Pasion, R., Ribes-Guardiola, P., Patrick, C., Stewart, R. A., Paiva, T. O., Macedo, I., Barbosa, F., Brislin, S. J., Martin, E. A., Blain, S. D., Cooper, S. E., Ruocco, A. C., Tiego, J., Wilson, S., Goghari, V. M., & the HiTOP Neurobiological Foundations Workgroup. (2023). Modeling relations between event-related potential factors and broader versus narrower dimensions of externalizing psychopathology.*Journal of Psychopathology and Clinical Science.* Advance online publication. https://doi.org/10.1037/abn0000856

Modeling Relations between ERP Factors and Broader versus Narrower Dimensions of Externalizing Psychopathology

Rita Pasion[1,2,#,*], Pablo Ribes-Guardiola[3,#], Christopher Patrick[4], Rochelle A. Stewart[4], Tiago O. Paiva[1,2], Inês Macedo[1], Fernando Barbosa[1], Sarah J. Brislin[5], Elizabeth A. Martin[9], Scott D. Blain[7], Samuel E. Cooper[8], Anthony C. Ruocco[6], Jeggan Tiego[10], Sylia Wilson[11], Vina M. Goghari[6], and the HiTOP Neurobiological Foundations workgroup

Author Note

[1] Laboratory of Neuropsychophysiology, Faculty of Psychology and Educational Sciences, Porto

[2] Lusófona University, HEI-Lab

[3] Department of Basic and Clinical Psychology, and Psychobiology, Universitat Jaume I

[4] Florida State University

[5] Department of Psychiatry, Robert Wood Johnson Medical School, Rutgers University

[6] Department of Psychological Clinical Science, University of Toronto

[7] Department of Psychiatry, University of Michigan

[8] Department of Psychiatry and Behavioral Sciences, University of Texas at Austin

[9] Department of Psychological Science, University of California, Irvine

[10] Turner Institute for Brain and Mental Health, Monash University, Clayton, Victoria Australia

[11] Institute of Child Development, University of Minnesota

[#] Rita Pasion and Pablo Ribes-Guardiola are first co-authors of this article.

[*] Correspondence concerning this article should be addressed to Rita Pasion, ritapasion@gmail.com.

Acknowledgments: This study was funded by Fundação para a Ciência e Tecnologia (POCH/FSE/NORTE2020) under grant SFRH/BD/117130/2016 awarded to Rita Pasion and UIDB/05380/2020 awarded to HEI-Lab.

Conflict of interests: The authors declare that they do not have any conflicts of interest.

Word count (main text, references, tables and captions): 9169

Transparency and Openness: Data presented in this article are publicly available in (https://osf.io/hyjsf/). This study was not preregistered.

Abstract

The organization of the Hierarchical Taxonomy of Psychopathology (HiTOP) model provides unique opportunities to evaluate whether neural risk measures operate as indicators of broader latent liabilities (e.g., externalizing proneness) or narrower expressions (e.g., antisociality, alcohol abuse). Following this approach, the current study recruited a sample of 182 participants (54% female) who completed measures of externalizing psychopathology (also internalizing) and associated traits. Participants also completed three tasks (Flanker – No-Threat, Flanker - Threat, and Go/No-Go tasks) with event-related potential (ERP) measurement. Three variants of two RDoC-based neurophysiological indicators—P3 and error-related negativity (ERN)—were extracted from these tasks and used to model two latent ERP factors. Scores on these two ERP factors independently predicted externalizing factor scores when accounting for their covariance with sex – suggesting distinct neural processes contributing to the broad externalizing factor. No predictive relation with the broad internalizing factor was found for either ERP factor. Analyses at the finer-grained level revealed no unique predictive relations of either ERP factor with any specific externalizing symptom variable when accounting for the broad externalizing factor, indicating that ERN and P3 index general liability for problems in this spectrum. Overall, this study provides new insights about neural processes in externalizing psychopathology at broader and narrower levels of the HiTOP hierarchy.

Keywords: HiTOP, psychopathology, externalizing, ERP, P3, ERN

General Scientific Summary: The Hierarchical Taxonomy Model of Psychopathology argues that some etiological factors might operate at broader levels of the psychopathological spectrum, conferring general risk for clinical problems Our results show that ERN and P3 responses are indicators of distinct neural processes and that both account for externalizing proneness.

There has been longstanding interest in relating psychopathology to neurobiological processes. However, several challenges have hampered progress in this area, including the complex nature of mental disorders, which often co-occur (diagnostic comorbidity) and vary in their clinical expression (diagnostic heterogeneity) (Clark et al., 2017; Haslam et al., 2020; Krueger et al., 2021). Efforts to understand mental health problems in neurobiological terms need to contend with the overlapping, complex nature of psychopathology – which is best represented by dimensional models like the Hierarchical Taxonomy of Psychopathology (HiTOP).

The HiTOP model characterizes psychopathology in terms of hierarchically organized dimensions. Specific symptom dimensions load onto broader syndromes and subfactors that load, in turn, onto even broader spectrum dimensions. At the uppermost level is the “p-factor” – representing general propensity toward any form of psychopathology (Caspi et al., 2014; Caspi & Moffitt, 2018; Kotov et al., 2017). At the next level below, one can find the internalizing and externalizing dimensions. The internalizing dimension encompasses lower-order anxious-depressive syndrome dimensions (e.g., phobias, obsessive-compulsive symptoms, anxiety, depression, and post-traumatic stress), organized around subordinate fear and distress subfactors. The externalizing broad factor subsumes impulsive personality pathology along with antisocial and substance use disorders, which are organized around antagonistic and disinhibited externalizing subfactors. At the lowest levels of HiTOP, several symptom and trait dimensions are represented (DeYoung et al., 2022; Forbes et al., 2021; Kotov et al., 2017).

The hierarchical organization of HiTOP implies that some etiological factors operate at broader levels of a spectrum, conferring general risk for problems, whereas others operate at the level of specific syndromes, or symptoms and traits associated with them (DeYoung et al., 2022). From this viewpoint, one would predict that neurobiological indicators of dysfunction would relate in some cases to broad risk dimensions, and in others to more specific expressions. Working from this perspective, this study examined the extent to which two brain event-related potential (ERP) components from the Research Domain Criteria (RDoC) system (Clark

et al., 2017) known to be associated with externalizing problems – the stimulus-evoked P3 and the response-elicited error-related negativity (ERN) (see Krueger et al., 2021 for an overview) – operate as indicators of transdiagnostic risk (broad externalizing psychopathology) or fine-grained clinical expression (specific syndrome level). Another key question addressed was whether these ERPs overlap in their associations with externalizing problems, as co-indicators of a common dysfunctional process, or if they instead show independent associations, as indicators of specific problem dimensions.

P3 and ERN as Neural Indicators of Externalizing Proneness

The P3 is comprised of various sub-components elicited by different tasks and stimuli, and has been functionally linked to different cognitive operations, such as context updating, attentional resource allocation, elaborative processing of motivational significance, inhibitory control, and behavioral adaptations (Friedman et al., 2001; Huster et al., 2013; Nieuwenhuis et al., 2005; Polich, 2007). Several overlapping functional processes contribute to P3 elicitation during the processing of motivationally significant events, including anterior-frontal processes mediating early attention-orienting responses, and temporal/parietal processes related to stimulus evaluation and context updating (see Polich, 2007 for a review).

Research to date suggests that reduced P3 amplitude indexes general risk for externalizing problems of various types, rather than being disorder-specific (Krueger et al., 2021). Reduced P3 amplitude has been reported in different clinical conditions subsumed under the broad externalizing factor (Euser et al., 2013; Gao & Raine, 2009; Iacono et al., 2003; Pasion & Barbosa, 2019). One key study by Patrick et al. (2006) found a robust negative association for oddball target P3 amplitude with externalizing problems defined as the common factor linking substance dependence, childhood conduct disorder, and adult antisocial symptoms, and showed that no individual syndrome among these was uniquely associated with P3 amplitude after accounting for the broad externalizing factor. These findings were replicated subsequently using trait-scale measures (Krueger et al., 2007; Patrick et al., 2013). Twin research

further demonstrated that P3's negative association with externalizing psychopathology is attributable to shared genetic variance, supporting the idea that reduced P3 indexes dispositional vulnerability to the broad factor of externalizing (Hicks et al., 2007; Krueger et al., 2021; Yancey et al., 2013).

