PhD Thesis by ***Daniela Batallas Ureña***

VNIVERSITAT DE VALÈNCIA

Biopsychosocial Predictors of Cognitive Functioning: A Focus on Stress, Loneliness, and Physiological Regulation in Young Adults

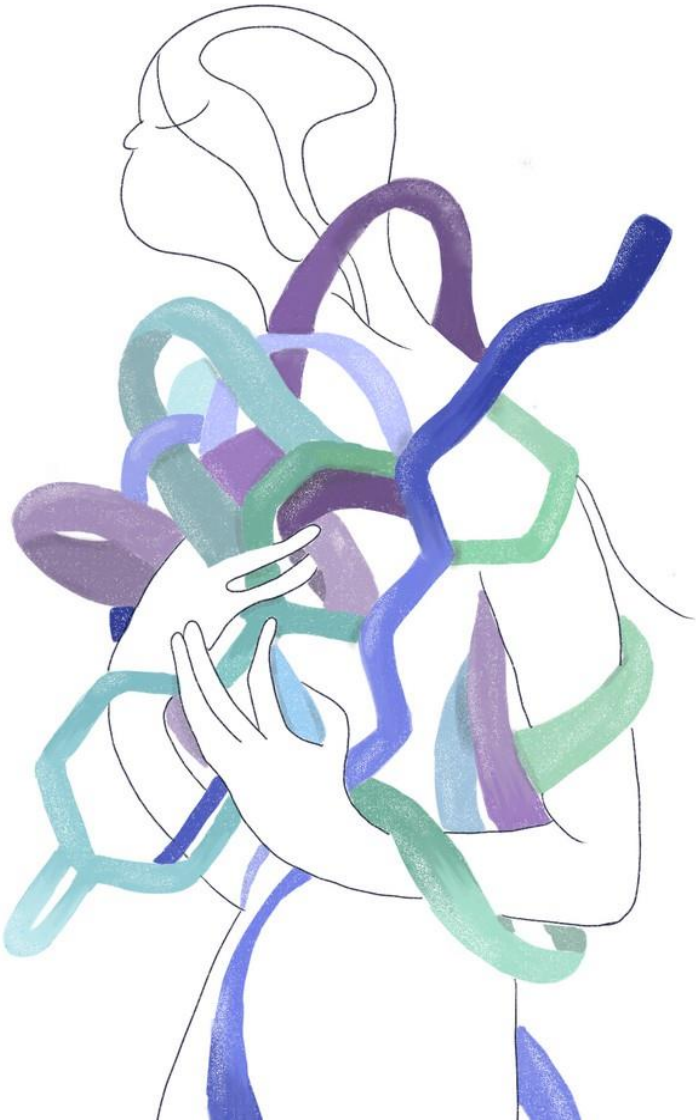
Promotors:

PhD. Alicia Salvador Fernández-Montejo

PhD. Vanesa Hidalgo Calvo

Valencia, February 2026

PhD Program in Neurosciences



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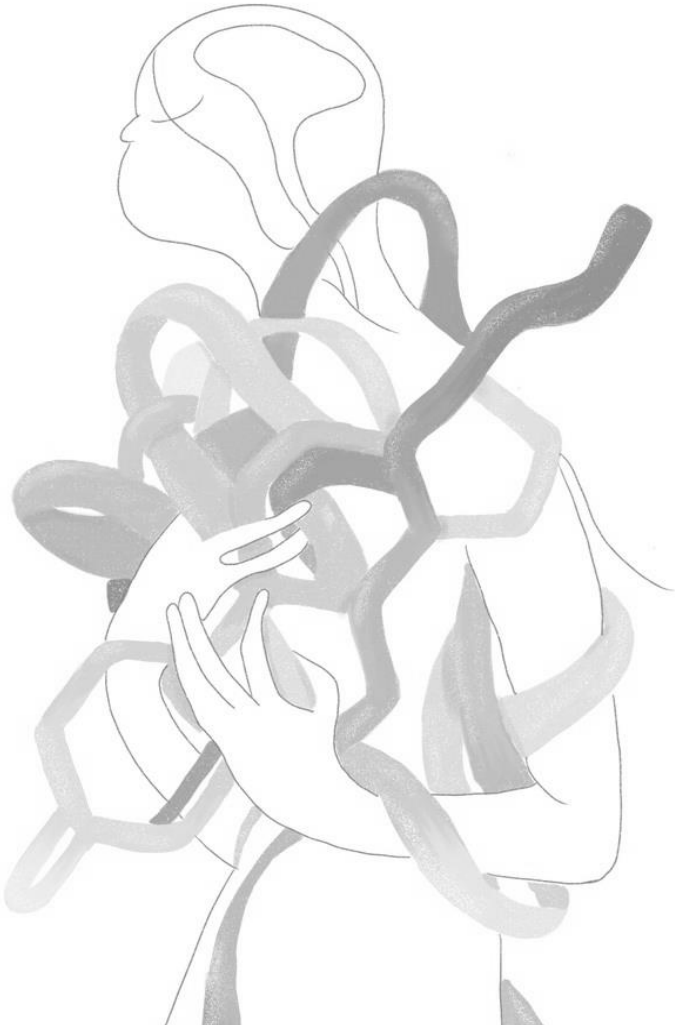

A G R A D E C I M I E N T O S

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Crecer implica equivocarse, avanzar sin certezas absolutas y aceptar que nunca dejamos del todo de estar aprendiendo. La realización de esta tesis ha sido un camino lleno de ilusión, esfuerzo y profundo aprendizaje. Este proceso no solo me ha permitido alcanzar un objetivo académico, sino que también me ha transformado como persona. Nada de esto habría sido posible sin las personas que me han acompañado, sostenido y alentado a lo largo de este recorrido, cuyos aportes puedo resumir en tres grandes enseñanzas: aprender desde el error, sostener la constancia y construir el camino junto a otros.

El primer aprendizaje es aceptar el error como parte del crecimiento. Ser aprendiz implica animarse a preguntar, dudar, equivocarse y volver a empezar sin perder la curiosidad ni la humildad. La investigación también es eso: un ejercicio permanente de ensayo, corrección y reformulación. Nada de este aprendizaje habría sido posible sin la guía de mis directoras, *Alicia y Vanesa.*

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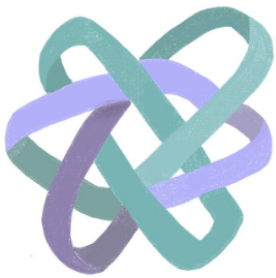
ABBREVIATIONS



Abbreviations

AAQ-II — Acceptance and Action Questionnaire–II

AG — Alone Group

ANS — Autonomic Nervous System

AUCg — Area Under the Curve with Respect to Ground

BDI-II — Beck Depression Inventory–II

COVID-19 — Coronavirus Disease 2019 (SARS-CoV-2)

DHEA — Dehydroepiandrosterone

DHEA-S — Dehydroepiandrosterone Sulfate

DM — Declarative Memory

DMI — Declarative Memory Retention Index

DS-Backward — Digit Span Backward

DS-Forward — Digit Span Forward

ECG — Electrocardiography

FAP — Final Adaptation Phase

FCSRT — Free and Cued Selective Reminding Test

FDR — False Discovery Rate

HB — Home-Based Group

HC — Hair Cortisol

HDHEA — Hair Dehydroepiandrosterone

HPA — Hypothalamic–Pituitary–Adrenal Axis

HRV — Heart Rate Variability

IAP — Initial Adaptation Phase

ISP — Prefrontal Symptom Inventory

MFE-30 — Memory Failures in Everyday Life Questionnaire

NAG — Not Alone Group

NEO-FFI — NEO Five-Factor Inventory

PM — Prospective Memory

PMT — Prospective Memory Total Score

PSS — Perceived Stress Scale

RBMT — Rivermead Behavioural Memory Test

RMSSD — Root Mean Square of Successive Differences

RPA-ProMem — Royal Prince Alfred Prospective Memory Test

R-UCLA — Revised UCLA Loneliness Scale

SA — Study Abroad Group

SMCs — Subjective Memory Complaints

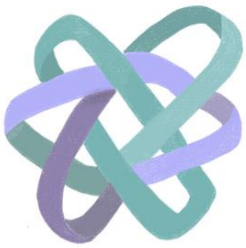
TCI-R-67 — Temperament and Character Inventory–Revised

UPLC–MS/MS — Ultra-performance Liquid Chromatography–Tandem Mass spectrometry

WM — Working Memory

WMI — Working Memory Index

THESIS OUTLINE



Thesis Outline

Contemporary young adulthood unfolds within a context of accelerated social change shaped by academic mobility, digitalized social interaction, and the lasting psychosocial effects of the COVID-19 pandemic. These shifts have altered routines, social connectedness, and regulatory demands, exposing young adults to prolonged uncertainty and fluctuating stress. Although cognitive functioning generally remains intact, sustained psychosocial strain and social disconnection may subtly influence how individuals perceive and regulate everyday cognitive activities, particularly those involving executive control and self-initiated regulation.

Cognitive functioning emerges not only from neurobiological maturation or intellectual capacity but from dynamic interactions among psychological dispositions, social context, and physiological regulation. From a biopsychosocial perspective, subjective cognitive complaints, such as memory complaints or perceived executive inefficiency, reflect emotional states, personality-related vulnerability, stress appraisal, and bodily regulation. Objective performance, especially in memory tasks requiring monitoring and flexible control, may likewise be sensitive to chronic stress, loneliness, and regulatory overload, making these processes especially relevant during transitional periods such as post-pandemic recovery or international mobility.

Psychosocial stress represents a key pathway linking environmental demands to cognition. Perceived stress, characterized by unpredictability and overload, is associated with negative affect and reduced cognitive efficiency. Vulnerability traits such as neuroticism or low self-directedness may heighten reactivity and rigidity, while resilience and adaptive coping support recovery. Social context further shapes outcomes: loneliness can amplify distress and negative self-appraisal of minor cognitive lapses, particularly during reduced in-person interaction or relocation. These influences interact with physiological regulatory systems, including the hypothalamic–pituitary–adrenal (HPA) axis and autonomic nervous system (ANS), indexed by cortisol, dehydroepiandrosterone (DHEA), and heart rate variability (HRV). Rather than directly determining cognition, these systems modulate when psychosocial vulnerability translates into cognitive inefficiency, with balanced activation supporting adaptation and prolonged dysregulation increasing risk under sustained strain. The present Doctoral Thesis adopts an integrative biopsychosocial approach to examine how psychosocial stress, loneliness, dispositional

vulnerability, and physiological regulation jointly shape subjective and objective cognitive functioning in young adults exposed to social change. Specifically, the Thesis addresses three overarching objectives: (1) to examine how psychosocial stress and dispositional vulnerability factors are associated with subjective cognitive functioning, focusing on subjective memory complaints (SMCs) and self-perceived prefrontal symptomatology; (2) to investigate how physiological indicators of stress regulation and mobility-related social living conditions are associated with objective memory performance in post-pandemic contexts, and to evaluate whether loneliness moderates vulnerability to stress-related cognitive inefficiency; and (3) to analyze how physiological regulation (endocrine and autonomic) contributes to cognitive adaptation during academic mobility, and whether physiological flexibility buffers vulnerability associated with loneliness and stress.

Chapter I presents the general introduction and theoretical framework. It contextualizes young adulthood within contemporary social transformation and reviews the conceptual foundations linking psychosocial stress, loneliness, personality vulnerability, and physiological regulation to subjective and objective cognitive functioning. Particular attention is given to memory systems and executive-related processes as sensitive indicators of adaptation and vulnerability.

Chapter II outlines the general objectives and hypotheses of the thesis. It specifies the overarching research aims guiding the empirical work and situates them within the integrative biopsychosocial model adopted throughout the dissertation.

Chapter III introduces the first empirical contribution by focusing on SMCs in young adults in the post-pandemic context. This chapter guides the reader through the examination of how perceived stress and dispositional emotional vulnerability relate to SMCs, and how chronic endocrine regulation is considered as a contextual biological factor shaping these associations.

Chapter IV presents the second empirical chapter, which addresses self-perceived prefrontal symptomatology. It introduces the reader to the examination of personality-based vulnerability and describes how psychological inflexibility is conceptualized as a mechanism linking temperament and character traits to perceived executive functioning difficulties.

Chapter V shifts toward objective cognitive performance and social context by introducing the investigation of loneliness and living conditions as ecological markers of mobility in the post-pandemic period. The chapter outlines how residential displacement, reflecting students living away from their home and primary support environments, together with physiological stress indicators, is examined in relation to memory functioning, thereby establishing a conceptual bridge toward mobility-related adaptation.

Chapter VI focuses on academic mobility as a naturalistic context of prolonged adaptation. It includes individuals at different stages of the mobility experience and introduces the examination of perceived stress, physiological regulation, and multiple memory domains within this transitional context.

Chapter VII extends the mobility framework by introducing the integrative examination of loneliness, SMCs, autonomic flexibility, and memory performance. This chapter guides the reader through the evaluation of physiological regulation as a buffering or amplifying mechanism in cognitive vulnerability pathways.

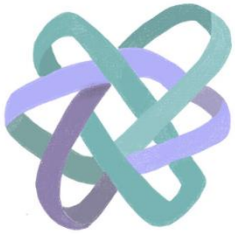
Chapter VIII provides the general discussion. It integrates findings across empirical chapters within a unified biopsychosocial model of cognitive vulnerability and regulatory capacity in young adulthood, highlighting conceptual convergence, theoretical implications, and interpretative synthesis.

Chapter IX presents the main conclusions of the Thesis, summarizing the central contributions to understanding cognitive functioning under psychosocial change and regulatory adaptation.

Chapter X offers a general summary of the dissertation in Spanish, ensuring accessibility and contextual integration within the national academic framework.

CHAPTER I

GENERAL INTRODUCTION



General Introduction

1.1. Contextual Transitions and Psychosocial Adaptation in Young Adulthood

1.1.1 Academic Mobility as a Contemporary Stress Context

In an increasingly globalised world, a growing proportion of undergraduate students pursue academic experiences outside their home country in order to enhance career opportunities, acquire intercultural competencies, and foster personal development (Shkoler & Rabenu, 2023; Zimmermann et al., 2017). In parallel, the rapid internationalization of higher education has reshaped academic trajectories worldwide, consolidating global engagement as a strategic institutional priority and driving a sustained expansion of international student mobility (Ahrari et al., 2019). As a result, academic mobility has become a normative developmental experience for many young adults, embedded within broader processes of educational, economic, and social transformation.

Despite the academic and personal benefits associated with international mobility, students are frequently exposed to a constellation of academic, cultural, and psychosocial stressors, including language barriers, homesickness, culture shock, discrimination, and social isolation (Almurideef, 2016; Hasnain & Hajek, 2022). Consistent with this accumulation of demands, international student populations have shown a sustained increase in mental health difficulties over the past decade, particularly loneliness, anxiety, and depressive symptoms (Forbes-Mewett & Sawyer, 2016; Zheng et al., 2023).

Adjustment during international mobility is not a static outcome but rather a dynamic process that unfolds over time. Longitudinal research on sojourner adaptation, including work derived from the traditional U-curve framework, indicates that stress levels typically fluctuate across the mobility trajectory, with an initial increase often followed by gradual improvement as individuals become more familiar with the host environment (Demes & Geeraert, 2015). More recent evidence in higher education similarly shows that acculturative stress and homesickness tend to decline across the first academic semester or year, whereas satisfaction and sociocultural competence progressively increase (English et al., 2020; Zhao, 2024). Importantly, these trajectories are highly heterogeneous. Some students experience early enthusiasm followed by later

difficulties, whereas others display relatively stable or persistently low levels of stress, underscoring substantial interindividual variability in adaptive pathways (Brown & Holloway, 2008; Dailey-Strand, 2021; Hirai et al., 2015).

Psychological adjustment, often understood as subjective well-being and a sense of comfort in the host environment, is strongly influenced by the availability and quality of social support, which represents one of the most consistent protective factors against acculturative stress (Zhang & Goodson, 2011). Successful adaptation therefore depends not only on exposure to cultural novelty but also on the individual's capacity to establish supportive interpersonal networks that facilitate emotional regulation, stress buffering, and a sense of belonging in the host context.

In this framework, social connectedness refers to the network of meaningful physical and virtual relationships individuals maintain with people, places, and institutions (Tran & Gomes, 2017). For internationally mobile students, establishing and maintaining social connections constitutes a key component of cross-cultural adjustment, yet it often presents significant challenges, particularly during the transition into a new sociocultural environment (Cao & Meng et al., 2022). When access to supportive relationships is limited or unstable, vulnerability to loneliness, emotional distress, and sustained stress exposure increases, potentially undermining adaptive capacity and compromising cognitive and psychosocial functioning.

These challenges became particularly salient during the COVID-19 pandemic, when public health restrictions constrained face-to-face interactions, shifted academic activities to online formats, and in many cases left internationally mobile students socially isolated and financially vulnerable within host countries (Sin et al., 2025). The pandemic amplified pre-existing structural vulnerabilities associated with academic mobility and underscored the importance of understanding how large-scale social disruptions interact with individual differences in stress regulation and adaptive capacity in young adults (Zhang et al., 2023). Beyond the pandemic context, these phenomena reflect a broader pattern of accelerated social change characterised by instability, relocation, and repeated transitions. For young adults navigating higher education, such environments generate sustained adaptive demands that may exceed available regulatory resources, increasing the likelihood of psychological strain and downstream cognitive consequences. Accordingly, academic mobility and post-pandemic conditions can be conceptualised not

as isolated stressors, but as converging expressions of contemporary social transformation that place prolonged pressure on individual adaptive systems.

1.1.2 Loneliness as a Central Psychosocial Vulnerability in Young Adults

Loneliness has emerged as a salient psychosocial vulnerability in contemporary societies marked by rapid social change, geographic mobility, and increasing disruption of stable interpersonal networks. Although loneliness affects individuals across the lifespan, evidence indicates that its prevalence is notable during young adulthood (18–30 years), and may carry heightened social stigma during this developmental stage (Hawkley et al., 2022). This vulnerability was substantially amplified during the COVID-19 pandemic, prolonged confinement measures and disruptions to everyday social routines substantially reduced opportunities for interpersonal contact, contributing to increased loneliness and deteriorations in mental health (Groarke et al., 2020; Pierce et al., 2020).

Beyond its immediate psychological impact, chronic loneliness is robustly associated with elevated risks of adverse physical and mental health outcomes, including anxiety, depression, cardiovascular problems, and increased mortality (Cacioppo & Cacioppo, 2014; Martín-María et al., 2020). Notably, young adults appear to have been disproportionately affected by these social disruptions, underscoring the need for focused research in this developmental group (Groarke et al., 2020).

Loneliness is commonly defined as the subjective discrepancy between desired and actual social relationships, reflecting perceived deficiencies in the quantity or quality of social connection rather than objective social isolation per se (Hawkley & Cacioppo, 2010; Russell et al., 1978). Individuals may therefore experience loneliness despite having frequent social contact, whereas others may live in relative isolation without necessarily perceiving themselves as lonely (De Jong Gierveld & Tesch-Roemer, 2012). Nevertheless, reductions in objective social engagement increase the probability of loneliness, particularly under conditions of environmental disruption (DyKstra, 2006).

From an evolutionary perspective, loneliness is understood as an adaptive alarm system signaling threats to social belonging and survival. Humans are intrinsically social beings who depend on interpersonal bonds for protection, care, and cooperation across the lifespan (Baumeister & Leary, 1995). Social exclusion historically increased vulnerability to environmental threats, making sensitivity to social disconnection

biologically adaptive. Accordingly, loneliness generates aversive affective states that motivate reconnection with others (Cacioppo et al., 2014, 2015). However, when loneliness becomes persistent rather than transient, it is consistently associated with heightened stress reactivity, impaired emotional regulation, and cumulative physiological burden (Park et al., 2020). Thus, while short-term loneliness may promote adaptive social behavior, chronic loneliness constitutes a significant risk factor for psychological and biological dysregulation.

Internationally mobile students constitute a population at heightened risk for loneliness due to geographic separation from established support networks, exposure to acculturative stress, language barriers, and initial difficulties in forming meaningful and stable relationships in host environments (Sawir et al., 2008; Wawera & McCamley, 2020). As a result, many students experience the paradox of being socially surrounded yet emotionally isolated, a distressing and increasingly common feature of contemporary international student life (Zheng et al., 2023).

Recent psychometric evidence further indicates that loneliness is not a unitary construct but comprises multiple interrelated dimensions. Analyses of the UCLA Loneliness Scale identify at least three components: Isolation (objective reduction in social contact), Relational Connectedness (perceived difficulties in maintaining meaningful interpersonal relationships), and Trait Loneliness, reflecting a more enduring and dispositional sense of emotional detachment (Bottaro et al., 2023). This multidimensional framework is particularly relevant in cross-cultural and mobility contexts, where temporary physical isolation and enduring emotional loneliness may exert distinct cognitive and physiological effects.

1.2 Psychophysiological Biomarkers of Stress Regulation: Endocrine and Autonomic Pathways

Physiological responses to stress provide objective indices of how individuals regulate environmental demands and maintain homeostasis. In this context, biomarkers derived from endocrine and autonomic systems offer valuable insights into individual differences in vulnerability and resilience. Among these systems, the HPA axis and the ANS have received particular attention due to their central role in coordinating stress responses and their established links with cognitive functioning.

1.2.1 Endocrine biomarkers and long-term stress exposure: Cortisol and DHEA

The HPA axis is a central neuroendocrine system supporting adaptation to psychological and physiological demands through the coordinated secretion of adrenal steroids (Herman et al., 2016). Within this system, cortisol, the primary glucocorticoid in humans, has been widely used as a core indicator of stress-related physiological activity, as it facilitates catabolic, metabolic, and immunosuppressive processes during both acute and chronic stress (Noushad et al., 2021). In contrast, DHEA has gained increasing attention as a complementary adrenal biomarker due to its modulatory and counter-regulatory properties, including anabolic, neuroprotective, and anti-glucocorticoid effects (Buoso et al., 2011; Kamin & Kertes, 2017). Together, these hormones provide a more integrative representation of HPA axis functioning and stress-related physiological regulation. Importantly, both hormones can be quantified using non-invasive biological samples, such as hair or saliva, which capture distinct temporal windows of endocrine function and strengthen their value as biomarkers in stress research.

A longstanding methodological challenge in HPA-axis research is that cortisol secretion is highly dynamic and strongly shaped by circadian rhythmicity and momentary situational influences (Androulakis, 2021). Salivary cortisol is therefore particularly informative when the goal is to characterize short-term neuroendocrine activity under controlled conditions (e.g., laboratory sessions, acute cognitive load, or recovery) (Hellhammer et al., 2009). However, single-sample approaches are limited by time-of-day variability and transient daily stressors. To address this, repeated sampling protocols allow researchers to derive summary indices such as the area under the curve with respect to ground (AUCg), which reflects total cortisol output across multiple time points and provides a more stable estimate of endocrine activity during the sampled period (Pruessner et al., 2003). This approach is especially useful when examining associations between endocrine activation and cognitive performance, as it reduces noise linked to isolated measurements.

Beyond short-term indices, increasing attention has focused on endocrine markers that capture cumulative exposure. Hair cortisol (HC) concentration provides an integrated estimate of cortisol secretion over weeks to months, reducing confounding by diurnal variation and acute situational effects (Russell et al., 2012; Stalder & Kirschbaum, 2012). Hair-based assessment has therefore been positioned as a particularly promising strategy

for studying chronic stress physiology, especially in contexts characterized by prolonged adaptive demands. Parallel advances have extended this approach to hair DHEA (HDHEA), offering an additional retrospective marker of long-term adrenal activity (Buoso et al., 2011; Kamin & Kertes, 2017).

Crucially, HPA axis biomarkers are not only relevant as indicators of stress exposure but also because they are mechanistically implicated in cognitive functioning. A substantial body of evidence links elevated glucocorticoid activity to poorer cognitive performance, with memory processes that depend on hippocampal integrity appearing particularly sensitive to stress-related neuroendocrine dysregulation (see review by Lupien et al., 2007). More recent empirical findings further indicate that heightened stress levels, especially under conditions of environmental instability and reduced social interaction, are associated with measurable declines across multiple memory domains, including Working Memory (WM), Declarative Memory (DM), and Prospective Memory (PM) (Ingram et al., 2021; Llana et al., 2024; Ouanes & Popp, 2019; Pisano et al., 2021). Together, these findings underscore the relevance of endocrine stress markers for understanding individual differences in cognitive vulnerability and adaptive functioning.

Complementing saliva-based findings, HC concentration has increasingly been used to examine associations between long-term endocrine exposure and cognitive functioning across populations (Feeney et al., 2020; Llorens et al., 2023; McLennan et al., 2016; Oumohand et al., 2020; Pulopulos et al., 2014; Santoso et al., 2022;). Findings remain mixed regarding both direction and cognitive domains. Positive associations with attention and memory have been reported in adolescents (Llorens et al., 2023), whereas in older adults both lower and higher cortisol exposure have been linked to poorer memory outcomes (Feeney et al., 2020; Pulopulos et al., 2014). Other studies report null associations across cognitive abilities or longitudinal outcomes after controlling for confounders (McLennan et al., 2016; Oumohand et al., 2020; Santoso et al., 2022). Overall, the predominance of research in older or heterogeneous samples highlights a limited understanding of these relationships in young adults and in contexts where chronic psychosocial demands are likely to be important, underscoring the need for further investigation in these populations.

1.2.2 Autonomic biomarkers: Heart rate variability (HRV) and regulatory flexibility

Complementing endocrine markers of stress, the ANS represents a second core regulatory pathway through which physiological arousal, emotional regulation, and cognitive functioning are dynamically coordinated. HRV, defined as the temporal fluctuations between successive heartbeats, provides a non-invasive and sensitive index of autonomic flexibility and vagal control (Forte et al., 2019; Thayer & Sternberg, 2006). HRV reflects the continuous interplay between sympathetic and parasympathetic influences on the sinoatrial node, capturing the organism's capacity to rapidly adjust physiological states in response to environmental demands and internal challenges.

From a regulatory perspective, the vagus nerve represents the primary parasympathetic pathway linking central neural systems with cardiovascular control, commonly indexed through HRV. Experimental and psychophysiological studies indicate that vagally mediated HRV is associated with cortisol responses to stress. For example, Vagus nerve stimulation has been shown to attenuate stress-induced cortisol release (Cuberos Paredes et al., 2025), and higher vagally mediated HRV has been associated with differences in cortisol reactivity to stress (Pellissier et al., 2014; Pulopulos et al., 2018), consistent with models proposing functional coupling between autonomic and HPA axis regulation (Thayer & Sternberg, 2006). Forthermore, reduced vagal tone has been associated with poorer emotion regulation and reduced stress adaptability, suggesting that autonomic flexibility may support adaptive affective and cognitive regulation (Chida & Hamer, 2008; Reyes del Paso et al., 2013). These findings suggest that autonomic flexibility serves as a physiological substrate supporting adaptive regulation across affective and cognitive domains.

The theoretical foundation linking HRV to cognitive regulation is articulated by the Neurovisceral Integration Model, which proposes that HRV indexes the functional integrity of a distributed prefrontal–subcortical network involved in executive control, attentional regulation, emotional modulation, and behavioral flexibility (Thayer & Lane, 2000; Thayer & Lane, 2009). This network encompasses the prefrontal cortex, anterior cingulate cortex, insula, amygdala, and brainstem autonomic nuclei, collectively forming the central autonomic network that integrates cognitive and visceral regulation (Thayer & Lane, 2009). Within this framework, HRV may reflect efficient inhibitory control and

capacity to flexibly allocate attentional and regulatory resources in response to changing task demands.

Consistent with this model, higher resting HRV has been linked to superior executive functioning, global cognition, and memory performance across healthy populations (Frewen et al., 2013; Forte et al., 2019). A large systematic review including more than 19,000 participants concluded that reduced parasympathetic activity and increased sympathetic dominance are reliably associated with poorer performance across multiple cognitive domains, including attention, processing speed, executive functions, and memory, even in non-clinical samples (Forte et al., 2019). These findings support the view that autonomic dysregulation may precede or accompany subtle cognitive inefficiencies, positioning HRV as a potential early biomarker of regulatory vulnerability.

Beyond resting-state indices, dynamic changes in vagally mediated HRV during cognitive engagement provide additional insight into regulatory flexibility. Particularly, time-domain indices such as RMSSD have been associated with enhanced attentional control, cognitive flexibility, and adaptive responsiveness during task performance (Schaich et al., 2020; Sharma et al., 2023). Individuals exhibiting greater task-related modulation of HRV tend to demonstrate more efficient executive coordination and better capacity to regulate competing cognitive and emotional demands. Conversely, reduced HRV reactivity has been observed in individuals with heightened emotional reactivity, diminished attentional regulation, and rigid behavioral responding (Park & Thayer, 2014), further underscoring the shared neural substrates supporting autonomic regulation, emotion processing, and executive control.

Importantly, HRV has also been implicated in social and affective vulnerability processes. Lower resting HRV has been associated with reduced social engagement capacity, impaired emotion regulation, and heightened sensitivity to psychosocial stressors, including loneliness (Roddick et al., 2021). These findings suggest that individuals with reduced autonomic flexibility may be particularly vulnerable to the cognitive and emotional costs of social disconnection, a pattern highly relevant in contexts characterized by mobility, isolation, and social instability.

Despite strong theoretical convergence, empirical studies examining direct associations between HRV and cortisol responses during stress exposure often report weak, inconsistent, or context-dependent relationships (Altemus et al., 2001; Bosch et al.,

2009; Looser et al., 2010; but see Doussard-Roosevelt et al., 2003). Such variability likely reflects methodological heterogeneity, differences in stress paradigms, temporal dynamics of endocrine versus autonomic responses, and individual differences in regulatory capacity.

Taken together, HRV provides a complementary physiological window into regulatory flexibility, capturing the capacity of the autonomic system to dynamically coordinate cognitive, emotional, and physiological responses to environmental demands. In young adults exposed to cumulative psychosocial stressors, such as post-pandemic disruption and international academic mobility, autonomic regulation may play a critical moderating role in shaping resilience, vulnerability, and downstream cognitive functioning.

1.3 Subjective Cognitive Functioning: Memory Complaints and Prefrontal Symptom Perception

Memory is a central psychological function that supports the encoding, storage, and retrieval of information, enabling efficient communication, learning, and adaptive behavior in daily life. In healthy individuals, these processes typically operate automatically and remain largely outside conscious awareness (Sridhar et al., 2023). However, when memory efficiency is perceived to decline, individuals often report everyday failures such as forgetting names, appointments, learned material, or difficulties in planning and temporal organization, these experiences are commonly conceptualized as SMCs (Reid & MacLullich, 2006).

SMCs refer to self-reported memory difficulties that occur in the absence of clear objective cognitive impairment (Broadbent et al., 1982; Molinuevo et al., 2017). Generally, SMCs have attracted strong scientific interest because of their potential role as early indicators of cognitive decline and dementia in older adults (Balash et al., 2013; Mitchell et al., 2014; Wang et al., 2004). Epidemiological and clinical studies have shown that, in later life, subjective complaints are modestly but consistently associated with objective cognitive performance and with an increased long-term risk of developing neurodegenerative conditions (Burmester et al., 2016; Mitchell et al., 2014).

However, growing evidence indicates that SMCs are not exclusive to aging populations. An increasing number of young adults reports memory-related concerns in

both clinical and non-clinical contexts, even when standardized neuropsychological assessments fail to detect objective cognitive impairments (Csábi et al., 2025; Molina-Rodríguez et al., 2018; Pellicer-Porcar et al., 2014). Nevertheless, the functional significance and clinical relevance of SMCs in young and cognitively healthy adults remain less clearly established than in older populations.

Importantly, although many studies fail to demonstrate robust objective deficits, some evidence suggests that subtle associations between SMCs and cognitive performance may emerge when individual vulnerability profiles are considered. For example, young adults with higher subjective complaints may show small differences in attention, executive functioning, or memory efficiency, even within normative ranges (Crespo-Sanmiguel et al., 2024; Ruiz-Sánchez de León et al., 2010).

Accumulating evidence further indicates that emotional vulnerability and personality traits play a central role in shaping subjective cognitive perceptions in young adults. Higher levels of neuroticism, as well as elevated perceived stress, anxiety, and depressive symptoms, consistently predict greater SMCs (Crespo-Sanmiguel et al., 2024; Csábi et al., 2025; Lozoya et al., 2012).

Beyond memory-specific complaints, individuals frequently report a broader constellation of everyday cognitive difficulties related to attention, planning, inhibitory control, monitoring, and emotional regulation. These experiences are commonly described as subjective prefrontal symptomatology, reflecting perceived inefficiencies in executive functioning supported by prefrontal networks (Pedrero & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014). Even in non-clinical populations, between 6% and 26% of adults report recurring everyday lapses consistent with mild executive inefficiency, including distractibility, impulsive responding, poor organization, and reduced cognitive flexibility (Llanero et al., 2008; Lozoya et al., 2012; Pedrero et al., 2009). Empirical studies further indicate that individuals endorsing higher levels of subjective executive complaints tend to show slightly lower (but still normative) performance on attention, memory, and executive tasks (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2010), supporting the ecological validity of these self-perceptions.

Importantly, SMCs and subjective prefrontal symptoms are not independent constructs but rather reflect overlapping dimensions of perceived cognitive functioning

in everyday life. Memory failures in naturalistic contexts frequently arise from inefficiencies in attentional control, planning, monitoring, and goal maintenance, core executive processes supported by prefrontal circuitry (Pedrero et al., 2013; Terán-Mendoza et al., 2016). Indeed, memory performance depends heavily on executive control mechanisms that govern encoding and retrieval (McCabe et al., 2010). Consistent with this view, SMCs have been shown to relate more consistently to declines in executive function and attentional control than to pure episodic memory deficits (Hohman et al., 2011) Neuroimaging evidence further supports this overlap, revealing reduced functional connectivity and altered frontal activation in individuals with subjective complaints even in the absence of objective memory impairment (López-Sanz et al., 2017). Moreover, in younger samples, these concerns often co-occur with everyday executive difficulties and attentional inefficiencies rather than with measurable episodic memory loss (Pellicer-Porcar et al., 2014). Consequently, SMCs are often mediated by executive and attentional dysfunction rather than by primary mnemonic deficits alone.

Young adulthood represents a particularly sensitive developmental window for the development of executive and prefrontal cognitive functions. During this stage, the prefrontal cortex continues to mature, supporting progressive refinement of executive control, self-regulation, and goal-directed behavior (Diamond, 2013). While most individuals achieve increasing cognitive efficiency, a subset of young adult's experiences persistent subclinical difficulties that become more salient in high-demand academic and social environments (Cazan & Schiopca, 2014; Montenegro et al., 2013). These perceived inefficiencies are often accompanied by emotional distress, reduced adaptability, and heightened sensitivity to daily stressors (Hammud et al., 2023), reinforcing the subjective experience of cognitive vulnerability.

From a dimensional perspective, subjective prefrontal symptomatology and SMCs can be conceptualized as continuous indicators of everyday executive–mnemonic efficiency (Ruiz-Sánchez de León et al., 2014). Individual differences in personality and emotional regulation further modulate how cognitive inefficiencies are perceived and reported (Crespo-Sanmiguel et al., 2024). Traits related to emotional reactivity, impulsivity, and self-regulatory capacity have been linked to variability in subjective cognitive functioning and everyday cognitive failures (DeYoung, 2010; Markett et al., 2020; Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Robinson & Wilkowski, 2015). Accordingly, SMCs may capture an integrative psychological signal reflecting the

interaction between executive control, emotional vulnerability, and environmental stress exposure.

1.3.1 SMCs, Prefrontal Symptoms and Perceived Stress

In contexts of heightened environmental stress, perceived stress has emerged as a particularly salient predictor of SMCs (Molina-Rodríguez et al., 2028; Santos et al., 2012). Perceived stress reflects individuals' appraisal of their lives as unpredictable, overwhelming, or exceeding their available coping resources, and has been consistently associated with reduced cognitive confidence, lower memory self-efficacy, and heightened sensitivity to everyday cognitive lapses (Könen & Karbach, 2020; Pearman, 2009).

Research in young adult populations indicates that perceived stress is not only directly related to SMCs but also interacts with executive control processes that are essential for effective everyday memory functioning. In a large sample of university students, Molina-Rodríguez et al. (2018) demonstrated that perceived stress and executive dysfunction are jointly associated with SMCs, with attentional and executive control difficulties playing a central role. Importantly, executive and attentional problems partially mediated the relationship between perceived stress and SMCs, suggesting that stress may influence daily memory complaints through its impact on higher-order cognitive control processes rather than through primary memory impairment alone.

Converging evidence further supports the role of prefrontal symptomatology as a key contributor to SMCs in young adults. Studies have shown that prefrontal symptoms are significantly associated with both perceived stress and SMCs and may exert a direct effect on this complains while also mediating the impact of stress on cognitive self-perceptions (López-Guerra et al., 2022; Ruiz-Sánchez de León et al., 2014). This pattern aligns with broader neuropsychological models emphasizing the central role of prefrontal executive systems in coordinating attentional resources, goal maintenance, and error monitoring during memory-dependent activities (Ruiz-Sánchez de León et al., 2014).

Consistent with this framework, research indicates that elevated stress levels can disrupt executive control functions such as attentional allocation, inhibitory control, and planning, which are critical for successful encoding, monitoring, and retrieval in everyday contexts (Shields et al., 2016). When these regulatory mechanisms are compromised,

individuals may experience more frequent everyday failures and interpret these lapses as memory problems, reinforcing subjective cognitive complaints even when objective performance remains within normal limits.

Finally, affective states commonly associated with perceived stress, including negative affect, anxiety, and depressive symptoms, appear to exert a stronger influence on SMCs than objective cognitive performance itself. Recent evidence in young adults suggests that emotional distress and executive inefficiencies contribute more substantially to SMCs than actual mnemonic deficits, suggesting that SMCs primarily reflect altered self-monitoring, emotional reactivity, and regulatory control (Csábi et al., 2025).

1.4 Objective Memory Performance: Working, Declarative, and Prospective Memory

Memory functioning plays a central role in academic achievement and everyday self-regulation, supporting the temporary maintenance and manipulation of information, the acquisition and retention of knowledge, and the execution of future intentions (Baddeley et al., 2021; Walter & Meier, 2014). Within cognitive research, three memory systems are particularly relevant for understanding adaptive functioning in young adults: WM, DM, and PM (Ashcraft & Kirk, 2001; Cowan et al., 2005; Einstein & McDaniel, 1990; Riedel & Blokland, 2015).

WM refers to the capacity to temporarily hold and manipulate information to support complex cognitive operations such as reasoning, comprehension, and problem solving (Ashcraft & Kirk, 2001; Cowan et al., 2005). It is critically involved in academic tasks requiring sustained attention, multitasking, and cognitive flexibility, making it highly sensitive to cognitive load and environmental stressors. DM, by contrast, encompasses the conscious acquisition and retrieval of facts and events, supporting learning, academic knowledge accumulation, and long-term retention (Riedel & Blokland, 2015).

