2006	10,641	Australia	IV	CIDI	lifetime	binary	N	Community members.
Starr et al., 2014	705	Australia	IV	SCID	lifetime	binary	Y	Subsample of mothers endorsing elevated depression symptoms drawn from a birth cohort study. ⁴
Vollebergh et al., 2001	7,076	Netherlands	III-R	CIDI	12-month	binary	N	Stratified random sample.
Wolf et al., 2010	6,735	United States	III-R	DIS	lifetime	binary	Y	Nationally-distributed twin pairs in active military duty.
Wright & Simms, 2015	628	United States	5	MINI, SCID Axis II Personality Disorders	current	counts	N	Community members screened for having received psychiatric treatment in past two years.
Wright et al., 2016	733	United States	IV	SCID, Diagnostic Interview for DSM-IV Personality Disorders	lifetime	binary/counts	Y	Patients that meet criteria for avoidant, borderline, obsessive-compulsive, schizotypal personality disorders or major depressive disorder without personality disorder, recruited by treating clinicians.

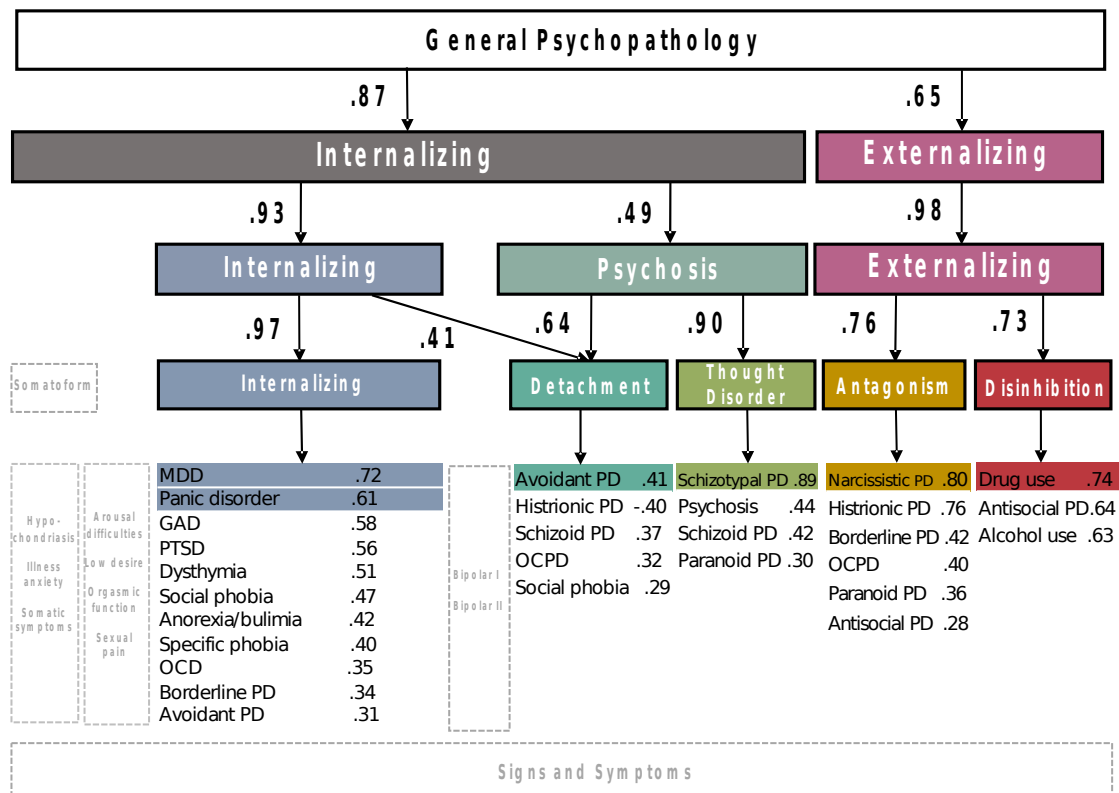
Note. Time frame = time frame of assessed diagnoses; Diagnosis measure = whether diagnosis was operationalized as binary indicator or dimensional symptom count; CIDI = Composite International Diagnostic Interview; DIS = Diagnostic Interview Schedule; IMAS = Interview for Mood and Anxiety Symptoms; KSADS = Kiddie Schedule for Affective Disorders and Schizophrenia; LEAD = Longitudinal, Expert, All Data procedure; MINI = Mini International Neuropsychiatric Interview; SCID = Structured Clinical Interview for DSM; SIDP = Structured Interview for DSM Personality

