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Do empirically-derived personality subtypes relate to cognitive inflexibility in anorexia nervosa and bulimia nervosa?

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Abstract

Background Accruing evidence suggests that personality-based approaches to eating disorder classification may offer several advantages over current diagnostic models, with prior research consistently identifying three personality-based groups characterized by either (1) high levels of impulsivity and dysregulation (termed the "undercontrolled" group), (2) high levels of rigidity and avoidance (termed the "overcontrolled" group), or (3) relatively normative levels of personality functioning (termed the "low psychopathology" group). Cognitive inflexibility (i.e., difficulty adjusting thoughts or behaviors) has theorized relevance to eating disorders. However, prior research has frequently failed to observe differences in cognitive inflexibility across eating disorder diagnostic groups. The present study aimed to identify personality-based groups in an eating disorder sample, and then to examine the relations between these groups and behavioral measures of cognitive inflexibility.

Method 83 men and women who met *DSM-5* criteria for anorexia nervosa or bulimia nervosa completed self-report questionnaires to assess trait-level approach/avoidance behaviors and impulsivity, as well as behavioral tasks assessing attentional set-shifting and reversal learning, two facets of cognitive inflexibility.

Results Latent profile analysis of measures assessing approach/avoidance behaviors and impulsivity supported a three-class model replicating the undercontrolled, overcontrolled, and low psychopathology groups. Notably, the low psychopathology group was characterized by elevated reward responding. One-way ANOVAs indicated that the low psychopathology group demonstrated heightened perseverative errors (an indicator of impaired reversal learning) relative to the other groups. No group differences were observed for attentional set-shifting errors or probabilistic switch errors.

Discussion Findings from the present study provide additional support for personality-based classification approaches identifying undercontrolled, overcontrolled, and low psychopathology eating disorder groups. Results also suggest that reward-related processes may contribute to disorder maintenance in the low psychopathology group, indicating potentially meaningful targets for intervention.

Keywords Anorexia nervosa, Bulimia nervosa, Classification, Personality, Latent profile analysis, Attentional set-shifting, Reversal learning, Reward

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Plain English summary

This study supports previous research indicating that individuals with eating disorders can be subdivided into three groups with either (1) high levels of impulsivity and dysregulation (termed the "undercontrolled" group), (2) high levels of rigidity and avoidance (termed the "overcontrolled" group), or (3) relatively normative levels of personality functioning (termed the "low psychopathology" group). This study also indicates that individuals in the "low psychopathology group" may experience abberations in reward functioning (e.g., elevated drive for rewards and difficulty adjusting to changing reward contingencies) that may contribute to eating disorder persistence.

Introduction

Eating disorders, including anorexia nervosa (AN) and bulimia nervosa (BN), are serious psychiatric disorders that are associated with significant psychosocial impairment and elevated risk for other psychiatric and medical conditions [35, 77]. Unfortunately, treatments for AN and BN have demonstrated limited efficacy [7, 31, 43, 49, 54] highlighting an urgent need to clarify the key factors that may maintain these disorders in order to illuminate meaningful intervention targets.

Current models of eating disorder diagnosis and classification have a number of limitations, and may contribute to difficulty identifying clinically-relevant maintenance mechanisms [81]. Existing diagnostic categories focus on distinguishing groups according to a subset of eating disorder symptoms and associated features, while other symptoms appear across diagnostic boundaries. For example, AN and BN are primarily distinguished by the presence or absence of a low body weight, while overvaluation of weight and shape, binge eating, and compensatory behaviors (e.g., restrictive eating) may occur in both disorders [1]. This classification approach results in significant heterogeneity in symptom presentation among individuals who carry the same eating disorder diagnosis and may contribute to observed differences in treatment response [33, 47, 49, 56]. Further, longitudinal research indicates a high degree of diagnostic crossover (e.g., transition from AN to BN), underscoring a lack of stability in eating disorder diagnoses [10, 20, 67]. Finally, current classification approaches provide limited insight into potential maintenance mechanisms that may perpetuate an eating disorder, ultimately reducing their ability to inform intervention approaches [37].

Personality-based classification approaches may have advantages over the current classification system

A number of alternative classification models have been proposed to help address these gaps (e.g., [45, 71, 84]). In particular, previous research documents significant heterogeneity in personality patterns both within and across individual eating disorder diagnoses [9, 35, 48, 55]. Across a range of different eating disorder samples (e.g., AN, BN, recovered), and using a variety of assessment approaches (e.g., self-report questionnaires, clinical interviews), numerous studies have identified three personality-based groups or profiles characterized by (a) elevations in risk-taking, impulsivity, and behavioral or emotional dysregulation relative to other eating disorder subgroups (termed the "undercontrolled" group); (b) elevatations in rigidity, inhibition, avoidance, and constraint relative to other eating disorder subgroups (termed the "overcontrolled" group); and (c) relatively normative levels of personality functioning (termed the "low psychopathology" group[1]) (for a review of relevant studies, see [81]). Indeed, research conducted within other clinical groups (e.g., post-truamatic stress disorder, anxiety, depression; [3]) and non-clinical samples (e.g., [28]) has identified similar personality patterns, suggesting that these groups are highly robust and associated with a range of deleterious mental health conditions and symptoms. Within the eating disorder literature, these personality subtypes appear to provide valuable prognostic information and may be superior to categorical eating disorder diagnoses in predicting patterns of treatment utilization and response, psychosocial functioning, and course of illness [75, 76, 79, 82]. For example, longitudinal data suggests that an undercontrolled personality type may predict subsequent eating disorder onset among the general population (e.g., [27]). In a study comparing diagnostic profiles (i.e., AN binge-eating/purging subtype versus restrictive eating subtype) to personality-based profiles as predictors of poor outcome among individuals receiving intensive treatment for AN, personality profiles were found to predict illness course (e.g., readmission rates) and treatment engagement (e.g., leaving treatment against medical advice), while diagnostic profiles did not [82]. Further, personality-based approaches to classification may offer valuable insight into unique maintenance mechanisms underlying disorder persistence, which could inform novel and more targeted treatments [79, 81, 82]. Given evidence