Another ERP component that has been proposed as a potential biomarker for general externalizing problems is reduced amplitude of ERN (e.g., Hall et al., 2007; Lutz et al., 2021; Pasion & Barbosa, 2019, for meta-analytic evidence). The ERN is an early (100-ms post-behavioral-response) frontocentral negative deflection that is enhanced following incorrect responses (Falkenstein et al., 1991; Gehring et al., 1993). While the ERN has been functionally linked to error/mismatch detection (Falkenstein et al., 2000), reinforcement learning (Holroyd & Coles, 2002), and/or post-response conflict processing (Yeung et al., 2004), all theoretical models converge around the idea that the ERN reflects an early signal for the implementation of control mechanisms following action mistakes (Gehring et al., 2012). The ERN has been consistently linked to the activity of structures in the posterior medial frontal brain, including the anterior cingulate cortex and pre-supplementary motor area (Herrmann et al., 2004; Iannaccone et al., 2015; van Veen & Carter, 2002) – regions found to be implicated in situations requiring increased cognitive control, such as response conflict, performance errors, and decision uncertainty (Ridderinkhof et al., 2004; Ullsperger et al., 2014). Aside from theories linking the ERN to cognitive control mechanisms, other theoretical views have highlighted the relevance of motivational factors, positing that variations in ERN amplitude may reflect, at least in part, a motivational defensive response to signals of potential threat (Hajcak & Foti, 2008; Weinberg et al., 2012).

Although limited research has examined the extent to which the ERN might operate as an indicator of the broad externalizing factor vs. specific clinical syndromes (Krueger et al., 2021), it is worth noting that results from two meta-analyses have found little evidence for a moderating role of diagnosis in explaining blunted ERN amplitudes within the externalizing

domain (Lutz et al., 2021; Pasion & Barbosa, 2019). Thus, reduced ERN may essentially represent a transdiagnostic liability indicator of general proneness to impulse control problems, reflected by the broad externalizing factor. Notably, some prior studies have reported *enhanced* ERN in relation to internalizing psychopathology problems, but effect sizes appear to be more modest, especially when considering the diversity of internalizing expressions and when correcting for publication bias (Macedo et al., 2021; Pasion & Barbosa, 2019; Saunders & Inzlicht, 2020). Associations of P3 with internalizing conditions have been more mixed as well, with some studies reporting reduced P3 amplitude in distress disorders but enhanced P3 amplitude in relation to fear disorders (Watson et al., 2022 for a review).

ERN and P3 as Distinct Processes Linked to Externalizing Problems

Factor analytic studies reveal that P3 and ERN may index distinct neurocognitive processes. There is evidence of a common P3 factor emerging from P3 responses measured in separate tasks: however, variants of the ERN loaded onto a separate response-monitoring factor in one study (Burwell et al., 2016) and onto a distinct ERN/N2 factor in another study (Ribes-Guardiola et al., 2020). These findings indicate that these components may index distinct neurocognitive processes linked to externalizing symptoms, with the former reflecting diminished elaborative-associative processing of motivationally significant events and the latter reflecting deficits in the engagement of early, reactive cognitive control processes following action mistakes (Gehring et al., 2012; Polich, 2007).

Given these prior findings, a compelling need exists for characterizing the nature of externalizing-related dysfunctions indexed by variants of the P3 and the ERN. Research has demonstrated the validity of combining several variants of the P3 response in conjunction with scale measures of externalizing psychopathology (Nelson et al., 2011; Patrick et al., 2013; Venables et al., 2018) but there is still a need to parse the nature of the externalizing-related reductions in other P3 variants vis-a-vis ERN measurements. Although a moderate degree of convergence between ERN's derived from different tasks is typically observed (i.e., in the .33 - .45 correlation range) (Burwell et al., 2016; Ribes-Guardiola et al., 2020; Riesel et al., 2013),

some studies have found that no-go variants of the ERN exhibit stronger associations with externalizing symptoms than other tasks (Pasion & Barbosa, 2019; Ribes-Guardiola et al., 2020). By contrast, a meta-analytic study reported no moderating effects of task type in studies assessing ERN-externalizing associations (Lutz et al., 2021). Thus, there is a need to further explore the convergence among distinct variants of the ERN in their relations with the broad externalizing factor and evaluate whether P3 and ERN index distinct externalizing-related processes.

Current Study

Our study sought to evaluate P3 and ERN amplitudes as indicators of broader vs. narrower dimensions of externalizing psychopathology and advance our understanding of the neurocognitive processes underlying externalizing-related reductions in these indicators. We used distinct variants of the P3 and ERN, extracted from three tasks administered to a relatively large sample also assessed for externalizing and internalizing problems. In line with the psychoneurometric approach to assessment (Patrick et al., 2013, 2019; Patrick & Hajcak, 2016), we sought to combine together sets of neurobiological indicators (i.e., ERN and P3 factors) and examine how these neurometric factors relate to a target psychological attribute (i.e., broad externalizing factor). In addition to addressing questions regarding diagnostic specificity and dimensionality, score aggregation is important when using ERP indicators because measures from different tasks are likely to contain method-specific variance separate from the target-construct related variance they share. This analytic plan corresponds with stages 3 and 4 of the psychoneurometric research strategy (Patrick et al., 2019), on which neurometric aggregates of neural indicators are created, and the psychological nature of such aggregated measures is clarified by assessing their predictive contributions to relevant criterion measures. Accordingly, we modeled internalizing and externalizing dimensions of HiTOP along with latent P3 and ERN factors and utilized these factors to test the following hypotheses:

1 Models specified for a latent externalizing factor (defined using scale measures of effortful control, antisocial behavior, and alcohol and other drug abuse) and distinct P3 and ERN

factors (defined using variants of the ERPs from three separate tasks: Flanker– No Threat, Flanker-Threat, and Go/No-Go) will evidence acceptable fit (as per Burwell et al., 2016; Ribes-Guardiola et al., 2020).

2 Based on previous factor analytic work suggesting that variants of the P3 and ERN load onto separate ERP factors indicative of distinct processes (Burwell et al., 2016; Ribes-Guardiola et al., 2020), we hypothesized that each ERP factor would show unique predictive relations with broad externalizing factor.

3 Considering that P3 and ERN seem to operate as neurophysiological indicators of general susceptibility to externalizing psychopathology (Lutz et al., 2021; Pasion & Barbosa, 2019; Patrick et al., 2006; Yancey et al., 2013), we predicted that specific problem dimensions loading onto the broad externalizing factor would not relate significantly to either ERP factor after accounting for the broad externalizing factor.

4 Given that internalizing problems correlate positively with externalizing proneness (Caspi et al., 2014; Caspi & Moffitt, 2018), we also performed some additional analyses for testing associations between the two ERP factors with internalizing psychopathology. Given the diversity of methods and findings for these ERPs across the internalizing spectrum (Macedo et al., 2021; Pasion & Barbosa, 2019; Saunders & Inzlicht, 2020), we did not have specific hypotheses for this domain and our analyses were exploratory in this regard.

Methods

Data presented in this article are publicly available in (https://osf.io/hyjsf/).

Sample

Participants 18 years of age or older were recruited from the Portuguese community via mailing lists and social media advertisements. Advertisements targeted common internalizing and externalizing symptoms to ensure adequate variability to effectively model these target psychopathology dimensions (Stanton et al., 2020; Van Dam et al., 2017). Limited exclusion criteria as follows were employed at the recruitment stage to optimize data quality:

(a) fluency in the [blinded] language, (b) no self-reported sensory, neurological, or motor deficits that could interfere with EEG.

The final sample included 182 participants (54% female) aged 18 to 60 (*M* = 30.1, *SD* = 9.84), with 15.2 years of formal education (*SD* = 3.38; range: 4-24 years). Fifty-one percent of participants reported having received a current or prior internalizing disorder diagnosis from a clinical specialist, and 31% reported experiencing one or more current or past externalizing-related problem (e.g., substance abuse, criminal record). In addition, 26% of participants reported using psychiatric medication at the time of data collection, mainly antidepressants (89.7%) and anxiolytics (62.1%).

This study was approved by the local Ethics Committee, and all participants gave informed consent. All procedures were conducted in a single session (2h00, approximately) and participants received a gift card (10€). The dataset published in this article are publicly available in (https://osf.io/hyjsf/).

Self-report Measures

The Personality Assessment Inventory (PAI; Morey, 2004) measures several dimensions of personality and psychopathology (4-point Likert scale from "Not true at all" to "Very true"). Antisocial Behavior, Alcohol, and Drug Abuse subscales of the PAI were used to compute Externalizing scores. Total scores on the Effortful Control subscale (24 items, Likert scale from 1 – "Totally false" to 7 – "Totally true) of the Adult Temperament Inventory (ATI; Evans & Rothbart, 2007) were employed as an additional Externalizing measure, to index variations in inhibitory control. Lower scores on this scale reflect deficits in effortful control, and thus higher impulsive tendencies.

Internalizing subscales of the PAI – Depression, Anxiety, Posttraumatic Stress, Obsessive-Compulsive, and Phobias – were used to model this psychopathology dimension in exploratory analyses of its relations with ERN and P3 factors.

Lab-Behavioral Tasks

Participants completed three tasks (Figure 1). To provide adequate data for quantifying ERN responses while reducing fatigue effects in P3 measurement, each task finished at the end of the block whenever participants committed 20 errors (4 blocks, 240 trials). For all tasks, each trial (500 ms) was preceded by a fixation point (500 ms) and followed by a black screen during which the neuronal activity related to the response was recorded (800 ms). Stimuli were presented fully randomly.