Beyond WM and DM, PM has received increasing attention due to its central role in self-regulated behavior and academic functioning. PM refers to the ability to form, retain, and execute intended actions at the appropriate moment in the future, often described as the capacity to “remember to remember” in everyday life (Einstein & McDaniel, 1990). Unlike retrospective memory, which focuses on recalling past

information, PM supports goal-directed behavior by enabling individuals to translate intentions into timely actions, such as keeping appointments or completing planned tasks (McDaniel & Einstein, 2000). This function plays a central role in self-regulation and adaptive functioning, as successful PM allows individuals to manage responsibilities and organize daily activities independently (Mahy et al., 2014). The effective operation of PM depends strongly on executive processes, including inhibition, updating, monitoring, and cognitive flexibility, which coordinate intention maintenance with ongoing environmental demands (Martin & Kliegel, 2003; Schnitzspahn et al., 2013).

PM is commonly classified into two main types: time-based PM and event-based PM. Time-based PM involves carrying out an intention at a specific moment and depends largely on self-initiated time monitoring and sustained attentional control (e.g., remembering to attend a meeting at 10 a.m.), whereas event-based PM is activated by external cues in the environment and generally requires fewer cognitive resources (e.g., remembering to take a pill when an alarm sounds or to call someone when receiving a notification) (Su et al., 2024; Talbot et al., 2014). In everyday contexts, individuals frequently need to maintain planned intentions while simultaneously performing ongoing tasks, which places additional demands on cognitive control (Cheie et al., 2021). This functional distinction highlights how different PM tasks rely on varying levels of internal monitoring and environmental support.

Neuroscientific research indicates that PM is supported by the coordinated activity of prefrontal and parietal brain regions, which remain active throughout the different stages of intention processing (Burgess et al., 2011). These areas help maintain intended actions in memory, monitor goals over time, and reduce interference from competing tasks and external distractions. This neural network works together with key cognitive processes such as retrospective memory, executive functions, and attention, enabling individuals to remember what needs to be done and to carry out the action at the appropriate moment (Ellis, 1996; Mahy et al., 2014). When attentional demands increase, PM performance may decline particulary for young adults (Bisiacchi et al., 2008). In addition, metamemory and motivation support strategic control and sustained engagement in completing intended actions (Schneider & Lockl, 2008).

1.4.1 Loneliness, stress, and objective memory performance

The mechanisms through which social isolation and loneliness influence objective cognitive performance remain incompletely understood. However, theoretical models propose that loneliness activates a state of heightened social vigilance characterized by intrusive thoughts, rumination, and increased stress reactivity, which may divert cognitive resources away from goal-directed processing (Cacioppo & Cacioppo, 2018; Cacioppo & Hawkley, 2009). This cognitive reallocation is thought to engage neuroendocrine pathways, including activation of the HPA axis and increased cortisol secretion, which may subsequently affect memory systems that are sensitive to stress modulation (Herman et al., 2016; McEwen, 2008).

Emerging evidence suggests that loneliness is associated with sustained activation of stress-related neuroendocrine pathways, which may confer increased vulnerability for downstream cognitive effects. In a recent study, higher levels of perceived loneliness in adolescents were associated with elevated HC concentrations, indicating greater chronic HPA-axis activity (Anderson et al., 2024). Given that prolonged cortisol exposure has been linked to impairments in memory systems reliant on prefrontal and hippocampal networks (Lupien et al., 2007; Ouanes & Popp, 2019), loneliness-related endocrine dysregulation may increase susceptibility to stress-sensitive cognitive domains. Particularly, PM may be especially vulnerable due to its strong dependence on self-initiated control, executive monitoring, and motivational processes, which are sensitive to chronic stress and regulatory load (McDaniel & Einstein, 2007). Although direct evidence linking loneliness, cortisol, and PM remains limited, these converging findings support the idea of a graded vulnerability–resilience pattern, whereby individuals experiencing greater loneliness may show amplified cognitive sensitivity to chronic stress physiology.

In line with this vulnerability framework, empirical evidence from the COVID-19 pandemic provides an opportunity to observe how prolonged social disruption and stress exposure translate into measurable changes in memory functioning, although findings remain heterogeneous. Pisano et al. (2021) observed that restrictive confinement measures were associated with increased perceived memory failures and objectively reduced performance in both WM and PM. In contrast, Ingram et al. (2021) reported improvements in WM performance as opportunities for social interaction increased

among individuals living alone. Despite the prominence of memory as an outcome in pandemic-related research, the magnitude, direction, and persistence of these cognitive effects remain inconclusive, as emphasized in recent reviews (Llana et al., 2022). While short-term hypervigilance may serve adaptive purposes, sustained engagement of stress-related cognitive states may gradually impair executive efficiency, compromise immune functioning, and increase vulnerability to adverse health outcomes (Quadt et al., 2020).

1.5 Emotional and Cognitive Vulnerability: Personality, and Psychological Inflexibility

Individual differences in stress sensitivity and cognitive functioning cannot be fully explained by contextual demands alone. A substantial proportion of variability in how young adults perceive, regulate, and adapt to stress (particularly in high-demand environments such as international academic mobility) appears to be shaped by stable personality dispositions that influence emotional reactivity, coping strategies, and self-regulatory capacity. Integrating personality frameworks that link affective tendencies with cognitive control therefore provides a useful lens for understanding vulnerability to subjective and objective cognitive difficulties.

Personality traits are commonly conceptualized as relatively enduring patterns of thinking, feeling, and behaving that predispose individuals to respond in consistent ways across situations (Roberts, 2009). Their relative temporal stability underpins their value as predictors of long-term psychological and health outcomes, although some evidence suggests that extreme or prolonged life events may modestly shape trait expression over time (Cobb-Clark & Schurer, 2012; Elkins et al., 2017). Two complementary approaches have been especially influential in characterizing individual differences relevant to stress and cognition: The Big Five trait taxonomy (McCrae & Costa, 1987) and Cloninger's Psychobiological Model of temperament and character (Cloninger, 1993).

Within the Big Five framework, neuroticism represents a central vulnerability dimension characterized by a persistent tendency toward negative affect, heightened threat sensitivity, and amplified stress perception (McCrae & Costa, 1987, 2010). A robust body of research indicates that higher neuroticism is associated with lower cognitive confidence, reduced metamemory accuracy, and greater frequency of self-reported cognitive failures and memory complaints (Könen & Karbach, 2020; Reid et al.,

2006). Although other traits such as conscientiousness may exert a protective influence, neuroticism consistently emerges as the strongest personality correlate of subjective cognitive vulnerability. These findings suggest that negative emotionality shapes not only affective functioning but also how individuals monitor, interpret, and evaluate their everyday cognitive efficiency.

A complementary perspective is offered by Cloninger's Psychobiological Model, which explicitly integrates neurobiological reactivity with higher-order self-regulatory development (Cloninger, 1993). This framework distinguishes temperament dimensions, rooted in genetically influenced emotional response tendencies and subcortical systems, from character dimensions, which reflect learned self-regulation and depend more strongly on prefrontal integration. This distinction is particularly informative for understanding prefrontal-related cognitive functioning, as it directly links emotional sensitivity to goal-directed control processes. Within this model, harm avoidance reflects heightened sensitivity to threat and punishment, whereas self-directedness captures the capacity for autonomous regulation, goal orientation, and adaptive self-control (De Fruyt et al., 2000). Empirical evidence supports the relevance of this temperament–character configuration for everyday cognitive functioning. Individuals characterized by high harm avoidance combined with low self-directedness tend to report more frequent SMCs and reduced executive efficiency (Pedrero-Pérez et al., 2013).

Higher self-directedness has been associated with stronger executive functioning, decision-making capacity, and adaptive coping strategies, whereas lower levels are linked to impulsivity and poorer self-regulatory control (Reijnen et al., 2018; Ruiz-Sánchez de León et al., 2014). In contrast, elevated harm avoidance is associated with anticipatory worry, vigilance, and avoidance-oriented coping, which may amplify stress reactivity and constrain cognitive flexibility under demanding conditions (Gabrys et al., 2018; Schreiber et al., 2012). Neuroimaging evidence further indicates that harm avoidance relates to functional and structural variability in prefrontal systems involved in cognitive control and conflict monitoring (Hu et al., 2016; Zhong et al., 2024).

Beyond trait-level descriptions, psychological inflexibility provides a process-oriented mechanism through which personality vulnerability may translate into emotional and cognitive difficulties. Psychological inflexibility refers to rigid patterns of responding to internal experiences and environmental demands, often characterized by experiential

avoidance and reduced capacity to adapt behavior in accordance with long-term goals (Bond et al., 2006; Latzman & Masuda, 2013). Higher levels of inflexibility have been consistently associated with emotional distress, stress-related symptomatology, and transdiagnostic vulnerability across anxiety and depressive conditions (Kashdan & Rottenberg, 2010; Ortega-Jiménez et al., 2021; Ruiz, 2014; Shen et al., 2024), as well as with diminished cognitive control and reduced flexibility in attentional and executive processes (Doorley et al., 2020; Grant & Cassidy, 2022). In this sense, psychological inflexibility may reflect the functional expression of heightened emotional reactivity combined with limited self-regulatory capacity, closely aligning with vulnerability profiles indexed by high harm avoidance and low self-directedness. Evidence further suggests that inflexibility mediates associations between personality vulnerability and outcomes such as stress, loneliness, and emotional dysregulation (Guerrini Usubini et al., 2022; Orouji et al., 2022; Ortega-Jiménez et al., 2021).

These vulnerability processes may become particularly salient during international academic mobility, a context characterized by uncertainty, novelty, social reconfiguration, and increased cognitive and emotional demands. Personality traits influence how individuals engage with such transitions, shaping coping strategies, tolerance for ambiguity, and capacity for sociocultural adjustment (Barańczuk, 2019). Individuals with higher emotional stability and openness tend to show more adaptive adjustment trajectories, whereas those with elevated anxiety-related traits display greater stress sensitivity and maladaptive coping in novel academic environments (Chamorro-Premuzic & Furnham, 2003). Social engagement traits such as extraversion and agreeableness may further support adaptation by facilitating the formation of supportive networks within host contexts (Barańczuk, 2019).

Although empirical research on the personality profiles of internationally mobile students remains limited and methodologically heterogeneous, existing studies indicate that certain personality dispositions are linked to variation in mobility experiences. Traits related to sociability and sensation-seeking have been associated with more successful adaptation and social engagement in host environments (e.g., lower anxiety, greater sociability, and exploratory drive) among exchange or international students (Muro et al., 2022). Moreover, broader personality dimensions such as openness to experience and extraversion have been shown to correlate positively with intercultural competence and adjustment processes during international mobility (Chédru & Ostapchuk, 2025).

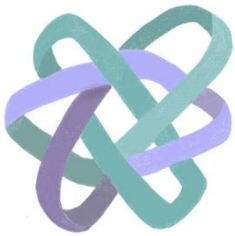
Conversely, higher levels of emotional vulnerability, including neuroticism, are linked to increased homesickness and adjustment difficulties, highlighting how affective personality traits can shape psychosocial stress responses in mobility contexts (Mohamud & Madderla, 2024).

Importantly, these personality-based vulnerability profiles are not only associated with emotional distress but also with how individuals perceive and experience their everyday cognitive functioning. Traits marked by heightened negative emotionality and reduced regulatory capacity are consistently linked to SMCs and prefrontal-related symptomatology in healthy populations (Pedrero-Pérez et al., 2013; Reid et al., 2006; Ruiz-Sánchez de León et al., 2014). Individuals high in neuroticism or harm avoidance tend to report more frequent attentional lapses, planning difficulties, and memory concerns, even when objective performance remains intact (Launay et al., 2026; Pedrero-Pérez & Ruiz-Sánchez de León, 2013). These perceptions likely reflect amplified monitoring of internal errors, increased sensitivity to stress-related cognitive fluctuations, and reduced tolerance for everyday inefficiencies rather than frank neurocognitive impairment. In parallel, low self-directedness and elevated psychological inflexibility may compromise executive self-monitoring and adaptive regulation (Moeck et al., 2023; Ruiz-Sánchez de León et al., 2010), further contributing to subjective experiences of cognitive inefficiency and behavioral disorganization.

Taken together, converging evidence indicates that young adults navigating contexts of heightened social change and uncertainty, such as post-pandemic recovery and international academic mobility, are exposed to sustained psychosocial demands that challenge emotional regulation, physiological stress systems, and cognitive functioning. Subjective indicators, including memory complaints and self-perceived prefrontal symptomatology, appear to capture early signs of regulatory strain, while objective memory performance (WM, DM and PM) provides complementary functional markers of adaptive capacity. At the biological level, endocrine and autonomic biomarkers offer insight into cumulative stress exposure and regulatory efficiency. Importantly, these processes are embedded within stable individual differences, including personality-based vulnerability (e.g., neuroticism, harm avoidance, self-directedness) and psychological inflexibility, which shape how environmental demands are perceived, regulated, and translated into cognitive outcomes.

CHAPTER II

AIMS AND HYPHOTESES



Aims and Hypotheses

The general objective of this Doctoral Thesis was to examine how psychosocial stress and loneliness, together with physiological regulation mechanisms, are associated with subjective and objective cognitive functioning in young adults exposed to contexts of social change (international academic mobility and post-pandemic conditions). Specifically, this Thesis integrates subjective indicators of cognitive difficulties (SMCs and self-perceived prefrontal symptomatology), objective memory performance (WM, DM, PM), and stress-regulation biomarkers (HPA axis indices and HRV), while also considering dispositional vulnerability factors (e.g., personality-related negative emotionality and psychological inflexibility).

The present Doctoral Thesis pursues two main objectives:

1. To examine how psychosocial stress and dispositional vulnerability factors are associated with subjective cognitive functioning in young adults, focusing on SMCs and self-perceived prefrontal symptomatology.
2. To investigate how physiological indicators of stress regulation (endocrine and autonomic) are associated with objective memory performance during academic mobility in post-pandemic contexts, analyzing the role of vulnerability factors (loneliness and perceived stress) in these associations.

To address these aims, five empirical studies were designed with the following specific objectives and hypotheses.

Study 1

This study aimed to examine, in young adults following the COVID-19 pandemic: (i) whether psychological vulnerability factors (neuroticism and perceived stress) and HPA axis biomarkers (HC and HDHEA) were associated with SMCs; and (ii) whether these biomarkers moderated the relationship between vulnerability factors and SMCs. These objectives are developed in Chapter III.

Higher levels of neuroticism (Könen & Karbach, 2020; Sutin et al., 2020) and perceived stress (Molina-Rodriguez et al., 2016) were expected to be associated with greater SMCs, given that subjective cognitive failures are more closely related to

personality characteristics and stress-related processes than to objective cognitive performance. Evidence consistently indicates that neuroticism is associated with an increased number of SMCs (Sutin et al., 2020), and that perceived stress substantially contributes to SMCs in young adults (Molina-Rodriguez et al., 2016). Given the mixed evidence regarding endocrine markers and subjective cognition in young adults, associations involving hair-based endocrine measures, including their potential moderating role, were examined exploratorily.

Study 2

This study examined: (i) whether personality traits such as harm avoidance and self-directedness were associated with self-perceived prefrontal symptomatology, and (ii) whether psychological inflexibility mediated these associations in young adults. These objectives are explored in Chapter IV.

Higher harm avoidance and lower self-directedness would be associated with greater prefrontal symptomatology. This expectation is grounded in evidence showing that elevated harm avoidance is linked to heightened emotional reactivity, anticipatory worry, stress sensitivity, and altered engagement of prefrontal regulatory systems, processes that may intensify perceived cognitive failures (Gabrys et al., 2018; Hu et al., 2016; Zhong et al., 2024). On the other hand, lower self-directedness has been associated with poorer self-regulation, impulsivity, executive dysfunction, and reduced metacognitive control in non-clinical populations (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014). Moreover, the combination of high harm avoidance and low self-directedness has been identified as a strong predictor of everyday cognitive complaints (Pedrero-Pérez et al., 2013), supporting their conceptualization as vulnerability-related personality configurations influencing perceived executive functioning. Furthermore, we hypothesized that psychological inflexibility would mediate these relationships, such that vulnerability-related personality configurations would predict higher inflexibility, which in turn would predict greater perceived executive dysfunction. This hypothesis builds on evidence indicating that psychological inflexibility reflects impaired integration between emotional reactivity and executive control, including reduced cognitive flexibility and set-shifting capacity (Bond et al., 2006; Grant et al., 2022; Kashdan & Rottenberg, 2010), and contributes to stress-related

cognitive and regulatory difficulties across populations (Doorley et al., 2020; Orouji et al., 2022).

Study 3

The objectives of this study were: (i) to analyze whether living arrangements during academic mobility in the post-pandemic context were associated with psychological (loneliness and perceived stress), biological (HC and HRV), and cognitive functioning (WM, DM, PM) in young adults; (ii) to examine the relationship between physiological indicators of stress regulation (HC and HRV) and memory performance; and (iii) to evaluate the moderating role of loneliness in the association between physiological regulation and memory performance. These objectives are developed in Chapter V.

Drawing on the social buffering hypothesis (Cohen & McKay, 1984) and previous evidence linking social isolation and contextual disruption to emotional distress, physiological dysregulation, and cognitive alterations (Groarke et al., 2020; Hopf et al., 2022; Li & Wang, 2020; Newby et al., 2020), we hypothesized that individuals experiencing higher loneliness and more socially constrained living conditions would exhibit poorer objective memory performance. We further hypothesized that less adaptive physiological regulation, reflected in higher cortisol levels and lower HRV, would be associated with poorer memory performance. Finally, we expected loneliness to moderate these associations, such that stronger negative relationships between physiological dysregulation and memory outcomes would be observed among individuals reporting higher levels of loneliness.

Study 4

This study examined academic mobility in students assessed at different phases of the mobility experience (beginning vs. end of the stay) by: (i) comparing perceived stress and physiological stress regulation indices (endocrine and autonomic) across groups, and (ii) analyzing whether endocrine and autonomic regulation indicators were associated with objective memory performance (WM, DM, and PM). These objectives are addressed in Chapter VI.

Based on previous findings, students assessed in the later adaptation phase were expected to report lower perceived stress than those evaluated shortly after arrival

(English et al., 2020; Zhao, 2024). In line with psychobiological models linking chronic stress exposure to dysregulation of the HPA axis and autonomic functioning (Forte & Casagrande, 2025; Hellhammer et al., 2009), reduced physiological stress activation at the later phase was also anticipated, reflected in lower salivary cortisol levels and more adaptive autonomic regulation indexed by HRV. Drawing on evidence that cortisol secretion and autonomic regulation influence memory functioning, associations between physiological stress markers (cortisol and HRV reactivity) and performance across WM and DM domains were expected. Specifically, greater integrated cortisol release was predicted to relate to poorer WM performance (Oei et al., 2006), whereas higher vagally mediated HRV was expected to relate to better memory performance (Forte & Casagrande, 2025). Because evidence directly linking integrated cortisol release to PM performance in young adults remains limited, expectations regarding this association were treated as exploratory.

Study 5

The aim of this study was to examine whether perceived loneliness (and its different dimensions) predicted PM through SMCs, while accounting for resting HRV, in young adults during academic mobility. This objective is developed in Chapter VII.

Based on evidence indicating that loneliness interferes with attentional control, memory processes, and cognitive efficiency (Bangee et al., 2014; Batallas et al., 2024; Ingram et al., 2021), and considering that PM relies heavily on executive monitoring and cue detection (McDaniel & Einstein, 2000; Talbot et al., 2014), higher levels of loneliness were expected to predict poorer performance in both event-based and time-based PM tasks. Accordingly, SMCs were hypothesized to mediate this association, reflecting the link between emotional vulnerability and perceived cognitive functioning (Crespo-Sanmiguel et al., 2024; Heffner et al., 2022).

Consistent with neurovisceral integration models, resting HRV was also expected to moderate the aforementioned mediation, such that the negative impact of loneliness on PM via SMCs would be stronger in individuals with lower HRV (Thayer & Lane, 2009; Forte et al., 2019). Finally, given the increased psychosocial demands associated with studying abroad, these effects were expected to be more pronounced in international students compared to their non-mobile peers (Greischel et al., 2018; Sawir et al., 2008).

CHAPTER III

STUDY 1

Psychosocial Stress and Dispositional Vulnerability in SMCs

The main results of this study have been submitted:

Batallas, D., Rodriguez-Hernandez, V., Hidalgo, V., & Salvador, A. (under rewiew). Predictors of Subjective Memory Complaints: The Role of Perceived Stress, Neuroticism, and HPA Axis Biomarkers in the Post-Pandemic Context.

3.1 Introduction

The COVID-19 pandemic has generated widespread psychological distress across the globe, with young people in numerous countries being among the most affected groups, experiencing heightened levels of stress, anxiety, and disruptions to their daily lives and overall well-being (Gloster et al., 2020; Matić et al., 2022). Recent evidence indicates notable increases in loneliness, depressive and anxiety symptoms, and perceived stress, largely associated with confinement measures, fear of contagion, reduced social interaction, and sustained exposure to information through traditional and digital media (Bendau et al., 2021; Gao et al., 2020; Li & Wang, 2020; Newby et al., 2020; Pierce et al., 2020).

Emerging evidence further suggests that the convergence of prolonged social restrictions, disruption of daily routines, and elevated stress during and after the pandemic may have significant implications for cognitive functioning, including domains such as memory, attention, and executive control (Basheti et al., 2021; Fiorenzato et al., 2021; Maia & Dias, 2020). These effects appear to be mediated by psychological factors such as uncertainty, isolation, and sustained emotional strain, which have been shown to influence both objective measures of cognitive performance (Ingram et al., 2021; Pisano et al., 2021) and individuals' subjective perceptions of their memory abilities (Feter et al., 2021; Feter et al., 2023).

Although objective memory impairments have been observed in individuals exposed to high stress, SMCs have emerged as a particularly relevant phenomenon. SMCs refer to self-perceived difficulties in everyday memory functioning in the absence of measurable impairment (Broadbent et al., 1982; Carrigan & Barkus, 2016; Molinuevo et al., 2017). These complaints are clinically meaningful, as they have been linked to early cognitive decline and dementia onset in older adults (Mitchell et al., 2014; Wang et al., 2004). Previous research has consistently shown a positive association between perceived stress and SMCs, particularly in older adults (Santos et al., 2012), although less is known about the mechanisms underlying this relationship in young populations. Existing evidence suggests that emotional and personality-related factors may play an important role in explaining this relationship, particularly during earlier stages of adulthood (Molina-Rodríguez et al., 2018; Zapater-Fajarí et al., 2022).

Among these factors, neuroticism, a trait characterized by a chronic tendency to experience negative emotions and heightened sensitivity to stress (McCrae & Costa, 1987, 2010) has been repeatedly associated with lower levels of metamemory and greater self-reported cognitive failures (Crespo-Sanmiguel et al., 2024; Reid et al., 2006). Likewise, perceived stress, which captures individuals' appraisal of their lives as unpredictable or overwhelming (Cohen et al., 1983), has been consistently linked to reduced cognitive confidence and memory self-efficacy (Pearman, 2009; Könen & Karbach, 2020). Although differing in temporal stability (neuroticism representing a dispositional trait and perceived stress a situational state) both constructs share a common affective core characterized by negative emotionality. Consequently, they can be viewed as psychological vulnerability factors that influence how individuals interpret and evaluate their cognitive performance.

Beyond these psychological mechanisms, neuroendocrine processes may also contribute to the emergence of SMCs under chronic stress. Along these lines, it is relevant to explore the role of the HPA axis, which is activated in response to threats and adverse circumstances (Herman et al., 2016; McEwen, 2008), to better understand the factors that might influence the relationship between perceived stress and SMCs in the context of the COVID-19 pandemic. The HPA axis plays an integral role in regulating the body's response to stress, and its dysregulation can significantly affect cognitive function and overall well-being. Cortisol and DHEA serve as biomarkers that reflect HPA axis activity (Ahmed et al., 2023; Dutheil et al., 2021). However, traditional methods, such as plasma or saliva sampling, may not adequately capture the exposure to chronic stress. As a result, HC is emerging as a promising biomarker for prolonged stress exposure, offering insights beyond traditional methods (Russell et al., 2012; Stalder & Kirschbaum, 2012). Similarly, there is growing interest in evaluating DHEA levels in hair as an indicator of chronic stress (Bürgin et al., 2020; Hennessey et al., 2020). DHEA presents an antagonistic relationship with cortisol (Buoso et al., 2011). It serves as a potential biomarker for neuroprotection and anti-inflammatory processes associated with reduced physical stress (Kamin and Kertes, 2017).

However, the relationship between psychological stress and DHEA or cortisol remains complex and sometimes inconsistent. While several studies have reported reduced DHEA or DHEA-S levels under chronic stress conditions (Brzoza et al., 2008; Lennartsson et al., 2013), others have observed elevated concentrations (Lac et al., 2012),

or no significant association between stress indices and DHEA levels (Du et al., 2011; Kim et al., 2010). These discrepancies suggest that the stress–hormone relationship may vary depending on context, duration, and individual differences in adaptation. Additionally, although both cortisol and DHEA respond to adrenocorticotropic hormone stimulation, their physiological patterns differ, leading to potentially distinct associations with psychological and cognitive outcomes (Kamin & Kertes, 2017). Cortisol has traditionally been considered a reliable marker of acute stress responses, whereas DHEA may reflect more integrative or compensatory adaptations to prolonged or cumulative stress exposure (Dutheil et al., 2021). Given these differences, investigating both hormones simultaneously are essential to better understand the divergent psychobiological pathways linking chronic stress and cognitive self-perceptions.

Despite the relevance of HPA axis activity for affective and cognitive functioning (Joseph et al., 2021; Ouanes & Popp, 2019; Pariante & Lightman, 2008), few studies have examined its association with SMCs (Fiocco et al., 2006; Peavy et al., 2013; Wolf et al., 2005), and only one has focused on young adults (Zapater-Fajarí et al., 2022). Nevertheless, recent evidence suggests that neuroticism contributes to how individuals perceive their memory functioning (Crespo-Sanmiguel et al., 2024). In this context, investigating how psychological indicators of negative affect (perceived stress and neuroticism) interact with physiological markers of chronic stress (HC and HDHEA) may provide a more comprehensive understanding of the mechanisms underlying subjective cognitive complaints. It is plausible that individuals showing both high psychological stress and greater HPA activation may be more prone to report SMCs, whereas higher DHEA levels could mitigate this effect.

Taken together, the post-pandemic context provides a unique framework to study how psychological and physiological stress markers interact in shaping SMCs. Therefore, the present study addresses these gaps by focusing on young adults during the post-pandemic period. Our aims were: (1) to examine whether perceived stress, neuroticism and hair-based HPA biomarkers (HC and HDHEA) predict SMCs; and (2) to examine whether these stress biomarkers act as moderators in the associations of perceived stress and neuroticism with SMCs. We hypothesized that: (i) higher perceived stress (Molina-Rodriguez et al., 2016) and higher neuroticism (Könen & Karbach, 2020; Merema et al., 2013; Pearman, 2009; Sutin et al., 2020) would be associated with more SMCs; (ii) higher HC would relate to more SMCs whereas higher HDHEA would relate to fewer SMCs

(Zapater-Fajarí et al., 2022); and; (iii) the perceived stress or neuroticism–SMCs link would be stronger at higher HC levels and lower levels of DHEA (Brzoza et al., 2008; Lennartsson et al., 2022; Pulopulos et al., 2014).

3.2 Materials and methods

3.2.1 Participants

The final sample was composed of 69 healthy volunteers (63 women and 6 men) with a mean age of 23.45 years (SD=3.53). All participants were students at the University of Valencia and were recruited in person between March and December 2021. Recruitment efforts included direct outreach during classes and campus events. To maintain consistency, all participants were native Spanish speakers.

Interested participants were contacted for an initial telephone interview to assess their eligibility based on specific inclusion and exclusion criteria. Participants were required to be aged between 18 and 35 years, with no history of cardiovascular or neuroendocrine alterations, neurological or psychiatric diseases, or current/past substance abuse. Smoking habits were evaluated, and only individuals smoking fewer than 10 cigarettes per day were included, as higher levels of smoking could influence HPA axis activity and cognitive performance. Alcohol consumption was assessed by inquiring about the type, frequency, and average quantity of alcoholic beverages consumed per week. Eligibility was determined using low risk drinking thresholds of <20 g/day for females and <30 g/day for males, based on internationally recognized guidelines (Spanish Ministry of Health, 2020). Participants exceeding these thresholds or with a history of alcohol abuse were excluded. Additionally, the use of illicit drugs or medications with potential cognitive or neuroendocrine effects was assessed, and participants with current or past substance abuse were excluded. Further criteria included not having been under anesthesia within the past three months and no reported stressful life events in the past year (e.g., death of a family member), as these factors could significantly impact stress physiology and cognitive outcomes. Participants' characteristics are shown in Table 1.

Table 1. Sample characteristics for Study 1

	Mean (SD) or (%)	Range	Min-max/%
Age (years)	23.46 (3.57)	-	18-33
Education Level			
High school degree	29 (43.28%)		
Undergraduate degree	31 (46.27%)		
Master's degree	7 (10.45%)		
SMCs	25.67 (15.55)	0-120	2-67
Perceived stress	6.24 (3.56)	0-16	1-14
Neuroticism	35.29 (8.77)	1-60	18-57
HC (pg/mg)	7.75 (8.60)	-	4.87-52.99
HDHEA(pg/mg)	13.5 (9.57)	-	0.95-57.60
HC/HDHEA ratio	0.732 (0.37)	-	-0.02-2.15

Note: Mean (*SD*) of the different variables in total sample. Number or percentage when indicated. SMCs: Subjective Memory Complaints. HC: Hair cortisol. HDHEA: Hair DHEA.

3.2.2 Procedure

Participants who met the inclusion criteria were invited to the University of Valencia to participate in a single evaluation session lasting approximately 2 hours. The study was carried out when preventive social distancing measures (e.g., hybrid classes, limited travel, no social or massive events, and mandatory use of face masks) were in place. Participants' well-being was prioritized throughout the protocol. All preventive measures were taken, such as disinfection, social distancing, obligatory use of masks, temperature screening, placement of transparent partitions to divide the space, etc. The

day before the session, participants were told to refrain from smoking, eating, or taking stimulants (e.g., tea or coffee) at least 2 hours before the session, and to avoid engaging in intense physical activity 24 hours before the session.

Upon arriving at the laboratory, all participants were provided with verbal and written explanations of the study, and they agreed to participate by signing an informed consent form. During the session, they completed standardized tests to evaluate SMCs, perceived stress, and neuroticism, as well as a general questionnaire to gather sociodemographic information. At the end of the session, three strands of hair samples were meticulously extracted from the posterior vertex region using stylist's scissors, ensuring proximity to the scalp, a method endorsed by the Society of Hair Testing (1997) and Favretto et al. (2023). Subsequently, each sample was carefully wrapped in aluminum foil and stored at room temperature until dispatch, following the laboratory protocols outlined by Gow et al. (2010) and Stalder and Kirschbaum (2012). These data were then utilized to conduct cross-sectional analyses.

The study was carried out in compliance with the Declaration of Helsinki, and it received approval from the Ethics Committee of the University of Valencia (register code: 1241475).

3.2.3 Psychological Measures

SMCs: SMCs were measured with the Spanish version (Lozoya-Delgado et al., 2012) of the Everyday Life Memory Failure Questionnaire (MFE-30; Sunderland et al., 1986). This questionnaire contains 30 items that explore SMCs in situations and activities of daily life. Items are rated on a Likert-type scale (from 0= never or almost never to 4= always or almost always). Higher scores indicate more everyday memory failures, with a maximum score of 120. Our study showed good internal consistency with a Cronbach's alpha of 0.93.

Perceived Stress Scale: For this research, we used the validated Spanish version (Remor, 2006) of the Perceived Stress Scale (PSS; Cohen et al., 1983). Participants respond to the PSS-4 (Items 2, 6, 7, and 14 from the original PSS-14) on a 5-point Likert scale from 0 (Never) to 4 (Very often). Items 6 and 7 were reverse-scored. The total score ranges from 0 to 16. Higher scores indicate higher levels of perceived psychological stress during the past month. The selection of this brief version was prompted by its brevity and

easy administration which ensured a short exposure of the participant without losing reliability in assessing perceived stress. Cronbach's α for the scale was 0.83.

Neuroticism: This study used the Spanish version (Costa and McCrae, 1999) of the NEO Five-Factor Inventory (NEO-FFI; Costa and McCrae, 1992) to measure neuroticism. This subscale consists of 12 items (e.g., "*I often feel inferior to others*"; "*Sometimes scary thoughts come to mind*"; "*Sometimes things seem bleak and hopeless to me*"), with a 5-point Likert-type response scale (from 1 = strongly disagree to 5 = strongly agree). The maximum score that can be obtained is 60 points. In the present study, Cronbach's α was 0.90.

3.2.4 HC and HDHEA analyses

Analyses focused on the proximal 4 cm of hair, equivalent to approximately 4 months of cumulative steroid hormone secretion (Russell et al., 2012), considering an average hair growth rate of 1 cm/month (Stalder & Kirschbaum, 2012). To ensure consistency, only hair strands adjacent to the scalp were selected for analysis due to variations in hair lengths. Hair samples were processed and analyzed at Prof. Kirschbaum's laboratory, located in the Department of Psychology at Technische Universität Dresden, Germany. The examination utilized an ultra-performance liquid chromatography–tandem mass spectrometry (UPLC–MS/MS) method, following the protocol established by Wang et al. (2019), for the HC and HDHEA sample analyses.

3.2.5 Statistical Analyses

The Kolmogorov–Smirnov test was used to assess the normality of the HC and HDHEA. As these variables were not normally distributed, log-transformations were applied. To address the first objective, linear regression analyses were conducted to examine whether perceived stress, neuroticism, HC and HDHEA predicted SMCs. To address the second objective, moderation analyses were performed to test whether HC and HDHEA moderated the association between perceived stress or neuroticism (independent variable, X) and SMCs (dependent variable, Y) Figure 1.

Figure 1. Conceptual framework of moderation models in study 1

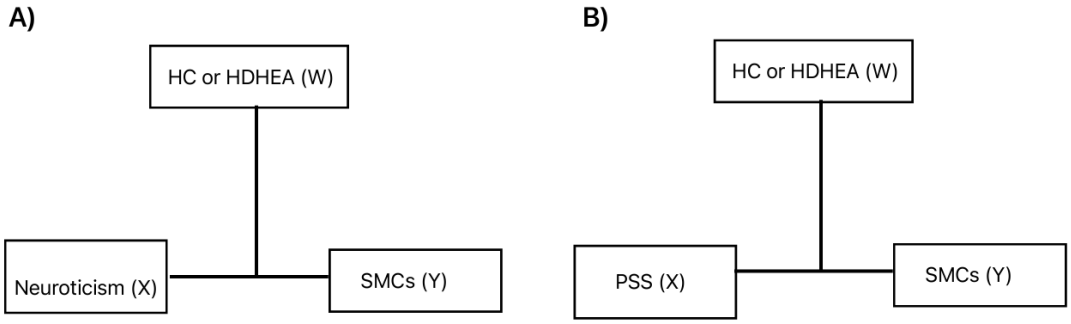


FIGURE 1. Conceptual framework of moderation models. A) Neuroticism (X) as independent variable and SMCs (Y) as dependent variable, stress-related hormones (W) as moderator variables. B) Perceived stress (PSS) (X) as independent variable and SMCs (Y) as dependent variable, stress-related hormones (W) as moderator variables.

All continuous variables were standardized (z-scores). Moderation analyses were carried out using Hayes' PROCESS macro for SPSS (Model 1; Hayes, 2018). Bias-corrected bootstrapping with 5,000 iterations was applied, and 95% confidence intervals not containing zero were interpreted as statistically significant.

The final sample included 66 participants, as two had missing data for perceived stress and one for SMCs. Statistical analyses were performed using SPSS 26.0 (IBM Corporation, Armonk, NY, USA). Post-hoc comparisons employed Bonferroni adjustments, with significance set at $p < .05$.

3.3 Results

3.3.1 Relationships between psychological factors, HPA axis hormones and SMCs

Linear regression analyses showed that SMCs were positively associated with perceived stress ($R^2 = 0.099$, $B = 1.487$, $p = 0.010$) and neuroticism ($R^2 = 0.119$, $B = 0.622$, $p = 0.004$). No significant associations could be identified between SMCs and the HPA hormones (both $p > 0.199$).

3.3.2 The moderating role of HPA axis hormones in the relationship between perceives stress and SMCs

Results of the moderation analysis indicated a significant main effect of perceived stress on SMCs (B = 0.354, p = 0.004), such that higher perceived stress was associated with greater SMCs. HC levels were not significantly related to SMCs (B = 0.169, p = 0.148). The interaction between perceived stress and HC was not significant (B = 0.206, p = 0.098), indicating that HC did not moderate the relationship between perceived stress and SMCs (Table 2).

In the second model, which included HDHEA as the moderator, results showed a significant main effect of perceived stress on SMCs (B = 0.353, p = 0.006), such that greater perceived stress was associated with more SMCs. HDHEA levels were not directly related to SMCs (B = 0.065, p = 0.611). However, the interaction between perceived stress and HDHEA was significant (B = 0.279, p = 0.044), indicating that HDHEA moderated the association between perceived stress and SMCs.

Conditional effects analyses revealed that perceived stress was positively associated with SMCs at moderate (B = 0.287, p = 0.022) and high (B = 0.670, p = 0.003) HDHEA, but not at low HDHEA concentrations (B = 0.150, p = 0.303) (Table 2).

Table 2. Conditional effects of perceived stress on SMCs at different levels of HC and HDHEA

HC as Moderator					
Independent variable (X): Perceived stress **Dependent variable (Y): SMCs**					
ΔR^2_interaction = 0.038, F(1,62) = 2.83, p = 0.098, LLCI = −0.039, ULCI = 0.450.					
HDHEA as Moderator					
Independent variable (X): Perceived stress **Dependent variable (Y): SMCs**					
ΔR^2_interaction = 0.058, F(1,62) = 4.23, p = 0.044, LLCI = 0.077, ULCI = 0.550.					
Level (Z value)	***B***	***SE***	***t***	***p***	***95% CI [LLCI, ULCI]***
Low (-0.73)	0.15	0.144	1.04	0.303	[-0.139, 0.438]

Moderate (-0,23)	**0.287**	**0.122**	**2.36**	**0.022**	**[0.044, 0.531]**
High (1,14)	**0.67**	**0.213**	**3.14**	**0.003**	**[0.244, 1.096]**

Note. Conditional effects derived from PROCESS Model 1 analyses testing perceived stress as predictor of subjective memory complaints, moderated by HC and HDHEA, respectively. CI = confidence interval.

3.3.3 The moderating role of HPA axis hormones in the relationship between neuroticism and SMCs

Results revealed a significant main effect of neuroticism on SMCs ($B = 0.379$, $p = 0.002$), indicating that higher neuroticism was associated with greater self-reported memory difficulties. HC levels were not directly related to SMCs ($B = 0.169$, $p = 0.141$). However, the interaction between neuroticism and HC was significant ($B = 0.293$, $p = 0.020$), suggesting that HC moderated the association between neuroticism and SMCs. Conditional effects analyses showed that neuroticism was positively associated with SMCs at moderate ($B = 0.366$, $p = 0.002$) and high ($B = 0.606$, $p < 0.001$), but not at low ($B = 0.109$, $p = 0.446$) HC levels. These results indicate that the relationship between neuroticism and SMCs strengthened as HC concentrations increased (Table 3).