[1] Note that while the "low psychopathology" group exhibits less *extreme* elevations on personality measures (e.g., impulsivity, rigidity) relative to the undercontrolled and overcontrolled groups, these symptoms may be still be somewhat elevated relative to healthy controls. Further, levels of eating pathology remain in the clinical range for this group of individuals.

that personality-based classification approaches exhibit several advantages over current diagnostic approaches, continued clarification of the unique features associated with each profile is needed to help identify possible distinct treatment targets.

Cognitive inflexibility may vary across personality-based profiles

Facets of cognitive inflexibility may be valuable features to evaluate in relation to observed personality-based profiles. Individuals with AN and BN often exhibit rigid patterns of thought and behavior, such as difficulties changing maladaptive eating behaviors despite their negative consequences. Given this, researchers theorize that cognitive inflexibility, including aberrations in attentional set-shifting and reversal learning, may contribute to the onset and persistence of eating disorder symptoms [24, 61, 66, 80]. Broadly, attentional set-shifting involves the ability to shift attention from one rule or "mental set" to another (Brown & Tait, 2010 [26],), while reversal learning refers to the ability to flexibly adjust one's behavior when the reward-related contingencies that were previously learned are changed [38]. Within eating disorders, abberations in attentional set-shifting may manifest in difficulties disengaging from disorder-salient stimuli (e.g., calorie information or body-related stimuli), while abberations in reversal learning may manifest in difficulties discontinuing behaviors previously perceived as rewarding (e.g., dieting that previously led to social rewards).

Importantly, previous research exploring differences in cognitive inflexibility, attentional set-shifting, and reversal learning across eating disorder diagnoses has produced mixed results, with studies frequently failing to observe group-level differences in these cognitive processes, including within the current sample (e.g., [18, 72]). Although eating disorder research has not examined attentional set-shifting and reversal learning in relation to personality-based subtypes, research on other psychiatric disorders suggests that reversal learning deficits may be particularly relevant to forms of psychopathology characterized by high levels of impulsivity, including substance use disorders [38, 57, 62], which are common in the undercontrolled eating disorder group (e.g., [83]). In addition, some work suggests that difficulties with attentional set-shifting may be particularly associated with increased levels of depression, anxiety, and social avoidance behaviors [12, 29, 30, 34, 39], which are common in the overcontrolled eating disorder group (e.g., [83]). Given this, it seems possible that the undercontrolled (i.e., more impulsive) eating disorder subtype may be associated with increased impairments in reversal learning, while the overcontrolled (i.e., more avoidant) subtype may be more strongly associated with impairments in attentional set-shifting. Finally, although the low psychopathology subtype has been identified in numerous samples [81], additional maintenance mechanisms (beyond overvaluation of weight and shape [22], underlying eating disorder symptoms in this group remain unclear [81].

In summary, existing diagnostic models of eating disorders demonstrate significant limitations, prompting a growing body of research intended to identify alternative classification approaches that may offer valuable insights into unique maintaining mechanisms for distinct forms of eating pathology. In particular, personality-based approaches have consistently identified three distinct profiles among individuals with eating disorders, which have been labeled the undercontrolled, overcontrolled, and low psychopathology groups. Although deficits in attentional set-shifting and reversal learning have been theorized to contribute to eating pathology, possible differences in these cognitive processes have not yet been explored in relation to personality-based eating disorder groups. Therefore, the goals of the current study were to (a) identify personality-based subtypes in a sample of individuals with AN or BN using latent profile analysis; and (b) examine the relationships between empirically-derived personality-based subtypes and behavioral measures of attentional set-shifting and reversal learning within the same sample.

Methods

Participants

Participants were 83 adults who met *DSM-5* [1] criteria for AN-restricting type (AN-R, $n=26$), AN-binge-eating/purging type (AN-BP, $n=22$), or BN ($n=35$). Approximately ninety-three percent of the sample ($n=77$) identified their biological sex as female and 7.2% ($n=6$) identified their biological sex as male. Participants self-identified as White (83.1%, $n=69$), Asian (12%, $n=10$), Black (7.2%, $n=6$), Hispanic/Latino (9.6%, $n=8$), or American Indian/Alaska Native (4.8%, $n=4$).[2] The mean age of the sample was 25.9 years ($SD=8.3$). The average duration of eating disorder symptoms was 9.1 years ($SD=7.1$). Sixty-three percent ($n=52$) of participants were diagnosed with a co-occurring psychiatric disorder, the most common being major depressive disorder (30%, $n=25$) and social anxiety disorder (30%, $n=25$).

Measures

Clinical interviews

Eating disorder examination (EDE) The Eating Disorder Examination Interview, 16th Edition (EDE; [21]) was used to establish *DSM-5* eating disorder diagnoses. In addition, the EDE includes four subscales (i.e., Restraint,

[2] Note that several participants endorsed multiple racial/ethnic identities, resulting in values that do not sum to the total sample size or 100%.

Eating Concern, Weight Concern, Shape Concern), which can be averaged to create a Global score in which higher scores indicate greater overall eating disorder symptom severity. Following identification of personality-based eating disorder groups, the EDE Global score was used in validation analyses to examine differences in eating disorder severity across groups. Eating disorder severity was not expected to vary across personality groups. Previous research supports the reliability and validity of the EDE [2]. In the present sample, the EDE Global score had high internal consistency (Cronbach's α = 0.90).