Flanker task – No-Threat. The arrowhead Flanker task (Eriksen & Eriksen, 1974) displays five horizontally aligned arrowheads in either congruent (‘‘<<<<<”; 40%) or incongruent directions (‘<<><<”; 60%). Participants were instructed to respond with the left or right button according to the direction of the central arrow (50% pointing to the right) as quickly as possible.

Flanker task – Threat. A modified version of the arrowhead Flanker Task was administered. It included a threat contingency for incorrect responses (Macedo et al., 2021; Pasion et al., 2018), consisting of an aversive white noise (50% probability) delivered within a random 5000-10000 ms interval following errors or omissions, succeeded by a black-silent display (1000 ms) to reduce punishment-related brain activity. During the punishment delay, an error-threat message [ERROR!] was presented in red.

Go/No-Go task. Two letters (V and Y) were designated as the go (70%) and no-go (30%) stimuli. Letter assignment to the go and no-go conditions was counterbalanced across participants. Participants were instructed to respond to the go letter as quickly and accurately as possible and to inhibit responding to the no-go letter.

[Figure 1]

EEG Recording and Data Pre-Processing

EEG was recorded using a 128-electrode Hydrocel Geodesic Sensor Net (Electrical Geodesics Inc., Oregon, USA). Data processing was conducted in EEGLAB V13.6.5b (Delorme & Makeig, 2004) and MATLAB 2017a (MathWorks, Inc., Natick, MA, USA) following procedures recommended by the Society of Psychophysiological Research (Keil et al., 2014).

Details regarding EEG recording and pre-processing are described in Supplementary Material: Section 1.

ERP Data Analysis

For both stimulus-locked (P3) and response-locked (ERN, Correct-Related Negativity (CRN)) components, 1000 ms epochs (-200 ms baseline[1]) were extracted and averaged by condition (i.e., incongruent flankers and no-go trials for P3; errors and hit trials for response-locked components). Each of the tasks continued until participants had committed 20 response errors (calculated at the end of each block), ensuring that response-locked ERNs from each task incorporated a consistent number of data samples across participants. To also ensure consistency of data samples for the stimulus-locked P3s across tasks and participants, these ERPs were computed using data only from the first 240 trials of each task (i.e., block 1). Use of trials only from the first block also helped reduce the influence of task-duration factors such as fatigue and inattentiveness.

The selection of electrodes for quantifying the ERPs was based on prior research indicating a more anterior distribution for P3 in inhibitory control paradigms (Huster et al., 2013), and a frontocentral distribution for ERN (Gehring et al., 2012). As shown in Figure 2, P3 amplitudes were maximal at central electrodes (Cz cluster: E7, E31, E55, E80, E106, E129), and ERN amplitudes were maximal at frontocentral electrodes (FCz cluster: E5, E6, E7, E12, E13, E106, E112). These regions were used for quantifying P3 and ERN amplitudes, providing for consistency of measurement sites across tasks. Two independent raters analyzed the visual morphology of ERP by participant. Descriptive statistics for each brain region, missing data and the final number of trials included in the ERP averages are provided in the Supplementary Materials (Table S1).

1 Following reviewers' suggestion, we conducted a control analysis testing for the consistency of results when using an ERN baseline period extending from -200 to -50ms (i.e., to remove time-points close to 0 given the ERN can begin slightly before the execution of the motor response). Results remained virtually identical in all cases.

P3 and ERN/CRN were computed using an adaptive method in which mean amplitudes were defined around their peaks by averaging 6 time points (24 ms pre-peak - 24 ms post-peak) for each participant. Thus, P3 amplitudes from all conditions were extracted around the most positive peak within 250 to 550 ms (Ribes-Guardiola et al., 2020). ERN and CRN were quantified as the averaged activity around the most negative peaks for errors and hits, respectively (0 to 150 ms post-response; Pasion et al., 2018). Given prior evidence indicating that externalizing proneness relates specifically to error-related brain activity, but not to the counterpart activity elicited during correct trials, – i.e., CRN, putatively reflecting generic performance monitoring (Hall et al., 2007) – we isolated error-specific activity by computing residualized ERN scores (e.g., Meyer et al., 2017). Given the evidence for higher reliability of ERN residual scores as compared to subtraction-based difference scores (Sandre et al., 2020), separate linear regressions were performed for each task, with CRN and ERN amplitudes entered (respectively) as predictor and criterion, and residual scores were saved out to index error-specific brain activity (Meyer et al., 2017).

The internal consistency of P3 and ERN measures was computed using a split-half approach (odd and even-numbered trials; Spearman-Brown formula). Estimated reliabilities for these ERP measures ranged from .94 (P3) to .66 (ERN) (see Supplementary Material for details).

[Figure 2]

Data Analytic Plan

Data checking was performed in SPSS 27 (IBM Corp., 2020). First, score distributions for study measures and ERP scores were screened for non-normality (i.e., skewness values between –2 and 2; kurtosis values between -3 and 3). The self-report measures pertaining to alcohol and drug use were found to exhibit mild to moderate non-normality. Therefore, primary analyses were conducted in Mplus version 8.4 using robust maximum likelihood

estimation for all models that included alcohol and drug use and maximum likelihood estimation for all other models. Missing data were handled using full information maximum likelihood (FIML).

Next, a CFA was run to model relationships between the externalizing factor, residual ERN components, and P3 components. The Antisocial Behavior, Alcohol Use, and Drug Abuse subscales of the PAI, along with the ATI Effortful Control scale, were used as indicators of the latent externalizing factor. Residualized ERN scores from the Flanker–No-Threat, Flanker–Threat, and Go/No-Go tasks were employed as indicators of a residual ERN factor. Likewise, P3 scores from those same three served as indicators of a P3 factor. Given sex differences in psychopathology symptoms and brain-ERP scores (Eaton et al., 2012; Fischer et al., 2016; Hill et al., 2018; Larson et al., 2011; Melynyte et al., 2017), the externalizing and ERP factors were regressed onto participant sex[2] to control for its effect in testing for the hypothesized associations. Model fit was evaluated using the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR) statistics. Fit was considered good if CFI and TLI values exceeded .95, and RMSEA and SRMR values were below .05

Following specification of the joint CFA including the externalizing factor together with the two ERP factors and participant sex, path models were run to examine the unique relationship of each ERP factor with the externalizing factor. In the first model (depicted in Figure 3), an additional pathway was specified in which the ERN factor was regressed onto the P3 factor. This model allowed for estimation of the association between the ERN factor and the externalizing factor after controlling for the variance shared between the ERN factor and the P3 factor. Similarly, in the second model (depicted in Figure 4), the P3 factor was regressed onto the ERN factor and evaluated for its unique association with the externalizing factor.

2 Results from analyses controlling only for sex-related variance in the externalizing factor (i.e., with only the externalizing factor regressed onto participant sex) fit the data acceptably (CFI/TLI = .92/.89, RMSEA/SRMR = .07/.10) and importantly, yielded nearly equivalent associations for the ERN and P3 factors with the externalizing factor (ψs = .20 and -.28, *ps* = .034 and .001).

Following this, we utilized hierarchical mediation analyses (e.g., Conway et al., 2022) to examine the extent to which variance attributable to the externalizing factor, versus variance unique to each indicator of the externalizing factor (e.g., antisocial behaviour), was associated with each ERP factor. We estimated total, direct, and indirect effects across the two levels of the dimensional hierarchy (i.e., higher-order HiTOP factors, and specific problem dimensions), allowing us to determine the degree to which variance in each ERP factor was best explained (i.e., statistically mediated) by the higher-order externalizing factor. Following Conway et al.' (2022), the rationale for the hierarchical mediation analyses was as follows: a) the total effect represents the zero-order correlation between variables, b) the direct effect calculates the extent to each individual indicator of externalizing relate to ERP factors, above and beyond any higher-order constructs, and c) the indirect effect reflects, in turn, the proportion of the association between variables that are mediated by higher-order constructs. As such, each mediation model was evaluated in terms of the indirect effect of the ERP factor on each specific indicator of externalizing via the externalizing factor.

In one set of hierarchical mediation analyses, the ERN factor was first regressed onto the P3 factor, after which each indicator of externalizing (antisocial behavior, alcohol use, drug abuse, and effortful control) was individually regressed onto the ERN factor along with the externalizing factor. Counterpart models, in which the P3 factor was first regressed onto the ERN factor, were run to examine the degree to which the externalizing factor accounted for observed associations of each externalizing indicator with P3 response. A final pair of models were run to test for associations of the ERN and P3 factors with an internalizing factor – modeled as the common factor among the Anxiety, Phobias, and Depression, Posttraumatic stress, Obsessive-compulsive subscales of the PAI – when adjusting for sex as a covariate. Paralleling the models for externalizing, the ERN factor was regressed onto the P3 factor, and the P3 factor was regressed onto the ERN factor, to allow for evaluation of their unique associations with the Internalizing factor.

Descriptive statistics for all variables included in the models are provided in Table S2 (Supplementary Material).