Table 3. Conditional effects of neuroticism on SMCs at different levels of HC and HDHEA

HC as Moderator (W)					
Independent variable (X): Neuroticism					
Dependent variable (Y): SMCs					
ΔR^2_interaction = 0.073, F(1,63) = 5.71, $p = 0.020$, LLCI = 0.048, ULCI = 0.538.					
Level (Z value)	***B***	***SE***	***t***	***p***	***95% CI [LLCI, ULCI]***
Low (-0.92)	0.11	0.142	0.767	0.445	[-0.175, 0.394]
Moderate (-0,04)	**0.366**	**0.115**	**3.193**	**0.002**	**[0.137, 0.595]**
High (0,77)	**0.61**	**0.165**	**3.667**	**0.001**	**[0.276, 0.936]**
HDHEA as Moderator (W)					
Independent variable (X): Neuroticism					
Dependent variable (Y): SMCs					
ΔR^2_interaction = 0.052, F(1,63) = 3.86, $p = 0.054$, LLCI = −0.005, ULCI = 0.541.					

Note. Conditional effects derived from PROCESS Model 1 analyses testing neuroticism as predictor of subjective memory complaints, moderated by HC and HDHEA, respectively. CI = confidence interval

The second model, which examined HDHEA as the moderator, indicate that neuroticism again showed a significant main effect (B = 0.370, p = 0.003), with higher neuroticism associated with greater SMCs. HDHEA levels were not directly related to SMCs (B = −0.005, p = 0.969). The interaction between neuroticism and HDHEA reached a marginal level of significance (B = 0.268, p = 0.054), indicating a trend toward moderation. Conditional effects analyses revealed that neuroticism was positively associated with SMCs at moderate (B = 0.307, p = 0.011) and high (B = 0.662, p = 0.003), but not at low (B = 0.176, p = 0.200) HDHEA levels. Although the interaction did not reach conventional significance, the pattern suggests that individuals with higher HDHEA concentrations tended to show a stronger relationship between neuroticism and SMCs (Table 3).

3.4 Discussion

The present study examined how psychological indicators of negative affect, specifically perceived stress and neuroticism, interact with hair-based biomarkers of chronic HPA axis activity (HC and HDHEA) to predict SMCs in young adults during a strong stress period. The post-pandemic period is particularly relevant, as the prolonged psychosocial strain, uncertainty, and disruption associated with the COVID-19 pandemic have had lasting effects on stress regulation, emotional stability, and cognitive self-perception (Fiorenzato et al., 2021; Xiong et al., 2020)

3.4.1 Psychological predictors of SMCs in the post-pandemic context

Consistent with our hypotheses, the simple regression analyses revealed positive associations between perceived stress, neuroticism, and SMCs. These findings are in line with previous research highlighting the detrimental effects of stress and negative affectivity on cognitive performance and subjective cognitive functioning (Lukasik et al., 2019; Stanek & Ones, 2023; Zhu et al., 2022). The present results support the idea that both acute emotional distress (perceived stress) and trait-based vulnerability (neuroticism) contribute to how individuals evaluate their memory abilities (Crespo-Sanmiguel et al., 2024; Podlesek et al., 2021; Sutin et al., 2020).

In the wake of the post-pandemic era, characterized by heightened levels of stress and uncertainty, the relationship between perceived stress and SMCs becomes quite significant. The general apprehension stemming from the COVID-19 pandemic, compounded by disruptions in everyday routines and heightened psychological distress, probably increased the association of both perceived stress and neuroticism with objective and subjective cognitive functioning (Podlesek et al., 2021). Moreover, along with the direct effects of stressors, our study revealed an independent contribution of stress vulnerability, as indicated by neuroticism and perceived stress levels. These findings agree with prior research highlighting the multifaceted association of stress and personality factors on objective and subjective memory (Bell et al., 2021; Hill et al., 2019; Rönnlund et al., 2013).

Furthermore, neuroticism was independently associated with SMCs, consistent with models suggesting that individuals high in neuroticism experience and interpret daily stressors more negatively (Neupert et al., 2008; Sutin et al., 2020). Within the cognitive–affective framework, high neuroticism may bias attentional and metacognitive processes, increasing worry and perceived cognitive inefficiency (Feng et al., 2021; Heffner et al., 2022). Given the female predominance in our sample and women's generally higher levels of rumination and emotional reactivity (Lippa, 2010; Singh & Mishra, 2023), the stronger neuroticism–SMCs link might also reflect sex-related differences in stress reactivity and cognitive appraisal.

3.4.2 The moderating role of HPA hormones: different psychobiological pathways for state-based and trait-based vulnerability

Although neither HC nor HDHEA showed direct associations with SMCs, both biomarkers moderated the relationships between the psychological variables and SMCs. This suggests that endocrine activity may be relevant not as a direct correlate of cognitive self-evaluations, but as a contextual factor influencing how psychological stress and personality traits relate to subjective cognition.

The absence of direct correlations between stress biomarkers and SMCs may reflect the complex and nonlinear nature of HPA axis functioning. Both cortisol and DHEA participate in adaptive responses to environmental demands, and their associations with cognition depend on concentration ranges, time scale, and physiological context. In healthy young adults, homeostatic regulation likely maintains hormonal stability within

functional limits, which may attenuate straightforward associations with self-reported memory complaints (Lupien et al., 2007).

Instead, these hormones appear to act as modulators of the psychological–cognitive association rather than as independent predictors of memory complaints. A notable pattern emerged in the moderation analyses: HDHEA, but not HC, moderated the relationship between perceived stress and SMCs. Specifically, the positive association between perceived stress and memory complaints was evident only among individuals with moderate or high HDHEA levels, while it was nonsignificant in those with low HDHEA concentrations. This suggests that higher HDHEA may not necessarily buffer the effects of stress, but could reflect a more active physiological engagement under sustained strain. Previous studies have reported mixed findings regarding HDHEA levels under chronic psychosocial stress, showing both reductions and elevations depending on the duration, intensity, and context of exposure (Dutheil et al., 2021; Lennartsson et al., 2022) indicating that its role in stress regulation is likely complex and context-dependent. Within the post-pandemic context, marked by persistent uncertainty and prolonged adaptation demands, elevated HDHEA levels may represent sustained physiological activation rather than effective recovery, thereby amplifying the link between perceived stress and subjective cognitive concerns.

In contrast, HC did not moderate the perceived stress–SMCs relationship. This aligns with extensive evidence indicating that subjective stress appraisals and cortisol activity often diverge, particularly under conditions of chronic or habituated stress (Leung et al., 2024; Sladek et al., 2016). Whereas HC reflects cumulative physiological activity over the past three to four months, perceived stress captures psychological appraisal during the most recent month. Consequently, chronic exposure to adversity, such as during and after the pandemic, may lead to attenuated cortisol levels despite sustained stress perception (Hannibal & Bishop, 2014; Lam et al., 2019). The absence of a cortisol–perceived stress interaction may therefore reflect this temporal and functional decoupling between psychological appraisal and long-term physiological activity.

Conversely, HC significantly moderated the association between neuroticism and SMCs, whereas HDHEA did not (or only marginally). This suggests that trait-like emotional vulnerability may align more closely with chronic levels of HC than with HDHEA. Although research using hair samples remains limited, studies employing

salivary cortisol have shown that individuals high in neuroticism display elevated or more reactive cortisol secretion across (Garcia-Banda et al., 2014), which may parallel their persistent negative affectivity and stress sensitivity. In the post-pandemic context, characterized by prolonged unpredictability and health-related concerns, such patterns of sustained HC secretion could reinforce the relationship between neuroticism and SMCs. In contrast, HDHEA, as a more dynamic and compensatory hormone, may be less associated with stable personality characteristics, which could explain its weaker moderating role in this pathway.

Taken together, these moderation patterns reveal two complementary psychobiological pathways: 1) A state-related pathway, where perceived stress interacts with HDHEA, reflecting situational and adaptive processes of stress regulation; and 2) A trait-related pathway, where neuroticism interacts with HC, representing longer-term alignment between personality-linked emotional vulnerability and physiological activation levels. These distinct associations illustrate how perceived stress and neuroticism engage different aspects of HPA axis function. In the post-pandemic period, when both stress perception and physiological regulation may remain altered, such differentiation underscores the multifaceted ways psychological and endocrine systems jointly relate to subjective cognition.

Several limitations should be acknowledged. Several limitations should be noted. First, the cross-sectional design prevents conclusions about causality or temporal direction among variables. Second, the female predominance in the sample may have influenced both hormonal profiles and subjective reports, as sex-related differences in HPA axis functioning and stress appraisal have been documented (DeSoto et al., 2015; Gao et al., 2013;). Future research should employ longitudinal designs and more balanced samples to clarify the time course and interdependence of perceived and biological stress recovery. In sum, this study illustrates how post-pandemic stress dysregulation may be expressed through complex psychological–biological interrelations. The differential moderation patterns of HC and HDHEA highlight the need for integrated models that jointly consider personality, stress perception, and chronic biomarkers to better understand the enduring cognitive and emotional consequences of prolonged stress exposure.

Overall, these findings indicate that, at least in the context studied, psychological and biological stress indicators may not operate in parallel, but rather show partial dissociation with complementary influences on subjective cognition. HDHEA appeared more closely associated with perceived stress, suggesting sensitivity to situational and adaptive aspects of physiological regulation, whereas HC was more consistently related to dispositional tendencies such as neuroticism. This pattern points to distinct but interacting pathways through which psychological and endocrine systems relate to subjective memory experiences. The results support the view that chronic stress biomarkers relate to cognitive self-perception indirectly, by reflecting how individuals appraise and adapt to stress. Moreover, the study adds to evidence that SMCs represent psychobiological phenomena arising from the interplay between emotional dispositions and physiological regulation. In this light, SMCs may function as early markers of stress-related cognitive vulnerability, even among healthy young adults.

CHAPTER IV

STUDY 2

Psychological Inflexibility as a Mechanism Linking Personality and Subjective Prefrontal Functioning

The main results of this study have been published in:

Batallas, D., López-Guerra, V., Jiménez, M., Hidalgo, V., & Salvador, A. (2026). The Psychological Cost of Rigidity: Exploring the Mediation of Psychological Inflexibility Between Personality and Prefrontal Functioning. Psychological reports, 332941251415326. Advance online publication. https://doi.org/10.1177/00332941251415326

4.1 Introduction

Young adulthood is a pivotal stage for cognitive and emotional development, during which individuals refine executive functions, self-regulation skills, and decision-making abilities (Wood et al., 2018). During this period, the prefrontal cortex continues to mature, supporting higher-order processes such as planning, inhibition, and goal-oriented behavior (Diamond, 2013). These abilities are essential for successful adaptation to the increasing cognitive and emotional demands of adult life.

However, not all young adults achieve optimal executive efficiency. Some experience subtle yet persistent difficulties, such as distractibility, forgetfulness, or impulsive decision-making that may interfere with behavioral adaptation in high-demand environments, particularly in academic and social settings (Cazan & Schiopca, 2014; Montenegro et al., 2013; Ruiz-Sánchez de León et al., 2010). Empirical studies have shown that individuals who report subjective cognitive complaints (e.g., memory lapses or attentional problems) often exhibit slightly lower performance on attention, memory, and executive tasks compared with those without complaints, although within normal statistical limits (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2010). This subclinical pattern of attentional, mnemonic, and executive inefficiency is thought to underlie what has been described as prefrontal-related cognitive symptomatology, manifesting as everyday errors, oversights, or poorly planned responses (Ruiz-Sánchez de León et al., 2014).

From a neuropsychological perspective, self-reported prefrontal symptoms can be understood as part of a dimensional continuum of executive functioning rather than a mere subjective bias. Even in healthy individuals without neurological or psychiatric diagnoses, between 6% and 26% report everyday difficulties linked to prefrontal functioning, such as occasional inattention, impulsive responding, poorly planned actions, limited monitoring, and reduced ability to generate alternatives (Lozoya, Ruiz & Pedrero, 2012; Llanero et al., 2008; Pedrero et al., 2009; 2011). This dimensional view aligns with models emphasizing distributed prefrontal–subcortical networks that support planning, cognitive flexibility, emotional regulation, and motivation. Thus, self-perceived prefrontal symptomatology may serve as a sensitive indicator of everyday executive efficiency across non-clinical populations (Ruiz-Sánchez de León et al., 2014).

Importantly, these difficulties are often experienced subjectively, even in the absence of clinical impairment. Individuals who perceive their daily lapses as pathological frequently report greater emotional distress, frustration, and reduced adaptability (Hammud et al., 2023). This self-perceived prefrontal symptomatology reflects the subjective awareness of mild executive inefficiencies that may interact with personality-based vulnerabilities, such as heightened emotional reactivity or stress sensitivity (Lozoya-Delgado et al., 2012).

While neurobiological and developmental factors contribute to prefrontal functioning, individual differences in personality also play a crucial role in how people experience and manage executive challenges. Personality traits have been consistently linked to variability in self-regulation, cognitive control, and emotional management, reflecting stable individual differences in prefrontal system efficiency (DeYoung, 2010). Variations in traits such as self-directedness or impulsivity have been associated with everyday cognitive failures and differences in goal-oriented behavior (Markett et al., 2020; Pedrero-Pérez & Ruiz-Sánchez de León, 2013). Moreover, theoretical work on personality processes and self-regulation emphasizes that emotional reactivity and executive control are dynamically intertwined, underscoring the role of personality in shaping both the severity and perception of executive dysfunction (Robinson & Wilkowski, 2015).

To account for these individual differences, it is useful to apply a personality framework that integrates neurobiological mechanisms with environmental modulation of behavior—a central aspect of prefrontal functioning. Unlike descriptive trait models such as the Big Five, Cloninger's psychobiological model (1993) offers a neurobiologically grounded perspective that aligns closely with prefrontal processes of self-regulation and stress reactivity. The model distinguishes between temperament, rooted in neurotransmitter systems and subcortical circuits, and character, which depends on higher-order prefrontal integration and learning. This makes Cloninger's framework particularly suitable for studying prefrontal–phenotype relationships, as it links emotional reactivity (e.g., harm avoidance) with executive and self-regulatory capacities (e.g., self-directedness), capturing how both cognitive and emotional functioning emerge from the interaction between temperament and character in young adults.

Empirical and theoretical evidence consistently supports the association between Cloninger's personality dimensions and prefrontal-related cognitive functioning. In particular, the combination of low self-directedness and high harm avoidance has been identified as a strong predictor of everyday cognitive complaints in non-clinical adults (Pedrero-Pérez et al., 2013). Self-directedness (a character dimension closely related to metacognitive and goal-directed control) has been positively associated with executive functioning, decision-making, and adaptive coping strategies (Reijnen et al., 2018; Richter & Eisemann, 2002), whereas lower levels of this trait are related to poor self-regulation, impulsivity, and executive dysfunction (Ruiz-Sánchez de León et al., 2014). This dimension is thus considered a metacognitive variable closely tied to prefrontal systems (Pedrero-Pérez & Ruiz-Sánchez de León, 2013). In contrast, high harm avoidance, a temperament trait reflecting sensitivity to threat and punishment (Cloninger et al., 2019), predisposes individuals to heightened vigilance, anticipatory worry, and avoidance-oriented coping (Schreiber et al., 2012). These tendencies can intensify perceived cognitive failures by amplifying stress reactivity and limiting emotional tolerance, ultimately hindering cognitive flexibility and adaptive regulation (Gabrys et al., 2018). Taken together, low self-directedness and high harm avoidance represent a personality-based vulnerability marked by increased stress sensitivity and diminished self-regulatory control, which may contribute to both objective and perceived executive inefficiencies, core features of prefrontal functioning (Diamond, 2013).

Therefore, individuals with higher harm avoidance show altered activation in brain regions associated with cognitive control and conflict anticipation, indicating reduced regulatory efficiency under stress (Hu et al., 2016). A recent meta-analysis also revealed that harm avoidance correlates with structural and functional variability in prefrontal regions, further supporting its connection to executive inefficiency and emotional overcontrol (Zhong et al., 2024). Additionally, studies on psychological inflexibility demonstrate that greater rigidity in responding to internal and external demands is associated with poorer cognitive control and reduced mental set-shifting capacity (Grant & Cassidy, 2022). These converging findings suggest that temperament-driven stress sensitivity (e.g., high harm avoidance) and limited self-regulatory capacity (e.g., low self-directedness) may manifest as psychological inflexibility, a process that reflects impaired integration between emotional reactivity and prefrontal executive control. Within this framework, psychological inflexibility represents a neurocognitively

grounded mechanism through which personality-related stress reactivity contributes to self-perceived prefrontal symptomatology in young adults.

The Mediating Role of Psychological Inflexibility

One possible mechanism through which harm avoidance and self-directedness influence prefrontal symptomatology is psychological inflexibility, a construct characterized by rigid responses to internal and external challenges. It contributes to emotional distress and various psychological difficulties, including anxiety, stress-related cognitive impairments, and executive dysfunction (Kashdan & Rottenberg, 2010). Closely related to experiential avoidance, psychological inflexibility reflects a tendency to prioritize automatic psychological reactions over personal values, making it difficult for individuals to tolerate discomfort while pursuing their goals (Bond et al., 2006; Latzman & Masuda, 2013). Those with high levels of psychological inflexibility and experiential avoidance are at greater risk for multiple mental health conditions, whereas individuals with strong cognitive flexibility can efficiently adapt to changing circumstances (Chou et al., 2018).

Psychological inflexibility has emerged as a central transdiagnostic process underlying a wide range of emotional and cognitive difficulties. It contributes to the maintenance of stress, anxiety, and depression by fostering avoidance of unpleasant thoughts and emotions (Ortega-Jiménez et al., 2021; Orouji et al., 2022; Ruiz, 2014; Shen et al., 2024). Individuals who display high levels of inflexibility tend to experience greater emotional distress, poorer cognitive control, and reduced self-regulation, all of which can impair executive functioning (Doorley et al., 2020). Within this framework, personality traits such as harm avoidance and self-directedness appear to play a crucial role. Harm avoidance has been associated with cognitive rigidity, emotional reactivity, and maladaptive stress responses, whereas self-directedness is linked to adaptive coping and better executive control (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Smith et al., 2005; Wachleski et al., 2008). Evidence across different populations further shows that psychological inflexibility mediates relationships between personality factors and a range of psychological outcomes, including stress and loneliness (Ortega-Jiménez et al., 2021), emotional eating and mood disturbances (Guerrini Usubini et al., 2022), as well as emotional dysregulation and sleep problems (Orouji et al., 2022). Altogether, these findings suggest that psychological inflexibility may represent a key pathway through

which harm avoidance and self-directedness influence self-perceived prefrontal and executive functioning.

Although previous research has linked harm avoidance and self-directedness to executive functioning and stress reactivity, the mechanisms underlying these associations remain insufficiently understood. In particular, it is unclear how personality-based vulnerabilities translate into subjective experiences of prefrontal inefficiency in non-clinical populations. Existing evidence has primarily examined these constructs in clinical or high-risk samples, leaving open the question of whether similar processes operate within the general young adult population. By proposing psychological inflexibility as a mediating mechanism, this study addresses this gap, offering a theoretical and empirical bridge between temperament-driven stress reactivity, self-regulatory character traits, and self-perceived prefrontal symptomatology. This approach advances prior work by conceptualizing executive functioning within a dynamic, process-oriented framework, emphasizing how personality and cognitive-emotional regulation jointly shape prefrontal-dependent behavior. Therefore, the present study aims to examine whether psychological inflexibility mediates the relationship between harm avoidance, self-directedness, and self-perceived prefrontal symptomatology in young adults. By addressing this gap, our research seeks to extend prior findings on personality and executive functioning, offering a more integrated understanding of how dispositional and cognitive-emotional factors jointly shape prefrontal-related functioning beyond clinical contexts.

4.2 Materials and Methods

4.2.1 Participants and procedure

A total of 501 undergraduate students (284 men, 217 women), aged 18 to 32 years (M = 21.00, SD = 2.62), participated in this cross-sectional study. Participants were selected through a convenience sampling method, as recruitment depended on voluntary participation among available university students. Students were recruited from various public and private university courses in Loja, Ecuador, via direct invitations during class sessions and institutional announcements. Eligibility required participants to be aged 18-35, native Spanish speakers, enrolled in an undergraduate program and a written informed consent. Exclusion criteria included medical conditions affecting cognitive functioning

(e.g., schizophrenia, bipolar disorder, intellectual disability, or history of stroke). Eligible participants completed a supervised, in-person survey in university facilities, followed by the required questionnaires.

The study used a self-report questionnaire, ensuring confidentiality and anonymity, with an average completion time of 30-35 minutes. To encourage honest responses and improve participation, participants received a summary of their individual scores. All procedures adhered to the ethical principles of the Helsinki Declaration.

4.2.2 Measures

Demographic Questionnaire: The questionnaire collected basic demographic information, including age, gender, highest level of education completed, marital status, and academic standing.

Prefrontal Symptomatology: The Prefrontal Symptom Inventory (ISP) (Ruiz et al., 2012) is a Spanish standardized tool used to assess dysfunctions in daily activities linked to prefrontal cortex neuropsychological alterations. The Spanish version includes 46 items (e.g., "*I have difficulty making decisions*", "*I get angry over insignificant things*", "*I struggle to get started*; *I lack energy*"), rated on a five-point Likert scale (0 = Never to 4 = Always). Its original validation was conducted on a large sample of 1,624 participants showing a stable three-factor structure comprising executive control, social behavior, and emotional regulation difficulties, with Cronbach's alphas ranging from .81 to .87. The ISP has demonstrated good convergent validity with other measures of dysexecutive symptoms and perceived stress. In the present study, the total score was used, showing excellent internal consistency ($\alpha = .937$). This study used the total score (0–184), with higher scores indicating more prefrontal symptomatology.

Personality traits: Harm Avoidance and Self-Directedness were assessed using the Spanish abbreviated version of the Temperament and Character Inventory-Revised (TCI-R-67) (Pedrero, 2009), a validated adaptation of Cloninger's TCI-R (1999) for Spanish-speaking samples. The TCI-R-67 was developed to reduce administration time while preserving the psychometric robustness of the original 240-item instrument. Validation studies conducted in both clinical and non-clinical samples demonstrated strong internal consistency across scales (Cronbach's $\alpha = .82–.89$) and high correlations with the full TCI-R dimensions ($r = .80–.87$), supporting

its reliability and structural validity. The instrument comprises 67 items rated on a five-point Likert scale (1 = False to 5 = True), measures seven personality traits: four temperament dimensions (Novelty Seeking, Harm Avoidance, Reward Dependence, and Persistence) and three character dimensions (Self-Directedness, Cooperativeness, and Self-Transcendence). For this study, we focused on Harm Avoidance and Self-Directedness, each assessed with 8 items and ranging from 1 to 40. The inventory also includes five validity items for response consistency. Internal consistency in our sample was acceptable (Cronbach's $\alpha = .734$).

Psychological inflexibility: Psychological inflexibility was assessed using the validated Spanish version of the Acceptance and Action Questionnaire–II (AAQ-II; Ruiz et al., 2013), originally developed by Bond et al. (2011). It is the most widely used self-reported questionnaire that provides a measure of psychological inflexibility. It is made up of seven questions participants must answer on a seven-point Likert-type scale, in which 1 = "never" and 7 = "always". Scores range from 7 to 49, in which higher ratings indicate greater psychological inflexibility. The Spanish adaptation was validated across six independent samples, demonstrating psychometric properties comparable to the original version. Exploratory and confirmatory factor analyses supported a unidimensional structure, and internal consistency ranged from $\alpha = .75$ to $\alpha = .93$ across samples. In this study, Cronbach's alpha coefficient for the reliability of internal consistency was 0.936.

4.2.3 Statistical Analysis

Descriptive statistics were calculated using means and standard deviations for continuous variables, and frequencies and percentages for categorical variables. Skewness and kurtosis values were calculated for all continuous variables, and none exceeded ±1. These results meet the commonly accepted criteria for reasonable normality in psychological data (Gravetter & Wallnau, 2014). In addition, bivariate correlations were conducted among all study variables to examine preliminary associations and assess whether the direction and strength of the relationships were consistent with the proposed theoretical model.

To examine the role of psychological inflexibility in the relationship between personality traits and prefrontal symptomatology, two mediation models were tested, with

harm avoidance and self-directedness as predictors, psychological inflexibility as the mediator, and prefrontal symptomatology as the outcome. Gender was included as a covariate in both models to control for potential mean-level differences in the study variables, as gender differences in personality and emotion regulation have been previously reported (Else-Quest et al., 2012). Additionally, gender differences have been observed in prefrontal-related cognitive functioning and emotion regulation (Gur et al., 2012), as well as in psychological inflexibility and stress reactivity (Ronkainen et al., 2024). Because gender was not a variable of theoretical interest in the mediation hypothesis, it was not modeled as a moderator.

All continuous variables were standardized (z-scores) prior to analysis to ensure comparability across measures and to facilitate interpretation of effect sizes. As a result, all coefficients represent standardized estimates (β). Mediation analyses were conducted using Model 4 of the PROCESS Macro for SPSS (Hayes, 2017).

Bootstrap resampling (10,000 iterations) established confidence intervals (CIs) to test the statistical significance of the indirect effect (Shrout & Bolger, 2002). CIs are considered significant if they do not include zero (Mallinckrodt et al., 2006). Analyses were performed using IBM SPSS version 26. (Armonk, NY, United States: IBM Corp).

4.3 Results

4.3.1 Descriptive Statistics and Bivariate Correlations

The sample was composed of 284 males (56,69%) and 217 (43.31%) females and aged between 18 and 32 years (M = 21.0; *SD* = 2.59). Descriptive statistics of the sample and measured variables were presented Table 4.

Regarding bivariate correlations, prefrontal symptomatology was positively correlated with psychological inflexibility (r = .61, p < .001) and harm avoidance (r = .52, p < .001), and negatively correlated with self-directedness (r = −.62, p < .001). Harm avoidance and self-directedness were also inversely correlated (r = −.61, p < .001) Table 5.

Table 4. Descriptive statistics of the sample for Study 2

	N (%)	MEAN ± SD	RANGE
GENDER			
Male	284 (56.69)		
Female	217 (43.31)		
AGE (YEARS)		21.00± (2.59)	18-32
ACADEMIC LEVEL (YEAR OF STUDY)			
First year	216 (43.1%)		
Second year	113 (26.6%)		
Third year	54 (10.8%)		
Fourth year	69 (13.8%)		
Fifth year	49 (9.8%)		
MARITAL STATUS			
Single	471 (94%)		
Married	17 (3.4%)		
Divorced	2 (0.4%)		
Common-law marriage	6 (1.2%)		
Widowed	5 (1%)		
HARM AVOIDANCE		22.17(5.99)	8-40
SELF-DIRECTEDNESS		29.97(5.95)	9-40
PSYCHOLOGICAL INFLEXIBILITY		20.14 (10.36)	7-49
PREFRONTAL SYMPTOMATOLOGY		55.89 (26.47)	0-136

Note: Descriptive statistics are presented as frequency (percentage) for categorical variables, and mean ± standard deviation (SD) (range) for continuous variables. N refers to the total sample size.

Table 5. Pearson Correlation Matrix for Study Variables.

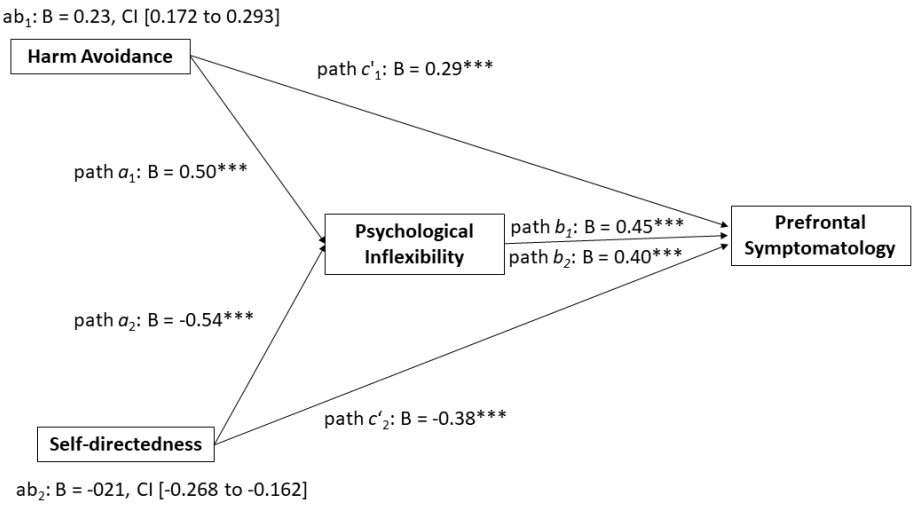
Variable	1	2	3	4
1. Prefrontal Symptomatology	—			
2. Psychological Inflexibility	0.61**	—		
3. Harm Avoidance	0.52**	0.50**	—	
4. Self-Directedness	-0.62**	-0.54**	-0.61**	—

Note: ** $p < .01$ (two-tailed).

Mediating effect of psychological inflexibility on the association between harm avoidance and self-directedness and prefrontal symptomatology

Figure 2 presents the results of the mediation model in which self-perceived prefrontal symptomatology is predicted by harm avoidance and self-directedness with psychological inflexibility as a mediator controlling by gender. Table 6 show direct, indirect, and total effects of Harm Avoidance and Self-Directedness on Prefrontal Symptomatology through Psychological Inflexibility.

Figure 2. Estimated mediation model of harm avoidance and self-directedness on prefrontal symptoms via psychological inflexibility.



Note: Estandardized coefficients *(B*) are presented. All analyses include a covariate (gender), but it is not shown for ease of presentation. ****p* < .001.

Table 6. Direct, Indirect, and Total Effects of Harm Avoidance and Self-Directedness on Prefrontal Symptomatology through Psychological Inflexibility

From variable	To variable	Direct effects	Indirect effects	Total effects	Explained variance
Harm avoidance	Psychological inflexibility	0.503**	–	0.503**	0.255
Harm avoidance	Prefrontal symptomatology	0.287**	0.229**	0.516**	0.471
Psychological inflexibility	Prefrontal symptomatology	0.455**	–	0.455**	–
Self-directedness	Psychological inflexibility	-0.538**	–	-0.538**	0.287
Self-directedness	Prefrontal symptomatology	-0.383**	-0.214**	-0.597**	0.512
Psychological inflexibility	Prefrontal symptomatology	0.397**	–	0.397**	–

Note: Reported coefficients are completely standardized. Explained variance values correspond to R^2 of the outcome in each equation. $p < .01$ is denoted by **.

Results showed that harm avoidance significantly predicted psychological inflexibility (path a_1: β= 0.50, SE = 0.04, 95% CI [0.427, 0.579], $p < .001$), indicating that higher harm avoidance is associated with greater psychological inflexibility. The overall model was significant, F (2, 498) = 85.37, $p < .001$ and explained 25.5% of the variance in psychological inflexibility (R^2 = 0.26).

Moreover, psychological inflexibility was positively related to prefrontal symptomatology (path b_1: β = 0.45, SE = 0.04, 95% CI [0.380,0.529], $p < .001$), suggesting that higher psychological inflexibility is associated with increased prefrontal symptomatology. The direct effect of harm avoidance on prefrontal symptoms remained significant (path c'_1: β = 0.29, SE = 0.04, 95% CI [0.213,0.362], $p < .001$) indicating that higher harm avoidance is associated with greater prefrontal symptomatology. The final model was significant (F(3, 497) = 147.44, $p < .001$, R^2 = 0.471), explaining 47.1% of the variance in prefrontal symptomatology.

The indirect effect of the relationship between harm avoidance and prefrontal symptoms through psychological inflexibility *was* significant (*path* ab_1*:* β = 0.23, *BootSE* = 0.03, 95% CI [0.172, 0.293]), indicating that psychological inflexibility partially mediates the relationship between harm avoidance and prefrontal symptomatology. Regarding the control for gender, it was not a significant (β = −0.082, p= 0.293). These results suggest that a higher harm avoidance experience greater prefrontal symptomatology via increased psychological inflexibility, while that a lower harm avoidance lower prefrontal symptomatology through reduced psychological inflexibility.

For self-directedness, results showed that this variable significantly predicted psychological inflexibility although in negative sense (path a_2: β = -0.54, *SE* = 0.04, 95% CI = [-0.613, -0.463], p < .001), indicating that lower self-directedness is associated with higher psychological inflexibility. The overall model was significant (F (2, 498) = 99.999, p < .001, R^2 = 0.2865), explaining 28.65% of the variance in psychological inflexibility. Moreover, psychological inflexibility was positively related to prefrontal symptomatology (path b_2: β = 0.40, *SE* = 0.04, 95% CI [0.324,0.470], p < .001), suggesting that higher psychological inflexibility is associated with increased prefrontal symptomatology. The direct effect of self-directedness on prefrontal symptomatology remained significant (path c'_2: β = -0.38, *SE* = 0.04, 95% CI [-0.457, -0.310], p < .001), indicating that lower self-directedness is directly associated with greater prefrontal symptomatology. The final model was significant *(*F (3, 497) = 173.886, p < .001, R^2 = 0.5121), explaining 51.21% of the variance in prefrontal symptomatology. Regarding the control for gender, it was not a significant (β= −0.047, p= 0.543). The indirect effect of self-directedness on prefrontal symptomatology via psychological inflexibility was also significant (path ab_2: β = -0.21, *BootSE* = 0.03, 95% CI [-0.268, -0.162]), indicating that psychological inflexibility mediates the relationship between self-direction and self-perceived prefrontal symptomatology.

4.4 Discussion

The present study examined the mediating role of psychological inflexibility in the relationship between some personality traits (i.e., harm avoidance and self-directedness) and prefrontal symptomatology in a sample of young adults. The findings indicate that psychological inflexibility acts as a key mechanism linking personality traits

to the self-perception of cognitive and emotional difficulties associated with executive functioning. These results align with Cloninger's psychobiological model of personality (Cloninger et al., 1993), which emphasizes that temperament and character traits influence self-regulatory processes that depend on prefrontal functioning. In this framework, individuals high in harm avoidance may be more vulnerable to stress-related interference in executive control, whereas greater self-directedness reflects more efficient prefrontal regulation, supporting autonomy and adaptive coping (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014).

From a neurocognitive standpoint, these results are consistent with evidence showing that emotional rigidity and stress can disrupt prefrontal circuits responsible for cognitive flexibility and inhibitory control (Arnsten, 2009; Diamond, 2012). Psychological inflexibility appears to play a central role in this process by reflecting a rigid and avoidance-based response style that limits attentional control and adaptive decision-making (Kashdan & Rottenberg, 2010). Thus, rather than representing an isolated cognitive deficit, prefrontal symptomatology may emerge from the interaction between stable personality tendencies and dynamic self-regulatory processes, such as psychological inflexibility.

Consistent with previous research (Pedrero-Pérez et al., 2019; Ruiz-Sánchez de León et al., 2010; Vierck & Joyce, 2015), harm avoidance and self-directedness were found to be significant predictors of perceived prefrontal symptomatology. Self-directedness appeared protective, while harm avoidance was positively associated with cognitive and emotional inefficiencies. Individuals high in harm avoidance tend to exhibit excessive fear, hypervigilance, and persistent worry, patterns that magnify attentional lapses and interfere with emotional regulation and impulse control (Pedrero-Pérez & Ruiz-Sánchez de León, 2013). These tendencies can increase stress reactivity, potentially reducing executive functioning efficiency (Arnsten, 2009). In contrast, self-directedness was inversely associated with prefrontal symptoms. This is consistent with prior findings showing that high self-directedness supports autonomy, persistence, and effective self-regulation (Oliveira & Simões, 2006; Stockdale & Brockett, 2011). In young adults, whose prefrontal systems are still maturing (Wood et al., 2018), these capacities are especially relevant for managing academic and social demands. Individuals with lower self-directedness may rely on maladaptive coping strategies and struggle with goal-

directed behaviors, contributing to academic or interpersonal difficulties (Cazan & Schiopca, 2014).

A central finding of this study is the mediating role of psychological inflexibility, which accounted for part of the variance between personality traits and prefrontal symptomatology. The indirect effects observed are consistent with prior research linking inflexibility to stress sensitivity, cognitive rigidity, and emotional dysregulation (Kashdan & Rottenberg, 2010; Latzman & Masuda, 2013). High harm avoidance was associated with greater inflexibility, indicating that chronic worry and avoidance-oriented coping may foster maladaptive control strategies that intensify perceived cognitive difficulties. Conversely, self-directedness was inversely associated with inflexibility, suggesting that effective self-regulation and acceptance-based coping protect against executive inefficiencies (Cloninger et al., 1993).

Although most prior studies have focused on clinical populations, such as those with anxiety, depression, or obesity (Cheng et al., 2021; Guerrini Usubini et al., 2022; Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Orouji et al., 2022), our results extend this evidence to a non-clinical young adult population. Unlike clinical samples, these participants reported subclinical levels of prefrontal inefficiency, yet the same personality-linked mechanisms were evident. Recent findings in non-clinical and university populations reinforce this interpretation. Across diverse samples, psychological inflexibility consistently predicts greater stress, worry, and emotional distress, as well as reduced life satisfaction and social connectedness (Bonilla-Sierra et al., 2021; Radyani et al., 2021; Tavakoli et al., 2019; Vaca-Gallegos et al., 2025). These studies converge in identifying inflexibility as a transdiagnostic self-regulatory mechanism that amplifies stress reactivity and loneliness even in the absence of clinical pathology. As Levin et al. (2014) emphasized, such rigidity in managing internal experiences undermines adaptive coping across both clinical and non-clinical contexts. Together, this evidence suggests that psychological inflexibility operates as a dimensional vulnerability underlying stress sensitivity and perceived cognitive inefficiency, extending beyond psychopathological manifestations to typical developmental stages such as young adulthood.

Integrating these perspectives, our findings support a multi-level conceptual model in which temperament and character traits influence cognitive–emotional

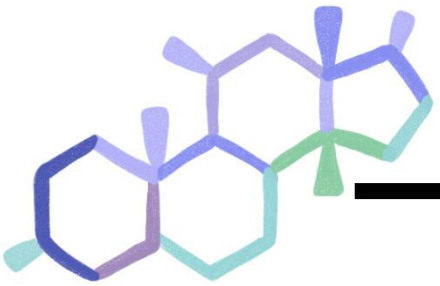
functioning through psychological inflexibility as a dynamic mediator. High harm avoidance may amplify threat perception and stress sensitivity, promoting rigid avoidance strategies that impair attentional control. Conversely, higher self-directedness may buffer against these effects by fostering flexible reappraisal and goal persistence (Oliveira & Simões, 2006; Stockdale & Brockett, 2011). These patterns align with neurobiological models of prefrontal regulation, where chronic stress and rigidity disrupt the integration of affective and executive networks (Miller et al., 2007). This model highlights the importance of cultivating psychological flexibility, a capacity to tolerate discomfort while acting in accordance with personal values as a potential protective factor for both cognitive and emotional functioning (Hayes et al., 2006). Interventions such as Acceptance and Commitment Therapy may strengthen these adaptive skills, enhancing academic adjustment and psychological well-being among young adults.