Structured clinical interview for DSM-5 (SCID) The Structured Clinical Interview for *DSM-5* Axis I Disorders, Research Version (SCID-5-RV; [23]) was used to evaluate eating disorder diagnostic status and co-occurring psychopathology, for the purpose of confirming eligibility. Age of onset items from the SCID-5-RV were also used to calculate eating disorder illness duration, which was used in the validation analyses and not expected to vary across personality-based groups. The SCID has demonstrated good reliability and validity in previous research (Osorio et al., 2019). In the present sample, SCID-established psychiatric diagnoses demonstrated acceptable interrater reliability (kappa range = 0.57–1.00).

Self-report questionnaires

Behavior inhibition scale (BIS)/behavior activation scale (BAS) The BIS/BAS [8] scales were used to measure reward and punishment sensitivity, and served as indicators to identify personality-based eating disorder groups in the present study. This measure generates four subscales. The single BIS subscale assesses negative affect and the tendency to avoid perceived threats (i.e., punishment sensitivity). The three BAS subscales assess distinct domains of positive affect and the tendency to approach goal-directed outcomes (i.e., reward sensitivity). More specifically, the BAS Reward Responsiveness subscale assesses the degree to which one experiences a positive response to rewards, the BAS Drive subscale assesses persistence in pursuing goals, and the BAS Fun-Seeking subscale assesses a desire for novel and spontaneous rewards. Participants responded to 24 items using a 4-point scale ranging from 1 (*very true for me*) to 4 (*very false for me*). All but two items (2 and 22) were first reverse scored, and then relevant item scores were summed to create subscale scores in which higher scores indicated greater reward or punishment sensitivity. Previous research supports the reliability and validity of BIS/BAS scores [40], and has utilized the BIS/BAS or similar scales to identify personality-based subgroups (e.g., [11, 42, 44, 70, 78]). In the present sample, internal consistency for the subscales was slightly lower than is generally desired (with alpha values of 0.70 or higher being desirable) but not unacceptable (Cronbach's α range = 0.55 – 0.68).

UPPS-P impulsive behavior scale (UPPS-P) The UPPS-P [50] was used to assess distinct facets of impulsivity, which served as additional indicators to identify personality-based eating disorder groups. The UPPS-P generates five subscales. The Negative Urgency subscale assesses the tendency to behave impulsively under conditions of negative affect, the Positive Urgency subscale assesses the tendency to behave impulsively under conditions of positive affect, the Premeditation (lack of) subscale assesses the tendency to act without consideration of consequences, the Perseverance (lack of) subscale assesses the ability to sustain attention on difficult or boring tasks, and the Sensation Seeking subscale assesses a preference for exciting and risky behaviors. Participants responded to 59 items using a 4-point scale ranging from 1 (*agree strongly*) to 4 (*disagree strongly*). Relevant item scores were averaged to create subscale scores, with higher scores indicating greater levels of impulsivity. Previous research supports the reliability and validity of UPPS-P scores [16, 58, 74], and has utilized the UPPS or similar scales to identify personality-based subgroups (e.g., [42, 63, 78, 83]). In the present sample, internal consistency for the subscales was good (Cronbach's α range = 0.84 –0.94).

Center for epidemiologic studies depression scale (CESD) Depressive symptoms were assessed using the 20-item Center for Epidemiologic Studies Depression Scale (CESD; [65]). Items are rated on a 4-point scale ranging from 0 (*rarely or none of the time*) to 3 (*most or almost all of the time*). Item scores were summed to create a scale score, with higher scores indicating greater depressive symptoms. CESD scores were then used in validation analyses. Lower levels of depression were expected in the low psychopathology group. Previous research supports the reliability and validity of CESD scores [14]. In the present sample, the CESD had acceptable internal consistency (Cronbach's α = 0.69).

State-trait anxiety inventory (STAI) Anxiety symptoms were assessed using the 20-item trait subscale of the State-Trait Anxiety Inventory for Adults (STAI; [69]). Items are rated on a 4-point scale ranging from 1 (*almost never*) to 4 (*almost always*), and summed to create a scale score with higher scores indicating greater levels of trait anxiety. STAI scores were then used in validation analyses, with lower levels of anxiety expected in the low psychopathology group. Previous research supports the reliability and validity of STAI scores [53]. In the present

sample, the trait subscale of the STAI had good internal consistency (Cronbach's $\alpha = 0.90$).

Behavioral tasks

Intradimensional/extradimensional (ID/ED) shift task The ID/ED shift task from the Cambridge Neuropsychological Test Automated Battery is a behavioral measure of attentional set-shifting [19]. Participants are presented with a pair of stimuli and must use feedback to determine which of the two stimuli is "correct." Stimuli in this task are comprised of two dimensions: lines and shapes. In early stages of the task, shape is the relevant stimulus dimension (i.e., participants must respond to the shape) whereas in later stages, line is the relevant stimulus dimension. There are nine stages in this task and 50 trials in each stage. Participants proceed to the next stage only if a criterion of six consecutive correct responses has been attained. In Stages 1–5, participants must decide which of the two relevant stimulus dimensions (i.e., shapes) is correct, while ignoring the irrelevant stimulus dimension (i.e., lines). In Stage 6, new lines and shapes are introduced but shape remains the relevant stimulus dimension. In Stage 7, a reversal occurs whereby the previously incorrect shape is now the correct shape; thus, participants must shift attention from one exemplar to another within the same stimulus dimension (i.e., perform an "intra-dimensional" shift). In Stage 8 (the "extra-dimensional" shift stage), lines become the relevant stimulus dimension; therefore, participants must shift attention to a previously irrelevant stimulus dimension (i.e., line). A greater number of attentional set-shifting errors (i.e., selecting the wrong stimulus) during the extra-dimensional shift stage (i.e., Stage 8) reflect greater impairment in attentional set-shifting. In the present study, observed participant attentional set-shifting errors ranged from 1 to 32.