Results

Hypothesis 1: Latent Measurement Model for ERN, P3, and Externalizing Psychopathology

Results from the CFA revealed that the measurement model provided excellent fit, $\chi 2(39) = 45.11$, $p = .232$, CFI = .99, TLI = .98, RMSEA = .03 [CI 90%: .000, .062], SRMR = .05. For latent externalizing, standardized loadings for the antisocial behavior, alcohol use, drug abuse, and effortful control subscales were large and well-balanced (λs = 0.85, 0.64, 0.69, and -.57 respectively, $ps < .001$). For the ERN factor, standardized loadings for each task were also well balanced (λs = 0.84, 0.73, and .67, $ps < .001$). Similarly for the latent P3 factor, standardized loadings for each of the three tasks were fairly balanced (λs = 0.91, 0.86, and .61, $ps < .001$).

Hypothesis 2: Unique Associations of ERN and P3 with the Broad Externalizing Factor

To investigate the unique relationship of each ERP factor with the externalizing factor, path models were run to isolate this association when controlling for the variance shared between the ERN and P3 factors. These analyses revealed that after regressing the ERN factor onto the P3 factor, the covariance of the ERN factor with externalizing was significant (ψ = .21 [CI 95%: .019; .395], $p = .031$). Likewise, after controlling for variance shared with the ERN factor, the covariance of the P3 factor with the externalizing factor was also significant (ψ = -.27 [CI 95%: -.420; -.111], $p = .001$). These results indicate that the ERN and P3 are each uniquely related to externalizing (Figures 3 and 4), with amplitudes in each case reduced (i.e., ERN less negative, and P3 less positive) as a function of higher externalizing.[3]

3 Our approach of testing for the unique association between each ERP factor and Externalizing was based on evidence indicating that stimulus-related activity (P3) that overlaps with response-related activity (ERN) can suppress – or account for – associations of the ERN with psychopathology (see Klawhon et al., 2020; Meyer et al., 2017). Covariance paths in the latent measurement model of ERN, P3 and Externalizing indicated that, without controlling for the ERN factor, the P3 factor was significantly associated with externalizing (ψ = -.24, $p = .003$), whereas the association between the ERN factor and externalizing fell short of significance (ψ = .17, p =

[Figure 3]

[Figure 4]

Hypothesis 3: Hierarchical Mediation Analyses: Specific Symptom/Trait Indicators of the Externalizing factor

Hierarchical mediation analyses were used to examine the degree to which observed relations of the ERN and P3 factors with the individual indicators of the externalizing factor could be accounted for by the externalizing factor. For each symptom or trait indicator of externalizing, the direct effect represents the extent to which ERP factors relate to one indicator independently of the common factor reflecting its covariance with other indicators. That is, it indexes the unique (residual) association of each latent ERP variable with each diagnostic indicator after accounting for its relationship to the broad externalizing factor.

As shown in Table 1, the majority of the total-effect association of the P3 factor with each diagnostic indicator was accounted for by the shared externalizing factor – and none of the individual indicators showed a significant direct-effect association with P3 (*p*s = .187 to .854). In the case of the ERN factor, a somewhat larger portion of indicator-specific variance accounted for its total-effect association with two of the diagnostic indicators – alcohol abuse and effortful control – but even in these cases, the direct effects for each were nonsignificant (*p*s = .059 and .149). These results indicate that much of the relationship between ERN and P3 factors with each indicator of the externalizing dimension was accounted for by their shared factor.

Exploratory Analyses: ERN, P3, and the broad Internalizing Factor

In order to evaluate the relations between the ERN and P3 factors with internalizing psyhcopathology, analogous CFAs were run to test for associations of the residual-ERN and

.100). These comparative results of analyses for each ERP factor controlling for the other indicate the presence of a cooperative suppressor effect for ERP factor in its association with the externalizing factor, and indicate that accounting for externalizing-related reductions in P3 amplitudes is important when examining associations of the ERN with externalizing symptom dimensions.

P3 factors with a counterpart internalizing factor, when controlling for sex. This model fit acceptably, $\chi2(49) = 119.3$, $p < .001$, CFI = .92, TLI = .89, RMSEA = .09 [CI 90%: .069, .109], SRMR = .06. The standardized loadings for ERN and P3 factors were extremely similar to those reported for the externalizing model. For the latent internalizing factor, standardized loadings for the anxiety, phobias, depression, and posttraumatic stress scales were similarly high (λs = 0.90, 0.75, 0.80, 0.79, respectively, *ps* < .001). However, the loading for the obsessive-compulsive scale was smaller (λ = 0.42, $p < .001$). After controlling for variance shared with the P3 factor, the covariance between the ERN factor and the internalizing factor was not significant (ψ = .10, [CI 95%: -.082; .050], $p = .295$). Similarly, after the P3 factor was regressed onto the ERN factor, the covariance between the P3 factor and the internalizing factor was not significant (ψ = -.12, [CI 95%: -.281; .272], $p = .171$). Thus, associations evident for ERN and P3 with general externalizing proneness were not observed for the broad internalizing factor.

Discussion

Research on neurophysiological indicators of externalizing problems such as P3 and ERN has been dominated by single-disorder studies, without consideration of shared and unique dimensions of psychopathology (Krueger et al., 2021). HiTOP invites researchers to test for neurobiological correlates at different levels of a hierarchical organization of psychopathology, in which narrower symptom and trait dimensions build up to broader comorbidity dimensions (DeYoung et al., 2022; Forbes et al., 2021; Kotov et al., 2017; Ruggero et al., 2019). Working from a HiTOP perspective, this study sought to clarify the status of two RDoC neurophysiological indicators of externalizing psychopathology – P3 and ERN –, at broader versus narrower levels of its hierarchical organization. We further tested whether these ERPs index a common externalizing-related process or separate neurocognitive processes.

Neural Measures and Symptom Granularity: Brain ERPs as Indicators of Broader vs. Narrow Psychopathology Dimensions

ERN and P3 factors independently predicted variations in general externalizing proneness (when accounting for their associations with sex), highlighting that these ERPs operate

as indicators of the externalizing superspectrum level of HiTOP. Importantly, hierarchical mediation analyses indicated that no individual indicator (i.e., antisocial, alcohol, or drug symptoms; effortful control) related significantly to either ERP factor when accounting for general externalizing scores. Collectively, these results indicate that ERN and P3 represent transdiagnostic rather than condition-specific biomarkers of externalizing psychopathology.

Converging with the work of Patrick et al. (2006), our findings reveal that broad externalizing factor accounted for the majority (i.e., 58% - 100%) of the total effect relationship of each specific diagnostic indicator with the P3 factor. This is also consistent with prior twin studies reporting a common genetic basis for the association between externalizing proneness and the P3 (Hicks et al., 2007; Yancey et al., 2013). Critically, research has reported associations between blunted P3 amplitude in adolescence and the development of externalizing problems in adulthood (Iacono et al., 2003). Therefore, reduced P3 seems to operate as a risk-liability indicator of general proneness to externalizing problems.

Reduced ERN amplitude is less well established as an indicator of externalizing psychopathology (Krueger et al., 2021), and previous meta-analytic work yielded little evidence of specificity in its relations with externalizing problems (Lutz et al., 2021; Pasion & Barbosa, 2019). In this regard, our results evidence that blunted ERN operates as an indicator of common externalizing proneness. Furthermore, our finding that reduced ERN covaried with the externalizing factor separately from reduced P3 suggests that these two ERP measures index separate neural processes related to impulse control problems. We will return to this point in the next section.

To assess the specificity of the associations between externalizing and ERP factors, we also performed analyses for general internalizing problems, modeled using scale measures of anxiety, depression, obsessive-compulsive, trauma, and phobic disorders as indicators. No evidence was found for a significant association of either ERP factor with the internalizing dimension – indicating that reduced amplitudes of these two neural measures in the current study were specifically indicative of general externalizing proneness. Previous meta-analytic

findings have highlighted inconsistencies in associations of internalizing symptomatology with ERN (e.g., Pasion & Barbosa, 2019; Saunders & Inzlicht, 2020). For example, enhanced rather than reduced ERN has been reported in relation to internalizing-related symptoms of ruminative worry (Moser et al., 2013) and error sensitivity (Meyer, 2022). Moreover, it has been suggested that reduced P3 operates as a state marker (i.e., evident within active episodes only) of certain internalizing conditions such as depression, rather than as a risk indicator (Yanai et al., 1997). More research is needed to clarify which symptom features of internalizing psychopathology (e.g., anhedonia, rumination, worry) relate most to ERN and P3, and the extent to which observed associations reflect active versus latent risk.

Of note, our null findings for P3 in relation to internalizing psychopathology appear at odds with results from a study by Bernat et al. (2020), which reported associations for two variants of oddball-task P3 with internalizing as well as externalizing symptoms. However, in contrast with the current study, these authors operationalized internalizing psychopathology as a composite of just two measures, a normative anxiety scale and a depressive symptom scale, and the variance in the internalizing dimension that related to P3 amplitude was that shared with externalizing proneness, as indexed by a more comprehensive measure of this latter problem domain (Krueger et al., 2007).