Despite the relevance of these findings, this study has several limitations. First, its cross-sectional design prevents establishing causal relationships. Future research should use longitudinal designs to explore these associations over time. Second, reliance on self-reported measures may introduce biases in symptom perception; incorporating objective neuropsychological assessments is recommended. Third, the relationship between psychological inflexibility and prefrontal symptomatology suggests the potential involvement of secondary mediators not examined here. Future studies could explore variables like stress reactivity, emotional dysregulation, or loneliness. Physiological markers, such as HRV, could offer a more comprehensive understanding of the neurobiological mechanisms behind psychological inflexibility and executive dysfunction (Perna et al., 2019).

This study highlights the mediating role of psychological inflexibility in the relationship between harm avoidance, self-directedness, and prefrontal symptomatology in young adults. The findings suggest that addressing psychological inflexibility is crucial for cognitive and emotional regulation and that fostering self-directedness may improve executive functioning and well-being. By situating psychological inflexibility as a modifiable, transdiagnostic process connecting personality and executive functioning, this work underscores its potential as a target for preventive and therapeutic interventions aimed at enhancing cognitive and emotional adaptability in young adults.

CHAPTER V

STUDY 3



Loneliness and Memory Functioning in the Post-Pandemic Period

The main results of this study have been published in:

Batallas, D., Rodriguez-Hernandez, V., Hidalgo, V., & Salvador, A. (2024). Loneliness during the post-confinement period: The significance of social living conditions for stress biomarkers and memory. Behavioural brain research, 459, 114771. https://doi.org/10.1016/j.bbr.2023.11

5.1 Introduction

Quarantines produced by the SARS-CoV2 (COVID-19) pandemic globally confined people to their homes, leading to social isolation from approximately March to June 2020. Additionally, even after the lockdowns were lifted, various sanitary measures continued to be enforced worldwide, particularly in public spaces, restricting both individual and community social interactions. Spain, for example, maintained measures such as distancing in crowded spaces, hybrid classes, limited travel, and the mandatory use of face coverings to prevent COVID-19 transmission, among others.

The recent pandemic lockdown has been widely acknowledged as a significant psychosocial stressor (Bridgeland et al., 2021; Cai et al., 2020) that has affected and continues to affect emotional, cognitive, and behavioral aspects (i.e., mood, daily habits, social relationships, etc.) that are central to human well-being (Li & Wang, 2020; Newby et al., 2020). Furthermore, it is important to note that loneliness and social isolation can have enduring implications for mental and physical health. Indeed, these variables have been associated with a wide range of physical, mental health, and cognitive issues, including psychosocial stress, depression, generalized anxiety, cardiovascular and pulmonary diseases, and even mortality (Beller & Wagner, 2018; Montoliu et al., 2019; Mushtaq et al., 2014).

Given the inherently stressful circumstances of the COVID-19 pandemic lockdown and the well-established connection between social isolation and cognitive performance found in earlier studies (Evans et al., 2019; Kuiper et al., 2016), it is reasonable to suggest that social isolation may have negatively impacted cognitive functions. Indeed, current research highlights the significance of factors such as living alone, lacking close relationships, and having a limited social network, all of which have been associated with a decline in overall mental well-being, impaired emotional and reasoning self-regulation, and an increased risk of cognitive impairment (Baumeister et al., 2005; Fellman et al., 2020; Ingram et al., 2021).

In this context, different types of memory have been extensively studied due to their pivotal role in daily activities (Fellman et al., 2020; Santangelo et al., 2021). Research has primarily focused on WM (Cowan et al., 2005), DM (Riedel & Blokland, 2015), and PM (Pisano et al., 2021). Notably, during the Covid-19 pandemic, studies shed light on the contrasting effects of confinement and the positive influence of social

interaction on memory performance. For instance, Pisano et al. (2021) established that the restrictive measures of the pandemic had a negative impact, given that the perceived memory failures of university students coincided with the results of standardized tests highlighting a decrease in both WM and PM. Similarly, Ingram et al. (2021) observed that individuals who were living alone demonstrated improved WM performance as opportunities for social contact increased. Although memory has been a predominant focus in the context of the Covid-19 pandemic, the extent of these cognitive deficits has not been definitively established, as discussed in the review by Llana et al. (2022).

The precise mechanism by which social isolation or loneliness affects cognitive processes is not well-defined. However, Cacioppo and Hawkley (2009) proposed that social isolation may lead to heightened social hypervigilance, characterized by intrusive thoughts, rumination, and stress. This activation could involve neurobiological mechanisms related to the HPA axis, resulting in elevated cortisol levels. Cortisol, a well-established hormone in the HPA axis (Lai et al., 2018; Steptoe et al., 2004), may serve as a short-term indicator of loneliness, predicting long-term adverse physical, cognitive, and mental health outcomes (Steptoe et al., 2004).

Moreover, some literature on the relationship between basal HPA axis activity and cognitive performance shows that higher cortisol release is related to worse cognitive performance (Gerritsen et al., 2011; Lupien et al., 2007; Ouanes & Popp, 2019), particularly on memory tasks dependent on hippocampal functioning (i.e. DM; Almela et al., 2012; Hidalgo et al., 2016). Additionally, the hair cortisol measure, an integrated measure of cortisol exposure for up to several months, has been used to explore the relationship between long-term endogenous cortisol levels and cognitive performance (for more details see: Russell et al., 2012). In this context, Pulopulos et al. (2014) proposed that individuals with lower long-term cortisol exposure might be more susceptible to the detrimental effects of HPA-axis dysregulation on cognitive processes (WM and short-term verbal memory). Similarly, some studies have observed adverse connections between hair cortisol levels and cognitive performance, especially verbal memory (Feeney et al., 2020; Santoso et al., 2022). Although these findings underscore the established value of hair cortisol as a marker of long-term stress and its association with cognitive functions, contradictory outcomes have also emerged in this domain (e.g., McLennan et al., 2016), with a significant portion of these studies conducted with older

populations (Pulopulos et al., 2014; Villada et al., 2020; Saez-Sanz et al., 2023). Thus, further exploration of these variables in young people is warranted.

Another system impacted by physical and psychosocial stress is the ANS, often assessed through HRV, which measures heart rate variation over time (Forte et al., 2019; Thayer & Sternberg, 2006). It has been suggested that the vagus nerve, part of the parasympathetic system, plays a role in regulating cortisol responses during stress conditions (Thayer & Sternberg, 2006). In this line, a bidirectional interaction between the vagus nerve and the HPA axis supports this connection (Thayer et al., 2012), which suggests that individuals with low vagal activity might show poor controlled emotional responses, worse stress adaptation, and impaired cognitive performance (Chida & Hamer, 2008; Reyes del Paso et al., 2013; Zeki Al Hazzouri et al., 2018). Moreover, HRV has been linked to cognitive performance, as in the Neurovisceral Integration Model (Thayer & Lane, 2000), potentially affecting cognitive function due to imbalances in parasympathetic and sympathetic input, which can lead to prolonged and exaggerated autonomous stress responses (Chida & Hamer, 2008; Reyes del Paso et al., 2013; Zeki Al Hazzouri et al., 2018).

However, studies investigating HRV and cortisol responses during stress often reveal weak or non-significant associations (Bosch et al., 2009; Cacioppo et al., 1995; Looser et al., 2010; La Marca et al., 2011; but see Doussard-Roosevelt et al., 2003), highlighting the need for additional research in this field.

Based on the above, the aim of this study was to examine how social contact restrictions in the post-pandemic context could affect people at psychological/affective, biological, and cognitive levels, with a focus on the role of perceived loneliness and the living situation. Drawing on the social buffering hypothesis (Cohen & McKay, 1984), we hypothesized that participants who were not living with their usual nuclear family and had to move from their home country during the restrictive social contact period after the Covid-19 lockdown would exhibit more significant mental, physical, and cognitive health consequences (Hypothesis 1). More precisely, based on previous studies (Groarke al., 2020; Hopf et al., 2022; Li & Wang, 2020; Newby et al., 2020), we anticipated that the current living situation would affect loneliness, depression, anxiety, stress, some biological variables (higher cortisol levels and lower HRV during assessments), and cognitive performance. Additionally, we examined the association between biological

variables and memory. Moreover, despite the heterogeneity in the previous findings, we expected to find negative relationships between biological factors and memory performance (Hypothesis 2), and a moderator role of loneliness in this association (Hypothesis 3) (See Figure 3).

Figure 3. Conceptual models for the theoretical framework of the hypotheses

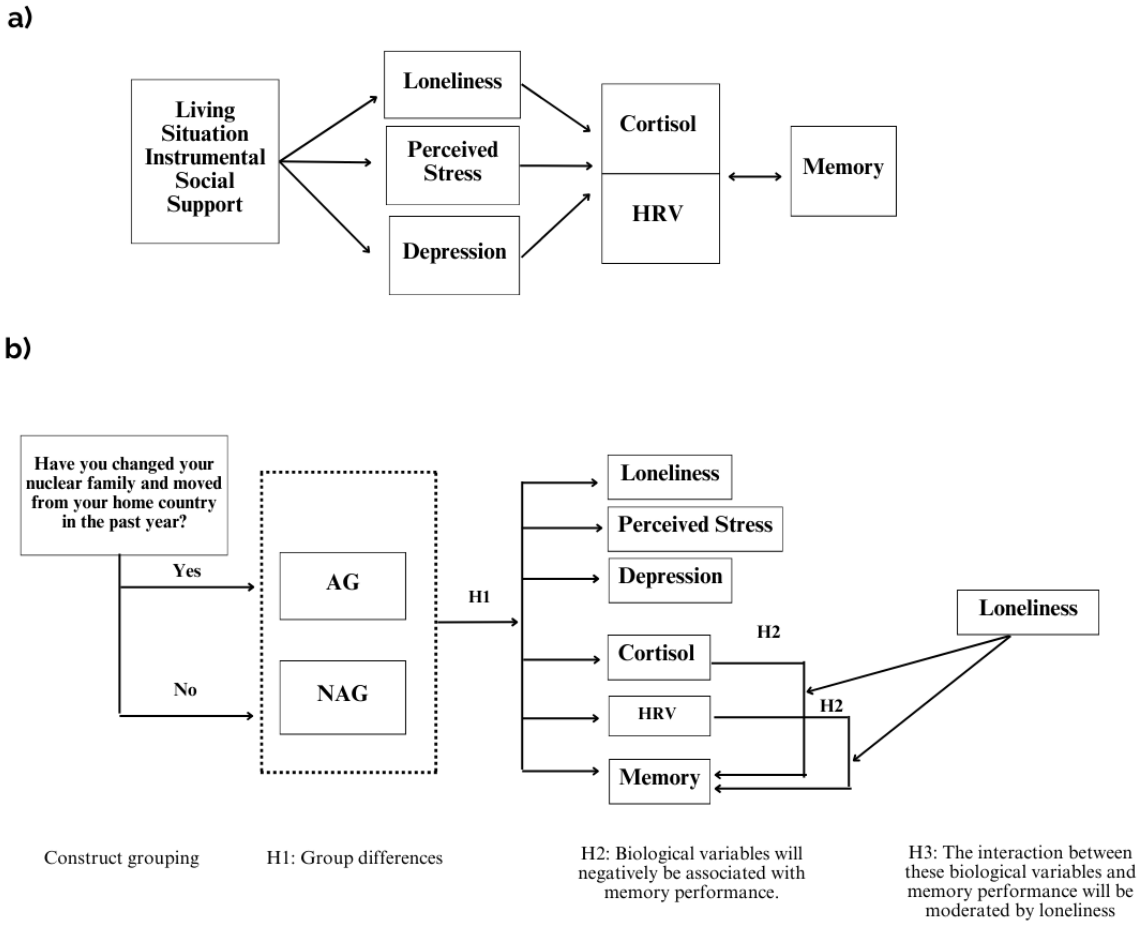


Figure 3. (a) Existing literature, suggesting that participants' living situations during the pandemic, whether living alone after relocation or with others, are associated with differences in key variables. It is emphasized that living alone during the pandemic has been linked to increased feelings of loneliness, stress, and depression, reflected in elevated cortisol levels and reduced Heart Rate Variability (HRV). Furthermore, it is posited that these factors may impact memory performance. (b) Framework of the hypotheses: We grouped people into two categories, AG and NAG, based on their living situation. H1: Group differences in psychological, biological and cognitive variables, H2: Correlations between biomarkers and memory performance, H3: We expected that the interaction between the biomarkers and memory performance will be moderated by loneliness.

5.2 Materials and Methods

5.*2.1 Participants*

A final sample of 45 young students between 20 and 33 years old (mean = 25.6 years old, SD = 3.107) participated in the study. They were recruited in person from March to April 2021. All the participants were students at the University of Valencia who were attending the last year of their bachelor's degree or starting a master's degree. All the participants were native Spanish speakers.

The groups were established according to their living situation (living alone far from their home country/or living with others in their home country) during the past 8 months, including the study period. The group that was *living alone* (Alone Group, AG) was composed of 23 participants consisting of a total of 16 women and 7 men with a mean age of 25.70 years (SD=2.721). The inclusion criteria for the AG group were as follows: having to change their family nucleus, having to move from the home country, and having lived alone during the past 8 months. The group that was *living with others* (not alone group, NAG) was composed of 14 women and 8 men with a mean age of 25.50 years (SD=3.529). For the NAG group, the inclusion criteria were: not having changed their family nucleus or moved from the home country, and having lived with relatives, friends, or spouse during the past 8 months, including the study period.

The exclusion criteria used for both groups encompassed the following conditions: the presence of cardiovascular or neuroendocrine abnormalities, a history of neurological or psychiatric disorders, the consumption of more than 10 cigarettes per day, or the excessive use of drugs or alcohol (not exceeding 20 g/day for women and 30 g/day for men). Individuals who reported meeting any of these exclusion criteria in a preliminary telephone interview were not invited to participate in the study. Approximately five participants were excluded from the AG group and 12 from the NAG group. Consequently, no data were collected from these individuals.

5.*2.2 Procedure*

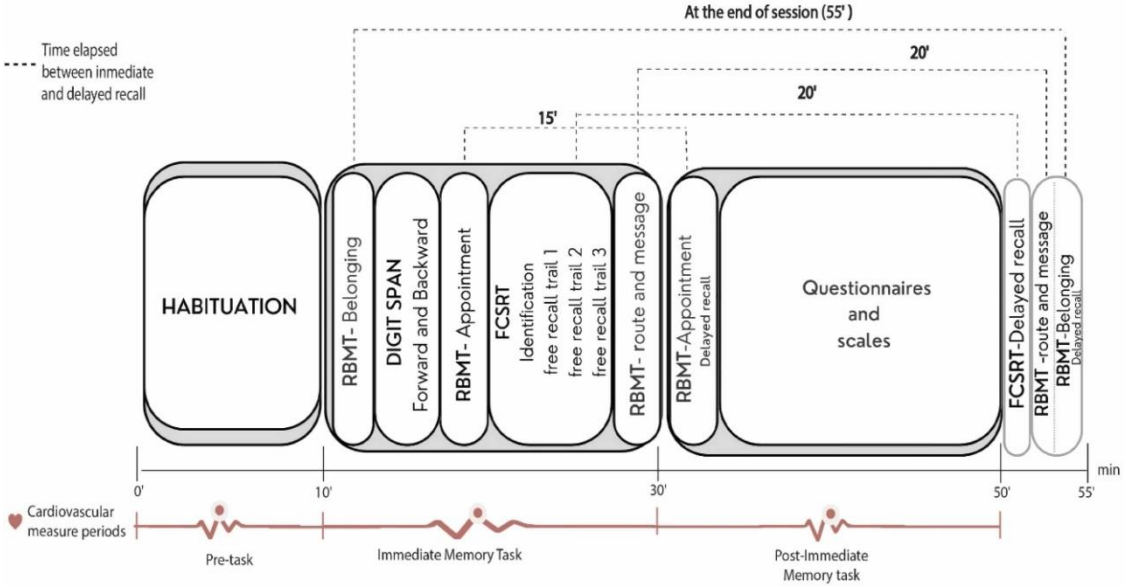
Participants who met the inclusion criteria were contacted by telephone and summoned to the University of Valencia to participate in a single evaluation session lasting approximately 55-60 minutes. The study took place between March and May

2021, when preventive social distancing measures (e.g., hybrid classes, limited travel, no social or mass events, and mandatory use of face masks) were in effect. Participants' well-being was prioritized throughout the protocol. All the necessary preventive measures were taken, such as disinfection, social distancing, obligatory use of masks, etc.

Before the session, participants were told to refrain from smoking, eating, or taking stimulants (e.g., tea or coffee) at least two hours before the session, and to avoid engaging in intense physical activity 24 hours before the session. The research protocol was the same for both groups (AG and NAG). All participants received written information about the study and signed an informed consent form to participate in the study, which was conducted in accordance with the Declaration of Helsinki. The Ethics Committee of the University of Valencia approved the study.

The research protocol (see Figure 4) started with habituation (*pre-tasks* phase) for 10 minutes to ensure the participant's adaptation to the setting. During this phase, a chest strap for heartbeat detection was placed, and participants did not receive any specific instructions other than to breathe normally, in order to avoid any disturbance in the cardiovascular measurement. Next, the *immediate memory-task* phase, which lasted approximately 20 minutes, took place, and participants performed the following memory tests or subtests: 1) RBMT-belonging (PM), 2) Digit Span-Forward and Digit Span-Backward (WM), 3) RBMT-Appointment (PM), 4) FCSRT-immediate (DM), and 5) RBMT-route and RBMT-message (PM). During the next phase, the *post-immediate memory task* phase, participants performed the delayed RBMT-Appointment and filled out some psychological questionnaires and scales. After that, participants completed the delayed-free and facilitated recall subtests of the FCSRT, as well as the delayed RBMT-route, RBMT-message, and RBMT-belonging. The cardiovascular recording was continuous throughout the session.

Figure 4. A representative timeline of the session



5.*2.3 Questionnaires and Psychological Scales*

Sociodemographic information related to COVID-19 and daily life habits

The questionnaire designed to collect data on socio-demographic variables consisted of three sections: 1) COVID-19 Conditions, which covers symptoms, diagnoses, hospitalization, lingering effects, and the impact on family and friends. The survey also assesses emotional well-being, changes in the living situation, household composition, and pandemic-related stressors. 2) Sociodemographic Characteristics, which allowed us to gather data on various variables of interest, including age, sex, completed education level, alcohol consumption, and cigarette smoking. 3) Lastly, participants responded to a section of questions about their social contact with family and friends, in order to assess their conditions during the study period. This section also included additional questions about aspects related to mobility and social interactions. It began by collecting information about the participant's nationality and then explored experiences of relocation in the past year, requesting details about the type of move and any time zone differences in the case of relocating to another country. Subsequently, the questions delved into aspects of social contact with family and friends, inquiring about the frequency (the average number of hours in a typical week in the past year) and communication methods employed (such as face-to-face, WhatsApp, phone calls). Detailed questions are found in Supplementary Data 1.

Loneliness

Perceived loneliness was assessed with the Spanish adaptation (Vázquez & Jiménez, 1994) of the revised UCLA loneliness scale (R-UCLA) (Russell et al., 1980). This scale contains 20 items rated on a four-point Likert scale ranging from 1 (never) to 4 (often). The total score ranges from 20 (low) to 80 (high). The internal consistency calculated in this study was 0.88.

Perceived stress

Perceived stress was assessed with the Spanish version of the 4-item PSS-4 (Remor, 2006; Vallejo et al., 2018), which was reduced from the original scale (Cohen et al., 1983, 1985). This scale is designed to measure the degree to which life situations are evaluated as stressful in the past month. The response scale is a five-point Likert-type scale (0 =never, 1 =rarely, 2 =sometimes, 3= quite often, and 4= very often). The total score ranges from 0 to 16. Our study showed good internal consistency, with a Cronbach's alpha of 0.85.

Depressive symptoms

Depressive symptoms were measured with the Spanish version (Perdig, 2003) of the Beck Depression Inventory-II (BDI-II) (Beck et al., 1996). This inventory is composed of 21 items that assess cognitive, somatic, and behavioral symptoms of depression experienced in the past two months. The response scale for each item ranges from 0 to 3, with four possible specific answers for each item (e.g., Mood: I do not feel sad; I feel sad most of the time; I am sad all the time; I am so sad and unhappy that I can't stand it). By directly adding up the score on each item, a total global score can be obtained (from 0 to 63), where higher scores indicate a greater degree of depression. For this study, Cronbach's alpha was 0.94.

SMCs

SMCs were measured with the Spanish version (Lozoya-Delgado et al., 2012) of the MFE-30 Questionnaire (Sunderland et al., 1984). This questionnaire contains 30 items that explore SMCs through situations and activities of daily life. Items are rated on a Likert-type scale (0= never or almost never to 4= always or almost always). Higher scores indicate more everyday memory failures, with a maximum score of 120. Our study

showed good internal consistency, obtaining a Cronbach's alpha of 0.94. In addition, we also used an initial question asking whether or not they had memory problems.

Memory

Working Memory

To measure the participants' working memory performance, the Spanish version of the Digit Span from the Wechsler Memory Scale III (Wechsler, 1997) was administrated. For this study, we used both the Digit Span Forward (DS-Forward) and Digit Span Backward (DS-Backward) subtests.

DS-Forward is a subtest used to measure the spatial component of working memory and attentional processes, whereas DS-Backward is used for the WM executive component (Conklin et al., 2000). These subtests require participants to repeat a series of numbers of increasing lengths (up to a maximum of 9 digits on the DS-Forward and a maximum of 8 on the DS-Backward). Participants had to repeat the numbers in the same order (DS-Forward) or the reverse order (DS-Backward) of their presentation. For both subtests, each enclosure length was tested twice. After two errors on the same length in each version, the test ends. The maximum possible score on the DS-Forward is 16, whereas for the DS-Backward, it is 14.

Declarative Memory

The Spanish adaptation (Labos et al., 2008) of the Free and Cued Selective Reminding Test (FCSRT; Grober & Buschke, 1987) was used to measure declarative memory performance. The FCSRT measures episodic memory by controlling attention and cognitive processing. The test starts with an identification phase by asking the person to recognize 16 words that belong to a different semantic category. During this phase, the individual is told to identify the 16 words (the participant can only go on to the next phase after identifying all 16 words). There are three recall trial phases, each preceded by 20 seconds of counting backward to prevent recall from short-term memory. Each recall trial consisted of two parts. First, each subject had up to 2 min to freely recall as many items as possible. Second, aurally presented category cues were provided for items that were not retrieved by free immediate recall. If subjects failed to retrieve the item with the category cue, they were reminded by presenting the cue and the item together. The same recall procedure (freely and cued) is carried out after a 20 min interval during which

subjects are required to perform non-verbal tasks. Following Hidalgo et al. (2016), we calculated one outcome from this test: (i) Retention Rate percentage of the total number of words recalled after a 30 min delay compared to the total number of words recalled on the first three trials (Delayed Recall/Immediate Recall × 100) (DMI).

Prospective Memory

To ecologically assess PM, we used four subtests (belonging, appointment, and route and message) from the Rivermead Behavioral Memory Test (RBMT, Wilson et al., 1985). The Belonging subtest is a remembering task where the examiner asks for a personal belonging that was hidden somewhere at the beginning of the session (range 0-4 points). The Appointment subtest consists of asking about a future appointment when an alarm rings (range 0-2 points). The route subtest involves remembering a route the examiner had previously shown. The message subtest is part of the route subtest, and it requires the participant to take an envelope and put it in the same place where the examiner put it when demonstrating the route subtest. The route and message subtests measure immediate and delayed recall, and we used both components. The score for both immediate and delayed recall on the route subtest is 5 points each; 1 point is awarded for each place covered in the correct order (range 0-10 points). The message subtest is scored separately; 2 points are awarded if the participant picks up the message instantly and 1 point if he/she leaves it in the correct place. The total score for both immediate and delayed recall ranges from 0 to 6 points. For the analyses, we used the total score on the PM Test, which ranges from 0 to 22 points, using the sum of the raw scores on each subtest.

Hair Cortisol

At the end of the session, three strands of hair samples were carefully cut from the posterior vertex region. Given a general growth rate of 1 cm/month (Stalder & Kirschbaum, 2012), these segments are assumed to reflect hair growth during the four months before the respective sampling points. Due to variability in lengths of strands of hair, only strands of hair (1x4 cm segmentation) adjacent to the scalp were analyzed. Hair samples were prepared and analyzed in the laboratory of Prof. Kirschbaum (Department of Psychology, Technische Universität Dresden, Germany). An ultra-performance liquid chromatography–tandem mass spectrometry (UPLC–MS/MS) method was used to examine hair cortisol samples, in line with the protocol by Wang et al. (2019).

Cardiovascular registry

Cardiac activity was measured with the Polar watch model RS800cx (PolarCIC, USA). This device has a chest strap for heartbeat detection and transmission and a watch for data storage. The Polar device measures R-R intervals with a sampling rate of 1000 Hz. The obtained data were subsequently analyzed with Kubios Analysis software (Biomedical Signal Analysis Group, University of Kuopio, Finland). The electrocardiogram was visually analyzed, and artifact correction was performed using the "mean" correction option offered directly by the program. Means were analyzed from the middle of the recorded periods, following the recommendations of the Task Force (1996). Hence, we used a 5-minute interval from each of the three periods (pre-tasks, immediate memory task, and post-immediate memory task).

To assess HRV, we employed a time domain variable, specifically, the RMSSD value. RMSSD is a reliable measure for capturing the short-term components of HRV, and it represents the square root of the mean of the sum of the squared differences between successive RR intervals. In healthy individuals, RMSSD serves as a robust indicator of vagal tone (Kleiger et al., 2005; Thayer and Lane, 2000). Importantly, RMSSD is less affected by respiratory influences, compared to high-frequency parameters (Hill and Siebenbrock, 2009).

5.*2.4 Statistical analyses*

To characterize the sample and assess the differences between the AG and NAG groups (Hypothesis 1) in the sociodemographic variables, psychological/affective characteristics (loneliness, perceived stress, depression, and SMCs), social interaction characteristics, and cortisol, independent Student's *t*-tests and chi-square were used. In cases of unequal variances, we applied *p*-value corrections based on Levene's test. To assess memory performance, we employed a working memory index (WMI), following the approach of Franz et al. (2011). DS Backward scores were adjusted for DS Forward. To calculate this adjusted index, we performed a one-way ANOVA and included ' DS forward' as a covariate. Then, to compare memory performance between groups, one-way ANOVAs were used, with the following memory outcomes as dependent variables: for working memory, WMI; for declarative memory, the retention rate (DMI); and for PM,

the total score (PMT). Effect size was assessed via partial eta-squared values, and the Greenhouse-Geisser correction was applied when the sphericity assumption was not met in the ANOVAs. For multiple comparisons, the False Discovery Rate (FDR) method was used to control for Type I error inflation, and all adjusted *p*-values were reported.

The Kolmogorov-Smirnoff test was used to test the normality of the biological variables. They were not normally distributed, and so they were log-transformed. Because not all the participants provided the hair sample or met the minimum required length, the total sample for this analysis consisted of 19 participants in the AG group (3 men and 16 women) and 12 in the NAG group (3 men and 9 women). In addition, for HRV analysis, the recordings of 1 man and 2 women in the AG group and 1 man in the NAG group had to be excluded due to movement artifacts or insufficient quality of the electrocardiogram signal. Therefore, the total sample for HRV was composed of 20 participants in the AG group (6 men and 14 women) and 21 in the NAG group (7 men and 14 women).

To measure cardiovascular activity during the memory task, a repeated-measures ANOVA was performed with Group (AG vs. NAG) as a between-subjects factor and Period (pre-tasks, immediate and post-immediate memory tasks) as an intra-individual factor. Post-hoc planned comparisons were performed using Bonferroni adjustments for the *p*-values.

To explore possible relationships between memory performance and hair cortisol and cardiovascular measures (Hypothesis 2), Pearson's correlations were calculated using the previously described memory outcomes, hair cortisol levels, and HRV-RMSSD during the memory task.

Finally, we conducted moderation analyses (Hypothesis 3) with cortisol and HRV as the independent variables separately, memory outcomes as the dependent variables, and loneliness as the moderating variable. For this analysis, we utilized PROCESS 3.4 in SPSS (Model 1). PROCESS employs bootstrapped bias-corrected 95% confidence intervals with 5,000 bootstrapped samples to determine the significance of the interaction effect in the moderation analysis. When the confidence interval for the interaction effect in the moderation analysis did not include zero, it was interpreted as indicating a significant interaction or indirect effect, following Hayes (2017).

The level of significance for all analyses was set at 0.05. All statistical analyses were performed with the statistical program SPSS version 21.0.

5.3 Results

5.3.1 Group differences

Sociodemographic and Psychological/affective characteristics

The sociodemographic and psychological/affective characteristics of both groups (described using means and standard deviations) are shown in Table 7. Student's *t*-tests showed no significant differences in age or years of education (all $p > 0.629$). Nor were there significant differences related to having contracted COVID-19, having a family member who died from COVID-19, or any other COVID-19-related questions on the questionnaire (see Supplementary Data 2) (all $p > 0.097$). Moreover, we found no significant differences in perceived stress and depression (both $p > 0.373$).

Although the AG group scored higher on loneliness ($p=0.018$), the two groups did not exhibit significant differences in the average number of hours in a typical week spent communicating or contacting family (t (43) $=-1.259$, $p=0.387$) and friends (t (43) $= -0.178$, $p= 0.910$), and they engaged in the same type of contact with family ($\chi 2 = 5.881$, $p=0.638$) and friends ($\chi 2 = 3.360$, $p= 0.245$) at the telematic level (WhatsApp, Zoom, or similar). However, significant differences were found in face-to-face contact with family ($\chi 2=8.696$, $p=0.018$) and friends ($\chi 2 = 11.761$, $p = 0.018$), with more participants in the NAG group reporting face-to-face contact than in the AG group (see Table 8).

Furthermore, we found a marginal difference in SMCs ($p=0.056$), given that AG reported more memory complaints. There were also significant differences on the yes/no question about having memory problems ($\chi 2 = 10.672$, $p = 0.002$), with a higher percentage of people in the AG group reporting memory problems (60.9%), compared to 13.6% of the NAG.

Table 7. Sample characteristics. Mean values (M), Standard Deviations (SD), and Student's t-test values for study 3

	AG (n=23)		**NAG (n=22)**		***t* (gl)**	***p***	***Adjusted p***
	M	SD	M	SD			
Sociodemographic characteristics							
Age (years)	25.696	2.721	25.500	3.529	0.209(43)	0.836	0.941
Years been in the education system	17.220	1.929	16.59	3.389	0.757(33.008)	0.454	0.584
Alcohol consumption (Nº of drinks per week)	1.914	2.466	1.909	1.716	0.006(43)	0.995	0.995
Cigarette consumption (Nº of cigarettes per week)	0.174	0.491	0.727	2.251	-1.128(22.911)	0.271	0.375
Psychological/affective characteristics							
Loneliness	38.087	9.657	30.636	5.169	3.246 (33.960)	0.003*	**0.018***
Perceives stress	6.565	3.883	5.773	3.436	0.724(43)	0.473	0.568
Depression	13.478	10.962	9.818	8.958	1.223(43)	0.228	0.342
SMCs test score**s**	29.522	17.170	20.182	14.575	1.963(43)	0.056	0.126

Abbreviations: AG, Along Group; NAG, Not Along Group; SMCs, SMCs. *$p < 0.05$.

Table 8. Sample Social interaction characteristics (weekly).

Social interaction characteristics	**AG (n=23)**	**NAG (n=22)**	**p**	***Adjusted p***
Hours of communication with family	5.00 (4.112	7.864 (10.073)	0.215	0.352
Hours of communication with friends	6.348 (4.579)	6.636 (6.184)	0.859	0.910
Type of telematic contact maintained with family				
None	0(0%)	4(18.2%)		
Zoom or similar	0(0%)	1(4.5%)	0.053	0.136
WhatsApp	23(100%)	17(77.3%)		
Type of telematic contact maintained with friends				
None	0(0%)	3(13.6%)		
Zoom or similar	0(0%)	0(0%)	0.109	0.218
WhatsApp	23(100%)	19(86.4%)		
Face-To-Face Family Interaction				
Yes	1(4.3%)	9(40.9%)	0.004	**0.018***
No	22(95.7%)	13(59.1%)		
Face-To-Face Friends Interaction				
Yes	0(0%)	9(40.9%)	0.001	**0.018***
No	23(100%)	13(59.1%)		

Abbreviations: AG, Along Group; NAG, Not Along Group. *$p < 0.05$. Weekly: The average number of contact hours in a typical week in the past year

5.3.2 Biomarkers

We found marginal differences in the hair cortisol concentrations ($t(29)=2.426$, $p=0.079$), with the AG group showing higher levels than the NAG group.

Analyses of the HRV response pattern during the memory tasks showed that, regarding the RMSSD, the Period factor reached statistical significance ($F[2,78]=8.248$, $p<0.001$, $n^2_p=0.174$), reflecting lower values during the immediate memory tasks than during the post-immediate memory task period ($p<0.001$). No significant differences were found between pre-task vs post-immediate memory tasks ($p=0.306$) and immediate memory tasks ($p=0.076$). In addition, no significant effects of the Group factor ($F[1,39]= 2,326$, $p=0.135$, $n^2_p=0.056$) or the Group x Period interaction ($F[2,78]= 1.402$, $p=0.252$, $n^2_p =0.035$) were found Figure 5.

Figure 5. HRV during pre-task, Immediate memory task, and post-immediate memory task by group.

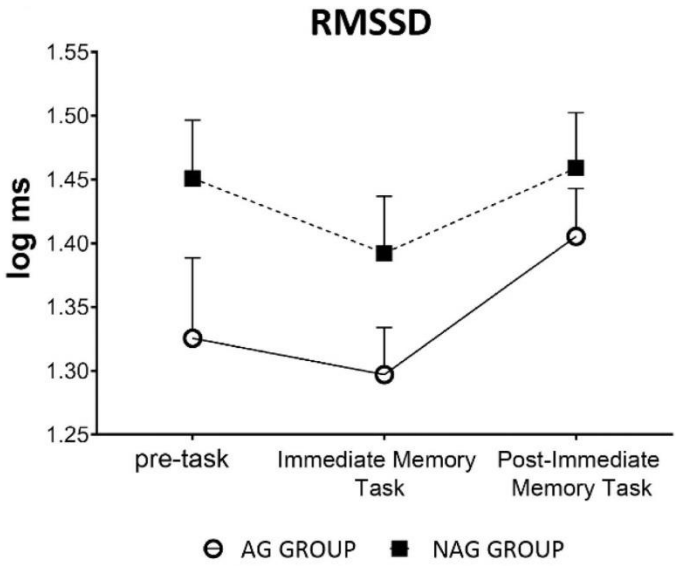


Figure 5. Values are shown as the means + standard error bars. The Y axis represents the log 10 transformed values of HRV and the X axis the 3 periods analyzed**.**

5.3.3 Memory performance

One-way ANOVAs revealed significant effects of the Group on WM (F(1,43) = 4.435, $p< 0.009$, $n^2_p = 0.286$). Thus, the AG group obtained lower scores than the NAG. Furthermore, a marginal difference was found in PM (F(1,43) = 20.826, $p= 0.072$, $n^2_p = 0.112$). No significant differences were found in DM ($p=0.262$) (see Table 9).

Table 9. Mean values and standard deviations (SD) of memory outcomes and statistics of group comparisons with one-way ANOVAs.

	AG N=23		**NAG N=22**		***F* [1,43]**	***p***	***Adjusted p***	**n^2_p**
	Mean	S.D.	Mean	S.D.				
Working Memory	4.435	1.674	7.091	1.377	16.805	0.001	**0.009***	0.286
Declarative Memory	262.032	39.185	245.212	33.857	2.364	0.131	0.236	0.052
Prospective Memory	20.826	1.267	21.636	1.049	5.436	0.024*	0.072	0.112

Abbreviations: AG, Along Group; NAG, Not Along Group. *$p < 0.05$.

5.3.4 Relationship between memory performance and biomarkers

We performed Pearson's correlations between memory performance outcomes and biomarkers, but no significant relationships were found (all p>0.340).

Moderation Analyses

Results of the moderation analyses showed a significant interaction effect of loneliness in the relationship between hair cortisol levels and PM (B = -0.423, p = 0.0004). Hair cortisol concentrations were negatively related to PM when participants scored high (p = 0.0003) and moderate (p = 0.0182) on loneliness. However, the relationship between cortisol and PM was marginally positive in those participants who scored lower on loneliness (p = 0.0513). No interaction effect of loneliness was found in the relationships between cortisol and WM (p = 0.832) or DM (p = 0.536) (Table 10).

Additionally, loneliness did not moderate the relationship between HRV and any type of memory (all p > 0.179) (Table 11).

Table 10. Adjusted moderation analyses with cortisol as a predictor and memory as a dependent variable in different values of loneliness.

Dependent variable: WM						
ΔR^2 interaction = 0.001 F=0.0461, df (1,2)=1, 26 p=0.832						
LLCI= -0.342 ULCI= 0.421						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	-0.731	1.343	-0.544	0.591	-3.492	2.031
34.000	-0.452	1.071	-0.421	0.677	-2.654	1.751
43.760	-0.626	2.423	-0.026	0.910	-5.043	4.917
Dependent variable: DM						
ΔR^2 interaction = 0.014 F=0.3921, df(1,2)=1, 27 p=0.536						
LLCI= -6.225 ULCI= 11.693						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	-5.665	31.247	0.181	0.858	-58.450	69.780
34.000	24.803	23.212	1.069	0.295	-22.8259	72.432
43.760	51.487	55.199	0.933	0.360	-61.776	164.749
Dependent variable: PM						

ΔR^2 interaction = 0.312 *F*= 15.953, df (1,2) = 1, 27 *p*= 0.0004						
LLCI= 0.065 ULCI= 0.338						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	1,547	0.759	2.039	0.051	-.0.009	3.104
34.000	**-1.417**	**0.564**	**-2,514**	**0.0182**	**-2.5733**	**-0.2603**
43.760	**-5,549**	**1,340**	**-4,1405**	**0.0003**	**-8,299**	**-2,799**

Table 11. Adjusted moderation analyses with HRV as a predictor and memory as a dependent variable in different values of loneliness.

