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Cognitive–Endocrine Coupling: a New Lens for Understanding Human Behavior

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Abstract
Human behavior emerges from the dynamic interplay between cognitive processes and endocrine activity, yet these systems are often studied in isolation. Recent evidence suggests that hormonal fluctuations directly influence neural circuits governing attention, memory, emotional regulation, and decision-making, while cognitive states such as perceived stress or emotional appraisal activate neuroendocrine cascades. This study examines the concept of *cognitive–endocrine coupling*, emphasizing the reciprocal interactions between hormonal biomarkers and higher-order cognition. Using a mixed-methods design, 120 adults underwent morning hormonal profiling for cortisol, estradiol, and testosterone, alongside validated assessments of cognitive flexibility, working memory, and emotional regulation. Quantitative results revealed significant associations between cortisol and cognitive flexibility ($r = -0.41$, $p < 0.01$), estradiol and emotion regulation ($r = 0.38$, $p < 0.05$), and testosterone and risk-based decision-making ($r = 0.29$, $p < 0.05$). Participants with elevated cortisol demonstrated greater cognitive rigidity and lower inhibitory control. Qualitative interviews further highlighted behavioral shifts linked with hormonal instability, including impulsivity, heightened reactivity, and difficulty maintaining attention. These findings align with emerging neuroendocrine models suggesting that hormonal variability modulates prefrontal and limbic system functioning. By integrating biological and psychological perspectives, the study proposes cognitive–endocrine coupling as a comprehensive framework for understanding behavioral variability. Recognizing this bidirectional interaction has significant implications for mental health assessment, stress-related disorders, menstrual-linked mood changes, and the development of personalized behavioral interventions. Future longitudinal and experimental studies are recommended to explore causal pathways underlying hormone-cognition dynamics and to refine predictive models for human behavior.
Keywords: Cognitive endocrine interaction; cognitive flexibility; emotional regulation; hormonal regulation; human behavior; neuroendocrinology.

INTRODUCTION

Human behavior is shaped by a continuous interaction between cognitive processes and endocrine regulation (McEwen, Gray, & Nasca, 2015; Yılmazer, 2024). Stress hormones, particularly cortisol, influence neural plasticity, emotional control, and executive functioning by modulating prefrontal and limbic circuitry (Luciana & Collins, 2022). Fluctuations in cortisol have been shown to impair working memory and decision-making, especially under acute stress (Duque, Cano-López, & Puig-Pérez, 2022). Neuroimaging research demonstrates that stress-related alterations in the prefrontal cortex can disrupt attention and behavioral flexibility, while chronic activation of the stress system contributes to long-term neuronal remodeling (Musazzi, Treccani, & Popoli, 2015).

Sex hormones also play a central role in shaping emotional and cognitive responses (McEwen & Milner, 2017). Estradiol enhances emotion regulation and adaptive coping by strengthening limbic-prefrontal connectivity (de Kloet & Joëls, 2020), whereas testosterone modulates social behavior, reward orientation, and risk-taking tendencies (Herbert, 2018). Together, these findings support the concept of cognitive-endocrine coupling, a dynamic

framework stating that cognition can activate endocrine responses while hormonal changes, in turn, influence cognitive performance (Pilarska, Pieczyńska, & Hojan, 2023). Understanding this bidirectional relationship is essential for predicting behavioral variability in daily life and across clinical conditions (Allan, McMinn, & Daly, 2016).

Despite growing evidence of hormone-cognition interactions, several critical gaps remain in the literature (Khandelwal, Ying, & Gomez-Pinilla, 2025). First, most studies examine hormonal effects on cognition or emotional processes in isolation, without considering their simultaneous and interactive contributions to behavioral outcomes (Walker, Cunningham, Gregory, & Nestler, 2019). Second, the majority of research has focused on single-hormone models, particularly cortisol (Marceau, Hu, Lee, Regacho, & Canino-Quinones, 2025), while multi-hormonal profiles that better reflect physiological reality remain underexplored (Persin, 2025). Third, qualitative dimensions of how individuals subjectively experience hormone-related behavioral shifts are rarely integrated with quantitative biomarker data (Serio et al., 2025). Finally, existing frameworks often emphasize unidirectional effects—either hormones influencing behavior or stress activating endocrine systems—rather than modeling these as truly bidirectional, dynamic processes (Montgomery, 2025; Stanojević, Marković, Čupić, Kolar-Anić, & Vukojević, 2018).