Symptom Dimensions and Neural-Systems Granularity: P3 and ERN as Indicators of Distinct Externalizing-related Processes

A notable feature of the current study is that it: 1) included multiple indicators of each ERP allowing for a latent representation of each neural process, and 2) focused on two distinct ERPs of interest, P3 and ERN. This approach aligns with calls for RDoC-oriented research to characterize patterns of covariance among different neural indicators of clinical symptom dimensions in order to gain insights into the functional basis of their relations with psychopathology (Patrick & Hajcak, 2016; Patrick, Iacono, & Venables, 2019). To the extent separate neural indicators overlap in their associations with a given psychopathology dimension, it can be inferred that they tap a common psychopathological process; to the extent

that they relate separately to a particular symptom dimension (i.e., capture different portions of variance in it), they can be presumed to tap distinct psychopathological processes.

Our data revealed that latent ERN and P3 factors covaried only modestly (see Figures 3 and 4) and exhibited independent associations with the broad externalizing factor. The implication is that nonoverlapping elements of the ERN and P3 accounted for separate portions of variance in general externalizing proneness – indicating that they tap distinctive neural and neurocognitive processes contributing to this general propensity. What might these distinctive processes consist of? Evidence from source localization and EEG-fMRI studies indicates that the ERN is principally generated by structures in the medial frontal cortex that are linked to attentional control and detection of response conflict (Dehaene et al., 1994; Herrmann et al., 2004; Iannaccone et al., 2015; van Veen & Carter, 2002). The P3, on the other hand, arises from widely distributed brain sources, including temporal and parietal areas believed to be involved in elaborative processing and context updating (Dien et al., 2003; Polich, 2007).

Considered in this light, ERN's association with general externalizing proneness may reflect the impaired engagement of unconscious, frontally-driven control mechanisms under conditions where the intended response does not match the executed response. P3's relationship with the externalizing factor, by contrast, may be indicative of reduced elaborative post-processing of motivational-salient events and/or impaired updating of internal representations of such events (for reviews, see: Gratton et al., 2018; Ullsperger et al., 2014). Impairments in each of these processes may increase the risk for persistent harmful behaviors characteristic of high-externalizing individuals (Patrick & Bernat, 2009; Patterson & Newman, 1993).

It should be noted that P3 and ERN differed somewhat in their patterns of association with broader versus narrower dimensions of externalizing symptomatology. As noted in the preceding section, P3's associations with all four specific diagnostic indicators were mostly accounted for by the broad externalizing factor. By contrast, broad externalizing predominantly accounted for ERN's association with only two of the four diagnostic indicators: antisocial

behavior and drug abuse (100% in each case). For the other two indicators, alcohol abuse and trait effortful control, the greater part of their total-effect relations with blunted ERN response (59.7% and 57.2%, respectively) were accounted for by variance specific to each (i.e., separate from the broad externalizing factor). These results must be regarded as tentative, given that the specific (i.e., indirect) effects for these two indicators fell below significance, but they have intriguing implications that warrant follow-up investigation. In line with the foregoing interpretation, variants of the ERN may index a distinct process especially indicative of susceptibility to, or consequences of, alcohol use. Indeed, there is evidence that impairments in cognitive control relate both to familial risk for alcoholism (Pihl et al., 1990) and sustained excessive use of alcohol (Malone et al., 2021). Further research with more robust measures of problematic alcohol use is needed to effectively evaluate the possibility that ERN response taps a process that is specifically sensitive to alcohol-related impairments in control capacity.

More broadly, our results highlight how systematically studying covariance patterns among different neurophysiological indicators, and their converging and diverging relations with symptom dimensions at differing levels of the HiTOP model, can help to elucidate the nature of processes contributing to broader and narrower psychopathological phenotypes. In the same way that factor analytic research on clinical symptomatology has served to delineate distinctive dimensions of psychopathology, the application of structural modeling methods to neural indicators can help to delineate clear dimensions of neurocognitive functioning to broad and narrower clinical phenotypes. Systematic work of this kind can provide a means for effectively characterizing the nature of neural processes contributing to clinical phenomena that can feed back in turn to the HiTOP nosological system.

Limitations and Future Directions

Some limitations of the current work warrant mention. First, and although our recruitment strategy targeted common internalizing and externalizing problems to ensure variability on these dimensions, the sample was recruited from the general population. Future studies oversampling individuals exhibiting clinical levels of both current internalizing and

externalizing psychopathology are needed to establish the robustness of our findings. It should also be noted that structural equation modeling requires larger sample sizes. Therefore, our hierarchical results need to be interpreted with caution given limits of statistical power. Considering that EEG data collection sessions are highly time-consuming, an international multicentric effort would be required to achieve larger sample sizes.

Another limitation is that our study focused only on P3 and ERN, but other ERPs can be highly informative as well. For example, reduced ERP responses to fear-face stimuli (N170, P2) have been found to be related to callousness, but not disinhibitory traits (Brislin et al., 2018; Palumbo et al., 2020). Moreover, research examining neural responses to substance-related cues – such as the alcohol-cue P3 (Bartholow et al., 2007) – might bear more relevance to understanding neural processes (e.g., incentive salience) involved in the emergence, or stages of current manifest symptomatology, of substance-related problems.

A more detailed characterization of the HiTOP hierarchy would also be needed. Although the scales employed in the current work captured a range of clinical symptoms, we were not able to model HiTOP in full. Follow-up studies using a wider range of candidate measures to effectively model narrower and higher-order dimensions of the HiTOP system are required (see Simms et al., 2022, for a description of multi-level symptom scales under development). For instance, it should be noted that ERN and P3 amplitude reductions have also been linked to schizophrenia and psychotic disorders (see Castro et al., 2019; Ford, 1999; Martin et al., 2019) – conditions subsumed by a separate thought disorder spectrum within the HiTOP system. Further research is needed to clarify overlap versus distinctiveness in the mechanisms underlying P3 and ERN amplitude reductions in psychotic as compared to externalizing disorders.

Further research is also needed to clarify the nature of associations of P3 and ERN with internalizing psychopathology at finer-grained levels, given that we did not find associations of either ERP factor with general internalizing vulnerability. While our null findings might conceivably be attributable to insufficient sample size, it is also possible that

internalizing-related processes indexed by these ERPs are disorder-specific rather than general. Recent evidence indicates, for example, that ERP modulation may relate more to symptom manifestations of internalizing at lower levels of the HiTOP hierarchy (e.g., anhedonia, worry, rumination, error sensitivity) than to general proneness to internalizing problems (Bruder et al., 2002; Klawohn et al., 2020; Macedo et al., 2021; Moser et al., 2013; Santopetro et al., 2022; Saunders & Inzlicht, 2020).

A final limitation of the current study is its cross-sectional design. Longitudinal and twin studies would be required to better disentangle whether P3 and ERN neurometric composites index causal risk factors (see Perkins et al., 2020, for an in-depth discussion). Longitudinal studies could also examine distinct developmental trajectories considering the ERN and P3 as separate risk factors for externalizing problems.

Conclusion

In summary, we used data for different variants of ERN and P3 response to evaluate these neurophysiological measures as indicators of general vs. specific propensities toward externalizing psychopathology. Our findings highlight not only that reduced ERN and P3 responses as indicators of a general externalizing factor, but also that these associations are indicative of distinct neural processes pertinent to externalizing proneness.

The current work illustrates how the application of a psychoneurometric approach to the study of clinical phenomena at different levels of the HiTOP system can help to advance knowledge of the role of neural processes in symptom expression and feed back into an understanding of the bases of diagnostic nosology.

References

Bartholow, B. D., Henry, E. A., & Lust, S. A. (2007). Effects of alcohol sensitivity on P3 event-related potential reactivity to alcohol cues. *Psychology of Addictive Behaviors*, *21*(4), 555–563. https://doi.org/10.1037/0893-164X.21.4.555

Brislin, S. J., Yancey, J. R., Perkins, E. R., Palumbo, I. M., Drislane, L. E., Salekin, R. T., Fanti, K. A., Kimonis, E. R., Frick, P. J., Blair, R. J. R., & Patrick, C. J. (2018). Callousness and affective face processing in adults: Behavioral and brain-potential indicators. *Personality Disorders*, *9*(2), 122–132. https://doi.org/10.1037/per0000235

Bruder, G. E., Kayser, J., Tenke, C. E., Leite, P., Schneier, F. R., Stewart, J. W., & Quitkin, F. M. (2002). Cognitive ERPs in Depressive and Anxiety Disorders during Tonal and Phonetic Oddball Tasks. *Clinical Electroencephalography*, *33*(3), 119–124. https://doi.org/10.1177/155005940203300308

Burwell, S. J., Malone, S. M., & Iacono, W. G. (2016). One-year developmental stability and covariance among oddball, novelty, go/no-go, and flanker event-related potentials in adolescence: A monozygotic twin study. *Psychophysiology*, *53*(7), 991–1007. https://doi.org/10.1111/psyp.12646