Dependent variable: WM						
ΔR^2 interaction = 0.032 *F*=1.888, df (1,2)= 1, 36 *p*= 0.179 **LLCI= -0.114 ULCI= 0.594**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	-0.685	2.111	-0.325	0.747	-4.967	3.596
34.000	1.232	1.452	0.849	0.402	-1.712	4.177
41.280	2.978	1.832	-1.625	0.113	-0.739	6.694
Dependent variable: DM						
ΔR^2 interaction = 0.006 F=0.248, df (1,2)= 1,37 *p*= 0.622 **LLCI= -9.457 ULCI= 5.728**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	64.474	46.056	1.400	0.170	-28.847	157.794
34.000	49.557	32.181	1.540	0.132	-15.650	114.762
41.280	35.982	40.119	0.897	0.376	-45.308	117.272
Dependent variable: PM						
ΔR^2 interaction = 0.007 *F*=0.323, df (1,2) = 1, 37 *p* =0.573 **LLCI= -0.296 ULCI= 0.166**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	1.356	1.401	0.968	0.339	-1.482	4.195
34.000	0.839	0.979	0.857	0.397	-1.145	2.822
41.280	0.367	1.220	0.301	0.765	-2.106	2.839

5.4 Discussion

The present study aimed to explore how social contact restrictions in the post-pandemic context could affect people at psychological/affective, biological, and cognitive levels, with a focus on the role of perceived loneliness and the living situation.

Overall, our results showed that individuals who had changed their nuclear family and were living alone outside their home country for the previous eight months had greater feelings of loneliness, marginally higher hair cortisol levels, and worse working memory and PM performance, compared to individuals who maintained their nuclear family and did not live alone during the previous eight months. Interestingly, although there were no significant differences in telematic communication time with family and friends, there were evident differences in face-to-face communication. Our results suggest that living alone in another country without the usual face-to-face contact with family and friends leads to higher perceived loneliness and worse cognitive performance.

These results replicate what was found by Ingram et al. (2021), who showed that performance on cognitive tasks (including memory tasks) was determined by the levels of social isolation of the individuals and improved significantly as the COVID-19 pandemic restrictions were lifted (greater mobility and more social contact). Our results are also consistent with pre-pandemic studies showing that loneliness and social isolation were associated with lower working memory, immediate and delayed recall of verbal fluency, and PM performance, particularly in middle- and older-aged adults (Haslam et al., 2014; Lara et al., 2019). Similarly, the results are consistent with research conducted in the older population that concluded that better cognitive functioning was associated with more social support (Evans et al., 2019; Kelly et al., 2017; Kuiper et al., 2016), whereas social isolation showed an inverse pattern (Cacioppo & Hawkley, 2009; Montoliu et al., 2019).

To the best of our knowledge, no previous studies have explored the relevance of social support in memory performance specifically in young adults during the pandemic. However, some studies have shown that the situation during the COVID-19 pandemic led to a significant increase in perceived stress, anxiety, and depression that has been negatively linked to cognitive performance (Basheti et al., 2021; Fiorenzato et al., 2021; Maia & Dias, 2020). Indeed, the scores for perceived stress and depression observed in our study, in both the AG and the NAG, align closely with the during-confinement scores

documented by Baliyan et al. (2021), who reported significant differences between the levels prior to the pandemic and those registered during the pandemic period. There was an increase in perceived stress, anxiety, and depression that was largely attributed to the uncertainty brought about by the restrictions, preventive measures (e.g., quarantines, limited mobility), and, therefore, sudden changes in daily activities, including studies and remote work.

These results align with the social buffering hypothesis (Cohen & McKay, 1984), which proposes that social relationships have a positive impact on both physical and mental health. Specifically, our findings are in line with a similar study by Hopf et al. (2022) during the COVID-19 lockdown, demonstrating that living with others becomes an increasingly important factor in mitigating loneliness. In our study, despite finding no significant differences in any of these perceived psychological factors, significant differences in loneliness and marginal differences in hair cortisol levels were reported. Furthermore, the absence of significant correlations between cortisol and memory outcomes, combined with the significant interaction effect between loneliness and PM in the moderation analysis, suggests that, although cortisol levels alone may not be indicative of memory performance, the interaction with loneliness is a crucial factor that highlights the complex relationship between psychological and physiological factors in memory function, leading us to suggest that both factors are relevant in memory performance.

The stronger negative relationship between cortisol and PM in individuals who report high levels of loneliness indicates a vulnerability in this subgroup. This finding is well-aligned with previous research indicating that chronic stress, reflected by elevated hair cortisol levels, may impact cognitive function, especially during major stressful events (e.g., Dajani et al., 2018; Gao et al., 2014). Therefore, loneliness might intensify the cognitive effects of stress, possibly due to an increased vulnerability to the harmful effects of stress hormones, as evidenced by the functioning of the HPA axis (Cacioppo et al., 2002; Montoliu, et al., 2019).

Moreover, the weaker but still negative relationship in those with moderate loneliness may indicate a dose-response relationship, where the degree of loneliness corresponds to the strength of the cortisol-PM link. Meanwhile, the marginal significance in the low loneliness group could indicate a resilience to these effects.

The absence of moderating effects of loneliness in the relationships between cortisol and working memory and declarative memory suggests that the observed interaction is specific to PM. It may be related to the unique cognitive processes involved in PM, which is more future-oriented and dependent on self-initiated actions and motivation than the other memory types investigated. In addition, the disruption of established routines during the pandemic led to the emergence of new behavior patterns, potentially affecting PM more profoundly. This specificity underscores the need for further research to explore the underlying mechanisms responsible for this phenomenon, primarily to comprehend the effects of chronic stress on this type of memory, given that the findings in the literature are inconsistent (Chen et al., 2019; Nater et al., 2006; Stewart & Mcfarland, 2020)

Regarding the two groups' cardiovascular responses, it is relevant to note that the physiological status of the participants was not experimentally manipulated with any psychosocial stressor. However, one of the essential components of psychosocial stress is evaluation, and so we consider that the neuropsychological assessment involved a high cognitive demand that required parasympathetic control. Consequently, we hypothesized that participants in the AG group would exhibit lower HRV. However, we did not find statistically significant differences between the two groups. Nevertheless, during specific periods, our results support the notion that reduced parasympathetic activity may function as a noteworthy biomarker of cognitive performance. This is particularly evident in the resting values, indicating an overall pattern of increased parasympathetic activity following a cognitive challenge (Roddick & Chen, 2021; Shah et al., 2021).

However, RMSSD showed no significant negative correlations with memory outcomes or a significant interaction in the moderation analysis. The lack of significant relationships is contrary to previous studies (Hansen et al., 2003) in which these measures were associated with better performance on working memory and other cognitive tasks, showing that strong trait-level prefrontal regulatory control buffers individuals' physiological state level. Nevertheless, the correlations between HRV and memory tasks are small and unstable across all studies (Allan et al., 2005; Britton et al., 2008; Holzman & Bridgett, 2017; Shah et al., 2011).

This study has some limitations. Although it is known that mental workload may be associated with cardiovascular disease, particularly on cognitive tasks requiring

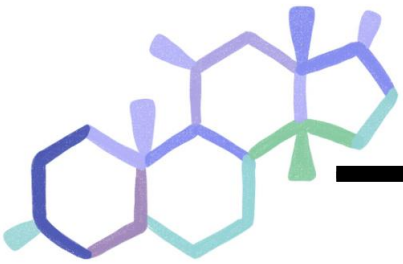
significant effort (Luque-Casado et al., 2015), our assessment was limited to memory performance. Therefore, it would have been interesting to evaluate other functions as well. Additionally, it is important to note that the non-random assignment of our participants in our study, due to ethical and practical considerations, limits our ability to draw causal conclusions. Furthermore, considering the NAG group's position within a spectrum of healthy social contact and interactions in stable situations, future research should take into account perceived social support and the quality of interactions as important factors. Moreover, we did not conduct a power analysis prior to the study, and the sample size could be limiting our statistical power. Therefore, future research could benefit from a larger sample.

In sum, the current study provides novel evidence showing that the lack of close, nearby personal contact, which could serve as instrumental support during the restrictive living conditions associated with the COVID-19 pandemic, was related to worse memory performance (working memory, declarative memory, and PM), and that loneliness played a crucial role in the relationship between cortisol and memory performance. Our findings allow us to understand the intricate relationship between loneliness, cortisol levels, and PM, while highlighting the paramount importance of direct, face-to-face social interactions in memory research. Although cortisol levels alone did not directly correlate with memory outcomes, our study highlights the role of loneliness in the relationship between hair cortisol levels and PM, emphasizing the need to consider both psychological and physiological factors. This research contributes to our understanding of the multifaceted dynamics among these factors, and it underscores the significance of examining individual differences when developing future research and interventions.

This result may contribute to our understanding of the detrimental consequences of social isolation at the cognitive and physiological levels. Additionally, further investigation into the underlying mechanisms that explain the observed interactions is warranted, especially in the context of pandemic-related stressors. Longitudinal studies could help to elucidate the directionality of these relationships and provide insights into potential interventions to mitigate the negative effects of loneliness on memory during challenging times, especially in young people.

CHAPTER VI

STUDY 4



Physiological Regulation and Cognitive Function During International Academic Mobility

The main results of this study have been submitted:

Batallas, D., Rivas-Diaz, P., Morejón, P., Peñaherrera, Peiró, T., A., Hidalgo, V., Salvador, A. (under rewiew). Adapting to Study Abroad: Perceived Stress, Physiological Regulation, and Memory in International Students.

6.1 Introduction

The internationalization of higher education has expanded rapidly worldwide (Iannelli & Huang, 2014), and universities increasingly emphasize global engagement as a core institutional priority (Robson et al., 2018; Wang, 2018). Consequently, international student mobility has grown substantially, with an increasing number of individuals pursuing academic programs abroad (Ahrari et al., 2019). Although studying abroad offers important academic, cultural, and personal benefits, it also exposes students to a broad range of psychological and sociocultural challenges that may hinder successful adaptation. Upon arrival, international students must cope with unfamiliar academic expectations, new cultural norms, language barriers, changes in living arrangements, and separation from established social environments. These demands frequently result in heightened perceived stress, homesickness, culture shock, discrimination, social isolation, and loneliness (Akanwa, 2015; Hasnain & Hajek, 2022; Liu et al., 2016), reflecting the substantial psychological load associated with academic mobility (Zheng et al., 2023).

Importantly, adjustment during international mobility is not a static process but unfolds dynamically over time. Longitudinal research on sojourner adaptation indicates that stress and psychological well-being often fluctuate across the stay abroad, with an initial period of elevated stress followed by gradual improvement as students become more familiar with the host environment (Demes & Geeraert, 2015; Ward et al., 1998;). More recent studies in higher education contexts show that acculturative stress and homesickness tend to decrease across the first academic semester or year, whereas satisfaction and sociocultural competence increase (English et al., 2020; Zhao, 2024). Nevertheless, adaptation trajectories vary substantially across individuals, with some students experiencing persistent or delayed difficulties (Brown & Holloway, 2008; Dailey-Strand, 2021; Hirai et al., 2015).

Stress plays a central role in adaptation and has well documented effects on both physiological regulation and cognitive functioning (McEwen, 2007). One of the primary biological systems involved in stress regulation is the HPA axis. Salivary cortisol is a widely used, non-invasive biomarker that responds to cognitive demands, novelty, social evaluation, and chronic psychosocial stress (Clow & Smyth, 2020; Hellhammer et al., 2009). Cortisol responses during cognitively demanding laboratory sessions have been

shown to reflect individual differences in stress-related symptomatology and cognitive–emotional processing (Oei et al., 2006). Importantly, these physiological stress responses are closely linked to cognitive processes and the neural systems that support learning and memory.

Beyond its general role in physiological regulation, stress has been shown to modulate cognitive functioning through glucocorticoid-mediated effects on neural systems underlying learning and memory. Recent empirical and systematic evidence indicates that elevated stress levels, along with conditions characterized by environmental instability and reduced social interaction, are associated with measurable declines in several memory domains such as WM, DM, and PM (Ingram et al., 202; Llana et al., 2024; Pisano et al., 2021).

These memory systems are critical for academic success: WM supports the temporary maintenance and manipulation of information (Ashcraft & Kirk, 2001; Cowan et al., 2005), DM underlies learning and long-term retention (Riedel & Blokland, 2015), and PM enables individuals to remember and execute intended actions in the future (McDaniel & Einstein, 2000; Schnitzspahn et al., 2013; Talbot & Kerns, 2014). Previously, we have found that academic mobility has been associated with poorer PM performance and elevated stress biomarkers, highlighting an additional pathway through which stress-related experiences may impair cognitive functioning in students abroad during the post Covid period (Batallas et al., 2024).

In addition to the HPA axis, the ANS represents a second physiological system relevant to stress adaptation. Heartbeat dynamics, including standard indices of HRV, provide quantitative metrics of sympathetic and parasympathetic outflow and are widely used to assess autonomic nervous system regulation (Valenza et al., 2018). Lower HRV has been associated with poorer emotion regulation, heightened stress sensitivity, and reduced cognitive flexibility (Forte et al., 2019; Thayer & Lane, 2000). According to the Neurovisceral Integration Model, reduced HRV reflects diminished prefrontal regulatory control, which may adversely affect executive functioning and memory processes (Hansen et al., 2003; Thayer et al., 2012). Recent evidence further suggests that task-related fluctuations in vagally mediated HRV, particularly changes in the RMSSD, are associated with enhanced attentional control and greater cognitive flexibility during demanding tasks (Forte & Casagrande; 2025; Schaich et al., 2020).

Despite growing evidence linking perceived stress, physiological regulation, and cognitive functioning, relatively few studies have examined these components jointly within the context of international academic mobility. Existing research frequently focuses on psychological adjustment, physiological stress markers, or cognitive performance in isolation, limiting our understanding of how these domains interact during adaptation abroad. To address these gaps, the present study investigates perceived stress, cortisol levels, HRV reactivity, and memory performance in international students assessed at different stages of their stay abroad. Specifically, we compared students evaluated shortly after arrival with those assessed at the end of a four-month academic stay to examine phase-related differences in stress, physiological regulation, and memory functioning. In addition, we explored whether integrated cortisol release across the assessment and HRV reactivity predict performance across multiple memory domains.

Based on longitudinal models of cross-cultural adaptation, we hypothesised that students assessed in the later adaptation phase would report lower levels of perceived stress than those evaluated shortly after arrival (Demes & Geeraert, 2015; English et al., 2020; Ward et al., 1998; Zhao, 2024). Consistent with psychobiological models linking chronic stress exposure to dysregulation of the HPA axis and autonomic functioning (Forte & Casagrande, 2025; Hellhammer et al., 2009;), we further expected reduced physiological stress activation at the later phase, reflected in lower salivary cortisol levels and more adaptive autonomic regulation indexed by HRV. Finally, drawing on evidence that stress-related cortisol secretion and autonomic regulation influence memory functioning, we expected associations between physiological stress markers (Cortisol and HRV reactivity) and performance across WM and DM memory domains. In line with prior findings, we specifically hypothesised that greater integrated cortisol release would be associated with poorer working memory performance (Oei et al., 2006), whereas higher vagally mediated HRV would be associated with better memory performance more broadly (Forte & Casagrande, 2025). However, because there is currently insufficient evidence directly linking integrated cortisol release to PM performance in young adults, we treat expectations for this specific association as exploratory rather than confirmatory.

6.2 Materials and Methods

6.2.1 Participants

The study sample comprised 74 undergraduate students participating in an international academic exchange program. Participants were recruited from the same exchange scheme and therefore shared comparable academic backgrounds and sociodemographic characteristics (e.g., home university, field and year of study, city of origin, and socioeconomic background). The study employed a cross-sectional design with two independent groups assessed at different stages of the exchange period. One group consisted of students evaluated within the first month of arrival at the host institution (Initial Adaptation Phase, IAP; n = 33), whereas the second group included students assessed at the end of the four-month academic stay (Final Adaptation Phase, FAP; n = 41). All participants completed identical assessment procedures.

Participants' ages ranged from 18 to 27 years. The IAP group had a mean age of 19.79 years (SD = 1.63), whereas the FAP group had a mean age of 19.41 years (SD = 2.15). The distribution of sex across groups was comparable (IAP: 24 women and 9 men; FAP: 29 women and 12 men), with no significant between-group differences observed ($\chi^2 = 0.04$, $p = .85$). Similarly, housing arrangements did not differ significantly between groups (IAP: 21 students in university residences and 12 in shared apartments; FAP: 22 in residences and 19 in shared apartments; $\chi^2 = 0.75$, $p = .39$).

Recruitment was carried out through classroom visits and announcements within the host university in Spain. All students received detailed information about the objectives of the project, the nature of the tasks to be administered (cognitive tests, psychophysiological measures, and self-report questionnaires), and the approximate duration of the session. Participation was voluntary, and as compensation students received individualized feedback about their results. Exclusion criteria applied to both groups included: cardiovascular or neuroendocrine disorders, a history of psychiatric or neurological conditions, smoking more than 10 cigarettes per day, or excessive alcohol or drug use (more than 20 g/day for women or 30 g/day for men). Students who reported meeting any exclusion criterion during a preliminary screening interview were not invited to participate.

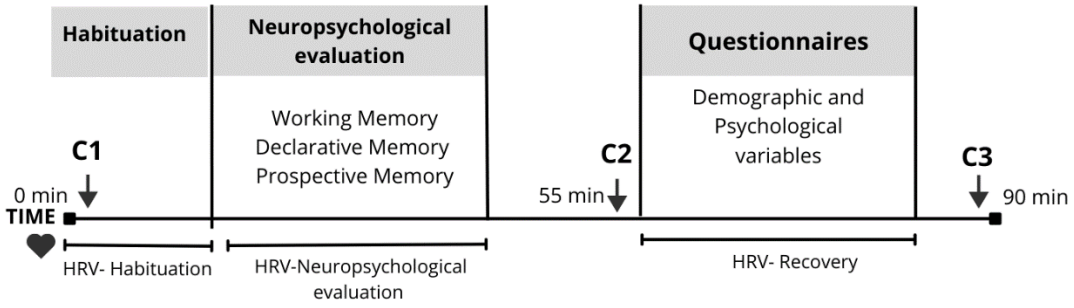
All participants provided written informed consent before inclusion in the study. The study protocols were approved by University of Valencia, Spain, Code 1034878 and adhered to the ethical guidelines of the Helsinki Declaration.

6.2.2 Procedure

Each participant completed a single assessment session lasting, approximately, 90 minutes. Sessions for both groups were conducted under same laboratory conditions at the Laboratory of Social Cognitive Neuroscience in Valencia, Spain. Prior to participation, students were instructed to maintain a regular sleep schedule, avoid alcohol and strenuous exercise the day before, and abstain from eating, smoking, or consuming caffeinated beverages for at least 2 hr before the session. Upon arrival, compliance with these recommendations was verified, and the procedure was explained in detail.

The research protocol consisted of three sequential phases and lasted approximately 90 minutes (Figure 6). Upon arrival, participants completed a 10-minute habituation period to allow physiological adaptation to the laboratory environment. During this phase, the HRV chest strap was placed, and participants were instructed to remain seated and breathe normally. The first saliva sample for cortisol assessment (C1) was also collected at this time (minute 0), providing a baseline endocrine measure. Immediately after habituation, participants began the neuropsychological evaluation phase, which lasted approximately 30 minutes. Following the completion of the cognitive tasks, a second saliva sample (C2) was collected exactly 15 minutes later, corresponding to the expected peak of the cortisol response to cognitive load. Participants then proceeded to a third phase, during which they completed a battery of demographic and psychological questionnaires. At the conclusion of this phase, a third saliva sample (C3) was collected. Cardiovascular activity was continuously monitored throughout all phases, allowing the derivation of HRV indices corresponding to habituation, neuropsychological evaluation, and post-task recovery.

Figure 6. A representative timeline of the session.



6.2.3 Measurements

Psychological questionnaries

Perceived Stress Scale: For this research, we used the validated Spanish version (Remor, 2006) of the PSS (Cohen et al., 1983). Participants respond to the PSS-4 on a 5-point Likert scale from 0 (Never) to 4 (Very often). Items 6 and 7 were reverse-scored. The total score ranges from 0 to 16. Higher scores indicate higher perceived psychological stress during the past month. Cronbach's α for the scale was 0.732.

Loneliness: Perceived loneliness was assessed with the Spanish adaptation (Vázquez & Ruls, 1994) of the R-UCLA (Russell at al., 1980). This scale contains 20 items rated on a four-point Likert scale ranging from 1 (never) to 4 (often). The total score ranges from 20 (low) to 80 (high). The internal consistency calculated in this study was 0.896.

Memory Tasks

Working Memory: To measure the participants' working memory performance, the Spanish version of the Digit Span from the Wechsler Memory Scale III (Wechsler, 1997) was administrated. The Digit Span task is a widely used measure of verbal working memory and attentional capacity. It consists of two conditions: DS-Forward, which primarily assesses attention span and short-term memory, and DS-Backward, which places greater demands on working memory by requiring the manipulation and reordering of information. In both conditions, participants are required to orally recall sequences of digits presented by the examiner, either in the same order (forward) or in reverse order

(backward), with sequence length increasing progressively until recall is no longer accurate. Performance is indexed by the total number of correctly recalled sequences, with higher scores reflecting better working memory functioning.

Declarive Memory: The Spanish adaptation (Labos et al., 2008) of the Free and Cued Selective Reminding Test (FCSRT;Grober & Buschke, 1987) was used. The FCSRT measures episodic memory by controlling attention and cognitive processing. We calculated two outcomes from this test: (i) Immediate Recall: total number of correct words recalled on the three trials (ii) Delayed Recall: total number of correct words recalled after a 30 min delay.

Prospective Memory: Participants completed the short-term items of the Royal Prince Alfred Prospective Memory Test (RPA-ProMem; Radford et al., 2011), a semi-naturalistic measure of PM with evidence of reliability and validity (Blondelle et al., 2020). The test evaluates two types of tasks: time-based (remembering to act at a specific time) and event-based (remembering to act when a particular event occurs). Consistent with RPA-ProMem scoring procedures, event-based and time-based PM performance were calculated separately by summing the relevant short- and long-term items (possible range for each subscale from 0 to 6), with higher scores indicating better PM performance. In this study, analyses were conducted using these two subscale scores (event-based PM and time-based PM) as distinct outcome measures.

Salivary cortisol

Saliva samples were collected using Salivette® devices (Sarstedt, Nümbrecht, Germany). Participants placed a cotton swab in their mouth for approximately 2 minutes, gently moving it without chewing to ensure saliva was collected from all major salivary glands. Each participant provided three saliva samples during the assessment session: a baseline sample obtained upon arrival to the laboratory (C1), a second sample collected 15 minutes after completing a series of cognitive tasks (C2), and a final sample taken at the end of the 90-minute session (C3).

After collection, samples were initially stored refrigerated for several days until processing. They were then centrifuged at 4,000 rpm for 15 minutes to obtain a clear supernatant, which was transferred to microtubes and stored at −80 °C until subsequent analysis. Cortisol concentrations were determined using a commercially available enzyme-linked immunosorbent assay (ELISA) for salivary cortisol (Salimetrics,

Newmarket, UK). The assay sensitivity was 0.007 μg/dL, and intra- and inter-assay coefficients of variation were below 10%. To minimize analytical variability, all samples from each participant were assayed within the same batch and run in duplicate.

Heart Rate Varibility

Electrocardiography (ECG) was recorded using the VU-AMS device (Vrije Universiteit Ambulatory Monitoring System; de Geus et al., 1995), a validated ambulatory psychophysiological monitoring system. Participants were seated comfortably during the entire experimental session. Disposable Ag/AgCl electrodes were placed according to the standard lead-II configuration recommended by the manufacturer: one below the right clavicle, one below the left clavicle (ground), and one on the left side of the lower ribs.

The ECG signal was continuously registered throughout the protocol. R–R intervals were detected automatically by the VU-AMS system, and built-in algorithms were used to correct artifacts and ectopic beats. From the interbeat interval series, HRV was computed as the RMSSD, a commonly used time-domain measure of short-term HRV that primarily reflects high-frequency variability associated with respiratory sinus arrhythmia and parasympathetic modulation (Quigley et al., 2024).

Recordings were segmented into three periods: (a) habituation phase, (b) neuropsychological evaluation, and (c) recovery phase. For each block, HRV values were extracted from the central 5 minutes to ensure stable estimates and to minimize transitional influences at the beginning and end of each period. HRV reactivity was calculated as the difference between recovery HRV and habituation HRV, such that higher values reflected increases in vagal activity from initial adaptation to later rest, whereas lower values indicated reduced autonomic recovery.

Due to missing data and excessive artifacts in some recordings, the final HRV sample was reduced. Specifically, usable HRV data were available for 28 (19 women and 9 men) participants in the IAP group and 31 (20 women and 11 men) participants in the FAP group.

All preprocessing and HRV calculations were conducted with the VU-AMS analysis software package, which provides standardized scoring and artifact correction procedures developed by the Vrije Universiteit research group.

6.2.4 Statistical analysis

To address differences between IAP and FAP groups, independent Student's *t*-tests were conducted for perceived stress and loneliness. When Levene's test indicated violations of homogeneity of variance, corrected *p*-values were reported. Memory performance was compared across WM (DS Forward and Backward), DM (Immediate and Delayed Recall), and PM (time-based and event-based subscales).

Regarding the contribution of physiological markers to cognitive performance, the normality of cortisol concentrations was examined using the Kolmogorov–Smirnov test, and non-normally distributed values were log-transformed. Cortisol and HRV dynamics across the session were analyzed using repeated-measures ANOVAs with Group (IAP vs FAP) as a between-subjects factor and Time (for cortisol: C1, C2 and C3; and for HRV: habituation, neuropsychological evaluation and recovery) as an intra-individual factor. *Post-hoc* planned comparisons were performed using Bonferroni adjustments for the *p*-values. Total cortisol output across the experimental session was quantified using the AUCg described by Pruessner et al. (2003), providing an index of overall hormonal secretion. These values were subsequently log-transformed for analysis. Multiple regression analyses were then performed to determine whether cortisol release and HRV reactivity predicted performance in each cognitive domain while controlling for group.

Across all analyses, statistical significance was set at $p < .05$ (two-tailed). All computations were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

6.3 Results

6.3.1 Group Differences in psychological variable and memory performance

Groups differed significantly in perceived stress, with the FAP group reporting lower levels than the IAP group ($t(70) = -2.02$, $p = .024$), but no differences we found in loneliness ($p = .922$), WM ($ps > .18$) and immediate DM recall ($p=0.13$). In contrast, the FAP group demonstrated significantly better performance in delayed DM recall compared with the IAP group ($t(72) = 2.90$, $p = .005$). Regarding PM, only time-based performance differed between groups, with higher scores observed in the FAP group ($t(72) = 2.03$, p

= .046) than in the IAP group. No significant differences were found for event-based or total PM (ps > .15; see Table 12).

Table 12. Group Differences in Memory performance

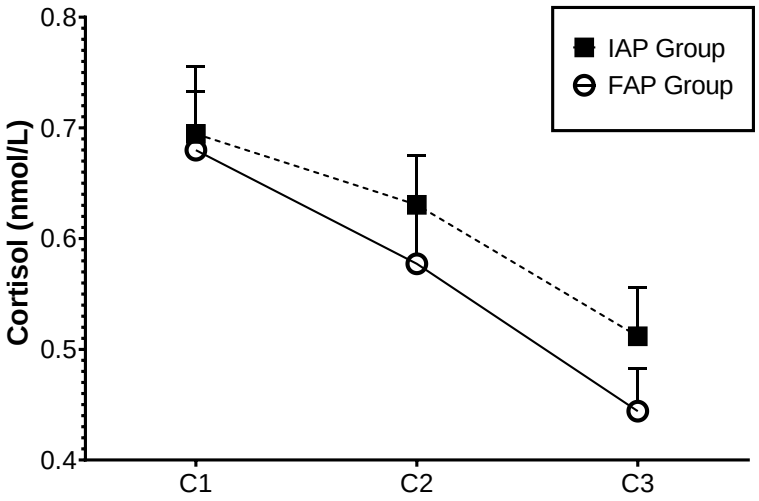
Variable	Initial Adaptation Phase Group (IAP)	Final Adaptation Phase Group (FAP)	*t*(df)	*p*
Digit Span – Forward	8.45 (0.31)	8.98 (0.24)	1.35 (71)	.182
Digit Span – Backward	6.00 (0.31)	5.85 (0.30)	–0.34 (71)	.732
Immediate Recall DM	31.82 (0.70)	33.37 (0.71)	1.53 (72)	.130
Delayed Recall DM	**11.97 (0.28)**	**13.17 (0.29)**	**2.90 (72)**	**.005**
Time-Based PM	**2.61 (0.27)**	**3.27 (0.20)**	**2.03 (72)**	**.046**
Event-Based PM	4.73 (0.28)	4.80 (0.22)	0.22 (72)	.824
Total PM	7.33 (0.43)	8.07 (0.34)	1.37 (72)	.147

Note. Values represent mean (standard error). Significant values (p < .05) appear in bold.

6.3.2 Salivary Cortisol

Cortisol decreased across the assessment session, as indicated by the significant Time effect ($F(2, 136) = 43.69$, $p < .001$, $\eta^2 = .39$). Pairwise comparisons with Bonferroni adjustment confirmed that each sampling point differed significantly: C1 was higher than C2 ($p = .002$) and C3 ($p < .001$), and C2 was higher than C3 ($p < .001$), reflecting a consistent decline over time (see Figure 7). In contrast, the Time × Group interaction was not significant ($F < 1$, $p > .46$). The between-subjects effect of Group was also nonsignificant ($F(1, 68) = 0.52$, $p = .48$), showing that overall cortisol levels did not differ between groups.

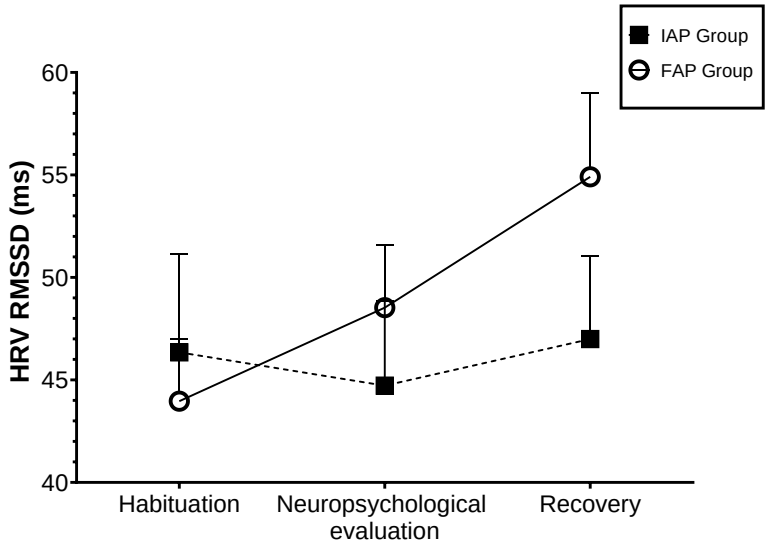
Figure 7. Estimated marginal means of salivary cortisol across the session for the IAP and the FAP groups.



6.3.3 Heart Rate Variability

A significant main effect of Time emerged, F(2,102) = 9.22, $p < .001$, $\eta^2p = .17$, indicating that HRV increased progressively across the session. Pairwise comparisons (Bonferroni-corrected) showed that the HRV was significantly higher during the recovery than both the habituation ($p = .005$) and the neuropsychological evaluation ($p < .001$), while the difference between the habituation and neuropsychological evaluation measurements did not reach significance ($p = .785$). The Time × Group interaction approached but did not reach significance, $F(2, 102) = 2.98$, $p = .055$, indicating only a marginal tendency. Finally, the main effect of Group was not significant, $F(1, 52) = 0.56$, $p = .457$, indicating that the two groups did not differ in their overall mean levels across the task (Figure 8).

Figure 8. HRV across the session for the IAP and the FAP groups



6.3.4 WM *prediction by cortisol and HRV reactivity controlling for Group*

For the DS-Forward, the model including cortisol reached statistical significance, $F(2, 66) = 3.54$, $p = .035$, $R^2 = .097$. Within this model, cortisol emerged as a significant predictor ($\beta = .24$, $p = .046$), suggesting that higher cortisol across the session was associated with better attentional component of WM performance. Group showed a marginal effect ($\beta = .22$, $p = .063$). In contrast, the regression model including HRV reactivity and group did not reach statistical significance, $F(2, 54) = 1.07$, $p = .351$, $R^2 = .038$. Neither HRV reactivity ($\beta = .11$, $p = .437$) nor group ($\beta = .13$, $p = .367$) significantly predicted DS-Forward performance.

For the DS-Backward, the model including cortisol was not significant, $F(2, 66) = 1.48$, $p = .236$, $R^2 = .043$. Neither cortisol ($\beta = .23$, $p = .098$) nor group ($\beta = –.03$, $p = .839$) significantly predicted DS-Backward performance. Similarly, the regression model including HRV reactivity and group did not reach statistical significance, $F(2, 54) = 0.07$, $p = .937$, $R^2 = .002$. Neither group ($\beta = –.05$, $p = .746$) nor HRV reactivity ($\beta = .04$, $p = .801$) predicted DS-Backward scores.

6.3.5 DM *prediction by cortisol and HRV reactivity controlling for Group*

For Immediate Recall, the model including cortisol was not significant, $F(2, 67) = 0.87$, $p = .422$, $R^2 = .025$. Neither cortisol ($\beta = .04$, $p = .751$) nor Group ($\beta = .16$, $p = .196$) contributed significantly to the prediction of Immediate Recall performance.

Similarly, the regression model including HRV reactivity and Group did not reach statistical significance, $F(2, 55) = 1.64$, $p = .204$, $R^2 = .056$. Neither HRV reactivity ($\beta = .14$, $p = .313$) nor group ($\beta = .15$, $p = .281$) significantly predicted Immediate Recall performance.

For Delayed Recall, the regression model including cortisol and Group was significant, $F(2, 67) = 7.08$, $p = .002$, $R^2 = .174$. Group significantly predicted delayed recall ($\beta = .35$, $p = .003$), confirming that students in the FAP group performed better than those in the IAP group. Additionally, higher cortisol predicted better delayed recall performance ($\beta = .27$, $p = .020$). Moreover, the regression model including HRV reactivity and Group was statistically significant, $F(2, 55) = 6.18$, $p = .004$, $R^2 = .183$. In this model, Group was a significant predictor ($\beta = .39$, $p = .004$). This indicates that FAP group showed higher delayed recall performance compared with IAP group. In contrast, HRV reactivity was not a significant predictor ($\beta = .09$, $p = .485$), showing no association with delayed recall scores.

6.3.6 PM prediction by cortisol and HRV reactivity controlling for Group

For event-based PM, the model including cortisol did not reach statistical significance [$F(2, 67) = 0.05$, $p = .953$, $R^2 = .001$]. However, for HRV the overall model reached statistical significance [$F(2, 51) = 3.31$, $p = .045$, $R^2 = .115$]. HRV reactivity emerged as a significant predictor ($\beta = –.33$, $p = .020$), indicating that greater HRV reactivity was associated with poorer event-based PM performance. Across both models, Group did not contribute significantly and was therefore excluded as a predictor (both $p > .115$).

For time-based PM, the model including cortisol also failed to reach statistical significance [$F(2, 67) = 2.09$, $p = .131$, $R^2 = .059$]. Within this model, cortisol was not a significant predictor of performance ($\beta = –.03$, $p = .817$), whereas Group was significant ($\beta = .24$, $p = .050$). Additionally, the overall model including HRV reactivity did not reach statistical significance [$F(2, 51) = 1.16$, $p = .322$, $R^2 = .043$]. HRV reactivity was not a significant predictor ($\beta = –.17$, $p = .240$), indicating that autonomic reactivity was not associated with time-based PM performance. Across the HRV-based model, however, Group did not contribute significantly ($p = .213$).

6.4. Discussion

The present study examined how perceived stress, physiological regulation, and memory performance are related to international students at different stages of their academic stay abroad. Using a cross-sectional design, we compared students assessed shortly after arrival with those evaluated after approximately four months abroad and investigated the role of integrated cortisol release across the assessment and HRV reactivity in shaping cognitive outcomes. By focusing on both psychological and physiological indicators of stress, this study contributes to a more integrative understanding of adaptation during international academic mobility.

6.4.1 Perceived stress and adaptation phase

Consistent with longitudinal models of cross-cultural adaptation, students assessed in the final adaptation phase reported significantly lower perceived stress than those evaluated shortly after arrival. This pattern aligns with the U-curve and related frameworks, which propose that international students typically experience heightened stress during the initial period abroad, followed by gradual psychological adjustment as familiarity with academic demands, cultural norms, and daily routines increases (Demes & Geeraert, 2015; Hirai et al., 2015; Zhao & Schartner, 2024). Although the present design does not allow for within-person conclusions, the observed group differences suggest that perceived stress decreases as students progress through their stay, supporting the view that adaptation is a dynamic process.

Interestingly, loneliness levels did not differ between groups, indicating that reductions in perceived stress may occur even in the absence of changes in perceived social disconnection. This finding echoes recent research suggesting that loneliness and stress, while related, may follow partially independent trajectories during international mobility, shaped by cognitive appraisals, expectations, and identity-related processes rather than by time abroad alone (Steptoe et al., 2004; Zheng et al., 2023).

6.4.2 Physiological regulation: cortisol and HRV trajectories

Contrary to expectations, cortisol levels did not differ between students in the initial and final adaptation phases. Across the experimental session, both groups exhibited a significant decline in salivary cortisol. This decrease likely reflects a combination of habituation to the laboratory context and the normative circadian pattern of cortisol

secretion, characterized by progressively lower levels as the day advances, particularly in the absence of a strong acute stressor. This pattern is consistent with previous evidence indicating that psychological stressors lacking elements of uncontrollability and social-evaluative threat tend to elicit minimal HPA-axis activation and modest endocrine responses, whereas conditions involving more explicit social or cognitive evaluation are required to provoke robust cortisol increases (e.g., Dickerson & Kemeny, 2004; Woody et al., 2018). The lack of group differences in total cortisol suggests that, despite differences in perceived stress, students at different adaptation stages did not differ in overall HPA-axis activation under these experimental conditions.

Similarly, HRV increased across the session in both groups, particularly from the cognitive task phase to recovery, indicating progressive parasympathetic reactivation. This finding is consistent with the view that vagally mediated HRV reflects adaptive autonomic flexibility and the capacity to recover following cognitive demand (Hansen et al., 2003; Thayer & Lane, 2000; Thayer et al., 2012). The absence of robust group differences in HRV reactivity suggests that autonomic regulation during a brief laboratory task may be relatively preserved across adaptation phases, even when subjective stress levels differ.

Together, these findings highlight a dissociation between perceived stress and physiological activation, a pattern frequently reported in stress research. Although prior work shows that subjective stress does not always translate into heightened endocrine or autonomic responses in non-clinical samples without strong psychosocial challenge, the evidence is mixed, and several moderating factors (e.g., appraisal style, coping, task characteristics) have been proposed to explain such discrepancies (Ali et al., 2017; Weber et al., 2022).

6.4.3 Cognitive performance and the role of adaptation phase

At the cognitive level, students in the FAP group demonstrated better delayed DM and superior time-based PM compared with those in the IAP group, whereas no group differences emerged for WM or immediate recall of DM. This selective pattern suggests that adaptation abroad may particularly benefit memory processes that rely on consolidation over time and self-initiated monitoring, rather than basic attentional capacity or short-term storage.