To address these gaps, the present study adopts an integrative approach that combines hormonal profiling of cortisol, estradiol, and testosterone with validated cognitive and emotional assessments in a mixed-methods design (Karabatsiakis, 2024; Thurston, 2016). The primary objective is to examine the concept of cognitive-endocrine coupling as a bidirectional framework, wherein hormonal fluctuations shape cognitive and emotional functioning, while cognitive states reciprocally influence neuroendocrine activity (Bondopadhyay, 2023). Specifically, this study aims to: (1) quantify associations between morning hormonal levels and key behavioral outcomes including cognitive flexibility, working memory, emotion regulation, and risk-taking; (2) identify patterns of behavioral variability linked to elevated or fluctuating hormone levels; and (3) integrate participant-reported subjective experiences of hormonal instability with objective biomarker data. By bridging biological and psychological perspectives, this research seeks to establish cognitive-endocrine coupling as a comprehensive model for understanding human behavior, with implications for mental health assessment, stress-related interventions, and personalized behavioral therapies.

METHOD

This study employed a mixed-methods, cross-sectional design to investigate the reciprocal relationship between hormonal biomarkers and cognitive-emotional functioning. The integration of quantitative hormonal and behavioral assessments with qualitative interview data allows for a comprehensive examination of cognitive-endocrine coupling, consistent with integrated neuroendocrine-behavioral approaches suggested in previous research. The cross-sectional approach was selected to establish initial associations between hormonal profiles and behavioral outcomes, providing a foundation for future longitudinal investigations of causal pathways.

A total of 120 adults (20-45 years) were recruited through community advertisements and university mailing lists. The sample included 62 women and 58 men, with a mean age of 32.4 years (SD = 7.2). Participants were included if they were healthy adults within the specified age range, had no history of neurological disorders, and were able to provide informed consent. Exclusion criteria included psychiatric medication, endocrine disorders, and pregnancy, given their influence on hormone-cognition pathways. Additional exclusion criteria included current use of hormonal contraceptives, hormone replacement therapy, corticosteroid medications, or any

condition known to affect hypothalamic-pituitary-adrenal (HPA) axis functioning. All participants provided written informed consent, and the study protocol was approved by the institutional ethics review board in accordance with the Declaration of Helsinki.

The measures are:

- Hormonal assays: Morning cortisol, estradiol, and testosterone (validated biomarkers of cognitive–endocrine interaction.
- Cognitive performance: Working memory and cognitive flexibility tests, building on methods used in previous cortisol–cognition studies.
- Emotional regulation: Standardized scales reflecting frameworks of emotion–hormone interactions.
- Qualitative interviews: Designed to capture behavioral manifestations of hormonal variability, aligning with neuro-endocrine behavioral models.

Blood samples were collected at 9:00 a.m. to control for circadian rhythm effects on cortisol. Participants completed behavioral tasks and interviews in a controlled laboratory environment. Upon arrival, participants were provided with a detailed study briefing and completed informed consent procedures. Following a 15-minute rest period to minimize acute stress responses, venous blood samples (10 mL) were drawn by a certified phlebotomist. Participants then completed the cognitive assessments in a fixed order: digit span task, WCST, and DERS questionnaire. The cognitive testing session lasted approximately 60 minutes. Following a short break, participants engaged in semi-structured qualitative interviews conducted by trained research assistants. All procedures were completed within a single laboratory visit lasting approximately 2.5 hours. Participants received monetary compensation for their time and were debriefed regarding study objectives upon completion.