Figure 1. Comparison of the current HiTOP model based on a narrative review and the HiTOP model based on our quantitative meta-analysis

Current HiTOP model



Meta-analytic HiTOP model



Note. Congruence coefficients between factors at subsequent levels are shown by single-headed arrows. For ease of interpretation, not all factors at every level are shown; factor congruences are only shown if the factor split at the subsequent level. Indicators with factor loadings $\geq .30$ are listed below factors. Factor loadings are listed beside each diagnosis. Components with grey, dotted outlines are specified in the current HiTOP model but were not included in our analysis. ADHD = attention deficit hyperactivity disorder, IED = intermittent explosive disorder, MDD = major depressive disorder, OCD = obsessive compulsive disorder, OCPD = obsessive-compulsive personality disorder, ODD = oppositional defiant disorder, PD = personality disorder, PTSD = post-traumatic stress disorder.

Figure 2. Flow chart of article selection process

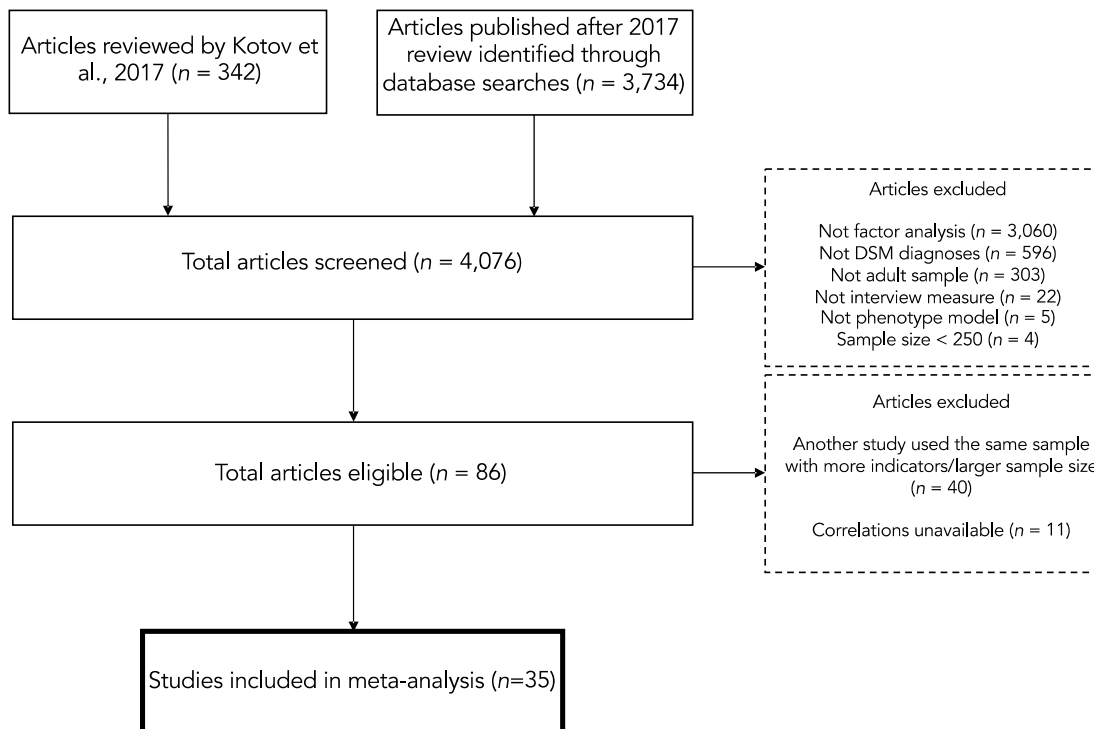


Table 2. Meta-analytic correlation coefficients and number of studies per diagnosis and per correlation