Probabilistic reversal learning task A Probabilistic Reversal Learning task was used to measure reversal learning [17]. In this task, participants must determine which of two stimuli is most likely to be correct based on feedback. The task consists of two stages with 40 trials in each stage. During each trial, participants are presented with a pair of stimuli and instructed to select one stimulus. After each selection, they receive feedback about whether their response was correct. They receive accurate feedback on 80% of trials, and false feedback on 20% of trials. In Stage 1 (the initial acquisition stage) stimulus 1 is the correct response. Thus, in this stage, a choice of stimulus 1 is reinforced 80% of the time and a choice of stimulus 2 is reinforced 20% of the time. Participants must achieve eight consecutive correct trials in this stage to show adequate learning of the stimulus-outcome contingency. In Stage 2 (the reversal stage), the stimulus-outcome contingency is reversed (i.e., stimulus 2 is now the correct response). Two types of errors reflect deficits in reversal learning: (a) perseverative errors during the reversal stage (i.e., continuing to select a previously rewarded stimulus despite punishment) and (b) probabilistic switch errors during the reversal stage (i.e., switching too easily in response to punishment that is not dependent on one's response). Perseverative errors are calculated as the number of consecutive incorrect choices (i.e., choosing stimulus 1) that occur between the initial reversal and the first, newly correct choice (i.e., choosing stimulus 2) during the reversal stage. Thus, a higher number of preservative errors would indicate that an individual took longer to make the initial switch from choosing stimulus 1 to choosing stimulus 2 after the reversal. Probabilistic switch errors are calculated as the number of times in which a participant chooses stimulus 1 following the receipt of false feedback for choosing stimulus 2, during the reversal stage. Thus, a higher number of probabilistic switch errors would indicate that an individual was more likely to switch back to stimulus 1 following false feedback about stimulus 2, during the reversal stage. In the present study, observed participant perseverative errors ranged from 1 to 38, while observed probabilistic switch errors ranged from 0 to 9.

Procedure

Participants were recruited through referrals from an eating disorders treatment program with multiple levels of care (inpatient, partial hospitalization program, intensive outpatient program), community advertisements, and a database of participants from previous studies. Interested individuals contacted research personnel and completed a phone screen to determine their initial eligibility. Inclusion criteria were (a) current diagnosis of AN-BP, AN-R, or BN; (b) BMI ≥ 14 kg/m^2; (c) age 18–55 years; and (d) fluency in English. Exclusion criteria were: (a) vital signs suggesting medical instability; (b) a history of AN prior to the onset of BN; (c) a history of binge eating or purging prior to the onset of AN-R; (d) daily smoking; (e) full-scale IQ estimate < 80; (f) current pregnancy; (g) metallic implants, dental or orthodonture plates; (h) use of medication that is known to affect attentional set-shifting or reversal learning (e.g., second generation antipsychotics); (i) claustrophobia; (j) current bipolar disorder; (k) current psychosis; or (l) current severe substance use disorder. Exclusion criteria b and c were implemented to support the original aims of the grant supporting this data-collection (i.e., to identify neurocognitive features specific to distinct diagnostic groups). Exclusion criterion d was implemented as smoking has been implicated in cognitive flexibility. Exclusion criteria g and i were implemented as participants underwent a functional magnetic

resonance imaging (fMRI) scan as part of the original data-collection. Exclusion criterion j was implemented as current mania was expected to significantly impact participants' ability to complete the study procedures.

Individuals who appeared eligible for the study based on the initial screening attended an in-person study visit, during which they provided informed consent, completed an assessement of medical stability (i.e., vital signs, blood work), had their height and weight measured, and completed clinical interviews assessing eating disorder symptoms and co-morbid psychopathology. Afterwards, they completed the self-report questionnaires and behavioral tasks. In a seprate study visit, participants completed an additional series of cognitive tasks while their brain activity was recorded using fMRI. However, results of these tasks are not reported here. Study assessments were performed by trained bachelor's or master's level clinicians who were supervised by licensed clinical psychologists. Study procedures were approved by the University of Pittsburgh Institutional Review Board (ethics approval number PRO14020217). Additional information regarding the study sample and procedure can be found in the primary publication [18].

Statistical analysis

Latent profile analysis (LPA) was used to separate individuals into profile-based groups or classes based on a set of indicator variables [13]. The LPA used nine continuous indicators, four from the BIS/BAS (BAS-Drive, BAS-Fun Seeking, BAS-Reward Responsiveness, and BIS) and five from the UPPS-P (Negative Urgency, Positive Urgency, Lack of Premeditation, Lack of Perseverance, and Sensation Seeking). The BIS/BAS and UPPS-P were chosen to capture distinct facets of impulsivity and approach/avoidance tendencies, consistent with the key features of the previously identified undercontrolled, overcontrolled, and low psychopathology groups [81]. These indicators were standardized to account for differences in response scale, and the LPA was conducted using Mplus Version 8.10 [59].