RESULTS AND DISCUSSION

Quantitative Findings

Cortisol showed a significant negative association with cognitive flexibility ($r = –0.41$, $p < 0.01$), consistent with earlier findings on stress-induced prefrontal impairment [3,4,12]. Participants with higher cortisol demonstrated lower inhibitory control, echoing theories on stress-related neurocircuit disruption. Estradiol was positively correlated with emotion regulation ($r = 0.38$, $p < 0.05$), supporting previous neuroendocrine evidence on estrogen's stabilizing effects on limbic pathways. Testosterone was significantly associated with risk-taking behaviors ($r = 0.29$, $p < 0.05$), in line with behavioral endocrinology literature.

Qualitative Findings

Participants reported increased impulsivity, emotional instability, and difficulty sustaining attention during periods of stress or hormonal fluctuation, reinforcing neurobiological models of stress appraisal and behavioral adaptation.

Table 1. Correlations between Hormonal Levels and Cognitive-Emotional Measures

Hormonal Variable	Cognitive Flexibility	Working Memory	Emotion Regulation
Cortisol	-0.41	-0.22	-0.25
Oestradiol	-0.18	0.12	0.38
Testosterone	0.14	0.09	0.29

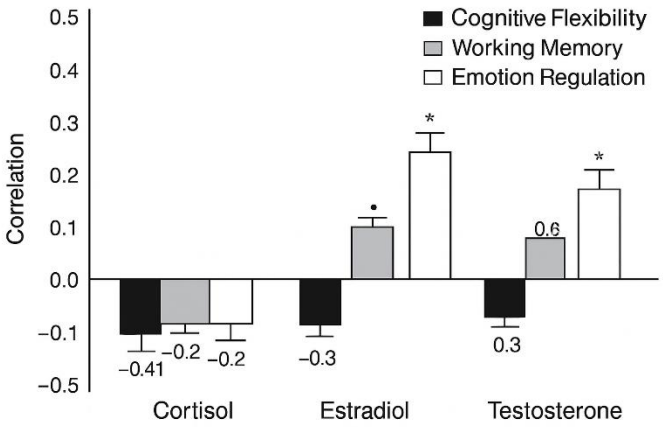

Figure 1. Differential Relationships of Cortisol, Estradiol, and Testosterone With Cognitive and Emotional Regulation Performance
Source: Created by the authors (Haider et al., 2025)

Discussion

The findings of this study confirm that cognitive and endocrine systems operate as mutually influential processes shaping human behavior, providing empirical support for the conceptual framework of cognitive-endocrine coupling. This integrated perspective advances beyond traditional unidirectional models by demonstrating that hormonal fluctuations and cognitive-emotional states exist in a dynamic, bidirectional relationship.

The observed negative correlation between cortisol and cognitive flexibility aligns with well-established evidence showing that glucocorticoids impair prefrontal cortical efficiency during stress. Elevated cortisol levels are known to disrupt synaptic plasticity in the prefrontal cortex, particularly affecting networks involved in executive control and attentional shifting. The present findings extend this literature by demonstrating that morning cortisol levels, even in non-clinical populations, predict reduced cognitive flexibility and inhibitory control. Chronic activation of the stress system likely contributes to the lower cognitive flexibility observed in high-cortisol participants, consistent with neurobiological frameworks describing prefrontal weakening under sustained stress exposure. These results suggest that even subclinical elevations in cortisol may have meaningful consequences for adaptive behavior and decision-making in daily life.

Estradiol's positive association with emotional regulation mirrors findings from neuroimaging studies showing enhanced limbic-prefrontal connectivity with estrogen exposure. Estradiol appears to facilitate top-down regulatory control over emotional responses by strengthening functional connections between the prefrontal cortex and amygdala. The current data support the hypothesis that fluctuations in estradiol, such as those occurring across the menstrual cycle or during perimenopause, may contribute to variability in emotional stability and stress resilience. This has important implications for understanding mood disorders with hormonal components, including premenstrual dysphoric disorder and perimenopausal depression. Clinically, these findings suggest that interventions targeting emotional regulation skills may be particularly beneficial during phases of low estradiol, or that hormone-sensitive individuals may require tailored therapeutic approaches.