Caspi, A., Houts, R. M., Belsky, D. W., Goldman-Mellor, S. J., Harrington, H., Israel, S., Meier, M. H., Ramrakha, S., Shalev, I., Poulton, R., & Moffitt, T. E. (2014). The p Factor: One General Psychopathology Factor in the Structure of Psychiatric Disorders? *Clinical Psychological Science: A Journal of the Association for Psychological Science*, *2*(2), 119–137. https://doi.org/10.1177/2167702613497473

Caspi, A., & Moffitt, T. E. (2018). All for One and One for All: Mental Disorders in One Dimension. *The American Journal of Psychiatry*, *175*(9), 831–844. https://doi.org/10.1176/appi.ajp.2018.17121383

Castro, M. K., Bailey, D. H., Zinger, J. F., & Martin, E. A. (2019). Late electrophysiological

potentials and emotion in schizophrenia: A meta-analytic review. *Schizophrenia Research*, *211*, 21–31. https://doi.org/10.1016/j.schres.2019.07.013

Clark, L. A., Cuthbert, B., Lewis-Fernández, R., Narrow, W. E., & Reed, G. M. (2017). Three Approaches to Understanding and Classifying Mental Disorder: ICD-11, DSM-5 , and the National Institute of Mental Health's Research Domain Criteria (RDoC). *Psychological Science in the Public Interest*, *18*(2), 72–145. https://doi.org/10.1177/1529100617727266

Clayson, P. E. (2020). Moderators of the internal consistency of error-related negativity scores: A meta-analysis of internal consistency estimates. *Psychophysiology*, *57*(8), e13583. https://doi.org/10.1111/psyp.13583

Conway, C. C., Forbes, M. K., & South, S. C. (2022). A Hierarchical Taxonomy of Psychopathology (HiTOP) Primer for Mental Health Researchers. *Clinical Psychological Science*, *10*(2), 236–258. https://doi.org/10.1177/21677026211017834

Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a Neural System for Error Detection and Compensation. *Psychological Science*, *5*(5), 303–305. https://doi.org/10.1111/j.1467-9280.1994.tb00630.x

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

DeYoung, C. G., Chmielewski, M., Clark, L. A., Condon, D. M., Kotov, R., Krueger, R. F., Lynam, D. R., Markon, K. E., Miller, J. D., Mullins-Sweatt, S. N., Samuel, D. B., Sellbom, M., South, S. C., Thomas, K. M., Watson, D., Watts, A. L., Widiger, T. A., Wright, A. G. C., & Workgroup, the H. N. P. (2022). The distinction between symptoms and traits in the Hierarchical Taxonomy of Psychopathology (HiTOP). *Journal of Personality*, *90*(1), 20–33. https://doi.org/10.1111/jopy.12593

Dien, J., Spencer, K. M., & Donchin, E. (2003). Localization of the event-related potential novelty response as defined by principal components analysis. *Cognitive Brain Research*, *17*(3), 637–650. https://doi.org/10.1016/S0926-6410(03)00188-5

Eaton, N. R., Keyes, K. M., Krueger, R. F., Balsis, S., Skodol, A. E., Markon, K. E., Grant, B. F., & Hasin, D. S. (2012). An invariant dimensional liability model of gender differences in mental disorder prevalence: Evidence from a national sample. *Journal of Abnormal Psychology*, *121*(1), 282–288. https://doi.org/10.1037/a0024780

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149. https://doi.org/10.3758/BF03203267

Euser, A. S., Evans, B. E., Greaves-Lord, K., Huizink, A. C., & Franken, I. H. A. (2013). Diminished error-related brain activity as a promising endophenotype for substance-use disorders: Evidence from high-risk offspring. *Addiction Biology*, *18*(6), 970–984. https://doi.org/10.1111/adb.12002

Evans, D. E., & Rothbart, M. K. (2007). Developing a model for adult temperament. *Journal of Research in Personality*, *41*(4), 868–888. https://doi.org/10.1016/j.jrp.2006.11.002

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology*, *78*(6), 447–455. https://doi.org/10.1016/0013-4694(91)90062-9

Falkenstein, M., Hoormann, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: A tutorial. *Biological Psychology*, *51*(2–3), 87–107. https://doi.org/10.1016/s0301-0511(99)00031-9

Fischer, A. G., Danielmeier, C., Villringer, A., Klein, T. A., & Ullsperger, M. (2016). Gender Influences on Brain Responses to Errors and Post-Error Adjustments. *Scientific Reports*,

6(1), Art. 1. https://doi.org/10.1038/srep24435

Forbes, M. K., Sunderland, M., Rapee, R. M., Batterham, P. J., Calear, A. L., Carragher, N., Ruggero, C., Zimmerman, M., Baillie, A. J., Lynch, S. J., Mewton, L., Slade, T., & Krueger, R. F. (2021). A Detailed Hierarchical Model of Psychopathology: From Individual Symptoms up to the General Factor of Psychopathology. *Clinical Psychological Science*, *9*(2), 139–168. https://doi.org/10.1177/2167702620954799

Ford, J. M. (1999). Schizophrenia: The broken P300 and beyond. *Psychophysiology*, *36*(6), 667–682.

Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: An event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neuroscience and Biobehavioral Reviews*, *25*(4), 355–373. https://doi.org/10.1016/s0149-7634(01)00019-7

Gao, Y., & Raine, A. (2009). P3 event-related potential impairments in antisocial and psychopathic individuals: A meta-analysis. *Biological Psychology*, *82*(3), 199–210. https://doi.org/10.1016/j.biopsycho.2009.06.006

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A Neural System for Error Detection and Compensation. *Psychological Science*, *4*(6), 385–390. https://doi.org/10.1111/j.1467-9280.1993.tb00586.x

Gehring, W. J., Liu, Y., Orr, J. M., & Carp, J. (2012). The error-related negativity (ERN/Ne). Em *The Oxford handbook of event-related potential components* (pp. 231–291). Oxford University Press.

Gratton, G., Cooper, P., Fabiani, M., Carter, C. S., & Karayanidis, F. (2018). Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. *Psychophysiology*, *55*(3), e13016. https://doi.org/10.1111/psyp.13016

Hajcak, G., & Foti, D. (2008). Errors are aversive: Defensive motivation and the error-related negativity. *Psychological Science*, *19*(2), 103–108. https://doi.org/10.1111/j.1467-

9280.2008.02053.x

Hall, J. R., Bernat, E. M., & Patrick, C. J. (2007). Externalizing psychopathology and the error-related negativity. *Psychological Science*, *18*(4), 326–333. https://doi.org/10.1111/j.1467-9280.2007.01899.x

Haslam, N., McGrath, M. J., Viechtbauer, W., & Kuppens, P. (2020). Dimensions over categories: A meta-analysis of taxometric research. *Psychological Medicine*, *50*(9), 1418–1432. https://doi.org/10.1017/S003329172000183X

Herrmann, M. J., Römmler, J., Ehlis, A.-C., Heidrich, A., & Fallgatter, A. J. (2004). Source localization (LORETA) of the error-related-negativity (ERN/Ne) and positivity (Pe). *Cognitive Brain Research*, *20*(2), 294–299. https://doi.org/10.1016/j.cogbrainres.2004.02.013

Hicks, B. M., Bernat, E., Malone, S. M., Iacono, W. G., Patrick, C. J., Krueger, R. F., & McGue, M. (2007). Genes mediate the association between P3 amplitude and externalizing disorders. *Psychophysiology*, *44*(1), 98–105. https://doi.org/10.1111/j.1469-8986.2006.00471.x

Hill, K. E., Ait Oumeziane, B., Novak, K. D., Rollock, D., & Foti, D. (2018). Variation in reward- and error-related neural measures attributable to age, gender, race, and ethnicity. *International Journal of Psychophysiology*, *132*, 353–364. https://doi.org/10.1016/j.ijpsycho.2017.12.009

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*(4), 679–709. https://doi.org/10.1037/0033-295X.109.4.679

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: Functional networks and cognitive contributions. *International Journal of Psychophysiology: Official Journal of*

the International Organization of Psychophysiology, *87*(3), 217–233. https://doi.org/10.1016/j.ijpsycho.2012.08.001

Iacono, W. G., Malone, S. M., & McGue, M. (2003). Substance use disorders, externalizing psychopathology, and P300 event-related potential amplitude. *International Journal of Psychophysiology*, *48*(2), 147–178. https://doi.org/10.1016/S0167-8760(03)00052-7

Iannaccone, R., Hauser, T. U., Staempfli, P., Walitza, S., Brandeis, D., & Brem, S. (2015). Conflict monitoring and error processing: New insights from simultaneous EEG-fMRI. *NeuroImage*, *105*, 395–407. https://doi.org/10.1016/j.neuroimage.2014.10.028

Keil, A., Debener, S., Gratton, G., Junghöfer, M., Kappenman, E. S., Luck, S. J., Luu, P., Miller, G. A., & Yee, C. M. (2014). Committee report: Publication guidelines and recommendations for studies using electroencephalography and magnetoencephalography. *Psychophysiology*, *51*(1), 1–21. https://doi.org/10.1111/psyp.12147