Delayed recall of DM depends on effective encoding–consolidation processes, which are known to be sensitive to stress-induced variations in cortisol. For example, post-encoding cortisol increases have been shown to negatively affect the consolidation of contextual elements of episodic memories, thereby impairing performance on delayed recognition tests (Sabia & Hupbach, 2020). More broadly, stress-related cortisol release modulates hippocampal function, a brain region critical for long-term memory consolidation, and can disrupt the storage of newly acquired information (Klier et al., 2020; Osborne et al., 2015). Students assessed shortly after arrival may still be allocating substantial cognitive resources to managing novelty and uncertainty, leaving fewer resources available for optimal consolidation. In contrast, students assessed later in their stay may benefit from increased environmental predictability and reduced stress, facilitating more efficient long-term memory formation.

The specific advantage in time-based, but not event-based PM also aligns with the notion that time-based tasks place greater demands on executive and self-regulatory processes, requiring continuous self-initiated monitoring rather than reliance on external cues (McDaniel & Einstein, 2000; Stewart & McFarland, 2020). From this perspective, the better time-based PM in the FAP group may reflect more mature self-regulation and planning in students who are further along the adaptation trajectory.

6.4.4 Cortisol output as a facilitator of memory performance

Contrary to our hypotheses, higher total cortisol predicted better delayed DM and forward digit span performance, with no evidence of detrimental associations between cortisol and any memory index. Our findings align with evidence showing that glucocorticoid-related arousal can enhance encoding–consolidation mechanisms relevant for delayed recall when cortisol elevations remain within adaptive ranges (Elzinga & Roelofs, 2005; Sabia & Hupbach, 2020).

Moderate elevations in cortisol have been shown to enhance specific aspects of memory consolidation when they occur during appropriate phases of mnemonic processing, consistent with findings that acute increases in cortisol around encoding or consolidation can facilitate detailed memory discrimination (Jiang et al., 2019). By contrast, chronic stress and prolonged cortisol dysregulation have been linked to structural and functional impairments and declines in DM. Sustained exposure to elevated glucocorticoids can reduce hippocampal volume and disrupt synaptic plasticity,

compromising long-term memory consolidation and recall (Ismail, 2025; McEwen, 2007).

6.4.5 HRV reactivity and PM

In the present study, HRV reactivity emerged as a significant negative predictor of event-based PM whereas neither HRV nor total cortisol predicted time-based PM performance. The effect size for HRV was modest and specific to event-based PM, suggesting domain-specific associations between autonomic regulation and PM. This pattern adds to a mixed literature on autonomic regulation and cognition. Although many studies link higher vagally-mediated HRV to better executive control and monitoring processes (e.g., La Marca et al., 2011; Looser et al., 2010; Thayer et al., 2012), recent work demonstrates that HRV reactivity can relate variably to PM outcomes depending on task demands and populations. For example, Hsu et al. (2025) showed that HRV reactivity mediated PM impairments, supporting parasympathetic contributions to PM performance, whereas our results indicate the opposite association in healthy students.

Although extensive research links vagally mediated HRV to executive functioning and attentional control, the specific role of autonomic regulation in PM remains largely underexplored. To date, only isolated studies have examined PM performance in relation to cardiac vagal control, including work showing that HRV reactivity can contribute to PM deficits in clinical populations (e.g., Hsu et al., 2025). Against this limited backdrop, our finding that greater vagal recovery predicted poorer event-based PM may reflect disengagement from sustained cue monitoring once task demands decreased, thereby reducing sensitivity to external triggers required for event-based PM execution. The modest effect sizes and absence of associations for time-based PM further suggest that HRV–cognition relationships are domain-specific and moderated by contextual and individual factors. Moreover, the weak correspondence between HRV and cortisol observed here aligns with evidence that autonomic and endocrine responses often operate partially independently under cognitive challenge and stress exposure.

6.4.6 Implications, limitations, and future directions

Taken together, these findings highlight the importance of situating international students' cognitive performance within an integrated framework that considers psychological stress and physiological regulation. Our data suggest that even in the absence of marked physiological dysregulation, early adaptation is characterized by

higher perceived stress and specific disadvantages in delayed recall and time-based PM, which may translate into everyday academic challenges. At the same time, moderate cortisol output appears to support, rather than impair, memory functioning in this normative sample.

Some limitations must be acknowledged. First, the design compared two groups at different time points but did not follow individuals longitudinally, limiting causal inferences about intra-individual change. Second, the sample size, especially for HRV, was modest, which may have contributed to the absence of some associations and moderation effects. Future research would benefit from longitudinal designs tracking psychological, physiological, and cognitive trajectories across the entire exchange period.

In conclusion, this study demonstrates that adaptation to studying abroad is associated with lower perceived stress and selective improvements in memory functioning, particularly in delayed recall of DM and time-based PM. While physiological stress markers did not differ across adaptation phases, moderate cortisol output was associated with enhanced cognitive performance, highlighting the adaptive role of stress hormones under manageable conditions. Together, these findings emphasize the value of a biopsychosocial approach to understanding how stress and physiological regulation shape cognitive functioning during international academic mobility.

CHAPTER VII

STUDY 5

Loneliness, SMCs, Autonomic Regulation, and Memory Performance

The main results of this study have been submitted:

Batallas, D., Rivas-Díaz, P., Castro-Guerrero, D; Morejón, P., Peñaherrera, A., Hidalgo, V., Salvador, A. (under rewiew). When loneliness turns into forgetting: heart rate variability as a protective factor in prospective memory among international exchange students.

7.1 Introduction

The experience of studying abroad is widely recognized as a formative stage that combines academic enrichment with profound personal and social challenges (Greischel et al., 2018; Vande et al., 2009; Zimmermann & Neyer, 2013). For many young adults, international mobility requires adaptation to new cultures, languages, and social networks, offering opportunities for identity development, intercultural competence, and greater autonomy (Zimmermann & Neyer, 2013). At the same time, these transitions involve substantial changes in socio-ecological systems, including home environment, peer groups, and educational contexts that may elicit psychological stress, feelings of inadequacy, and difficulties establishing fulfilling social ties (Sawir et al., 2008).

Although these adaptation challenges are not new for international students, recent global events have intensified their impact. The COVID-19 pandemic and other stress-inducing circumstances highlighted the heightened vulnerability of young adults to stress, depressive symptoms, and anxiety (Kauhanen et al., 2023; Ochnik et al., 2021; Wiedemann et al., 2024), while disrupting key cognitive processes such as working and PM (Pisano et al., 2021) and attention and decision-making (Ingram et al., 2021). In this broader context of accumulated stressors, loneliness, defined as the perceived gap between desired and actual social connection, emerges as a particularly salient psychological condition, with well-documented negative consequences and increased relevance under global disruptions that intensify social disconnection and emotional vulnerability (Holt-Lunstad et al., 2017; Russell et al., 1978).

Given its heightened relevance in the current context, recent research has increasingly examined the broad consequences of loneliness for physical health, psychological well-being, and cognition. Loneliness has been linked to diminished immune competence and acute reductions in cognitive performance, and, when chronic, to increased cardiovascular risk and all-cause mortality (Cacioppo & Patrick, 2008; Igarashi et al., 2025). It is also a robust correlate of impairments in attention, memory, and broader cognitive functioning (Bangee et al., 2014; Ingram et al., 2021; Tao et al., 2022). Recent psychometric work with the UCLA Loneliness Scale (Bottaro et al., 2023) further refines this understanding by showing that loneliness is not a unitary construct but comprises three interrelated dimensions: Isolation (objective reduction in social contact), Relational Connectedness (difficulties maintaining meaningful interpersonal bonds), and

Trait Loneliness (a stable dispositional sense of emotional detachment). This multidimensional perspective is especially relevant for international students, for whom temporary social isolation and enduring emotional loneliness may have distinct cognitive, behavioral, and physiological implications.

Assumed the differentiated ways in which dimensions of loneliness may affect cognition, it is relevant to examine domains that are central to students' academic functioning. One such domain is PM, the ability to remember and execute intended actions at the appropriate moment, such as attending commitments or meeting deadlines (McDaniel & Einstein, 2000). PM relies on cognitive control and core executive functions, including inhibition, updating, and cognitive flexibility (Martin & Kliegel, 2003; Schnitzspahn et al., 2013), as maintaining an intention during ongoing activity requires continuous monitoring and coordination (Zuber et al., 2020). PM is typically divided into time-based tasks, which depend on internally monitoring time and thus demand sustained attention, and event-based tasks, which are triggered by external cues and generally tax resources less (Talbot et al., 2014; Su et al., 2024). In high-stress academic environments, the cognitive demands of PM may exceed available resources, leading to failures that compromise both academic performance and daily functioning (Ji et al., 2021; Stewart, 2020).

Previous research has demonstrated that loneliness is associated with poorer PM performance, particularly in restrictive social contexts where heightened feelings of isolation and elevated stress biomarkers predicted reduced cognitive functioning (Batallas et al., 2024). A possible explanatory mechanism lies in the cognitive shifts triggered by loneliness. Specifically, loneliness acts as a signal of survival risk linked to the absence of social bonds, redirecting cognitive resources toward increased vigilance and processing of social information as a compensatory strategy (Cacioppo & Cacioppo, 2018). While potentially adaptive in the short term, this shift in cognitive priorities may impair PM by diverting attentional and executive resources away from goal-directed tasks. Over time, such alterations can exacerbate stress responses, weaken immune defenses, and heighten vulnerability to adverse health outcomes (Quadt et al., 2020). Thus, understanding these mechanisms of cognitive reallocation is crucial to explaining the pervasive influence of loneliness on both cognitive functioning and psychosocial well-being.

In this regard, feelings of forgetfulness or attentional lapses, commonly assessed through SMCs, may offer additional insight into these processes. Although SMCs have been studied predominantly in older adults, emerging evidence shows that in young adults they often reflect subtle cognitive inefficiencies shaped by psychosocial factors such as personality traits, stress sensitivity, and maladaptive self-monitoring (Crespo-Sanmiguel et al., 2024; Pedrero-Pérez & Ruiz-Sánchez de León, 2013). Recent studies also indicate that SMCs in youth are not simply inaccurate perceptions of decline, but may signal difficulties in emotion regulation: individuals reporting more frequent memory complaints frequently exhibit higher negative affect, anxiety, and depressive symptoms, as well as reduced physiological or self-regulatory control (Csábi et al., 2025; Zapater-Fajarí et al., 2022). From this perspective, SMCs can be understood as integrative markers that capture the interplay between cognitive functioning and the individual's emotional and physiological state (Heffner et al., 2022).

Following this, physiological resilience provides an additional lens to explain individual differences. HRV, a non-invasive marker of autonomic flexibility, is a well-established index of self-regulatory capacity and prefrontal–autonomic integration (Thayer & Lane, 2009). Higher resting HRV has been consistently associated with better executive functioning, global cognition, and memory (Forte et al., 2019; Frewen et al., 2013). Likewise, dynamic changes in vagally mediated HRV, particularly in the RMSSD, during cognitive tasks have been associated with enhanced attentional control, executive functioning, and greater flexibility in adapting to task demands and environmental challenges (Schaich et al., 2020; Sharma et al., 2023). Conversely, reduced HRV has been observed in individuals with poor attentional regulation and heightened reactivity to negative emotional cues (Park & Thayer, 2014), underscoring the shared neural pathways underlying autonomic regulation, emotion, and cognition. Additionally, loneliness has also been associated with diminished HRV and impaired autonomic recovery (Roddick et al., 2021), suggesting that individuals with low HRV may be particularly vulnerable to the cognitive costs of psychosocial stress.

In summary, this study aims to examine whether perceived loneliness (and its different dimensions) predicted PM through SMCs, while accounting for resting HRV, in young adults during academic mobility. Based on evidence that loneliness disrupts attentional control, memory processes, and cognitive efficiency (Bangee et al., 2014; Batallas et al., 2024; Ingram et al., 2021), and that PM performance depends on executive

resources and sensitivity to external cues (McDaniel & Einstein, 2000; Talbot et al., 2014), we hypothesize that higher loneliness will predict poorer event- and time-based PM. We further propose that SMCs will mediate this association, reflecting the interplay between emotional vulnerability and perceived cognitive functioning (Crespo-Sanmiguel et al., 2024; Heffner et al., 2022). Consistent with neurovisceral models linking autonomic flexibility with executive control (Thayer & Lane, 2009; Forte et al., 2019), we also expect resting HRV to moderate this indirect pathway, such that the combined impact of loneliness and SMCs on PM will be exacerbated when HRV is low. Finally, given that studying abroad entails heightened psychosocial demands and greater susceptibility to loneliness-related cognitive and physiological dysregulation (Greischel et al., 2018; Sawir et al., 2008), we anticipate that these effects will be more pronounced in international students than in their home-based peers.

7.2 Methods

7.2.1 Materials and procedure

The study sample consisted of 83 undergraduate students of the same nationality (Ecuadorian). Forty students were enrolled in an international academic exchange program (Study Abroad group: SA, n = 40), while 43 peers who remained in their home country served as the comparison group (Home-Based group: HB, n = 43). Both groups were assessed during the same academic year (2024–2025). Participants' ages ranged from 18 to 27 years (M = 19.98, SE = 0.44). The SA group included 28 women and 12 men, and the HB group included 28 women and 15 men.

Recruitment was conducted through classroom announcements and personal visits by the research team. Students were informed about the general objectives, the types of data to be collected (cognitive performance, psychophysiological measures, and self-report questionnaires), the approximate duration of the assessment session, and the voluntary nature of their participation. As compensation, participants received personalized feedback on their individual results along with general information about the relationship between psychophysiological measures and cognitive functioning.

Each participant completed a single experimental session lasting approximately 90 minutes. Sessions for the SA group were conducted in the laboratory facilities of the Laboratory of Social Cognitive Neuroscience in Valencia, Spain, whereas sessions for

the HB group were carried out in designated spaces at their home university (International University of Ecuador). Prior to participation, students of both groups were asked to follow specific recommendations: maintain their regular sleep routine, avoid alcohol consumption and intense physical exercise the day before, and refrain from eating, smoking, or consuming caffeinated drinks at least 2 hr prior to the session. On arrival, compliance with these recommendations was verified, and the procedure was explained. Written informed consent was obtained in accordance with the Declaration of Helsinki.

The exclusion criteria used for both groups included the following conditions: the presence of cardiovascular or neuroendocrine abnormalities, a history of neurological or psychiatric disorders, the consumption of more than 10 cigarettes per day, or the excessive use of drugs or alcohol (not exceeding 20 g/day for women and 30 g/day for men). Individuals who reported any of these exclusion criteria in a preliminary telephone interview were not invited to participate in the study.

All procedures were approved by the corresponding Ethics Committees of the institutions involved in the study (Codes: 1) OB_16_2025_UIDE_AF; 2) 1034878).

7.2.2 Measurements

Loneliness

Perceived loneliness was assessed with the Spanish adaptation (Vázquez & Jiménez, 1994) of the R-UCLA (Russell et al., 1980). This scale contains 20 items rated on a four-point Likert scale ranging from 1 (never) to 4 (often). Following Bottaro et al. (2023), we applied the three-factor structure that differentiates subscales: (a) Isolation: perceived separation from others, (b) Relational Connectedness: feelings of closeness and intimacy in relationships, and (c) Trait Loneliness: a dispositional tendency to experience loneliness across contexts. Mean scores were calculated for each subscale (i.e., Isolation, Real Connectedness and Trait Loneliness) and for the full scale (Total UCLA loneliness), with higher values indicating greater perceived loneliness. Internal consistency in the present sample was Cronbach's $\alpha = .878$.

SMCs

SMCs were measured with the Spanish version (Lozoya-Delgado et al., 2012) of the MFE-30 Questionnaire (Sunderland et al., 1984). This questionnaire contains 30 items that explore SMCs through situations and activities of daily life. Items are rated on a

Likert-type scale from 0 (never or almost never) to 4 (always or almost always). Higher scores indicate more everyday memory failures, with a maximum score of 120. Our study showed good internal consistency, obtaining a Cronbach's alpha of 0.944.

Prospective Memory

Participants completed the short-term items of the Royal Prince Alfred Prospective Memory Test (RPA-ProMem; Radford, Lah, Say & Miller, 2011), a semi-naturalistic measure of PM with evidence of reliability and validity (Blondelle et al., 2020). The test evaluates two types of tasks: time-based (remembering to act at a specific time) and event-based (remembering to act when a particular event occurs). Specifically, the RPA-ProMem comprises both short-term and long-term PM tasks, allowing for the assessment of performance across different temporal intervals: (i) short-term tasks. In the time-based condition, participants were instructed to remind the examiner to move a car after 15 minutes to avoid receiving a fine. A digital clock was placed in clear view to facilitate time monitoring. In the event-based condition, participants were told to request a drink from the examiner when a mobile phone alarm sounded after approximately 30 minutes. The phone was placed out of sight to prevent visual cues. (ii) Long-term tasks. At the end of the session, two further intentions were assigned. In the event-based condition, participants were asked to send a WhatsApp message to the examiner upon arriving home that day, reporting the local weather. In the time-based condition, participants were instructed to send an email exactly two weeks later, including their name and a description of their dinner plans.

Each task was scored on a 0–3 scale following the standardized scoring guidelines. A score of 3 was assigned when the intention was carried out correctly and within the appropriate time window; scores of 2 were given when the response was correct but occurred with a moderate delay (approximately 2–5 minutes for short-term tasks or when only part of the target action was correct in long-term tasks); scores of 1 reflected performance that was correct, but substantially delayed or incomplete; and 0 was assigned when the intention was omitted or performed outside the acceptable time limits. Consistent with RPA-ProMem scoring procedures, event-based and time-based PM performance were calculated separately by summing the relevant short- and long-term items (possible range for each subscale from 0 to 6), with higher scores indicating better

PM performance. In this study, analyses were conducted using these two subscale scores (event-based PM and time-based PM) as distinct outcome measures.

Cardiovascular Data

Electrocardiography (ECG) was recorded using the VU-AMS device (Vrije Universiteit Ambulatory Monitoring System; de Geus et al., 1995), a validated ambulatory psychophysiological monitoring system. Participants were seated comfortably during the entire experimental session. Disposable Ag/AgCl electrodes were placed according to the standard lead-II configuration recommended by the manufacturer: one below the right clavicle, one below the left clavicle (ground), and one on the left side of the lower ribs.

The ECG signal was recorded continuously during the entire protocol. R–R intervals (heart periods, HP) were detected automatically by the VU-AMS system. Automated artifact detection and correction algorithms were applied, followed by visual inspection to ensure signal quality and to identify potential residual artifacts or ectopic beats. When necessary, corrupted intervals were corrected using the system's built-in interpolation procedures.

HRV was quantified using the RMSSD, a commonly used time-domain measure of short-term HRV that primarily reflects high-frequency variability associated with respiratory sinus arrhythmia and parasympathetic modulation (Quigley et al., 2024).

Recordings were segmented into three periods: (a) a 7-minute resting-state habituation phase, (b) a 15-minute experimental task period, and (c) a 7-minute post-task recovery phase. For each block, HRV values were extracted from the central 5 minutes to ensure stable estimates and to minimize transitional influences at the beginning and end of each period. Resting-state HRV was considered an indicator of stable individual differences in autonomic regulation.

Due to missing data and excessive artifacts in some recordings, the final HRV sample was reduced. Usable HRV data were obtained for 29 participants (19 women, 10 men) in the SA group and 38 participants (23 women, 15 men) in the HB group.

All preprocessing and HRV calculations were conducted with the VU-AMS analysis software package, which provides standardized scoring and artifact correction procedures developed by the Vrije Universiteit research group.

7.2.3 Statistical analysis

To characterize the sample and examine group differences between SA and HB groups, independent *t*-tests and chi-square tests were conducted for sociodemographic and psychological variables (SMCs, loneliness, and PM measures). Levene's test for equality of variances was applied, and corrected *p*-values were reported when the homogeneity assumption was not met.

In addition, bivariate Pearson's correlations were computed to explore unadjusted associations between loneliness (UCLA total and subscales), SMCs, and PM outcomes (event and time based).

Tests of skewness and kurtosis indicated values within the acceptable range (–1 to +1), suggesting that the variables exhibited an approximately normal distribution (George & Mallery, 2010). A moderated mediation model was conducted using the PROCESS macro for SPSS, applying the bootstrap method (5,000 samples) to obtain robust inferences in the presence of potential deviations from normality (version 3.4; Hayes, 2018). Specifically, Model 14 was employed to examine whether the effect of loneliness (Trait, Isolation, Relational Connectedness, and the UCLA total score) (X) on PM (Y: event-based or time-based) was mediated by SMCs (M), with resting HRV (baseline RMSSD) included as a moderator (W). All continuous variables were standardized (z-scores). Conditional direct and indirect effects were estimated using bootstrapped bias-corrected 95% confidence intervals, and moderated mediation was considered significant when the index of moderated mediation excluded zero. Three participants had missing SMC data, and were therefore excluded from analyses involving this variable.

Additional analyses using Isolation, Relational Connectedness, and the total loneliness score as predictors did not produce significant effects for either PM outcome. The full results of these supplementary models are presented in Supplementary Material 2.

The level of significance was set at $p < .05$ (two-tailed). All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

7.3 Results

7.3.1 Preliminary analyses

No group differences were found in age [$t(81) = -1.57$, $p = .120$], nor in the distribution of sex across groups, $\chi^2 = 0.23$, $p = .635$.

Likewise, the groups did not differ in SMCs [$t(77,51) = 0.59$, $p = .557$), event-based PM [$t(81) = 0.48$, $p = .631$], isolation [$t(81) = 1.63$, $p = .107$], real connection [$t(81) = 0.62$, $p = .535$], nor total UCLA loneliness score [$t(81) = 1.28$, $p = .205$]. However, the SA group obtained significantly higher scores on time-based PM [$t(81) = 2.21$, $p = .030$], and as a trend, trait loneliness [$t(77.21) = 1.86$, $p = .067$] than HB group (Table 13).

Table 13. Psychological and cognitive differences between groups.

Variable	SA group (N=40) M ± SE	HB group (N=43) M ± SE	*t*(df)	*p*
Event-based PM	4.78 ± 0.22	4.44 ± 0.29	0.48 (79)	.631
Time-based PM	3.28 ± 0.20	2.23 ± 0.29	2.21 (81)	**.030 ***
SMCs	31.27 ± 2.55	30.98 ± 3.24	0.59 (78)	.557
UCLA – Isolation	9.48 ± 0.45	8.36 ± 0.39	1.63 (81)	.107
UCLA – Real Connection	22.70 ± 0.95	21.74 ± 0.88	0.62 (81)	.535
UCLA – Trait Loneliness	7.33 ± 0.32	6.44 ± 0.25	1.86 (81)	.067
UCLA – Total	39.50 ± 1.49	36.54 ± 1.33	1.28 (81)	.205

Note: SA=study abroad; HB=home based; PM= prospective memory.

7.3.2 Bivariate Correlations

To examine the general pattern of associations among the main study variables (i.e., loneliness, SMCs and PM), we performed bivariate Pearson correlations (Table 14). A significant positive association was observed between time-based PM and event-based PM ($r = 0.23$, $p = 0.037$). In addition, neither time-based nor event-based PM correlated significantly with the total UCLA loneliness score, its subscales, or SMCs (all *ps* > 0.05).

SMCs were positively correlated with the total UCLA loneliness ($r = 0.37$, $p < 0.001$) as well as with each subscale: isolation ($r = 0.28$, $p = 0.013$), real connection ($r = 0.34$, $p = 0.002$), and trait loneliness ($r = 0.32$, $p = 0.004$).

Table 14. Bivariate correlations among PM, loneliness, and SMCs in total sample.

	Event based PM	**Time based PM**	**SMCs**	**UCLA-Isolation**	**UCLA-Real Connection**	**UCLA-Trait Loneliness**	**UCLA-Total**
Event based PM		0.229*	-0,052	0,119	0,211	0,008	0,172
Time based PM	0.229*		0,057	-0,009	-0,035	-0,037	0,008
SMCs	-0,052	0,057		0.276*	0.339**	0.318**	0.371**
UCLA-Isolation	0,119	-0,009	0.276*		0.636**	0.554**	0.825**
UCLA-Real Connection	0,211	-0,035	0.339**	0.636**		0.515**	0.941**
UCLA-Trait Loneliness	0,008	-0,037	0.318**	0.554**	0.515**		0.708**
UCLA-Total	0,172	0,008	0.371**	0.825**	0.941**	0.708**	

* p < 0.05 (two-tailed). ** p < 0.01 (two-tailed). Abbreviations: SMC; SMCs; PM Prospective Memory.

7.3.3Moderated mediation analysis

Analyses using Isolation, Relational Connectedness, and the total loneliness score as predictors did not yield significant associations with either PM measure; full results for these models are provided in Supplementary Material 2. We therefore focused subsequent analyses on the moderated mediation model involving trait loneliness, SMCs, and resting HRV.

7.3.4 Effects of trait loneliness on PM (Event or time based) through SMCs considering the influence of resting-state HRV

Total Sample

Event-based PM. Trait loneliness was a significant positive predictor of SMCs (path *a*: *B* = 0.39, *SE* = 0.13, *p* = 0.004, 95% CI [0.12, 0.65]). The direct effect of trait loneliness (path *c′: B* = −0.00, *SE* = 0.16, *p* = 0.979, 95% CI [−0.31, 0.31]) and SMCs (path *b*: *B* = −0.14, SE = 0.14, *p* = 0.338, 95% CI [−0.42, 0.15]) on event-based PM were not significant. In addition, the interaction between SMCs and resting-state HRV was not significant (*B* = 0.07, SE = 0.14, *p* = 0.619, 95% CI [−0.20, 0.34]).

Analysis of conditional indirect effects showed that the pathway from trait loneliness to event-based PM through SMCs was not significant at any level of resting-state HRV (all 95% BootCIs included zero) (Table 15). The index of moderated mediation was also nonsignificant *B* = 0.03, BootSE = 0.06, 95% BootCI [−0.07, 0.16]).

Time-based PM. Trait loneliness significantly predicted higher SMCs (path *a B = 0.39, SE = 0.13, p = 0.004, 95% CI [0.12, 0.65*). However, SMCs did not significantly predict time-based PM (path *b*: B = −0.07, SE = 0.14, *p* = 0.624, 95% CI [−0.35, 0.21), and the direct effect of trait loneliness on time-based PM was also nonsignificant (path *c′*: B = 0.05, SE = 0.16, *p* = 0.758, 95% CI [−0.27, 0.36]). The interaction between SMCs and HRV did not reach significance (B = −0.10, SE = 0.14, *p* = 0.472, 95% CI [−0.37, 0.17]) and, consequently, conditional indirect effects across different values of HRV were nonsignificant.

Analysis of conditional indirect effects showed that the pathway from trait loneliness to time-based PM through SMCs was not significant at any level of HRV (all 95% BootCIs included zero) (Table 15). The index of moderated mediation was also nonsignificant (B = −0.04, BootSE = 0.06, 95% BootCI [−0.18, 0.07]).

Table 15. Conditional indirect effects of Loneliness on PM (Event- and Time-Based) via SMCs, moderated by resting-state HRV in total sample.

Outcome	LB (Resting HRV)	Indirect Effect	BootSE	BootLLCI	BootULCI
Event based PM	Low HRV	-0.081	-0.107	-0.365	0.057
	Mean HRV	-0.053	0.071	-0.233	0.047
	High HRV	-0.026	0.076	-0.191	0.117
Time based PM	Low HRV	0.016	0.095	-0.149	0.235
	Mean HRV	-0.026	0.064	-0.164	0.104
	High HRV	-0.066	0.086	-0.247	0.100

Note. LB = resting-state heart rate variability (HRV). Indirect effects represent the pathway through SMCs on Prospective Memory (event-based or time-based) considering the influence of HRV. BootSE = bootstrapped standard error; BootLLCI and BootULCI = lower and upper limits of the 95% bootstrapped confidence interval. Confidence intervals that include zero indicate nonsignificant conditional indirect effects.

Study Abroad Group

Event-Based PM. Trait loneliness was a significant positive predictor of SMCs (path *a*: B = 0.59, SE = 0.17, *p* = 0.002, 95% CI [0.24, 0.95]). The direct effect of trait loneliness (path *c′:* B = 0.05, SE = 0.25, *p* = 0.847, 95% CI [−0.46, 0.56]) and SMCs (path *b*: B = −0.26, SE = 0.24, *p* = 0.286, 95% CI [−0.77, 0.24]) on event-based PM were nonsignificant. In addition, the interaction between SMCs and Resting-State HRV was significant (B = 0.53, SE = 0.23, *p* = 0.034, 95% CI [0.04, 1.02]).

Conditional effects revealed that at low levels of HRV, higher SMCs scores were marginally associated with poorer event-based PM (*B* = −0.69, SE = 0.35, *p* = 0.060, 95% CI [−1.42, 0.03]). However, at medium levels of HRV (*B* = −0.14, SE = 0.23, *p* = 0.566, 95% CI [−0.62, 0.35]) and at high levels of HRV (*B* = 0.28, SE = 0.29, *p* = 0.341, 95% CI [−0.32, 0.87]), this association was not significant.

Analysis of conditional indirect effects showed that the pathway from trait loneliness to event-based PM through SMCs was significant at low resting-state HRV, but not at medium or high HRV (see Table 16). The index of moderated mediation was significant (*B* = 0.31, BootSE = 0.13, 95% BootCI [0.05, 0.57]).

Time-Based PM. Trait loneliness significantly predicted higher SMCs (path *a:* B = 0.59, SE = 0.17, *p* = 0.002, 95% CI [0.24, 0.95]). However, the effect of SMCs (path *b*: B = 0.04, SE = 0.23, *p* = 0.853, 95% CI [−0.43, 0.51]) and trait loneliness (path *c′:* B = 0.08, SE = 0.23, *p* = 0.730, 95% CI [−0.40, 0.56]) on time-based PM were not significant. The interaction between SMCs and resting- state HRV was not significant (*B* = −0.06, SE = 0.22, *p* = 0.790, 95% CI [−0.52, 0.40]).

Conditional indirect effects of trait loneliness on time-based PM via SMCs across different values of resting HRV were also nonsignificant (Table 16). The index of moderated mediation was nonsignificant (*B* = −0.04, BootSE = 0.16, 95% BootCI [−0.40, 0.24]).

Table 16. Conditional Indirect Effects of Trait Loneliness on PM (Event- and Time-Based) via SMCs, Moderated by Resting-State HRV in the SA Group.

Outcome	LB (Resting HRV)	Indirect Effect	BootSE	BootLLCI	BootULCI
Event based PM	**Low HRV**	**-0.412**	**0.172**	**-0.729**	**-0.053**
	Mean HRV	0.080	0.118	-0.307	0.163
	High HRV	0.165	0.165	-0.153	0.529
Time based PM	Low HRV	0.054	0.252	-0.403	0.600
	Mean HRV	0.017	0.119	-0.247	0.228
	High HRV	-0.011	0.125	-0.318	0.187

Note. LB = resting-state heart rate variability (HRV). Indirect effects represent the pathway through SMCs on Prospective Memory (event-based or time-based) considering the influence of HRV. BootSE = bootstrapped standard error; BootLLCI and BootULCI = lower and upper limits of the 95% bootstrapped confidence interval. Confidence intervals that include zero indicate nonsignificant conditional indirect effects.

Home Based Group

Event-Based PM. Trait loneliness did not significantly predict SMCs (path *a*: *B* = 0.25, *SE* = 0.19, *p* = .201, 95% CI [–0.14, 0.63]). Similarly, trait loneliness (path c′: *B* = 0.03, SE = 0.22, *p* = .891, 95% CI [–0.41, 0.47]) nor SMC (path *b*: B = –0.17, SE = 0.19, *p* = .367) predicted event-based PM. In addition, the SMCs × resting state-HRV interaction (B = –0.08, SE = 0.18, *p* = .655) was no significant.

Analysis of conditional indirect effects revealed that the pathway from trait loneliness to event-based PM through SMCs was nonsignificant at all levels of HRV (Table 5). The index of moderated mediation was also nonsignificant (*B* = –0.020, BootSE = 0.061, 95% BootCI [–0.149, 0.110]).

Time-Based PM. Trait loneliness did not predict SMCs (path *a:* B = 0.25, SE = 0.19, *p* = .201, 95% CI [–0.14, 0.63]). The effect of trait loneliness (path *c′:* B = −0.08, SE = 0.22, *p* = 0.732, 95% CI [–0.53, 0.38]) and SMCs (*B* = –0.15, SE = 0.19, *p* = .448) on event-based PM were not significant. The interaction between SMCs and resting-state HRV was also nonsignificant (*B* = –0.11, SE = 0.19, *p* = .564).

Conditional indirect effects of trait loneliness on time-based PM through SMCs at different levels of HRV were nonsignificant (Table 17). The index of moderated mediation was nonsignificant (*B* = –0.027, BootSE = 0.064, 95% BootCI [–0.181, 0.084]).

Table 17. Conditional Indirect Effects of Loneliness on PM (Event- and Time-Based) via SMCs, Moderated by Resting-State HRV in HB Group.

Outcome	LB (Resting HRV)	Indirect Effect	BootSE	BootLLCI	BootULCI
Event based PM	Low HRV	-0.0182	0.109	-0.324	0.121
	Mean HRV	-0.039	0,087	-2680	0.06
	High HRV	-0.066	0.117	-0.362	0.113
Time based PM	Low HRV	-0.004	0.085	-0.159	0.205
	Mean HRV	-0.032	0.070	-0.193	0.102
	High HRV	-0.068	0.121	-0.355	0.160

Note. LB = resting-state heart rate variability (HRV). Indirect effects represent the pathway Trait Loneliness through SMCs on Prospective Memory (event-based or time-based) considering the influence of HRV. BootSE = bootstrapped standard error; BootLLCI and BootULCI = lower and upper limits of the 95% bootstrapped confidence interval. Confidence intervals that include zero indicate nonsignificant conditional indirect effects.

7.4 Discussion

The present study investigated the interplay between loneliness, SMCs, and PM, with HRV as a potential moderator of these associations, in a sample of study abroad students and their peers who remained in their home country. We sought to clarify whether loneliness predicts cognitive difficulties indirectly through subjective memory performance, and whether physiological resilience, as indexed by resting HRV, buffers or amplifies these effects.

Loneliness and all its dimensions were consistently associated with greater SMCs across the full sample, replicating and extending previous evidence that perceived social disconnection and subjective memory concerns often co-occur. This association suggests that loneliness may heighten self-monitoring of cognitive functioning and amplify perceived cognitive lapses, even when objective performance remains intact (Luchetti et al., 2025). Recent evidence further shows that individuals who experience greater loneliness tend to report more frequent cognitive concerns in daily life, and that social isolation and loneliness are reliable predictors of subjective cognitive decline and poorer perceived cognitive health (Guarnera et al., 2023; Luchetti et al., 2025). These findings collectively support the notion that loneliness operates as a psychosocial stressor influencing how individuals perceive and evaluate their own cognitive abilities.

Regarding our moderated mediation models, notably, the observed associations emerged only for trait loneliness, while neither isolation nor relational connectedness showed significant effects (Supplementary data 2). This finding supports the multidimensional conceptualization of loneliness proposed in recent psychometric work (Bottaro et al., 2023), suggesting that the dispositional aspect of loneliness may exert a stronger and more stable influence on self-perceived cognition than transient or context-dependent forms of social disconnection. Trait loneliness reflects an enduring emotional detachment and self-referential processing style linked to heightened self-focused attention and reduced perceived social support (Cacioppo et al., 2010; Hawkley & Cacioppo, 2010). These characteristics may increase vulnerability to cognitive self-monitoring and negative affective appraisal, thereby strengthening the link between loneliness and SMCs. In contrast, situational isolation or temporary reductions in connectedness may be less detrimental for young adults, particularly in highly mobile or transitional contexts such as studying abroad, where social networks are undergoing

change and temporary disconnection may not carry the same emotional weight (Batallas el at., 2024).

Furthermore, trait loneliness and SMCs did not predict PM performance uniformly across conditions. The absence of a direct association between loneliness and PM suggests that their relationship is likely indirect and context-dependent. Loneliness primarily reflects an affective and social state, whereas PM relies on executive and attentional control processes that are less directly influenced by emotional distress (McDaniel & Einstein, 2007). Thus, loneliness may not impair PM performance per se, but rather affect how individuals perceive and evaluate their cognitive abilities. This interpretation is consistent with evidence linking loneliness to increased SMCs rather than objective deficits (Luchetti et al., 2023). Our findings imply that loneliness influences PM indirectly through SMCs and physiological regulation rather than through a direct cognitive impairment pathway.

Therefore, the moderated mediation analyses revealed that, among international students, trait loneliness indirectly influenced event-based PM through SMCs, and this pathway was conditioned upon resting-state HRV. Specifically, when HRV was low, higher trait loneliness predicted more memory complaints, which in turn were associated with poorer event-based PM performance. In contrast, at medium and high levels of HRV, these associations diminished or even suggested a protective effect.

HRV results further provide novel insights. Crucially, within the SA group, resting HRV interacted with loneliness and SMCs to predict PM outcomes. This finding supports the idea that physiological resilience becomes particularly relevant under psychosocial strain, buffering the translation of perceived cognitive difficulties into measurable performance decrements. These results align with previous research demonstrating that higher HRV is associated with greater cognitive flexibility, attentional control, and adaptive responses to stress (Frewen et al., 2013; Mathewson et al., 2010; Park et al., 2014), while extending this work by showing that HRV also shapes how social-emotional factors influence cognition. The fact that this pattern emerged exclusively among SA group suggests that contextual stressors inherent to the adaptation process, such as social isolation, limited in-person social support, alongside cultural adjustment demands, may amplify the effects of loneliness on self-perceived cognitive difficulties and subsequent memory performance (Batallas et al., 2024; Tanaka et al., 2024; Smith & Khawaja, 2011;

Sawir et al., 2008). Finally, students with higher vagal tone appeared better able to sustain effective performance despite subjective difficulties, consistent with the neurovisceral integration model (Thayer & Lane, 2009), which posits that greater cardiac vagal control supports flexible emotional and cognitive regulation under stress.

At a broader level, these findings may point to the relevance of general emotion-regulation processes in shaping SMCs. Individuals reporting SMCs may show an expression of emotional dysregulation phenotype in the absence of cognitive decline such as trait neuroticism, anxiety and excessive worrying in relation to memory performance (Crespo et al., 2024; Jenkins et al., 2021; Pedrero-Perez & Ruiz 2013). These mechanisms may involve cognitive self-monitoring and negative affective reactivity to minor memory failures (Efklides & Touroutoglou, 2010), thus creating a feedback-loop between loneliness, stressor internalization and cognitive inefficiency. Supporting this view, resting HRV has been shown to correlate with cognitive-affective flexibility in cognitive and affective processing (Frewen et al., 2013; Thayer et al., 2009; Park et al., 2014), and low vagal tone could indicate low control capacity. Chronic social and acculturative stressors experienced by international students (Finley and Schaefer, 2022; Smith and Khawaja, 2011; Sawir et al., 2008) may interact with the described emotional and autonomic processes to make loneliness-related processes and their consequences more salient for cognitive functioning (perceived and actual) in this population.