We expected to identify a 3-class LPA solution similar to previous research, with groups reflecting undercontrolled, overcontrolled, and low psychopathology traits [81]. To examine the appropriateness of the 3-class solution quantitatively, it was compared to 1-, 2-, 4-, and 5-class solutions using three approaches. First, the Bayesian Information Criterion (BIC [68]) and Consistent Akaike Information Criterion (cAIC,[5]) fit indices were examined, with lower values indicating a better fit of the model to the data, similar to previous studies (e.g., [46, 82]). In addition, parametric bootstrap likelihood ratio tests (BLRT) were used to determine if each model of k classes provided a significant improvement in model fit over the model of k-1 classes [60], with a significant *p*-value supporting class k. Finally, a bootstrapping procedure was used to assess the consistency of individual class assignments, whereby each LPA was repeated 100 times using independent random samples of 95% of the original sample. Consistency was quantified as the mean percentage of agreement in the assignment of each individual to a particular class, between the LPAs with bootstrapped samples and the LPA with the full sample [46, 83]. This provided a measure of the robustness of the class assignments despite variations in the sample, which is particularly important for establishing a stable LPA solution when, as in the current study, the full sample size is relatively small [83].

For the selected LPA solution, a one-way ANOVA was conducted for each indicator variable to test if scores on the indicator significantly differed between the classes. In addition, a validation analysis was conducted by comparing the classes on depression (CESD) and anxiety (STAI), as well as eating disorder diagnosis, eating disorder severity (EDE Global), and eating disorder illness duration using one-way ANOVAs (for continuous variables) or χ^2 tests (for categorical variables). Finally, to test whether the classes differed in cognitive inflexibility, one-way ANOVAs were conducted on the number of attentional set-shifting errors, probabilistic switch errors, and perseverative errors derived from the behavioral tasks. Effect sizes (η^2) of 0.01, 0.06, and 0.14 represent small, medium, and large effects, respectively.

Results

LPA results

As demonstrated in Table 1, the quantitative metrics were equivocal on whether a 2-, 3-, or 4-class solution best characterized the data. Specifically, while the cAIC suggested that a 2- or 3-class solution best fit the data (with a negligible difference between these two solutions), the BIC and BLRT tests suggested a preference for the 4-class solution. Importantly, the bootstrapping analysis indicated that the assignment of individuals to classes was robust only for the 2- and 3-class solutions (i.e., > 90% consistency). Given this, the 2- and 3-class solutions were further evaluated.

The 2-class solution separated individuals exclusively based on the UPPS-P measures (and not the BIS/BAS measures) into a low impulsivity class ($n = 38$; 45.8% of the sample) and a high impulsivity class ($n = 45$; 54.2% of the sample). In contrast, the 3-class solution differentiated individuals using all indicator variables, and did so in a way that strongly converged with theory and findings from previous research (see Fig. 1A and Table 2). For the 3-class solution, Class 1 ($n = 28$; 33.7% of the sample) corresponded to the hypothesized undercontrolled

Table 1 Indices of model fit and class assignment consistency for 1- to 5-class solutions in the latent profile analysis

Number of classes	Parameters	LL	BIC	cAIC	BLRT	Bootstrapped class assignment consistency
1	18	−1055.42	2190.38	2208.38	–	–
2	28	−1018.22	2160.16	2188.16	$p<.001$	93%
3	38	−991.61	2151.14	2189.14	$p<.001$	92%
4	48	−966.51	2145.13	2193.13	$p<.001$	60%
5	58	−952.09	2160.47	2218.47	$p=.120$	76%

LL Log-likelihood, *BIC* Bayesian Information Criterion, *cAIC* Consistent Akaike Information Criterion, *BLRT* bootstrap likelihood ratio test

Underlining indicates preferred solution(s) based on indicator

class, and was distinguished by relatively high scores on the UPPS-P Negative Urgency, Positive Urgency, Lack of Premeditation, and Lack of Perseverance subscales. Class 2 ($n=16$; 19.3% of the sample) corresponded to the hypothesized overcontrolled class, and was distinguished by relatively high scores on the BIS scale, while being low on all other indicators. Class 3 ($n=39$; 47.0% of the sample) corresponded to the hypothesized low psychopathology class (confirmed in the validation analysis below), and was distinguished by relatively high scores on the UPPS-P Sensation Seeking subscale, and BAS Drive, Fun Seeking, and Reward Responsiveness subscales. Thus, given the previous theoretical and empirical support for the 3-class solution, the clear delineation of these three classes based on the indicators, and the robustness of the class assignments for the 3-class solution, we maintained the theorized 3-class solution for subsequent analyses [13].

Group comparison results

The validation analysis further supported the interpretation of the three classes (see Table 3). Specifically, Class 3 (low psychopathology) was associated with the lowest levels of both depression and anxiety (large effects), while there were no significant class differences in EDE global scores or illness duration.[3] Further (see Fig. 1B; overall $\chi^2=21.8$, $p<0.001$), individuals with AN-R were rarely categorized into Class 1 (undercontrolled), while individuals with AN-BP and BN were rarely categorized into Class 2 (overcontrolled). Finally, there was a relatively even distribution of individuals with AN-R, AN-BP, and BN into Class 3 (low psychopathology), confirming that these classes were not simply replicating eating disorder diagnostic groups.

With regard to cognitive inflexibility (see Fig. 2), there were no significant class differences in attentional set-shifting errors ($F=0.44$, $p=0.646$, $\eta^2=0.014$) or probabilistic switch errors ($F=1.41$, $p=0.251$, $\eta^2=0.036$). However, there was a medium-large significant difference in perseverative errors ($F=5.64$, $p=0.005$, $\eta^2=0.126$), with Class 3 (low psychopathology) demonstrating heightened perseverative errors, relative to the other groups (Class 3 vs Class 1: $t=3.01$, $p=0.004$, $d=0.65$; Class 3 vs Class 2: $t=3.28$, $p=0.002$, $d=0.66$).