Klawohn, J., Santopetro, N. J., Meyer, A., & Hajcak, G. (2020). Reduced P300 in depression: Evidence from a flanker task and impact on ERN, CRN, and Pe. *Psychophysiology*, *57*(4), e13520. https://doi.org/10.1111/psyp.13520

Kotov, R., Krueger, R. F., Watson, D., Achenbach, T. M., Althoff, R. R., Bagby, R. M., Brown, T. A., Carpenter, W. T., Caspi, A., Clark, L. A., Eaton, N. R., Forbes, M. K., Forbush, K. T., Goldberg, D., Hasin, D., Hyman, S. E., Ivanova, M. Y., Lynam, D. R., Markon, K., … Zimmerman, M. (2017). The Hierarchical Taxonomy of Psychopathology (HiTOP): A dimensional alternative to traditional nosologies. *Journal of Abnormal Psychology*, *126*(4), 454–477. https://doi.org/10.1037/abn0000258

Krueger, R. F., Hobbs, K. A., Conway, C. C., Dick, D. M., Dretsch, M. N., Eaton, N. R., Forbes, M. K., Forbush, K. T., Keyes, K. M., Latzman, R. D., Michelini, G., Patrick, C. J., Sellbom, M., Slade, T., South, S. C., Sunderland, M., Tackett, J., Waldman, I., Waszczuk, M. A., … Workgroup, H. U. (2021). Validity and utility of Hierarchical

Taxonomy of Psychopathology (HiTOP): II. Externalizing superspectrum. *World Psychiatry*, *20*(2), 171–193. https://doi.org/10.1002/wps.20844

Krueger, R. F., Markon, K. E., Patrick, C. J., Benning, S. D., & Kramer, M. D. (2007). Linking antisocial behavior, substance use, and personality: An integrative quantitative model of the adult externalizing spectrum. *J Abnorm Psychol*, *116*(4), 645–666. https://doi.org/10.1037/0021-843X.116.4.645

Larson, M. J., South, M., & Clayson, P. E. (2011). Sex differences in error-related performance monitoring. *NeuroReport*, *22*(1), 44–48. https://doi.org/10.1097/WNR.0b013e3283427403

Lutz, M. C., Kok, R., Verveer, I., Malbec, M., Koot, S., van Lier, P. A. C., & Franken, I. H. A. (2021). Diminished error-related negativity and error positivity in children and adults with externalizing problems and disorders: A meta-analysis on error processing. *Journal of Psychiatry & Neuroscience: JPN*, *46*(6), E615–E627. https://doi.org/10.1503/jpn.200031

Macedo, I., Pasion, R., Barbosa, F., & Ferreira-Santos, F. (2021). A dimensional approach to the neural correlates of anxiety, depression, and perfectionism: A transdiagnostic dissociation of error-related brain activity. *Behavioural Brain Research*, 113271. https://doi.org/10.1016/j.bbr.2021.113271

Malone, S. M., Wilson, S., Bair, J. L., McGue, M., & Iacono, W. G. (2021). A co-twin-control analysis of adolescent and young adult drinking effects on learning and memory. *Addiction (Abingdon, England)*, *116*(7), 1689–1699. https://doi.org/10.1111/add.15334

Martin, S., Zabala, C., Del-Monte, J., Graziani, P., Aizpurua, E., Barry, T. J., & Ricarte, J. (2019). Examining the relationships between impulsivity, aggression, and recidivism for prisoners with antisocial personality disorder. *Aggression and Violent Behavior*, *49*, 101314. https://doi.org/10.1016/j.avb.2019.07.009

Melynyte, S., Ruksenas, O., & Griskova-Bulanova, I. (2017). Sex differences in equiprobable auditory Go/NoGo task: Effects on N2 and P3. *Experimental Brain Research*, *235*(5), 1565–1574. https://doi.org/10.1007/s00221-017-4911-x

Meyer, A. (2022). On the relationship between the error-related negativity and anxiety in children and adolescents: From a neural marker to a novel target for intervention. *Psychophysiology*, *59*(6). https://doi.org/10.1111/psyp.14050

Meyer, A., Lerner, M. D., De Los Reyes, A., Laird, R. D., & Hajcak, G. (2017). Considering ERP difference scores as individual difference measures: Issues with subtraction and alternative approaches. *Psychophysiology*, *54*(1), 114–122. https://doi.org/10.1111/psyp.12664

Morey, L. C. (2004). The Personality Assessment Inventory (PAI). Em *The use of psychological testing for treatment planning and outcomes assessment: Instruments for adults, Volume 3, 3rd ed* (pp. 509–551). Lawrence Erlbaum Associates Publishers.

Moser, J. S., Moran, T. P., Schroder, H. S., Donnellan, M. B., & Yeung, N. (2013). On the relationship between anxiety and error monitoring: A meta-analysis and conceptual framework. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00466

Nelson, L. D., Patrick, C. J., & Bernat, E. M. (2011). Operationalizing proneness to externalizing psychopathology as a multivariate psychophysiological phenotype. *Psychophysiology*, *48*(1), 64–72. https://doi.org/10.1111/j.1469-8986.2010.01047.x

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin*, *131*(4), 510–532. https://doi.org/10.1037/0033-2909.131.4.510

Olvet, D. M., & Hajcak, G. (2009). The stability of error-related brain activity with increasing trials. *Psychophysiology*, *46*(5), 957–961. https://doi.org/10.1111/j.1469-

8986.2009.00848.x

Palumbo, I. M., Perkins, E. R., Yancey, J. R., Brislin, S. J., Patrick, C. J., & Latzman, R. D. (2020). Toward a multimodal measurement model for the neurobehavioral trait of affiliative capacity. *Personality Neuroscience*, *3*. https://doi.org/10.1017/pen.2020.9

Pasion, R., & Barbosa, F. (2019). ERN as a transdiagnostic marker of the internalizing-externalizing spectrum: A dissociable meta-analytic effect. *Neuroscience and Biobehavioral Reviews*, *103*, 133–149. https://doi.org/10.1016/j.neubiorev.2019.06.013

Pasion, R., Paiva, T. O., Fernandes, C., Almeida, R., & Barbosa, F. (2018). ERN modulation under sustained threat: A pre-registered report. *Journal of Research in Personality*, *77*, 137–146. https://doi.org/10.1016/j.jrp.2018.10.009

Patrick, C. J., & Bernat, E. M. (2009). Neurobiology of psychopathy: A two process theory. Em *Handbook of neuroscience for the behavioral sciences, Vol 2.* (pp. 1110–1131). John Wiley & Sons Inc. https://doi.org/10.1002/9780470478509.neubb002057

Patrick, C. J., Bernat, E. M., Malone, S. M., Iacono, W. G., Krueger, R. F., & McGue, M. (2006). P300 amplitude as an indicator of externalizing in adolescent males. *Psychophysiology*, *43*(1), 84–92. https://doi.org/10.1111/j.1469-8986.2006.00376.x

Patrick, C. J., & Hajcak, G. (2016). RDoC: Translating promise into progress. *Psychophysiology*, *53*(3), 415–424. https://doi.org/10.1111/psyp.12612

Patrick, C. J., Iacono, W. G., & Venables, N. C. (2019). Incorporating neurophysiological measures into clinical assessments: Fundamental challenges and a strategy for addressing them. *Psychological Assessment*, *31*(12), 1512–1529. https://doi.org/10.1037/pas0000713

Patrick, C. J., Venables, N. C., Yancey, J. R., Hicks, B. M., Nelson, L. D., & Kramer, M. D. (2013). A construct-network approach to bridging diagnostic and physiological do-

mains: Application to assessment of externalizing psychopathology. *Journal of Abnormal Psychology*, *122*(3), 902–916. https://doi.org/10.1037/a0032807

Patterson, C. M., & Newman, J. P. (1993). Reflectivity and learning from aversive events: Toward a psychological mechanism for the syndromes of disinhibition. *Psychological Review*, *100*(4), 716–736. https://doi.org/10.1037/0033-295X.100.4.716

Perkins, E. R., Joyner, K. J., Patrick, C. J., Bartholow, B. D., Latzman, R. D., DeYoung, C. G., Kotov, R., Reininghaus, U., Cooper, S. E., Afzali, M. H., Docherty, A. R., Dretsch, M. N., Eaton, N. R., Goghari, V. M., Haltigan, J. D., Krueger, R. F., Martin, E. A., Michelini, G., Ruocco, A. C., … Zald, D. H. (2020). Neurobiology and the Hierarchical Taxonomy of Psychopathology: Progress toward ontogenetically informed and clinically useful nosology. *Dialogues in Clinical Neuroscience*, *22*(1), 51–63. https://doi.org/10.31887/DCNS.2020.22.1/eperkins

Pihl, R. O., Peterson, J. B., & Finn, P. (1990). An heuristic model for the inherited predisposition to alcoholism. *Psychology of Addictive Behaviors*, *4*, 12–25. https://doi.org/10.1037/h0080590