Additionally, moderated mediation analysis was not observed for time-based PM, nor in the home-based student group. The differential pattern observed between event-based and time-based PM tasks is consistent with prior evidence highlighting their distinct cognitive underpinnings. Event-based PM, which is triggered by external cues, tends to depend more on spontaneous retrieval and reactive attentional processes, making it particularly sensitive to fluctuations in attention and to the influence of contextual or emotional factors (McDaniel & Einstein, 2000; Kliegel et al., 2008). In the exchange student group, higher loneliness and reduced physiological regulation may have disrupted the integration between attentional and emotional systems required for effective cue detection, thereby amplifying SMCs. In contrast, time-based PM relies more heavily on self-initiated strategic monitoring of elapsed time, which imposes greater executive and working memory demands (Cona et al., 2015; Martin et al., 2003). Therefore, the absence of significant effects for time-based PM in the present study may reflect the higher cognitive load associated with sustained self-monitoring, which could mask subtle

psychosocial influences. Alternatively, it may be that SMCs in young adults will be more closely align with difficulties in cue-triggered processes rather than with purely time-driven monitoring, an interpretation consistent with evidence that event-based PM is especially vulnerable to attentional variability.

The applied relevance of these results is twofold. First, they highlight the need for universities to systematically address loneliness and SMCs among exchange students, not only for mental health, but also for academic success. Screening tools for SMCs, combined with brief HRV assessments, could help identify students at risk for cognitive difficulties during adaptation periods. Second, interventions that enhance physiological resilience such as mindfulness training, HRV biofeedback, or aerobic exercise may serve as protective strategies, mitigating the negative impact of loneliness on cognitive functioning. By adopting a biopsychosocial lens, universities can design support programs that simultaneously target social integration, self-perceived cognitive difficulties, and physiological regulation.

Several limitations should be acknowledged. The sample size, particularly in subgroup analyses, was modest, which may have limited statistical power to detect smaller effects, especially for time-based PM. In addition, our cross-sectional design prevents causal inference. Longitudinal studies could clarify whether loneliness and SMCs predict subsequent cognitive deficits, and whether enhancing HRV can buffer such trajectories.

In summary, this study advances understanding of how loneliness, SMCs, and physiological resilience (resting-state HRV) interact to shape PM in young adults. Our findings reveal that among international students, trait loneliness predicts more memory complaints, which in turn are linked to poorer event-based PM performance, but only under conditions of low resting-state HRV. This suggests that vagal regulation serves as a key moderator, buffering against the cognitive costs of psychosocial stress. No such effects were observed in home-based students or for time-based PM, highlighting the context-specific and task-specific nature of these mechanisms. These insights support a biopsychosocial model of cognitive functioning in young adults and underscore the importance of considering both subjective and physiological indicators when addressing the academic and psychological needs of students in transition.

CHAPTER VIII

GENERAL DISCUSSION

General discussion

This Doctoral Thesis aimed to examine how psychosocial stress and loneliness, together with physiological regulation mechanisms, are associated with subjective and objective cognitive functioning in young adults exposed to contexts of social change, particularly international academic mobility and post-pandemic conditions. Across several studies, this Thesis integrated subjective indicators of cognitive vulnerability (SMCs and self-perceived prefrontal symptomatology), objective memory performance (WM, DM, PM), and physiological biomarkers of stress regulation (HPA axis indices and HRV), while also considering dispositional vulnerability factors such as personality-related negative emotionality and psychological inflexibility.

The following section provides a synthesis of the main findings, a critical interpretation of their implications, and a global reflection on limitations and future directions derived from the results obtained in this Thesis.

In line with the first specific objective, to examine how psychosocial stress and dispositional vulnerability factors are associated with subjective cognitive functioning in young adults, we explored how perceived stress and neuroticism relate SMCs during the post-pandemic period, and whether hair-based endocrine biomarkers (HC and HDHEA) contribute to these associations. This context is particularly relevant, as prolonged uncertainty and disruption following the COVID-19 pandemic have had lasting effects on emotional stability, stress regulation, and cognitive self-perception (Fiorenzato et al., 2021; Xiong et al., 2020).

As anticipated, higher levels of perceived stress and neuroticism were associated with increased SMCs. This pattern is consistent with prior research showing that negative affectivity and exposure to stress are related to both objective aspects of memory functioning (Stanek & Ones, 2023; Zhu et al., 2022) and subjective evaluations of memory performance (Crespo-Sanmiguel et al., 2024; Molina Rodriguez et al., 2018). Together, these findings suggest that situational distress (perceived stress) alongside stable dispositional vulnerability (neuroticism) contribute to how young adults interpret and judge their everyday cognitive performance (Crespo-Sanmiguel et al., 2024; Podlesek et al., 2021; Sutin et al., 2020).

A key contribution of this study is the differentiated role of endocrine activity. Although HC and HDHEA did not show straightforward direct associations with SMCs, both hormones moderated psychological pathways to subjective cognition. This pattern suggests that chronic HPA biomarkers may be more informative as biological contexts that shape the expression of psychological vulnerability rather than as direct correlates of cognitive complaints. Importantly, the moderation results were not uniform: HC primarily interacted with neuroticism, HDHEA more clearly interacted with perceived stress. This implies two complementary pathways: a more trait-linked pathway in which chronic cortisol output aligns more closely with dispositional emotional vulnerability, and a more state-linked psychobiological pathway in which perceived stress relates to memory complaints depending on HDHEA levels (possibly reflecting sustained physiological engagement under prolonged strain). Consistent with daily process evidence showing variable coupling between perceived stress and cortisol as a function of coping and individual differences, this pattern supports the notion that psychological appraisal and endocrine output can be partially decoupled under chronic or habituated stress (Sladek et al., 2016), and that hair biomarkers reflect cumulative physiology that does not necessarily correspond to recent perceived stress.

Together, this study supports a stress-related account of SMCs in young adults: SMCs are meaningfully embedded in negative emotionality and stress sensitivity, while endocrine activity helps explain when these psychological risk factors become most salient for subjective cognitive functioning.

The second study of this Thesis examined personality-based vulnerability in relation to self-perceived prefrontal symptomatology, testing psychological inflexibility as a mediating mechanism linking harm avoidance and self-directedness to executive-related cognitive and emotional difficulties. The results indicated that psychological inflexibility accounted for a substantial portion of the pathway between temperament–character traits and prefrontal symptomatology, supporting the interpretation that subjective executive problems often emerge from an interaction between stable dispositions and dynamic self-regulatory processes.

These findings align with Cloninger's Model (Cloninger et al., 1993) by showing that harm avoidance, characterized by fearfulness, hypervigilance, and worry, was associated with greater perceived executive symptomatology, whereas self-directedness

was protective, consistent with its link to autonomy, persistence, and adaptive regulation (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014). From a neurocognitive perspective, the pattern is also consistent with evidence that stress and emotional rigidity can compromise prefrontal circuitry supporting flexibility and inhibitory control (Arnsten, 2009; Diamond, 2013). Psychological inflexibility provides a functional bridge in this relationship, reflecting a rigid, avoidance-based coping style that undermines attentional control and adaptive decision-making (Bond et al., 2006; Kashdan & Rottenberg, 2010).

A central contribution of this study is the demonstration that psychological inflexibility partially mediates the association between personality and perceived executive symptomatology. High harm avoidance was associated with greater inflexibility, suggesting that avoidance-oriented coping and persistent threat monitoring promote rigid regulatory strategies that magnify perceived cognitive inefficiency. Conversely, higher self-directedness was conceptually linked to lower psychological inflexibility, reflecting better self-regulation and a greater tendency toward acceptance-based coping processes, consistent with models of adaptive behavior that emphasize flexible engagement with internal experience (Kashdan & Rottenberg, 2010). Self-directed behavior reflects the ability to adapt one's actions to situational demands and personal values, whereas inflexible response patterns limit such adaptive regulation (De Freyt et al., 2000). Moreover, these findings converge with prior work linking psychological inflexibility to stress sensitivity, cognitive rigidity, and emotional dysregulation (Latzman & Masuda, 2013; Paulus et al., 2016).

Importantly, this study extends previous evidence beyond clinical populations by demonstrating that these mechanisms operate in non-clinical young adults, where prefrontal symptomatology may be subclinical but still psychologically meaningful (Pedrero-Pérez & Ruiz-Sánchez de León, 2013). Psychological inflexibility therefore emerges as a dimensional vulnerability factor that amplifies stress reactivity and perceived cognitive inefficiency across normative development (Bonilla-Sierra et al., 2021; Radyani et al., 2021; Tavakoli et al., 2019).

This mechanism also provides a useful conceptual link to the wider idea: if stress and loneliness increase cognitive self-monitoring and perceived inefficiency, then,

inflexibility offers a plausible process through which vulnerable personality profiles translate environmental strain into everyday executive difficulties.

Taken together, the findings from the first two studies address ***General Objective 1*** by showing that psychosocial stress and dispositional vulnerability factors are systematically associated with subjective cognitive functioning in young adults, as reflected in SMCs and self-perceived prefrontal symptomatology. Study 1 showed that perceived stress and neuroticism, representing state-related distress and trait-like emotional vulnerability, respectively, were positively associated with greater SMCs, supporting the notion that everyday cognitive self-evaluations are strongly shaped by affective and stress-related processes. Moreover, the moderating role of hair-based endocrine biomarkers (HC and HDHEA) suggests that the expression of psychological vulnerability depends in part on the physiological context of stress regulation, reinforcing a psychobiological interpretation of subjective cognitive functioning. Complementarily, Study 2 extended this framework by showing that temperament–character traits linked to harm avoidance and self-directedness were associated with self-perceived executive difficulties, and that these relationships were mediated by psychological inflexibility as a core self-regulatory process. This mediation indicates that stable personality dispositions influence subjective cognitive functioning not directly, but through rigid and avoidance-based regulatory styles that compromise adaptive control and emotional flexibility. When integrated, both studies converge in showing that SMCs in young adults are unlikely to reflect isolated cognitive deficits, but rather emerge from the interaction between emotional vulnerability, psychosocial stress, and self-regulatory mechanisms, modulated by stress regulation. In this sense, subjective cognitive functioning can be conceptualized as a dynamic, multidimensional construct that captures how individuals experience and regulate cognitive efficiency under conditions of psychological demand, highlighting the relevance of integrative biopsychosocial models for understanding early cognitive vulnerability in young adulthood.

While these findings provide a coherent account of subjective cognitive vulnerability, they also highlight the need to extend the analysis beyond self-perceived functioning. Accordingly, the Thesis next addresses ***General Objective 2*** by shifting the focus toward objective memory performance, examining how physiological indicators of stress regulation and mobility-related living conditions are associated with cognitive

outcomes in post-pandemic contexts, and to evaluate the role of loneliness in these associations. Therefore, in Study 3 we addressed how post-pandemic social contact restrictions affected young adults at psychological, biological, and cognitive levels, with a focus on loneliness and living conditions. Individuals who had moved away from their home country and were living alone (i.e., without their usual nuclear family) reported higher loneliness, showed marginally higher HC, and performed worse on WM and PM than those who remained with their nuclear family and did not live alone. Notably, group differences were driven less by telematic contact and more by reduced face-to-face communication, underscoring the specific protective value of in-person support.

These results are consistent with evidence that cognitive outcomes during the pandemic were shaped by the degree of social isolation and improved as restrictions lifted (Ingram et al., 2021). They also resonate with pre-pandemic findings linking loneliness and social isolation to worse WM and PM performance, particularly in later life (Haslam et al., 2014; Lara et al., 2019), as well as studies showing that stronger social support relates to better cognitive functioning, whereas isolation shows the opposite pattern (Evans et al., 2019; Kelly et al., 2017).

A central contribution of Study 3 is that loneliness shaped the relationship between cortisol and PM. Although cortisol alone did not correlate robustly with memory outcomes, loneliness moderated the cortisol–PM association: individuals with high loneliness showed a stronger negative cortisol–PM link, suggesting heightened vulnerability under combined psychosocial and physiological strain. This finding fits with work indicating that chronic stress (indexed by HC) can affect cognition during major stressful periods (Dajani et al., 2018; Gao et al., 2014), and supports the view that loneliness may intensify stress-related cognitive costs by amplifying the impact of stress-related physiology (Cacioppo et al., 2002). The specificity of this interaction for PM is theoretically meaningful: PM depends strongly on self-initiated control and executive monitoring, since individuals must maintain future intentions, detect cues, and initiate action without external prompts (Martin et al., 2003). This executive involvement makes PM disproportionately vulnerable under conditions of routine disruption and sustained regulatory demands (Stewart & McFarland, 2020). This also provides an empirical bridge to the mobility studies, where PM repeatedly emerges as a sensitive domain during adaptation and psychosocial strain.

Regarding autonomic regulation, HRV did not differ significantly between groups, and RMSSD was not strongly associated with memory outcomes, echoing the broader literature showing that HRV–cognition correlations are often small and unstable (Allan et al., 2005; Britton et al., 2008; Holzman & Bridgett, 2017). Nevertheless, the observed increases in parasympathetic activity following cognitive challenge are consistent with the idea that recovery-related vagal reactivation is a meaningful marker of regulatory flexibility (Roddick & Chen, 2021; Shah et al., 2021).

Taken together, these findings address General Objective 2 by demonstrating that loneliness and displacement-related living conditions in the post-pandemic context are associated with objective memory performance, and that loneliness increases vulnerability to stress-related cognitive inefficiency. The inclusion of stress-regulation biomarkers further indicates that physiological processes do not exert uniform direct effects on cognition, but rather shape the conditions under which psychosocial vulnerability translates into measurable cognitive costs.

Importantly, the mobility-like characteristics of the sample (young adults living abroad and separated from their usual social environment) position Study 3 as a conceptual bridge toward Studies 4 and 5, where academic mobility becomes the explicit contextual focus and PM is examined in greater depth. Whereas Study 3 establishes that loneliness and displacement-related social conditions heighten vulnerability in PM during post-pandemic disruption, the subsequent studies refine this framework by differentiating time- and event-based PM and by testing whether physiological flexibility, particularly autonomic regulation, buffers or exacerbates vulnerability during longer-term adaptation. In this way, Study 3 connects post-pandemic social disruption with emerging models of cognitive adaptation in mobile young adults, providing a coherent transition from psychosocial risk toward physiological modulation of cognitive resilience.

Therefore, the fourth study examined perceived stress, physiological regulation, and memory performance in international students at different stages of their academic stay abroad using a cross-sectional comparison between two independent groups (IAP and FAP). Students in the later adaptation phase reported lower perceived stress, consistent with adaptation frameworks suggesting that stress tends to peak early and decline with increased familiarity and routine (Demes & Geeraert, 2015; Hirai et al., 2015; Zhao & Schartner, 2024). Crucially, loneliness did not differ between groups,

suggesting that reductions in perceived stress may occur even when perceived social disconnection remains relatively stable. This interpretation is consistent with longitudinal and trajectory-based evidence indicating that loneliness follows distinct developmental patterns that do not necessarily mirror changes in stress or other psychosocial variables (Cadigan et al., 2023). Studies conducted during the COVID-19 pandemic have identified multiple loneliness trajectories (e.g., stable or increasing), showing that loneliness can persist or fluctuate independently of broader emotional adaptation processes (Laham et al., 2021). Structural longitudinal models further indicate that although loneliness and perceived stress are related, their reciprocal influences are modest and their temporal dynamics only partially overlap (Laustsen et al., 2024). Together, this evidence supports the conclusion that stress appraisal may improve with contextual adaptation even when loneliness remains relatively unchanged, particularly in mobility contexts where social networks require longer-term reconstruction.

Physiologically, cortisol did not differ between phases and declined across the session, consistent with this pattern may also reflect the normative diurnal decline in cortisol secretion observed across the day, the absence of a strong social-evaluative stressor and with evidence that robust cortisol activation typically requires uncontrollability and social evaluation (Dickerson & Kemeny, 2004; Woody et al., 2018). HRV increased across the session, reflecting parasympathetic recovery after cognitive demand, consistent with models of autonomic flexibility (Hansen et al., 2003; Thayer & Lane, 2000; Thayer et al., 2012). Together, these results highlight a familiar dissociation: perceived stress can vary even when physiological activation remains stable, particularly in non-clinical samples and under mild laboratory challenge (Ali et al., 2017; Weber et al., 2022).

At the cognitive level, students in the later adaptation phase showed better delayed DM and better time-based PM, suggesting that adaptation may especially benefit memory processes dependent on consolidation and self-initiated monitoring. This pattern is compatible with evidence that stress-related cortisol dynamics can disrupt hippocampal consolidation processes and delayed recall (Klier et al., 2020; Osborne et al., 2015; Sabia & Hupbach, 2020), and with the distinction between time-based and event-based PM, where time-based tasks demand sustained self-initiated monitoring (McDaniel & Einstein, 2000; Stewart & McFarland, 2020). Interestingly, cortisol AUCg predicted

better delayed memory and WM, aligning with evidence that moderate glucocorticoid activity can facilitate memory consolidation when levels remain within adaptive ranges (Elzinga & Roelofs, 2005; Jiang et al., 2019; Sabia & Hupbach, 2020), while detrimental effects are more typical under prolonged dysregulation (McEwen, 2007).

Finally, HRV reactivity showed a modest negative association with event-based PM. Given the limited literature on HRV–PM link, this domain-specific and counterintuitive pattern suggests that autonomic–cognitive associations may depend strongly on task demands and attentional strategies, and that HRV recovery may reflect disengagement from cue monitoring under certain conditions. The broader implication is that endocrine and autonomic systems may contribute to cognition in partially independent ways, shaped by appraisal, context, and task characteristics.

The last study of this Thesis, the fifth study, provided an integrative model of vulnerability and resilience by testing whether HRV moderated the pathway linking loneliness to PM through SMCs. Across the full sample, loneliness was robustly associated with greater SMCs, consistent with evidence that perceived social disconnection is reliably linked to cognitive concerns in daily life (Guarnera et al., 2023; Luchetti et al., 2025). Notably, effects emerged specifically for trait loneliness, supporting recent multidimensional psychometric work suggesting that dispositional loneliness may exert more stable influence on cognitive self-appraisal than transient isolation or relational connectedness (Bottaro et al., 2023). Trait loneliness, as an enduring tendency toward emotional detachment and self-focused processing, may promote heightened cognitive self-monitoring and negative appraisal of minor memory failures (Cacioppo et al., 2010; Hawkley & Cacioppo, 2010).

Crucially, moderated mediation analyses showed that among exchange students, trait loneliness predicted higher SMCs, which in turn related to poorer event-based PM performance, but only under conditions of low resting HRV. At higher HRV levels, the indirect pathway diminished, supporting the interpretation that autonomic flexibility buffers the translation of subjective cognitive concerns into measurable performance decrements. This aligns with Neurovisceral Integration Perspectives suggesting that higher vagal tone supports flexible emotional and cognitive regulation under stress (Thayer & Lane, 2009) and extends prior work by demonstrating that HRV also conditions how social-emotional vulnerability influences cognitive outcomes.

The fact that this pattern emerged specifically among study-abroad students underscores the importance of context: mobility involves disruption of routines, reduced face-to-face support, and acculturative demands that may amplify loneliness processes and their cognitive consequences (Sawir et al., 2008; Smith & Khawaja, 2011; Tanaka et al., 2024). The specificity for event-based PM, and the absence of effects for time-based PM, is also theoretically coherent: event-based PM depends more on cue-triggered attentional processes, whereas time-based PM relies more heavily on sustained strategic monitoring and executive load, which may overshadow subtle psychosocial effects (Cona et al., 2015; Kliegel et al., 2008; McDaniel & Einstein, 2000).

Therefore, these studies directly address ***General Objective 2*** by examining how physiological regulation contributes to cognitive adaptation during academic mobility and by testing whether physiological flexibility buffers vulnerability associated with stress and loneliness. Study 4 adopts a phase-based perspective on adaptation, comparing international students assessed shortly after arrival with those evaluated after several months abroad. The findings indicate that perceived stress decreases in the FAP group, while endocrine and autonomic activity remain relatively stable, highlighting a partial dissociation between psychological appraisal and physiological activation during non-clinical mobility contexts. Importantly, cognitive benefits emerged selectively for delayed DM and time-based PM in the later adaptation phase, suggesting that prolonged exposure to the host environment supports memory processes dependent on consolidation and self-initiated monitoring. Within this framework, moderate cortisol output was associated with better memory performance, consistent with an adaptive role of glucocorticoid activity when physiological regulation remains within functional ranges. Autonomic dynamics further revealed domain-specific associations, with HRV reactivity modestly predicting event-based PM, underscoring that endocrine and autonomic systems may contribute to cognition through partially independent and task-sensitive pathways. Study 5 extends this physiological perspective by explicitly testing regulatory flexibility as a buffering mechanism. Using a moderated mediation model, it demonstrates that among exchange students, trait loneliness predicts greater SMCs and poorer event-based PM only under conditions of low resting HRV, whereas higher HRV attenuates this vulnerability pathway. This finding may be interpreted as consistent with the possibility that autonomic flexibility contributes to moderating the association between psychosocial vulnerability and objective cognitive performance during mobility. Together, these

studies converge in showing that physiological regulation does not merely reflect stress exposure but actively shapes cognitive adaptation and resilience in mobile young adults, clarifying when stress and loneliness translate into cognitive inefficiency and when regulatory capacity supports adaptive functioning.

Based on the results obtained, a biopsychosocial model of cognitive vulnerability and adaptation in young adults can be proposed. Across the thesis, two complementary pathways emerge: a subjective vulnerability pathway, where perceived stress, neuroticism, loneliness, and psychological inflexibility shape how young adults monitor, interpret, and report their cognitive functioning (Studies 1, 2, 5). Second, a modulation pathway, where physiological regulation (HPA and especially HRV) does not consistently predict cognition directly, but conditions vulnerability by shaping the strength of psychological–cognitive links (Studies 1, 3, 5). In this framework, SMCs and prefrontal symptoms can be understood as psychobiological phenomena emerging from the interplay between emotional dispositions, regulatory processes, and social context, especially under prolonged or destabilizing transitions.

This integration is particularly relevant in contemporary settings marked by uncertainty and mobility. Post-pandemic conditions and academic relocation represent converging forms of social disruption that challenge both psychological and physiological regulatory systems. The present findings suggest that not all individuals respond similarly: those with higher dispositional vulnerability (e.g., neuroticism, harm avoidance, low self-directedness, trait loneliness) and reduced regulatory capacity (e.g., low HRV) may be more likely to experience amplified cognitive self-perception difficulties and, under some conditions, measurable memory costs, especially for PM, a domain tightly linked to self-initiated control.

Limitations

Each study in this work addressed its own specific methodological constraints. Therefore, this section focuses on overarching limitations and directions that apply across the project. First, most designs were cross-sectional or relied on independent group comparisons, which restrict causal inference and limit conclusions about within-person change over time. Although this approach was appropriate for the exploratory and integrative aims of the Thesis, longitudinal and intensive repeated-measure designs would

be necessary to capture dynamic trajectories of stress regulation, loneliness, and cognitive functioning across transitional contexts. A second limitation concerns sample composition. In some studies, sample size and sex/gender imbalance constrained the possibility of systematically examining sex/gender-related effects, despite evidence that sex/gender differences may influence stress appraisal, endocrine activity, and autonomic regulation. Larger and more balanced samples would allow future research to model individual differences more robustly and to test potential sex/gender-related moderators.

Strengths

This Doctoral Thesis presents several strengths that contribute to its conceptual and methodological coherence in examining cognitive functioning in young adulthood. One of these lies in its integrative perspective, grounded in a biopsychosocial framework that considers biological, psychological, and social influences on cognitive vulnerability and adaptation. The inclusion of endocrine and autonomic indicators alongside personality traits, stress appraisal, loneliness, and contextual living conditions allows to progressively identify multiple factors relevant to functioning during periods of social change across the different studies.

Another strength lies in the depth with which academic mobility is examined as a context of adaptation. The research considers experiences shortly after the post-pandemic reopening period, follows different stages of the mobility trajectory, and includes comparison with peers residing in their home environments. This approach allows mobility to be investigated in greater depth than is typically addressed in the literature, supporting a more comprehensive understanding of how cognitive and psychosocial functioning relate to ongoing adaptation rather than isolated relocation events.

The Thesis also reflects analytical depth through its examination of specific cognitive domains, particularly PM and executive-related processes, which are considered sensitive to self-regulatory demands. Across studies, PM appeared responsive to periods of instability and transition, while psychological inflexibility and autonomic flexibility were identified as potential mechanisms through which vulnerability profiles may relate to perceived, and in some cases measurable, cognitive difficulties.

Taken together, these features provide a coherent and ecologically informed examination of cognitive vulnerability and adaptation. By integrating multiple levels of

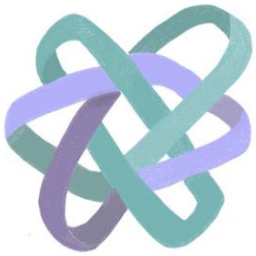
analysis and situating findings within meaningful transitional contexts, the Thesis offers insights that may inform future research and applied work in university and mobility settings.

Future directions

Future research should extend this framework by adopting longitudinal designs that track individuals before, during, and after major transitions such as academic mobility, allowing causal modeling of adaptation and resilience processes. Experimental and intervention-based studies targeting psychological flexibility, social connectedness, and autonomic regulation may also clarify whether modifying these processes leads to measurable improvements in cognitive functioning and well-being. Furthermore, research should incorporate denser physiological sampling, ambulatory monitoring, and ecological momentary assessment to better capture real-life regulatory dynamics and their temporal coupling with psychological states and cognitive performance. Additionally, although subjective cognitive measures were central to the research questions, the inclusion of broader objective neurocognitive batteries and neurobiological markers (e.g., neuroimaging or inflammatory indices) could further expand understanding of the mechanisms linking psychosocial vulnerability to cognitive outcomes.

CHAPTER IX

CONLUSIONS



Conclusions

The main conclusions reached in this Doctoral Thesis are presented below:

1) Higher levels of perceived stress and neuroticism are associated with greater SMCs in young adults in the post-pandemic context.

2) Chronic physiological stress markers (i.e., HC and HDHEA) do not directly predict SMCs, however, they influence the conditions under which psychological vulnerability is associated with subjective cognitive functioning in young adults in the post-pandemic context.

3) A personality profile characterized by high harm avoidance and low self-directedness is associated with greater self-perceived prefrontal symptomatology.

4) Psychological inflexibility mediates the relationship between personality traits and self-perceived prefrontal symptomatology, acting as a potential central mechanism underlying this association.

5) Living alone abroad and being separated from one's usual familial environment was associated with higher levels of perceived loneliness; however, no significant differences were observed in hair cortisol or HRV. At the cognitive level, this group demonstrated poorer objective memory performance, particularly in WM and PM, but not in DM.

6) Physiological stress indicators (cortisol and HRV) did not show consistent direct associations with memory performance, suggesting that their contribution to cognitive outcomes in young adults is modest and context-dependent.

7) Loneliness moderated the association between physiological stress indicators and memory performance. This interaction was observed specifically for PM and primarily at moderate to high levels of perceived loneliness.

8) Perceived stress differed across adaptation phases during academic mobility, with lower levels reported at more advanced stages, whereas endocrine and autonomic indicators did not show consistent differences. This pattern suggests a partial dissociation between subjective and physiological stress responses.

9) Endocrine and autonomic indicators were selectively associated with memory performance: cortisol levels were related to DM and WM outcomes, whereas HRV reactivity showed modest and task-specific associations with PM, suggesting domain-dependent physiological contributions to cognition.

10) Greater loneliness predicts poorer event-based PM performance through higher SMC scores when resting HRV is lower, specifically among students engaged in academic mobility. This finding highlights the importance of autonomic flexibility in cognitive vulnerability during prolonged transitional processes.

CHAPTER X

GENERAL SUMMARY IN SPANISH

General summary in Spanish

10. Introducción

10.1 Transiciones contextuales y adaptación psicosocial en la adultez joven

10.1.1 Movilidad académica como contexto contemporáneo de estrés

En un mundo cada vez más globalizado, una proporción creciente de estudiantes de grado cursa experiencias académicas fuera de su país de origen con el fin de mejorar sus oportunidades profesionales, adquirir competencias interculturales y fomentar el desarrollo personal (Shkoler & Rabenu, 2023; Zimmermann et al., 2017). Paralelamente, la rápida internacionalización de la educación superior ha transformado las trayectorias académicas a nivel mundial, consolidando la participación global como una prioridad estratégica institucional e impulsando una expansión sostenida de la movilidad estudiantil internacional (Ahrari et al., 2019). Como resultado, la movilidad académica se ha convertido en una experiencia evolutiva normativa para muchos adultos jóvenes, integrada en procesos más amplios de transformación educativa, económica y social.

A pesar de los beneficios académicos y personales asociados a la movilidad internacional, los estudiantes suelen enfrentarse a una constelación de estresores académicos, culturales y psicosociales, entre los que se incluyen barreras lingüísticas, nostalgia por el hogar, choque cultural, discriminación y aislamiento social (Almurideef, 2016; Hasnain & Hajek, 2022). En consonancia con esta acumulación de demandas, las poblaciones de estudiantes internacionales han mostrado un aumento sostenido de dificultades de salud mental durante la última década, especialmente en términos de soledad, ansiedad y síntomas depresivos (Forbes-Mewett & Sawyer, 2016; Zheng et al., 2023).

La adaptación durante la movilidad internacional no constituye un resultado estático, sino un proceso dinámico que se despliega a lo largo del tiempo. La investigación longitudinal sobre adaptación de residentes temporales, incluyendo trabajos derivados del modelo tradicional en curva en U, indica que los niveles de estrés suelen fluctuar a lo largo de la trayectoria de movilidad, con un incremento inicial seguido con frecuencia de una mejora gradual a medida que las personas se familiarizan con el entorno receptor

[1]Las abreviaturas empleadas en este capítulo remiten a los términos en inglés utilizados a lo largo de la Tesis, con el propósito de garantizar la coherencia terminológica

(Demes & Geeraert, 2015). La Evidencia más reciente en educación superior muestra igualmente que el estrés aculturativo y la nostalgia tienden a disminuir durante el primer semestre o año académico, mientras que la satisfacción y la competencia sociocultural aumentan progresivamente (English et al., 2020; Zhao, 2024).

Es importante destacar que estas trayectorias son altamente heterogéneas. Algunos estudiantes experimentan entusiasmo inicial seguido de dificultades posteriores, mientras que otros presentan niveles relativamente estables o persistentemente bajos de estrés, lo que subraya una variabilidad interindividual sustancial en las rutas adaptativas (Brown & Holloway, 2008; Dailey-Strand, 2021; Hirai et al., 2015).

La adaptación psicológica, entendida habitualmente como bienestar subjetivo y sensación de comodidad en el entorno receptor, está fuertemente influida por la disponibilidad y calidad del apoyo social, uno de los factores protectores más consistentes frente al estrés aculturativo (Zhang & Goodson, 2011). Por tanto, la adaptación exitosa depende no solo de la exposición a la novedad cultural, sino también de la capacidad individual para establecer redes interpersonales de apoyo que faciliten la regulación emocional, amortigüen el estrés y promuevan un sentido de pertenencia en el contexto de acogida.

En este marco, la conectividad social hace referencia a la red de relaciones significativas físicas y virtuales que las personas mantienen con individuos, lugares e instituciones (Tran & Gomes, 2017). Para estudiantes internacionalmente móviles, establecer y mantener conexiones sociales constituye un componente clave del ajuste intercultural, aunque suele presentar desafíos importantes, especialmente durante la transición hacia un nuevo entorno sociocultural (Cao & Meng et al., 2022). Cuando el acceso a relaciones de apoyo es limitado o inestable, aumenta la vulnerabilidad a la soledad, el malestar emocional y la exposición prolongada al estrés, lo que puede socavar la capacidad adaptativa y comprometer el funcionamiento cognitivo y psicosocial.

Estos desafíos se hicieron particularmente evidentes durante la pandemia de COVID-19, cuando las restricciones de salud pública limitaron las interacciones presenciales, trasladaron la actividad académica a formatos en línea y, en muchos casos, dejaron a estudiantes internacionales socialmente aislados y financieramente vulnerables en los países de acogida (Sin et al., 2025). La pandemia amplificó vulnerabilidades estructurales preexistentes asociadas a la movilidad académica y subrayó la importancia

de comprender cómo las disrupciones sociales a gran escala interactúan con las diferencias individuales en regulación del estrés y capacidad adaptativa en adultos jóvenes (Zhang et al., 2023).

Más allá del contexto pandémico, estos fenómenos reflejan un patrón más amplio de cambio social acelerado caracterizado por inestabilidad, relocalización y transiciones repetidas. Para los adultos jóvenes que cursan estudios superiores, tales entornos generan demandas adaptativas sostenidas que pueden superar los recursos regulatorios disponibles, incrementando la probabilidad de tensión psicológica y consecuencias cognitivas posteriores. En consecuencia, la movilidad académica y las condiciones posteriores a la pandemia pueden conceptualizarse no como estresores aislados, sino como expresiones convergentes de la transformación social contemporánea que ejercen presión prolongada sobre los sistemas adaptativos individuales.

10.1.2 Soledad como vulnerabilidad psicosocial central en adultos jóvenes

La soledad ha emergido como una vulnerabilidad psicosocial destacada en sociedades contemporáneas marcadas por cambios sociales rápidos, movilidad geográfica y una creciente disrupción de redes interpersonales estables. Aunque la soledad afecta a las personas a lo largo del ciclo vital, la evidencia indica que su prevalencia es notable durante la adultez joven (18–30 años) y que puede conllevar un mayor estigma social en esta etapa del desarrollo (Hawkley et al., 2022). Esta vulnerabilidad se amplificó de manera sustancial durante la pandemia de COVID-19: las medidas de confinamiento prolongadas y las alteraciones de las rutinas sociales cotidianas redujeron significativamente las oportunidades de contacto interpersonal, contribuyendo al aumento de la soledad y al deterioro de la salud mental (Groarke et al., 2020; Pierce et al., 2020).

Más allá de su impacto psicológico inmediato, la soledad crónica se asocia de forma robusta con mayores riesgos de resultados adversos de salud física y mental, incluyendo ansiedad, depresión, problemas cardiovasculares e incremento de la mortalidad (Cacioppo & Cacioppo, 2014; Martín-María et al., 2020). En particular, los adultos jóvenes parecen haber sido afectados de manera desproporcionada por estas disrupciones sociales, lo que subraya la necesidad de investigación centrada en este grupo evolutivo (Groarke et al., 2020).

La soledad se define habitualmente como la discrepancia subjetiva entre las relaciones sociales deseadas y las realmente existentes, reflejando déficits percibidos en

la cantidad o calidad de la conexión social, más que el aislamiento social objetivo en sí mismo (Hawkley & Cacioppo, 2010; Russell et al., 1978). Por tanto, las personas pueden experimentar soledad a pesar de tener contacto social frecuente, mientras que otras pueden vivir en relativo aislamiento sin percibirse necesariamente como solas (De Jong Gierveld & Tesch-Roemer, 2012). No obstante, las reducciones en el compromiso social objetivo incrementan la probabilidad de soledad, especialmente bajo condiciones de disrupción ambiental (DyKstra, 2006).

Desde una perspectiva evolutiva, la soledad se entiende como un sistema adaptativo de alarma que señala amenazas a la pertenencia social y a la supervivencia. Los seres humanos son intrínsecamente sociales y dependen de los vínculos interpersonales para la protección, el cuidado y la cooperación a lo largo del ciclo vital (Baumeister & Leary, 1995). Históricamente, la exclusión social aumentaba la vulnerabilidad ante amenazas ambientales, lo que hacía biológicamente adaptativa la sensibilidad a la desconexión social. En consecuencia, la soledad genera estados afectivos aversivos que motivan la reconexión con los demás (Cacioppo et al., 2014, 2015). Sin embargo, cuando la soledad se vuelve persistente en lugar de transitoria, se asocia consistentemente con mayor reactividad al estrés, regulación emocional deteriorada y carga fisiológica acumulativa (Park et al., 2020). Así, aunque la soledad a corto plazo puede promover conductas sociales adaptativas, la soledad crónica constituye un factor de riesgo significativo para la desregulación psicológica y biológica.

Los estudiantes internacionalmente móviles constituyen una población con riesgo elevado de soledad debido a la separación geográfica de las redes de apoyo establecidas, la exposición al estrés aculturativo, las barreras lingüísticas y las dificultades iniciales para formar relaciones significativas y estables en los entornos de acogida (Sawir et al., 2008; Wawera & McCamley, 2020). Como resultado, muchos estudiantes experimentan la paradoja de estar socialmente rodeados, pero emocionalmente aislados, un rasgo angustiante y cada vez más común de la vida contemporánea del estudiantado internacional (Zheng et al., 2023).

La evidencia psicométrica reciente indica además que la soledad no constituye un constructo unitario, sino que comprende múltiples dimensiones interrelacionadas. Los análisis de la UCLA Loneliness Scale identifican al menos tres componentes: Aislamiento (reducción objetiva del contacto social), Conectividad relacional

(dificultades percibidas para mantener relaciones interpersonales significativas) y Soledad rasgo, que refleja un sentido más duradero y disposicional de desapego emocional (Bottaro et al., 2023). Este marco multidimensional resulta especialmente relevante en contextos interculturales y de movilidad, donde el aislamiento físico temporal y una soledad emocional más persistente pueden ejercer efectos cognitivos y fisiológicos diferenciados.

10.2 Biomarcadores psicofisiológicos de la regulación del estrés: vías endocrinas y autonómicas

Las respuestas fisiológicas al estrés proporcionan índices objetivos de cómo los individuos regulan las demandas ambientales y mantienen la homeostasis. En este contexto, los biomarcadores derivados de los sistemas endocrino y autonómico ofrecen información valiosa sobre diferencias individuales en vulnerabilidad y resiliencia. Entre estos sistemas, el eje Hipotálamo Hipófisis-Adrenal (HPA) y el Sistema Nervioso Autónomo (ANS) han recibido particular atención debido a su papel central en la coordinación de las respuestas al estrés y sus vínculos establecidos con el funcionamiento cognitivo.

10.2.1 Biomarcadores endocrinos y exposición al estrés a largo plazo: cortisol y DHEA

El eje HPA es un sistema neuroendocrino central que sostiene la adaptación a demandas psicológicas y fisiológicas mediante la secreción coordinada de esteroides adrenales (Herman et al., 2016). Dentro de este sistema, el cortisol, el principal glucocorticoide en humanos, se ha utilizado ampliamente como un indicador clave de actividad fisiológica relacionada con el estrés, dado que facilita procesos catabólicos, metabólicos e inmunosupresores tanto durante el estrés agudo como crónico (Noushad et al., 2021). En contraste, la dehidroepiendosterona (DHEA) ha recibido creciente atención como biomarcador adrenal complementario debido a sus propiedades moduladoras y contrarreguladoras, incluyendo efectos anabólicos, neuroprotectores y anti-glucocorticoides (Buoso et al., 2011; Kamin & Kertes, 2017). En conjunto, estas hormonas proporcionan una representación más integradora del funcionamiento del HPA axis y de la regulación fisiológica relacionada con el estrés. Es importante señalar que ambas hormonas pueden cuantificarse mediante muestras biológicas no invasivas, como

pelo o saliva, que capturan ventanas temporales distintas de la función endocrina y refuerzan su valor como biomarcadores en investigación del estrés.