	AUD	AN/BN	AsPD	AvPD	Bipolar	BPD	DPD	DUD	Dys.	GAD	HPD	MDD	NPD	OCD	OCPD	Panic	PPD	Psy.	PTSD	Social Ph.	Spec. Ph.	StPD	SzPD
AUD	97,947	7	18	5	11	6	5	25	12	19	5	22	5	13	6	19	6	7	17	14	11	6	6
AN/BN	.10	24,983	5	2	5	3	3	7	4	6	3	6	3	4	4	7	3	2	6	5	4	3	3
AsPD	.46	.10	73,635	6	7	7	6	18	7	13	6	15	6	8	7	12	7	5	13	9	6	7	7
AvPD	.09	.12	.15	41,263	2	5	5	5	5	5	5	5	5	3	5	5	6	1	5	5	3	6	6
Bipolar	.21	.09	.25	.32	71,305	2	2	11	6	13	2	13	2	9	2	12	3	5	12	10	10	3	3
BPD	.3	.25	.47	.33	.27	9,937	6	6	4	5	6	6	6	5	6	6	6	2	6	5	3	6	6
DPD	.12	.22	.17	.46	.04	.45	9,510	5	4	5	6	5	6	4	6	5	6	2	5	4	3	6	6
DUD	.52	.09	.52	.13	.27	.34	.06	115,944	13	22	5	25	5	12	6	20	6	7	20	15	11	6	6
Dys.	.12	.19	.21	.41	.12	.31	.30	.21	93,492	13	4	14	4	5	4	14	5	2	13	13	10	5	5
GAD	.15	.18	.18	.33	.31	.30	.18	.19	.43	106,307	5	26	5	11	5	20	6	6	20	16	13	6	6
HPD	.18	.22	.27	.02	.23	.41	.28	.13	.06	.04	9,510	5	6	4	6	5	6	2	5	4	3	6	6
MDD	.19	.23	.21	.33	.25	.41	.24	.22	.51	.47	.14	110,049	5	14	5	24	6	7	23	18	14	6	6
NPD	.17	.07	.33	.12	.08	.38	.22	.14	.12	.11	.51	.12	9,510	4	6	5	6	2	5	4	3	6	6
OCD	.11	.19	.19	.23	.29	.33	.25	.11	.17	.32	.05	.30	.12	26,713	4	14	4	5	12	10	7	4	4
OCPD	.07	.12	.09	.22	.15	.23	.16	.00	.11	.27	.13	.13	.31	.23	10,086	5	6	2	5	4	3	6	6
Panic	.12	.22	.16	.31	.26	.35	.25	.20	.35	.39	.12	.39	.07	.29	.12	104,602	6	5	21	18	15	6	6
PPD	.16	.11	.31	.37	.30	.46	.22	.21	.32	.29	.25	.28	.39	.23	.32	.26	44,163	2	6	5	4	7	7
Psy.	.09	.14	.21	.23	.38	.29	.13	.14	.34	.21	.10	.16	.15	.22	.14	.13	.31	14,294	5	3	2	2	2
PTSD	.18	.23	.24	.26	.37	.46	.21	.25	.33	.33	.13	.44	.11	.3	.14	.38	.33	.24	97,588	17	13	6	6
Social Ph.	.16	.16	.20	.52	.26	.35	.32	.19	.35	.38	.05	.37	.08	.32	.17	.35	.28	.23	.28	90,419	13	5	5
Spec. Ph.	.03	.20	.07	.20	.25	.20	.13	.09	.27	.28	.13	.25	.11	.21	.13	.30	.30	.22	.27	.36	79,839	4	4
StPD	.18	.05	.27	.35	.34	.39	.28	.21	.34	.16	.20	.17	.31	.23	.18	.25	.52	.48	.35	.28	.27	44,163	7
SzPD	.08	.05	.14	.38	.12	.20	.16	.04	.30	.16	-.04	.18	.13	.19	.21	.15	.39	.28	.19	.26	.13	.47	44,163