Discussion

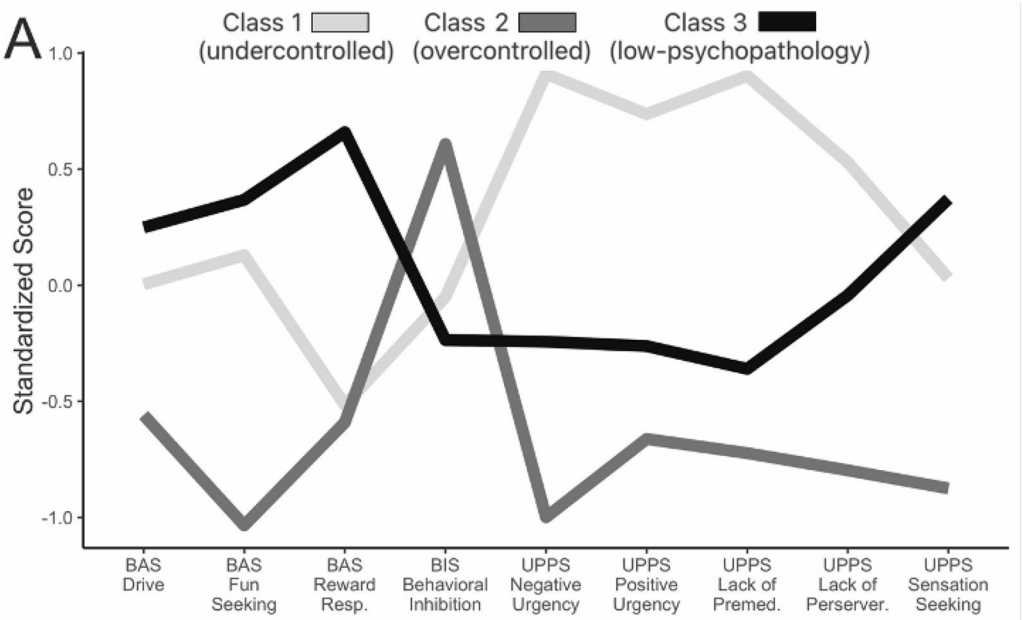
Existing diagnostic models of eating disorders exhibit a number of significant limitations and previous research suggests that personality-based approaches to eating disorder classification may offer a valuable alternative to the current diagnostic system. In particular, a growing literature base suggests the presence of three eating disorder classes labeled the undercontrolled, overcontrolled, and low psychopathology groups [81]. In the present study,

Table 2 One-Way ANOVA results comparing scores on the indicator variables across the three retained groups (undercontrolled, overcontrolled, and low psychopathology)

Indicator	*F*	*p*	η^2
Drive (BAS)	4.58	= .013	.103
Fun seeking (BAS)	19.08	< .001	.323
Reward responsivity (BAS)	29.27	< .001	.423
BIS	4.91	= .010	.109
Negative urgency (UPPS-P)	44.43	< .001	.526
Positive urgency (UPPS-P)	32.45	< .001	.448
Premeditation (UPPS-P)	13.70	< .001	.255
Perseverance (UPPS-P)	19.28	<.001	.325
Sensation seeking (UPPS-P)	12.34	<.001	.236

BAS Behavior activation scale, *BIS* Behavior inhibition scale, *UPPS-P* UPPS-P Impulsive behavior scale

[3] Supplemental analyses indicated that groups also did not differ on age ($F=.88$, $p=.418$, $\eta^2=.02$) or IQ (assessed by the Wechsler Abbreviated Scale of Intelligence 2nd Edition, $F=.76$, $p=.470$, $\eta^2=.02$). Further, pairwise comparisons were conducted to examine whether there might be differences between subsets of the classes on EDE global scores, illness duration, age, or IQ. However, there were no significant pairwise differences on these variables (all p-values > .069).



B

	LPA Class			
	1 (undercontrolled)	2 (overcontrolled)	3 (low-psychopathology)	Total
Diagnosis				
AN-R	1 (3.8%)	11 (42%)	14 (54%)	26 (100%)
AN-BP	12 (55%)	1 (4.5%)	9 (41%)	22 (100%)
BN	15 (43%)	4 (11%)	16 (46%)	35 (100%)
Total	28 (34%)	16 (19%)	39 (47%)	83 (100%)

Fig. 1 Indicator means for the 3-Class LPA solution (Panel **A**) and contingency table for LPA class by ED diagnosis (Panel **B**). Cell percentages in panel B reflect row percentages (i.e., percentage of individuals with a given diagnosis being categorized into each LPA class)

we first aimed to identify personality-based subgroups in a sample of individuals with AN or BN using latent profile analysis, and then to examine the relations between these personality subtypes and behavioral measures of attentional set-shifting and reversal learning (i.e., two facets of cognitive inflexibility with theorized relevance to eating disorder psychopathology [24, 61, 66, 80],).

Results from the current study supported the presence of three distinct personality-based profiles. Specifically, individuals in Class 1 were distinguished by elevated risk-taking, impulsivity, behavioral/emotional dysregulation (i.e., undercontrolled personality traits); individuals in Class 2 were distinguished by elevated rigidity, inhibition, avoidance, and constraint (i.e., overcontrolled personality traits); and individuals in Class 3 were distinguished by low endorsement of co-occurring depression and anxiety (i.e., low psychopathology traits). These results converge with a robust litereature identifying similar personality-based classes across a range of samples (e.g., those with eating disorders, other forms of psychopathology, and general community samples) and using a variety of indicators [3, 28, 80], providing additional support for the presence of these groups across a range of eating disorder diagnoses.