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Ribes-Guardiola, P., Poy, R., Patrick, C. J., & Moltó, J. (2020). Electrocortical measures of performance monitoring from go/no-go and flanker tasks: Differential relations with trait dimensions of the triarchic model of psychopathy. *Psychophysiology*, *57*(6), e13573. https://doi.org/10.1111/psyp.13573

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science (New York, N.Y.)*, *306*(5695), 443–447. https://doi.org/10.1126/science.1100301

Riesel, A., Weinberg, A., Endrass, T., Meyer, A., & Hajcak, G. (2013). The ERN is the ERN is the ERN? Convergent validity of error-related brain activity across different tasks. *Biological Psychology*, *93*(3), 377–385. https://doi.org/10.1016/j.biopsycho.2013.04.007

Ruggero, C. J., Kotov, R., Hopwood, C. J., First, M., Clark, L. A., Skodol, A. E., Mullins-Sweatt, S. N., Patrick, C. J., Bach, B., Cicero, D. C., Docherty, A., Simms, L. J., Bagby, R. M., Krueger, R. F., Callahan, J. L., Chmielewski, M., Conway, C. C., De Clercq, B., Dornbach-Bender, A., … Zimmermann, J. (2019). Integrating the Hierarchical Taxonomy of Psychopathology (HiTOP) into clinical practice. *Journal of Consulting and Clinical Psychology*, *87*(12), 1069–1084. https://doi.org/10.1037/ccp0000452

Sandre, A., Banica, I., Riesel, A., Flake, J., Klawohn, J., & Weinberg, A. (2020). Comparing the effects of different methodological decisions on the error-related negativity and its association with behaviour and gender. *International Journal of Psychophysiology*, *156*, 18–39. https://doi.org/10.1016/j.ijpsycho.2020.06.016

Santopetro, N. J., Kallen, A. M., Threadgill, A. H., Amir, N., & Hajcak, G. (2022). Blunted Flanker P300 Demonstrates Specificity to Depressive Symptoms in Females during Adolescence. *Research on Child and Adolescent Psychopathology*, *50*(4), 537–548. https://doi.org/10.1007/s10802-021-00876-z

Saunders, B., & Inzlicht, M. (2020). Assessing and adjusting for publication bias in the relationship between anxiety and the error-related negativity. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *155*, 87–98. https://doi.org/10.1016/j.ijpsycho.2020.05.008

Simms, L. J., Wright, A. G. C., Cicero, D., Kotov, R., Mullins-Sweatt, S. N., Sellbom, M., Watson, D., Widiger, T. A., & Zimmermann, J. (2022). Development of Measures for the Hierarchical Taxonomy of Psychopathology (HiTOP): A Collaborative Scale Development Project. *Assessment*, *29*(1), 3–16. https://doi.org/10.1177/10731911211015309

Stanton, K., McDonnell, C. G., Hayden, E. P., & Watson, D. (2020). Transdiagnostic approaches to psychopathology measurement: Recommendations for measure selection, data analysis, and participant recruitment. *Journal of Abnormal Psychology*, *129*(1), 21–28. https://doi.org/10.1037/abn0000464

Ullsperger, M., Danielmeier, C., & Jocham, G. (2014). Neurophysiology of Performance Monitoring and Adaptive Behavior. *Physiological Reviews*, *94*(1), 35–79. https://doi.org/10.1152/physrev.00041.2012

Van Dam, N. T., O'Connor, D., Marcelle, E. T., Ho, E. J., Cameron Craddock, R., Tobe, R. H., Gabbay, V., Hudziak, J. J., Xavier Castellanos, F., Leventhal, B. L., & Milham, M. P. (2017). Data-Driven Phenotypic Categorization for Neurobiological Analyses: Beyond DSM-5 Labels. *Biological Psychiatry*, *81*(6), 484–494. https://doi.org/10.1016/j.biopsych.2016.06.027

van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: FMRI and ERP studies. *Physiology & Behavior*, *77*(4–5), 477–482. https://doi.org/10.1016/s0031-9384(02)00930-7

Venables, N. C., Foell, J., Yancey, J. R., Kane, M. J., Engle, R. W., & Patrick, C. J. (2018). Quantifying Inhibitory Control as Externalizing Proneness: A Cross-Domain Model. *Clinical Psychological Science*, *6*(4), 561–580. https://doi.org/10.1177/2167702618757690

Watson, D., Levin-Aspenson, H. F., Waszczuk, M. A., Conway, C. C., Dalgleish, T., Dretsch, M. N., Eaton, N. R., Forbes, M. K., Forbush, K. T., Hobbs, K. A., Michelini, G., Nelson, B. D., Sellbom, M., Slade, T., South, S. C., Sunderland, M., Waldman, I., Witthöft, M., Wright, A. G. C., … Workgroup, H. U. (2022). Validity and utility of Hierarchical Taxonomy of Psychopathology (HiTOP): III. Emotional dysfunction superspectrum. *World Psychiatry*, *21*(1), 26–54. https://doi.org/10.1002/wps.20943

Weinberg, A., Riesel, A., & Hajcak, G. (2012). Integrating multiple perspectives on error-related brain activity: The ERN as a neural indicator of trait defensive reactivity. *Motivation and Emotion*, *36*(1), 84–100. https://doi.org/10.1007/s11031-011-9269-y

Yanai, I., Fujikawa, T., Osada, M., Yamawaki, S., & Touhouda, Y. (1997). Changes in auditory P300 in patients with major depression and silent cerebral infarction. *Journal of Affective Disorders*, *46*(3), 263–271. https://doi.org/10.1016/S0165-0327(97)00100-6

Yancey, J. R., Venables, N. C., Hicks, B. M., & Patrick, C. J. (2013). Evidence for a Heritable Brain Basis to Deviance-Promoting Deficits in Self-Control. *Journal of Criminal Justice*, *41*(5). https://doi.org/10.1016/j.jcrimjus.2013.06.002

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review*, *111*(4), 931–959. https://doi.org/10.1037/0033-295x.111.4.939

Table 1

Total and Direct Effects of the ERP Factors on Externalizing Indicators via the Externalizing Factor (when controlling for other ERP factor)

ERP Factors	Total Effect (*SE*)	Direct Effect (*SE*)	Percent Accounted for by EXT Factor
ERN Factor			
Antisocial Symptoms	.087 (.09)	-.105 (.06)	100%
Alcohol Symptoms	.200 (.08)**	.119 (.06)	40.50%
Drug Use Symptoms	.073 (.08)	-.047 (.07)	100%
Effortful Control	-.179 (.08)*	-.104 (.07)	41.90%
P3 Factor			
Antisocial Symptoms	-.199 (.08)*	.025 (.08)	100%
Alcohol Symptoms	-.231 (.08)**	-.094 (.07)	59.31%
Drug Use Symptoms	-.121 (.08)	.060 (.07)	100%
Effortful Control	.147 (.08)	.013 (.07)	91.16%

Note. Standardized parameter estimates are shown; **$p < .01$; *$p < .05$.

Figure Captions

Figure 1. Schematic representation of the three experimental tasks utilized to elicit P3 and ERN components

Figure 2. Grand averaged waveforms (left) and topographical scalp maps (right) for P3 (at Cz) and ERN (at FCz) components derived from each experimental task. Note: the gray area depicts the time window used for scoring each ERP component

Figure 3. Unique association of ERN with the Broad Externalizing Factor. Note: Latent Model of Externalizing psychopathology, Residual ERN, and P3 when controlling for sex and P3. Rectangles represent observed variables, and ellipses represent latent factors. Single-headed arrows from each latent factor to each observed variable represent their standardized factor loadings. Single-headed arrows from Sex to each latent factor represents standardized regression coefficients. Single-headed arrow from P3 to ERNResid factor depicts the standardized coefficient of the path regressing P3 onto the ERNResid. Double-headed arrows represent the standardized coefficients for the covariation between the latent externalizing factor (EXT) and each ERP latent factor. ANT = Antisocial Behavior; DRG = Drug Abuse; ALC = Alcohol abuse; EFF CON = Effortful control; GNG = Go/No-Go task; NTH = Flanker-NoThreat task; TH = Flanker-Threat task.

Figure 4. Unique association of P3 with the Broad Externalizing Factor. Note: Latent Model of Externalizing Psychopathology, Residual ERN, and P3 when controlling for sex and ERN. Rectangles represent observed variables, and ellipses represent latent factors. Single-headed arrows from each latent factor to each observed variable represent their standardized factor loadings. Single-headed arrows from Sex to each latent factor represents standardized regression coefficients. Single-headed arrow from ERNResid to P3 represents the standardized coefficient of the path regressing ERNResid onto P3. Double-headed arrows represent the standardized coefficients for the covariation between the latent externalizing dimension (EXT) and each ERP latent factor. ANT = Antisocial Behavior; DRG = Drug Abuse; ALC = Alcohol abuse;

EFF CON = Effortful control; GNG = Go/No-Go task; NTH = Flanker-NoThreat task; TH = Flanker-Threat task.