Note. Below the diagonal are meta-analytic correlations; above the diagonal are the number of studies that estimated correlations between diagnoses; on the diagonal is the total sample size assessed per diagnosis. AUD = Alcohol use disorder, AN/BN = anorexia/bulimia, AsPD = antisocial personality disorder, AvPD = avoidant personality disorder, BPD = borderline personality disorder, DPD = dependent personality disorder, DUD = drug use disorder, Dys. = dysthymia, GAD = generalized anxiety disorder, HPD = histrionic personality disorder, MDD = major depressive disorder, NPD = narcissistic personality disorder, OCD = obsessive-compulsive disorder, OCPD = obsessive-compulsive personality disorder, PPD = paranoid personality disorder, Psy. = psychotic disorders, PTSD = post-traumatic stress disorder, Soc. Ph. = social phobia/social anxiety disorder, Spec. Ph. = specific phobia, StPD = schizotypal personality disorder, SzPD = schizoid personality disorder.

Table 3. Factor loadings for the one to five-factor exploratory factor-analysis models

	1 Factor	2 Factor		3 Factor			4 Factor				5 Factor				
	<i>G</i>	<i>Int</i>	<i>Ext</i>	<i>Int</i>	<i>Ext</i>	<i>Psy</i>	<i>Int</i>	<i>Dis</i>	<i>Ant</i>	<i>Psy</i>	<i>Int</i>	<i>Dis</i>	<i>Ant</i>	<i>Tht</i>	<i>Det</i>
AUD	<u>.34</u>	.00	<u>.46</u>	.02	<u>.62</u>	<u>-.31</u>	.01	<u>.64</u>	.07	-.03	.01	<u>.63</u>	.09	-.02	.00
AN/BN	<u>.30</u>	.22	.14	<u>.29</u>	.10	-.07	<u>.38</u>	-.04	.21	-.20	<u>.42</u>	-.07	.17	-.10	-.17
AsPD	<u>.48</u>	.02	<u>.64</u>	-.05	<u>.81</u>	-.22	-.01	<u>.61</u>	.25	.05	-.03	<u>.64</u>	<u>.28</u>	.00	.05
AvPD	<u>.56</u>	<u>.63</u>	-.02	<u>.46</u>	-.01	<u>.32</u>	<u>.41</u>	-.06	-.03	<u>.36</u>	<u>.31</u>	-.03	.03	.13	<u>.41</u>
BPD	<u>.70</u>	<u>.29</u>	<u>.60</u>	.22	<u>.61</u>	.02	<u>.35</u>	.21	<u>.46</u>	.02	<u>.34</u>	.20	<u>.42</u>	.07	-.05
DUD	<u>.40</u>	.09	<u>.43</u>	.11	<u>.62</u>	<u>-.34</u>	.06	<u>.78</u>	-.05	.00	.11	<u>.74</u>	-.04	.01	-.03
Dys.	<u>.58</u>	<u>.65</u>	-.01	<u>.57</u>	.01	.15	<u>.53</u>	.03	-.05	.22	<u>.51</u>	.01	-.05	.15	.16
GAD	<u>.54</u>	<u>.62</u>	-.03	<u>.67</u>	-.03	-.03	<u>.67</u>	.01	-.04	-.03	<u>.58</u>	.02	.02	-.16	.25
HPD	<u>.32</u>	-.19	<u>.67</u>	-.20	<u>.59</u>	-.01	.01	.00	<u>.81</u>	-.26	.03	-.02	<u>.76</u>	.00	<u>-.40</u>