Analyses examining differences in cognitive inflexibility across the three identified groups indicated greater perseverative errors (a marker of impaired reversal learning) in the low psychopathology group, relative to the undercontrolled and overcontrolled groups. This finding is notable, as researchers frequently suggest that

Table 3 One-way ANOVA results comparing scores on the validator and cognitive flexibility variables across the three retained groups (undercontrolled, overcontrolled, and low psychopathology)

Validator	Class 1 mean (*SD*)	Class 2 mean (*SD*)	Class 3 mean (*SD*)	*F*	*p*	η^2
Depression (CESD)	26.8 (13.8)	25.8 (9.8)	17.8 (8.8)	6.37	=.003	.137
Anxiety (STAI)	57.4 (9.9)	54.3 (9.5)	48.0 (11.6)	6.54	=.002	.141
ED Severity (EDE)	3.04 (1.2)	3.00 (1.3)	2.48 (1.2)	2.03	=.139	.048
ED Illness Duration (years, EDE)	9.30 (6.7)	11.73 (11.1)	7.81 (4.9)	1.67	=.196	.043

CESD Center for Epidemiologic Studies Depression Scale, *STAI* State-Trait Anxiety Index, *EDE* Eating Disorder Examination

Note that follow-up, pairwise comparisons for depression and anxiety indicated that Class 3 was significantly lower in depression compared to Class 1 ($p = 0.002$) and Class 2 ($p = 0.016$), and that Class 3 was significantly lower in anxiety than Class 1 ($p < 0.001$). However, the difference between Class 3 and Class 2 in anxiety was non-significant at $p = .053$

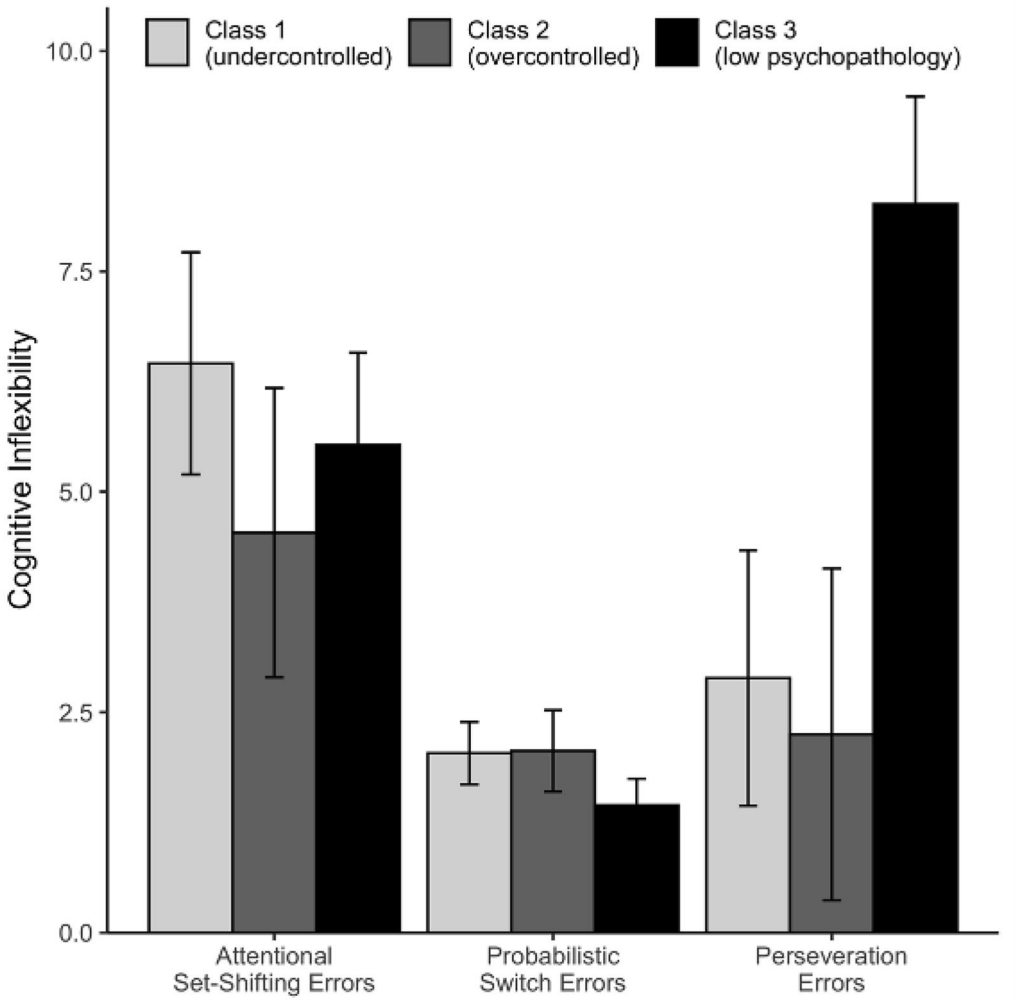


Fig. 2 Cognitive Inflexibility for each LPA Class. Error bars respresent the standard error of the mean

personality-based classification systems may offer valuable insights into distinct maintenance mechanisms underlying group membership [81]. However, no previous study had yet identified unique features of the low psychopathology group that may contribute to disorder maintenance. The present study suggests that deficits in reversal learning (specifically, continuing to select a previously rewarded stimulus despite later punishment)

may underlie eating disorder persistence in this group. Notably, the low psychopathology group also exhibited elevated reward sensitivity and sensation seeking, further highlighting the possible role of reward-related processes within this class of patients. Overall, this pattern of results suggests that increased sensitivity to rewards (e.g., those associated with obtaining a thin physique or consuming food) and/or an inability to learn from changing reward contingencies (e.g., difficulty relinquishing maladaptive eating disorder behaviors despite experiencing negative consequences) may represent key maintenance mechanisms for this group. In other words, patients in this group may continue to pursue highly valued rewards from eating or dieting, even when those rewards become less frequent, less potent, or increasingly associated with aversive consequences such as excessive weight gain or medical complications. Further research clarifying the exact nature of reversal learning deficits in those with relatively low co-occurring psychopathology may help to clarify the specific underlying processes contributing to disorder maintenance in this group. For example, computational modeling approaches (which are able to parse apart distinct neurocognitive processes contributing to task performance) may help to clarify whether increased perseverative errors observed in this group are driven by differences in learning rate, decision-making (e.g., explore versus exploit), sensitivity to reward versus punishment, or other neurocognitive processes.