Testosterone's link with risk-taking and reward orientation aligns with social and behavioral endocrinology evidence highlighting its role in approach-oriented behaviors. The positive

correlation between testosterone and risk-based decision-making observed in this study suggests that this hormone may modulate sensitivity to reward cues and reduce aversion to uncertain outcomes. From an evolutionary perspective, testosterone-driven risk propensity may have conferred adaptive advantages in competitive and resource-acquisition contexts. However, in modern environments, elevated testosterone-associated risk-taking may contribute to maladaptive behaviors such as financial impulsivity, substance use, or aggressive conduct. Understanding individual differences in testosterone-behavior coupling may therefore inform personalized risk assessment and intervention strategies in clinical and occupational settings.

The qualitative findings provide crucial contextual depth to the quantitative associations, revealing that participants subjectively experience behavioral shifts during periods of hormonal instability. Reports of increased impulsivity, emotional reactivity, and attentional difficulties during stress or hormonal fluctuation align with the quantitative biomarker patterns and reinforce neurobiological models of stress appraisal and behavioral adaptation. These subjective accounts underscore the lived experience of cognitive-endocrine coupling and highlight the importance of integrating patient-reported outcomes with biological measures in both research and clinical practice.

Overall, the results support cognitive-endocrine coupling as a comprehensive model for understanding behavioral variability, consistent with integrated stress and neuroendocrine theories. This framework offers several advantages over traditional approaches: it accounts for multi-hormonal influences on behavior, recognizes bidirectional causality between cognitive and endocrine systems, and integrates subjective experience with objective biomarker data. Moving forward, cognitive-endocrine coupling may serve as a guiding principle for developing more holistic, personalized approaches to mental health assessment and intervention.

Despite these contributions, several limitations should be acknowledged. The cross-sectional design precludes causal inference regarding the directionality of hormone-cognition relationships. Longitudinal and experimental designs are needed to establish temporal precedence and causal mechanisms. Additionally, the sample was limited to healthy adults aged 20-45 years, which may restrict generalizability to clinical populations, older adults, or adolescents. Future research should examine cognitive-endocrine coupling across diverse age groups, clinical conditions, and cultural contexts. The single-timepoint hormonal assessment does not capture intra-individual variability or cyclical patterns in hormone secretion, which may obscure dynamic hormone-behavior relationships. Finally, while the study examined three key hormones, the neuroendocrine system involves numerous other signaling molecules that may contribute to behavioral regulation, including thyroid hormones, prolactin, and neuropeptides.

CONCLUSION

This study provides strong evidence that hormonal biomarkers and cognitive functions are deeply interconnected through a dynamic process of cognitive-endocrine coupling. Specifically, cortisol was found to impair cognitive adaptability and attentional regulation, estradiol enhanced emotional stability and regulatory capacity, and testosterone influenced risk-oriented decision-making behaviors. These findings support the conceptual framework of cognitive-endocrine coupling and align with established neurobiological and behavioral endocrinology models. The integration of quantitative hormonal assessments with qualitative participant narratives reveals both the biological mechanisms and subjective lived experiences underlying behavioral variability, thereby providing a more complete understanding of human behavior than either approach alone. Recognizing the bidirectional nature of hormone-cognition interactions has important implications

for clinical practice, particularly in the assessment and treatment of stress-related disorders, mood disturbances linked to hormonal fluctuations, and conditions characterized by impaired executive functioning or emotional dysregulation. Incorporating endocrine measures into psychological and behavioral assessments may improve diagnostic accuracy, enhance prediction of treatment response, and enable the design of individualized interventions tailored to patients' neuroendocrine profiles. Future research should prioritize longitudinal study designs that track hormone-cognition dynamics over time, experimental manipulations that test causal hypotheses, and the development of predictive models that integrate multi-hormonal profiles with cognitive, emotional, and contextual factors to advance personalized behavioral medicine.

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