MDD	<u>.58</u>	<u>.61</u>	.04	<u>.73</u>	.03	-.11	<u>.76</u>	.04	.02	-.13	<u>.72</u>	.03	.03	-.15	.08
NPD	<u>.39</u>	-.11	<u>.67</u>	-.25	<u>.61</u>	.18	-.08	.00	<u>.73</u>	.03	-.21	.05	<u>.80</u>	.03	.03
OCD	<u>.45</u>	<u>.42</u>	.09	<u>.37</u>	.09	.09	<u>.40</u>	-.01	.07	.09	<u>.35</u>	.00	.08	.04	.14
OCPD	<u>.34</u>	.21	.19	.09	.13	.25	.17	-.16	.29	.12	.02	-.11	<u>.40</u>	-.06	<u>.32</u>
Panic	<u>.52</u>	<u>.55</u>	.03	<u>.57</u>	.03	.00	<u>.58</u>	.02	.03	-.01	<u>.61</u>	-.02	-.02	.04	-.02
PPD	<u>.64</u>	<u>.36</u>	<u>.40</u>	.08	<u>.41</u>	<u>.43</u>	.15	.01	<u>.36</u>	<u>.43</u>	.09	.04	<u>.36</u>	<u>.30</u>	.23
Psy.	<u>.45</u>	<u>.34</u>	.17	.11	.20	<u>.35</u>	.08	.04	.10	<u>.44</u>	.14	.01	.02	<u>.44</u>	.04
PTSD	<u>.58</u>	<u>.49</u>	.17	<u>.46</u>	.19	.04	<u>.47</u>	.11	.07	.09	<u>.56</u>	.06	-.02	.19	-.10
Social Ph.	<u>.57</u>	<u>.65</u>	-.03	<u>.57</u>	.00	.13	<u>.53</u>	.03	-.06	.19	<u>.47</u>	.04	-.03	.04	<u>.29</u>
Spec. Ph.	<u>.42</u>	<u>.45</u>	.00	<u>.36</u>	-.02	.21	<u>.37</u>	-.12	.09	.15	<u>.40</u>	-.14	.05	.15	.02
StPD	<u>.60</u>	<u>.36</u>	<u>.34</u>	-.01	<u>.38</u>	<u>.54</u>	-.04	.08	.23	<u>.69</u>	-.02	.02	.07	<u>.89</u>	.00
SzPD	<u>.44</u>	<u>.44</u>	.04	.13	.05	<u>.53</u>	.05	-.07	-.01	<u>.65</u>	.01	-.04	.00	<u>.42</u>	<u>.37</u>

Note. Factor loadings with confidence intervals including $> |.30|$ are bolded and underlined. Nearly all standard errors for all factor loadings round to .01 (range = .004 - .021) and are reported in the supplementary material. AUD = Alcohol use disorder, AN/BN = anorexia/bulimia, AsPD = antisocial personality disorder, AvPD = avoidant personality disorder, BPD = borderline personality disorder, Dis = Disinhibition, Det = Detachment, DUD = drug use disorder, Dys. = dysthymia, Ext = Externalizing, G = general psychopathology, GAD = generalized anxiety disorder, HPD = histrionic personality disorder, Int = Internalizing, MDD = major depressive disorder, NPD = narcissistic personality disorder, OCD = obsessive-compulsive disorder, OCPD = obsessive-compulsive personality disorder, PPD = paranoid personality disorder, Psy = psychotic disorders, PTSD = post-traumatic stress disorder, Soc. Ph. = social phobia/social anxiety disorder, Spec. Ph. = specific phobia, StPD = schizotypal personality disorder, SzPD = schizoid personality disorder, Tht = Thought Disorder.