It is notable that the overcontrolled and undercontrolled groups did not exhibit relative impairments in attentional set-shifting or reversal learning, particularly given previous evidence suggesting that deficits in attentional set-shifting deficits may be associated with depression, anxiety, and social avoidance (common in the overcontrolled group; [12, 29, 30, 34, 39]), while reversal learning may be associated with forms of psychopathology characterized by high levels of impulsivity (common in the undercontrolled group; [38, 57, 62]). Notably, research is mixed with regard to the role of cognitive inflexibility in eating disorders. Indeed, attentional set-shifting or reversal learning difficulties were not found to be elevated relative to healthy controls in the present sample [18]. These differences in findings may be due, in part, to differences in measurement. Here again, computational modeling approaches and/or more extensive test batteries could be used to more precisely evaluate potential differences in distinct neurocognitive processes underlying attentional set-shifting and reversal learning.

Clinical implications

Findings from the present study have important clinical implications. First, these results provide additional support for personality-based approaches to eating disorder classification [81], and suggest the value of these approaches to advancing the field's understanding of risk and maintenance mechanisms underlying distinct eating disorder groups. Although prior research suggests the relevance of cognitive inflexibility to eating disorders broadly, efforts to identify the specific aspects of cognitive inflexibility that may be most relevant to specific eating disorder diagnoses have generated mixed findings [25, 72, 73]. While a previous study using the current sample found no difference in reversal learning across *DSM-5* eating disorder diagnoses [18], the present study showed that perseverative errors differentiated the low psychopathology subgroup from the undercontrolled and overcontrolled subtypes. Thus, the cognitive inflexibility that often appears to characterize individuals with eating disorders may vary more strongly with personality or comorbidity patterns, rather than diagnosis. Overall, these findings suggest that personality-based classification approaches may be useful for identifying clinically meaningful neurocognitive mechanisms that maintain eating disorders.

Results further suggest that individuals who exhibit low levels of co-occurring psychopathology (but high reward seeking and responsiveness) may uniquely benefit from treatments that explicitly address reward-related abnormalities (e.g., [4, 15, 41]), while individuals who exhibit undercontrolled traits may uniquely benefit from treatments targeting emotion regulation and impulsivity (e.g., [36, 52, 64]), and those exhibiting overcontrolled traits may uniquely benefit from treatments targeting anxiety, perfectionism, and rigidity (e.g., [32, 51]). Similar to the "broad form" modules provided in enhanced cognitive behavioral therapy, which address hypothesized eating disorder maintaining mechanisms (i.e., clinical perfectionism, core low self-esteem, marked interpersonal difficulties [22]), future eating disorder treatments may seek to include treatment modules for each personality class that target each group's unique maintenance mechanisms. Similarly, it is possible that early intervention or prevention programs targeting reward abnormalities (e.g., high levels of reward seeking or deficits in reward learning) could be beneficial in preventing the onset of some eating disorders. However, as the current data are not able determine whether observed reward abnormalities represent a risk or maintenance factor for the low psychopathology eating disorder group, additional longitudinal research would be needed to probe this possibility.

Study limitations

The present study possesses many notable strengths (e.g., the inclusion of AN and BN diagnoses within the sample, and use of behavioral measures of attentional set-shifting

and reversal learning). However, the study is limited by the cross-sectional design, homogeneity in the demographic characteristics (e.g., sex, race) of the sample, and focus on only AN and BN. Future research should utilize experimental designs and longitudinal follow-up to evaluate the utility of treatments targeting possible unique maintenance mechanisms within personality-based groups. In addition, enhanced recruitment of underrepresented demographic groups and other diagnostic groups (e.g., binge-eating disorder) is needed to clarify the generalizability of these findings. Lower than desired internal consistency for the BIS/BAS scores also limits the reliability of these scales, suggesting the need for replication and attention to reliable measurement of reward and punishment sensitivity in future studies. Finally, the current study represents a secondary analyses of a dataset that was not specifically designed for LPA. Given this, the study is limited by relatively small sample sizes within each LPA-identified group. An a priori power analysis indicates that a total sample size of 159 would be needed to detect a medium effect, and a sample size of 66 would be needed to detect a large effect (current $N = 83$). Notably, group differences in perseverative errors were medium-large in size and statisticailly significant, while group differences in attentional set-shifting errors and probabilistic switch errors were small and non-significant. Importantly, it will be necessary to replicate these findings with larger sample sizes.

Conclusions

In sum, the present study provides support for personality-based approaches to eating disorder classification, including preliminary evidence that cognitive inflexibility may vary more strongly with personality patterns, than diagnosis. Given this, the use of pesonality-based classification approaches may enhance the field's understanding of neurocognitive mechanisms maintaining eating disorders and inform more targeted treatments for these disorders.

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Author contributions
L.M.S.: Conceptulization, Writing-Original Draft; G.F.: Conceptulization, Formal Analysis, Writing-Original Draft; E.N.D.: Conceptulization, Writing-Original Draft; A.R.B.: Conceptulization, Writing-Original Draft; E.E.F.: Conceptulization, Writing-Review and Editing, Supervision, Funding Acquisition; J.E.W.: Conceptulization, Writing-Review and Editing, Supervision, Funding Acquisition.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All study procedures were approved by the Institutional Review Board at the University of Pittsburgh, and all participatns provided informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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