Un reto metodológico clásico en la investigación del eje HPA es que la secreción de cortisol es altamente dinámica y está fuertemente determinada por la ritmicidad circadiana y por influencias situacionales momentáneas (Androulakis, 2021). Por ello, el cortisol salival es particularmente informativo cuando el objetivo es caracterizar la actividad neuroendocrina a corto plazo bajo condiciones controladas (p. ej., sesiones de laboratorio, carga cognitiva aguda o recuperación) (Hellhammer et al., 2009). Sin embargo, los enfoques basados en una única muestra están limitados por la variabilidad asociada al momento del día y por estresores diarios transitorios. Para abordar esto, los protocolos de muestreo repetido permiten derivar índices resumen como el área bajo la curva con respecto al suelo (AUCg), que refleja la producción total de cortisol a través de múltiples puntos temporales y proporciona una estimación más estable de la actividad endocrina durante el periodo muestreado (Pruessner et al., 2003). Este enfoque es especialmente útil al examinar asociaciones entre activación endocrina y rendimiento cognitivo, ya que reduce el ruido vinculado a mediciones aisladas.

Más allá de los índices a corto plazo, ha aumentado la atención hacia marcadores endocrinos que capturan exposición acumulativa. El cortisol en cabello (HC) proporciona una estimación integrada de la secreción de cortisol a lo largo de semanas o meses, reduciendo la confusión derivada de la variación diurna y de efectos situacionales agudos (Russell et al., 2012; Stalder & Kirschbaum, 2012). Por ello, la evaluación basada en cabello se ha posicionado como una estrategia particularmente prometedora para estudiar la fisiología del estrés crónico, especialmente en contextos caracterizados por demandas adaptativas prolongadas. Avances paralelos han extendido este enfoque al DHEA en cabello (HDHEA), ofreciendo un marcador retrospectivo adicional de la actividad adrenal a largo plazo (Buoso et al., 2011; Kamin & Kertes, 2017).

De forma crucial, los biomarcadores del eje HPA no solo son relevantes como indicadores de exposición al estrés, sino también porque están implicados en la regulación de los procesos cognitivos. Existe evidencia que vincula la actividad glucocorticoide elevada con peor rendimiento cognitivo, siendo los procesos de memoria que dependen de la integridad hipocampal particularmente sensibles a la desregulación neuroendocrina relacionada con el estrés (véase la revisión de Lupien et al., 2007). Hallazgos empíricos

más recientes indican además que niveles elevados de estrés, especialmente bajo condiciones de inestabilidad ambiental y menor interacción social, se asocian con descensos medibles en múltiples dominios de memoria, incluyendo La memoria de trabajo (WM), la memoria declarativa (DM) y la memoria prospectiva (PM) (Ingram et al., 2021; Llana et al., 2024; Pisano et al., 2021; Ouanes & Popp, 2019). En conjunto, estos hallazgos subrayan la relevancia de los marcadores endocrinos del estrés para comprender diferencias individuales en vulnerabilidad cognitiva y funcionamiento adaptativo.

Complementando los hallazgos basados en saliva, el HC se ha utilizado cada vez más para examinar asociaciones entre exposición endocrina a largo plazo y funcionamiento cognitivo en distintas poblaciones (Feeney et al., 2020; Llorens et al., 2023; McLennan et al., 2016; Oumohand et al., 2020; Pulopulos et al., 2014; Santoso et al., 2022). Los resultados son mixtos tanto en la dirección como en los dominios cognitivos. Se han reportado asociaciones positivas con atención y memoria en adolescentes (Llorens et al., 2023), mientras que, en adultos mayores, tanto una exposición más baja como más alta al cortisol se han vinculado con peores resultados de memoria (Feeney et al., 2020; Pulopulos et al., 2014;). Otros estudios informan asociaciones nulas entre habilidades cognitivas o resultados longitudinales tras controlar con factiores como edad y sexo (McLennan et al., 2016; Oumohand et al., 2020; Santoso et al., 2022). En general, el predominio de estudios en muestras de mayores o heterogéneas genera una comprensión limitada de estas relaciones en adultos jóvenes y en contextos donde las demandas psicosociales crónicas probablemente sean relevantes, lo que subraya la necesidad de investigación adicional en estas poblaciones.

10.2.2 Biomarcadores autonómicos: Variablidad de la frecuencia cardíaca (HRV) y flexibilidad regulatoria

Complementando los marcadores endocrinos del estrés, el ANS representa una segunda vía regulatoria central mediante la cual se coordinan dinámicamente la activación fisiológica, la regulación emocional y el funcionamiento cognitivo. La HRV, definida como las fluctuaciones temporales entre latidos consecutivos, proporciona un índice no invasivo y sensible de flexibilidad autonómica y control vagal (Forte et al., 2019; Thayer & Sternberg, 2006). La HRV refleja la interacción continua entre influencias simpáticas y parasimpáticas sobre el nodo sinoauricular, capturando la

capacidad del organismo para ajustar rápidamente estados fisiológicos en respuesta a demandas ambientales y desafíos internos.

Desde una perspectiva regulatoria, el nervio vago representa la principal vía parasimpática que conecta los sistemas neurales centrales con el control cardiovascular, comúnmente indexado mediante la VFC. Estudios experimentales y psicofisiológicos indican que la VFC mediada por el nervio vago se asocia con las respuestas de cortisol ante el estrés. Por ejemplo, se ha demostrado que la estimulación del nervio vago atenúa la liberación de cortisol inducida por el estrés (Cuberos Paredes et al., 2025), y que una mayor VFC mediada vagalmente se relaciona con diferencias en la reactividad del cortisol frente al estrés (Pellissier et al., 2014; Pulopulos et al., 2018), en consonancia con modelos que proponen un acoplamiento funcional entre la regulación autonómica y la del eje hipotalámico-hipofisario-adrenal (Thayer y Sternberg, 2006). Asimismo, un tono vagal reducido se ha asociado con una menor capacidad de regulación emocional y una menor adaptabilidad al estrés, lo que sugiere que la flexibilidad autonómica puede sustentar una regulación afectiva y cognitiva adaptativa (Chida y Hamer, 2008; Reyes del Paso et al., 2013). En conjunto, estos hallazgos sugieren que la flexibilidad autonómica constituye un sustrato fisiológico que favorece la regulación adaptativa en los dominios afectivo y cognitivo.

La base teórica que vincula la HRV con la regulación cognitiva se articula en el Modelo de Integración Neurovisceral, el cual propone que la HRV constituye un indicador de la integridad funcional de una red distribuida prefrontal–subcortical implicada en el control ejecutivo, la regulación atencional, la modulación emocional y la flexibilidad conductual (Thayer & Lane, 2000, 2009). Esta red incluye la corteza prefrontal, la corteza cingulada anterior, la ínsula, la amígdala y los núcleos autonómicos del tronco encefálico, configurando en conjunto la red autonómica central, que integra la regulación cognitiva y visceral (Thayer & Lane, 2009). En este marco, la HRV puede reflejar la eficiencia del control inhibitorio y la capacidad de asignar de manera flexible recursos atencionales y regulatorios ante demandas cambiantes de la tarea.

En consonancia con este modelo, una HRV en reposo más alta se ha relacionado con un mejor funcionamiento ejecutivo, cognición global y rendimiento de memoria en poblaciones sanas (Forte et al., 2019; Frewen et al., 2013). Una revisión sistemática amplia con más de 19.000 participantes concluyó que una actividad parasimpática

reducida y una dominancia simpática aumentada se asocian de forma fiable con peor rendimiento en múltiples dominios cognitivos, incluyendo atención, velocidad de procesamiento, funciones ejecutivas y memoria, incluso en muestras no clínicas (Forte et al., 2019). Estos hallazgos respaldan la idea de que la desregulación autonómica puede preceder o acompañar ineficiencias cognitivas sutiles, situando la HRV como un biomarcador temprano potencial de vulnerabilidad regulatoria.

Más allá de índices en reposo, los cambios dinámicos de la HRV mediada vagalmente durante el compromiso cognitivo aportan información adicional sobre flexibilidad regulatoria. En particular, índices del dominio temporal como la RMSSD se han asociado con mayor control atencional, flexibilidad cognitiva y respuesta adaptativa durante el desempeño en tareas (Schaich et al., 2020; Sharma et al., 2023). Las personas que muestran mayor modulación de HRV relacionada con la tarea tienden a exhibir una coordinación ejecutiva más eficiente y una mejor capacidad para regular demandas cognitivas y emocionales competitivas. Por el contrario, se ha observado una reactividad de HRV reducida en individuos con mayor reactividad emocional, menor regulación atencional y respuestas conductuales rígidas (Park & Thayer, 2014), lo que refuerza la idea de sustratos neurales compartidos que sostienen regulación autonómica, procesamiento emocional y control ejecutivo.

Es importante destacar que la HRV también se ha implicado en procesos de vulnerabilidad social y afectiva. Una HRV en reposo menor se ha asociado con menor capacidad de compromiso social, regulación emocional deteriorada y mayor sensibilidad a estresores psicosociales, incluyendo la soledad (Roddick et al., 2021). Estos hallazgos sugieren que individuos con menor flexibilidad autonómica pueden ser especialmente vulnerables a los costes cognitivos y emocionales de la desconexión social, un patrón altamente relevante en contextos caracterizados por movilidad, aislamiento e inestabilidad social.

A pesar de una fuerte convergencia teórica, los estudios empíricos que examinan asociaciones directas entre HRV y respuestas de cortisol durante la exposición al estrés a menudo informan relaciones débiles, inconsistentes o dependientes del contexto (Altemus et al., 2001; Bosch et al., 2009; Looser et al., 2010; pero véase Doussard-Roosevelt et al., 2003). Esta variabilidad probablemente refleja heterogeneidad metodológica, diferencias

en paradigmas de estrés, dinámica temporal diferencial entre respuestas endocrinas y autonómicas, y diferencias individuales en capacidad regulatoria.

En conjunto, la HRV proporciona una ventana fisiológica complementaria hacia la flexibilidad regulatoria, capturando la capacidad del sistema autonómico para coordinar de manera dinámica respuestas cognitivas, emocionales y fisiológicas ante demandas ambientales. En adultos jóvenes expuestos a estresores psicosociales acumulativos, como la disrupción postpandémica y la movilidad académica internacional, la regulación autonómica puede desempeñar un papel moderador crítico en la configuración de la resiliencia, la vulnerabilidad y el funcionamiento cognitivo.

10.3 Funcionamiento cognitivo subjetivo: quejas de memoria y percepción de síntomas prefrontales

La memoria es una función psicológica central que sustenta la codificación, el almacenamiento y la recuperación de información, permitiendo una comunicación eficiente, el aprendizaje y la conducta adaptativa en la vida diaria. En individuos sanos, estos procesos suelen operar de manera automática y permanecen en gran medida fuera de la conciencia (Sridhar, 2023). Sin embargo, cuando se percibe un descenso en la eficiencia de la memoria, las personas suelen informar fallos cotidianos como olvidar nombres, citas, material aprendido o dificultades en planificación y organización temporal; estas experiencias se conceptualizan comúnmente como fallos o quejas subjetivas de memoria (SMCs) (Reid & MacLullich, 2006).

Las SMCs se refieren a dificultades de memoria autoinformadas que ocurren en ausencia de un deterioro cognitivo objetivo claro (Broadbent et al., 1982; Molinuevo et al., 2017). En general, las SMCs han atraído un gran interés científico por su potencial papel como indicadores tempranos de deterioro cognitivo y demencia en adultos mayores (Balash et al., 2013; Mitchell et al., 2014; Wang et al., 2004). Estudios epidemiológicos y clínicos han mostrado que, en etapas tardías de la vida, las quejas subjetivas se asocian de manera modesta pero consistente tanto con el rendimiento cognitivo objetivo como con un mayor riesgo a largo plazo de desarrollar condiciones neurodegenerativas (Burmester et al., 2016; Mitchell et al., 2014).

Sin embargo, evidencia creciente indica que las SMCs no son exclusivas de poblaciones envejecidas. Un número cada vez mayor de adultos jóvenes informa preocupaciones relacionadas con la memoria en contextos clínicos y no clínicos, incluso

cuando las evaluaciones neuropsicológicas estandarizadas no detectan deterioros cognitivos objetivos (Csábi et al., 2025; Molina-Rodríguez et al., 2018; Pellicer-Porcar et al., 2014). No obstante, la significación funcional y la relevancia clínica de las SMCs en adultos jóvenes cognitivamente sanos permanecen peor establecidas que en poblaciones mayores.

Es importante señalar que, aunque muchos estudios no demuestran déficits objetivos robustos, cierta evidencia sugiere que pueden emerger asociaciones sutiles entre SMCs y rendimiento cognitivo cuando se consideran perfiles individuales de vulnerabilidad. Por ejemplo, adultos jóvenes con SMCs más elevadas pueden mostrar pequeñas diferencias en atención, funcionamiento ejecutivo o eficiencia de memoria, incluso dentro de rangos normativos (Crespo-Sanmiguel et al., 2024; Ruiz-Sánchez de León et al., 2010).

Evidencia acumulada indica además que la vulnerabilidad emocional y los rasgos de personalidad desempeñan un papel central en la configuración de percepciones cognitivas subjetivas en adultos jóvenes. Niveles más altos de neuroticismo, así como estrés percibido elevado, ansiedad y síntomas depresivos, predicen consistentemente mayores SMCs (Crespo-Sanmiguel et al., 2024; Csábi et al., 2025; Lozoya et al., 2012).

Más allá de las quejas específicas de memoria, las personas con frecuencia informan un conjunto más amplio de dificultades cognitivas cotidianas relacionadas con atención, planificación, control inhibitorio, monitorización y regulación emocional. Estas experiencias se describen comúnmente como sintomatología prefrontal subjetiva, reflejando ineficiencias percibidas en el funcionamiento ejecutivo sustentado por redes prefrontales (Pedrero & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014). Incluso en poblaciones no clínicas, entre el 6% y el 26% de los adultos reporta lapsos cotidianos recurrentes consistentes con una ineficiencia ejecutiva leve, incluyendo distractibilidad, respuestas impulsivas, mala organización y menor flexibilidad cognitiva (Llanero et al., 2008; Lozoya et al., 2012; Pedrero et al., 2009). Estudios empíricos indican además que las personas con niveles más altos de quejas ejecutivas subjetivas tienden a mostrar un rendimiento ligeramente menor (aunque aún normativo) en tareas de atención, memoria y función ejecutiva (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2010), lo que apoya la validez ecológica de estas autopercepciones.

Es importante destacar que las SMCs y los síntomas prefrontales subjetivos no son constructos independientes, sino que reflejan dimensiones solapadas del funcionamiento cognitivo percibido en la vida cotidiana. Los fallos de memoria en contextos naturalistas frecuentemente se originan en ineficiencias del control atencional, la planificación, la monitorización y el mantenimiento de objetivos, procesos ejecutivos centrales sustentados por la circuitería prefrontal (Pedrero et al., 2013; Terán-Mendoza, 2016). De hecho, el rendimiento de la memoria depende fuertemente de mecanismos de control ejecutivo que gobiernan la codificación y la recuperación (McCabe et al., 2010). En línea con esta visión, se ha sugerido que las SMCs se relacionan de manera más consistente con descensos en la función ejecutiva y el control atencional que con déficits puros de memoria episódica (Hohman et al., 2011). Estudios de neuroimagen respalda adicionalmente este solapamiento, mostrando conectividad funcional reducida y activación frontal alterada en individuos con SMCs incluso en ausencia de deterioro objetivo de memoria (López-Sanz et al., 2017). Además, en muestras más jóvenes, estas preocupaciones suelen co-ocurrir con dificultades ejecutivas cotidianas e ineficiencias atencionales más que con una pérdida episódica medible (Pellicer-Porcar et al., 2014). En consecuencia, las SMCs suelen estar mediadas por disfunción ejecutiva y atencional más que por déficits mnésicos primarios por sí solos.

La adultez joven representa una ventana evolutiva particularmente sensible para el desarrollo de funciones cognitivas ejecutivas y prefrontales. Durante esta etapa, la corteza prefrontal continúa madurando, apoyando el refinamiento progresivo del control ejecutivo, la autorregulación y la conducta dirigida a metas (Diamond, 2013). Aunque la mayoría de las personas alcanza una eficiencia cognitiva creciente, un subgrupo de adultos jóvenes experimenta dificultades subclínicas persistentes que se vuelven más salientes en entornos académicos y sociales de alta demanda (Cazan & Schiopca, 2014; Montenegro et al., 2013). Estas ineficiencias percibidas suelen acompañarse de malestar emocional, menor adaptabilidad y mayor sensibilidad a estresores diarios (Hammud et al., 2023), reforzando la experiencia subjetiva de vulnerabilidad cognitiva.

Desde una perspectiva dimensional, la sintomatología prefrontal percibida y las SMCs pueden conceptualizarse como indicadores continuos de eficiencia ejecutiva–mnésica cotidiana (Ruiz-Sánchez de León et al., 2014). Las diferencias individuales en personalidad y regulación emocional modulan además cómo se perciben y reportan las ineficiencias cognitivas (Crespo-Sanmiguel et al., 2024). Rasgos relacionados con

reactividad emocional, impulsividad y capacidad autorregulatoria se han vinculado con variabilidad en funcionamiento cognitivo subjetivo y fallos cognitivos cotidianos (DeYoung, 2010; Markett et al., 2020; Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Robinson & Wilkowski, 2015). En consecuencia, las SMCs pueden captar una señal psicológica integradora que refleja la interacción entre el control ejecutivo, la vulnerabilidad emocional y la exposición a estrés ambiental.

10.3.1 SMCs, Sintomatología prefrontal y estrés percibido

En contextos de elevado estrés ambiental, el estrés percibido ha emergido como un predictor particularmente relevante de las SMCs (Molina-Rodríguez et al., 2028; Santos et al., 2012). El estrés percibido refleja la valoración que realizan las personas de sus vidas como impredecibles, abrumadoras o superiores a sus recursos disponibles de afrontamiento, y se ha asociado consistentemente con menor confianza cognitiva, menor autoeficacia mnésica y mayor sensibilidad a lapsos cognitivos cotidianos (Könen & Karbach, 2020; Pearman, 2009).

La investigación en poblaciones de adultos jóvenes indica que el estrés percibido no solo se relaciona directamente con las SMCs, sino que también interactúa con procesos de control ejecutivo esenciales para el funcionamiento efectivo de la memoria cotidiana. En una muestra amplia de estudiantes universitarios, Molina-Rodríguez et al. (2018) demostraron que el estrés percibido y la disfunción ejecutiva se asocian con las SMCs, desempeñando las dificultades atencionales y ejecutivas un papel central. De forma importante, los problemas ejecutivos y atencionales mediaron parcialmente la relación entre el estrés percibido y las SMCs, sugiriendo que el estrés puede influir en las quejas mnésicas cotidianas a través de su impacto en procesos de control cognitivo de orden superior más que mediante un deterioro primario de la memoria.

La evidencia convergente respalda además el papel de la sintomatología prefrontal como contribuyente clave a las SMCs en adultos jóvenes. Diversos estudios han mostrado que los síntomas prefrontales se asocian significativamente tanto con el estrés percibido como con las SMCs, pudiendo ejercer un efecto directo sobre estas quejas y mediar simultáneamente el impacto del estrés sobre las autopercepciones cognitivas (López-Guerra et al., 2022; Ruiz-Sánchez de León et al., 2014). Este patrón concuerda con modelos neuropsicológicos más amplios que enfatizan el papel central de los sistemas ejecutivos prefrontales en la coordinación de recursos atencionales, mantenimiento de

objetivos y monitorización de errores durante actividades dependientes de memoria (Ruiz-Sánchez de León et al., 2014).

En consonancia con este marco, la investigación indica que niveles elevados de estrés pueden perturbar funciones de control ejecutivo como asignación atencional, control inhibitorio y planificación, que son críticas para la codificación, monitorización y recuperación exitosas en contextos cotidianos (Shields et al., 2016). Cuando estos mecanismos regulatorios se ven comprometidos, las personas pueden experimentar fallos diarios más frecuentes e interpretar estos lapsos como problemas de memoria, reforzando las quejas cognitivas subjetivas incluso cuando el rendimiento objetivo permanece dentro de límites normales.

Finalmente, los estados afectivos asociados habitualmente al estrés percibido, incluyendo afecto negativo, ansiedad y síntomas depresivos, parecen ejercer una influencia mayor sobre las SMCs que el propio rendimiento cognitivo objetivo. Evidencia reciente en adultos jóvenes sugiere que el malestar emocional y las ineficiencias ejecutivas contribuyen en mayor medida a las SMCs que los déficits mnésicos reales, apoyando la idea de que las SMCs reflejan principalmente alteraciones en automonitorización, reactividad emocional y control regulatorio (Csábi et al., 2025).

10.4 Rendimiento de memoria objetivo: WM, DM y PM

El funcionamiento de la memoria desempeña un papel central en el rendimiento académico y la autorregulación cotidiana, apoyando el mantenimiento y la manipulación temporal de información, la adquisición y la retención de conocimiento, y la ejecución de intenciones futuras (Baddeley et al., 2021; Walter & Meier, 2014). Dentro de la investigación cognitiva, tres sistemas de memoria resultan particularmente relevantes para comprender el funcionamiento adaptativo en adultos jóvenes: WM, DM y PM (Ashcraft & Kirk, 2001; Cowan et al., 2005; Einstein & McDaniel, 1990; Riedel & Blokland, 2015).

La WM se refiere a la capacidad para mantener y manipular temporalmente información con el fin de apoyar operaciones cognitivas complejas como razonamiento, comprensión y resolución de problemas (Ashcraft & Kirk, 2001; Cowan et al., 2005). Está críticamente implicada en tareas académicas que requieren atención sostenida, multitarea y flexibilidad cognitiva, lo que la hace altamente sensible a la carga cognitiva y a estresores ambientales. La DM, en contraste, engloba la adquisición y recuperación

consciente de hechos y eventos, apoyando el aprendizaje, la acumulación de conocimiento académico y la retención a largo plazo (Riedel & Blokland, 2015).

Más allá de la WM y la DM, la PM ha recibido creciente atención debido a su papel central en la conducta autorregulada y el funcionamiento académico. La PM se refiere a la capacidad para formar, mantener y ejecutar acciones intencionadas en el momento adecuado en el futuro, descrita a menudo como la capacidad de "recordar recordar" en la vida cotidiana (Einstein & McDaniel, 1990). A diferencia de la memoria retrospectiva, centrada en recordar información pasada, la PM sostiene la conducta dirigida a metas permitiendo traducir intenciones en acciones oportunas, como acudir a citas o completar tareas planificadas (McDaniel & Einstein, 2000). Esta función desempeña un papel clave en la autorregulación, ya que una PM eficaz permite gestionar responsabilidades y organizar actividades diarias de manera independiente (Mahy et al., 2014). Su funcionamiento depende en gran medida de procesos ejecutivos como inhibición, actualización, monitorización y flexibilidad cognitiva, que coordinan el mantenimiento de intenciones con demandas ambientales en curso (Martin & Kliegel, 2003; Schnitzspahn et al., 2013).

La PM se clasifica habitualmente en dos tipos principales: PM basada en tiempo y PM basada en evento. La primera implica ejecutar una intención en un momento específico y depende en gran medida de la monitorización temporal auto-iniciada y del control atencional sostenido, mientras que la segunda se activa por señales externas del entorno y generalmente requiere menos recursos cognitivos (Su et al., 2024; Talbot et al., 2014). En la vida cotidiana, las personas suelen mantener intenciones mientras realizan tareas simultáneas, lo que incrementa las demandas de control cognitivo (Cheie et al., 2021). Esta distinción funcional ilustra cómo diferentes tareas de PM dependen de niveles variables de monitorización interna y apoyo ambiental.

La investigación neurocientífica indica que la PM está sustentada por la actividad coordinada de regiones prefrontales y parietales, que permanecen activas a lo largo de las distintas fases del procesamiento de la intención (Burgess et al., 2011). Estas áreas ayudan a mantener acciones previstas en memoria, monitorizar objetivos en el tiempo y reducir interferencias de tareas competidoras o distracciones externas. Esta red neural interactúa con procesos cognitivos clave como memoria retrospectiva, funciones ejecutivas y atención, permitiendo recordar qué debe hacerse y ejecutar la acción en el momento

apropiado (Ellis, 1996; Mahy et al., 2014). Cuando aumentan las demandas atencionales, el rendimiento en PM puede disminuir particularmente en jóvenes (Bisiacchi et al., 2008). Asimismo, la metamemoria y la motivación apoyan el control estratégico y el compromiso sostenido en la ejecución de acciones previstas (Schneider & Lockl, 2008).

10.4.1 Soledad, estrés y rendimiento de memoria objetivo

Los mecanismos mediante los cuales el aislamiento social y la soledad influyen en el rendimiento cognitivo objetivo aún no se comprenden completamente. Sin embargo, algunos modelos teóricos proponen que la soledad activa un estado de vigilancia social elevada caracterizado por pensamientos intrusivos, rumiación y mayor reactividad al estrés, lo que puede desviar recursos cognitivos del procesamiento dirigido a metas (Cacioppo & Cacioppo, 2018; Cacioppo & Hawkley, 2009). Esta reasignación cognitiva implicaría vías neuroendocrinas, incluyendo activación del eje HPA e incremento de la secreción de cortisol, que pueden afectar posteriormente a sistemas de memoria sensibles a la modulación por estrés (Herman et al., 2016; McEwen, 2008).

Evidencia emergente sugiere que la soledad se asocia con activación sostenida de vías neuroendocrinas relacionadas con el estrés, lo que podría incrementar la vulnerabilidad a efectos cognitivos posteriores. En un estudio reciente, niveles más altos de soledad percibida en adolescentes se asociaron con mayores concentraciones de HC, indicando mayor actividad crónica del eje HPA (Anderson et al., 2024). Dado que la exposición prolongada al cortisol se ha vinculado con deterioro en sistemas de memoria dependientes de redes prefrontales e hipocampales (Lupien et al., 2007; Ouanes & Popp, 2019), la desregulación endocrina asociada a la soledad puede aumentar la susceptibilidad de dominios cognitivos sensibles al estrés. En particular, la PM podría ser especialmente vulnerable debido a su fuerte dependencia del control auto-iniciado, la monitorización ejecutiva y procesos motivacionales sensibles al estrés crónico y a la carga regulatoria (McDaniel & Einstein, 2007).

La evidencia empírica derivada de la pandemia de COVID-19 ofrece una oportunidad para observar cómo la disrupción social prolongada y la exposición al estrés se traducen en cambios medibles en el funcionamiento de la memoria, aunque los resultados siguen siendo heterogéneos. Pisano et al. (2021) observaron que las medidas de confinamiento restrictivo se asociaron con un incremento de fallos mnésicos percibidos y una reducción objetiva del rendimiento en WM y PM. Por su parte, Ingram

et al. (2021) informaron mejoras en WM a medida que aumentaban las oportunidades de interacción social entre personas que vivían solas. En conjunto, la magnitud, dirección y persistencia de estos efectos cognitivos siguen siendo inconclusas (Llana et al., 2022). Mientras que la hipervigilancia a corto plazo puede tener funciones adaptativas, la activación sostenida de estados cognitivos relacionados con el estrés puede deteriorar gradualmente la eficiencia ejecutiva, comprometer el funcionamiento inmunitario e incrementar la vulnerabilidad a resultados adversos de salud (Quadt et al., 2020).

10.5 Vulnerabilidad emocional y cognitiva: personalidad e inflexibilidad psicológica

Las diferencias individuales en sensibilidad al estrés y funcionamiento cognitivo no pueden explicarse de formas plena únicamente por las demandas contextuales. Una proporción sustancial de la variabilidad en cómo los adultos jóvenes perciben, regulan y se adaptan al estrés (particularmente en entornos de alta demanda como la movilidad académica internacional) parece ser moldeada por disposiciones de personalidad estables que influyen en la reactividad emocional, las estrategias de afrontamiento y la capacidad de autorregulación. Por tanto, integrar marcos de personalidad que vinculan tendencias afectivas con el control cognitivo ofrece una lente útil para comprender la vulnerabilidad a dificultades cognitivas subjetivas y objetivas.

Los rasgos de personalidad se conceptualizan comúnmente como patrones relativamente duraderos de pensar, sentir y comportarse que predisponen a los individuos a responder de manera consistente a través de situaciones (Roberts, 2009). Su relativa estabilidad temporal sustenta su valor como predictores de resultados psicológicos y de salud a largo plazo, aunque cierta evidencia sugiere que acontecimientos vitales extremos o prolongados pueden moldear en cierta medida la expresión de los rasgos a lo largo del tiempo (Cobb-Clark & Schurer, 2012; Elkins et al., 2017). Dos aproximaciones complementarias han sido especialmente influyentes para caracterizar diferencias individuales relevantes para el estrés y la cognición: la taxonomía de rasgos de los 5 Grandes (Big Five, McCrae & Costa, 1987) y el Modelo Psicobiológico de Temperamento y Carácter de Cloninger (TCR; Cloninger, 1993).

Dentro del marco de los 5 Grandes, el neuroticism representa una dimensión central de vulnerabilidad caracterizada por una tendencia persistente hacia el afecto negativo, mayor sensibilidad a la amenaza y una percepción amplificada del estrés

(McCrae & Costa, 1987; 2010). Un cuerpo robusto de investigación indica que un mayor neuroticism se asocia con menor confianza cognitiva, menor precisión metamnemónica y una mayor frecuencia de fallos cognitivos y SMCs (Könen & Karbach, 2018; Reid et al., 2006). Aunque otros rasgos como la responsabilidad pueden ejercer una influencia protectora, el neuroticismo emerge de forma consistente como el correlato de personalidad más fuerte de la vulnerabilidad cognitiva subjetiva. Estos hallazgos sugieren que la afectividad negativa no solo configura el funcionamiento afectivo, sino también cómo las personas monitorizan, interpretan y evalúan su eficiencia cognitiva cotidiana.

Una perspectiva complementaria la aporta el Modelo Psicobiológico de Cloninger, que integra explícitamente la reactividad neurobiológica con el desarrollo autorregulatorio de orden superior (Cloninger, 1993). Este marco distingue dimensiones temperamentales, enraizadas en tendencias de respuesta emocional influidas genéticamente y en sistemas subcorticales, de dimensiones de carácter, que reflejan autorregulación aprendida y dependen en mayor medida de la integración prefrontal. Esta distinción es especialmente informativa para comprender el funcionamiento cognitivo relacionado con lo prefrontal, ya que vincula directamente la sensibilidad emocional con procesos de control dirigidos a metas. Dentro de este modelo, la evitación al daño refleja una sensibilidad incrementada a la amenaza y el castigo, mientras que la autodirección capta la capacidad de regulación autónoma, orientación a metas y autocontrol adaptativo (De Fruyt et al., 2000). La evidencia empírica respalda la relevancia de esta configuración temperamento–carácter para el funcionamiento cognitivo cotidiano. Las personas caracterizadas por alta evitación al daño combinada con baja autodirección tienden a informar SMCs más frecuentes y menor eficiencia ejecutiva (Pedrero-Pérez et al., 2013). Una autodirección más alta se ha asociado con un funcionamiento ejecutivo más sólido, mayor capacidad de toma de decisiones y estrategias de afrontamiento más adaptativas, mientras que niveles más bajos se vinculan con impulsividad y peor control autorregulatorio (Reijnen et al., 2018; Ruiz-Sánchez de León et al., 2014). En contraste, una evitación al daño elevada se asocia con preocupación anticipatoria, vigilancia y afrontamiento orientado a la evitación, lo que puede amplificar la reactividad al estrés y restringir la flexibilidad cognitiva bajo condiciones demandantes (Gabrys et al., 2018; Schreiber et al., 2012). La evidencia en neuroimagen indica además que la evitación al daño se relaciona con variabilidad funcional y estructural en sistemas prefrontales

implicados en control cognitivo y monitorización del conflicto (Hu et al., 2016; Zhong et al., 2024).

Más allá de descripciones a nivel de rasgo, la inflexibilidad psicológica aporta un mecanismo orientado a procesos mediante los cuales la vulnerabilidad de personalidad puede traducirse en dificultades emocionales y cognitivas. La inflexibilidad psicológica se refiere a patrones rígidos de respuesta ante experiencias internas y demandas ambientales, a menudo caracterizados por evitación experiencial y una capacidad reducida para adaptar la conducta de acuerdo con metas a largo plazo (Bond et al., 2006; Latzman & Masuda, 2013). Niveles más altos de inflexibilidad se han asociado de forma consistente con malestar emocional, sintomatología relacionada con el estrés y vulnerabilidad transdiagnóstica en trastornos de ansiedad y depresión (Kashdan & Rottenberg, 2010; Ortega-Jiménez et al., 2021; Ruiz, 2014; Shen et al., 2024), así como con menor control cognitivo y menor flexibilidad en procesos atencionales y ejecutivos (Doorley et al., 2020; Grant & Cassidy, 2022). En este sentido, la inflexibilidad psicológica puede reflejar la expresión funcional de una reactividad emocional elevada combinada con una capacidad autorregulatoria limitada, alineándose estrechamente con perfiles de vulnerabilidad indexados por alta evitación al daño y baja autodirección. La evidencia sugiere además que la inflexibilidad media asociaciones entre vulnerabilidad de personalidad y resultados como estrés, soledad y desregulación emocional (Guerrini Usubini et al., 2022; Orouji et al., 2022; Ortega-Jiménez et al., 2021).

Estos procesos de vulnerabilidad pueden hacerse especialmente salientes durante la movilidad académica internacional, un contexto caracterizado por incertidumbre, novedad, reconfiguración social y mayores demandas cognitivas y emocionales. Los rasgos de personalidad influyen en cómo las personas se implican en estas transiciones, configurando estrategias de afrontamiento, tolerancia a la ambigüedad y capacidad de ajuste sociocultural (Barańczuk, 2019). Las personas con mayor estabilidad emocional y apertura tienden a mostrar trayectorias de ajuste más adaptativas, mientras que quienes presentan rasgos elevados relacionados con la ansiedad exhiben mayor sensibilidad al estrés y afrontamiento desadaptativo en entornos académicos novedosos (Chamorro-Premuzic & Furnham, 2003). Rasgos de implicación social como extraversión y amabilidad pueden apoyar adicionalmente la adaptación al facilitar la formación de redes de apoyo en los contextos de acogida (Barańczuk, 2019).

Aunque la investigación empírica sobre perfiles de personalidad de estudiantes internacionalmente sigue siendo limitada y metodológicamente heterogénea, los estudios existentes indican que ciertas disposiciones de personalidad se vinculan con variación en las experiencias de movilidad. Rasgos relacionados con sociabilidad y busquedad de novedad se han asociado con una adaptación más exitosa y mayor implicación social en entornos de acogida (p.e., menor ansiedad, mayor sociabilidad y mayor impulso exploratorio) en estudiantes de intercambio o internacionales (Muro et al., 2022). Además, dimensiones como la apertura a la experiencia y la extraversión se han relacionado positivamente con la competencia intercultural y procesos de ajuste durante la movilidad internacional (Chédru & Ostapchuk, 2025). En cambio, niveles más altos de neocriticismo, se asocian con mayores dificultades de ajuste, destacando cómo los rasgos afectivos de personalidad pueden moldear respuestas de estrés psicosocial en contextos de movilidad (Mohamud & Madderla, 2024).

De manera importante, estos perfiles de vulnerabilidad basados en personalidad no solo se asocian con malestar emocional, sino también con cómo las personas perciben y experimentan su funcionamiento cognitivo cotidiano. Rasgos marcados por emocionalidad negativa elevada y menor capacidad regulatoria se vinculan de forma consistente con SMCs y sintomatología prefrontal relacionada con actividad prefrontal en poblaciones sanas (Pedrero-Pérez et al., 2013; Reid et al., 2006; Ruiz-Sánchez de León et al., 2014). Las personas con niveles altos de neuroticismo o evitación al daño tienden a informar lapsos atencionales más frecuentes, dificultades de planificación y preocupaciones mnésicas, incluso cuando el rendimiento objetivo permanece intacto (Launay et al., 2026; Pedrero-Pérez & Ruiz-Sánchez de León, 2013). Es probable que estas percepciones reflejen una monitorización amplificada de errores internos, mayor sensibilidad a fluctuaciones cognitivas relacionadas con el estrés y menor tolerancia a ineficiencias cotidianas, más que un deterioro neurocognitivo franco. En paralelo, una autodirección baja y una inflexibilidad psicológica elevada pueden comprometer la automonitorización ejecutiva y la regulación adaptativa (Moeck et al., 2023; Ruiz-Sánchez de León et al., 2010), contribuyendo adicionalmente a experiencias subjetivas de ineficiencia cognitiva y desorganización conductual.

En conjunto, la evidencia convergente indica que los adultos jóvenes que transitan contextos de cambio social elevado e incertidumbre, como la recuperación post-pandemia y la movilidad académica internacional, están expuestos a demandas psicosociales

sostenidas que desafían la regulación emocional, los sistemas fisiológicos del estrés y el funcionamiento cognitivo. Los indicadores subjetivos, incluyendo las SMCs y sintomatología prefrontal percibida, parecen captar señales tempranas de tensión regulatoria, mientras que el rendimiento objetivo de memoria (WM, DM y PM) aporta marcadores funcionales complementarios de capacidad adaptativa. A nivel biológico, biomarcadores endocrinos y autonómicos ofrecen información sobre exposición acumulativa al estrés y eficiencia regulatoria. De forma crucial, estos procesos están incrustados en diferencias individuales estables, incluyendo vulnerabilidad basada en personalidad (p. ej., neuroticismo, evitación al daño, autodirección) e inflexibilidad psicologica, que configuran cómo las demandas ambientales se perciben, regulan y se traducen en resultados cognitivos

Objetivos e hipótesis

El objetivo general de esta Tesis Doctoral fue examinar cómo el estrés psicosocial y la soledad, junto con mecanismos de regulación fisiológica, se asocian con el funcionamiento cognitivo subjetivo y objetivo en adultos jóvenes expuestos a contextos de cambio social (movilidad académica internacional y condiciones post-pandemia). En concreto, esta Tesis integra indicadores subjetivos de dificultades cognitivas (SMCs y sintomatología prefrontal percibida), rendimiento objetivo de memoria (WM, DM, PM) y biomarcadores de regulación del estrés (índices del eje HPA y HRV), considerando además factores disposicionales de vulnerabilidad (p. e., emocionalidad negativa relacionada con la personalidad y la inflexibilidad psicológica).

Los objetivos generales de esta Tesis Doctoral son dos:

1) Examinar cómo el estrés psicosocial y los factores de vulnerabilidad se asocian con el funcionamiento cognitivo subjetivo en adultos jóvenes, con especial atención a las SMCs y a la sintomatología prefrontal autopercibida.
2) Investigar cómo los indicadores fisiológicos de regulación del estrés (endocrinos y autonómicos) se asocian con el rendimiento objetivo en memoria durante la movilidad académica en contextos pospandémicos, analizando el papel de los factores de vulnerabilidad (soledad, estrés percibido) en estas asociaciones.

Para abordar estos objetivos generales, se han realizado cinco estudios empíricos con los siguientes objetivos específicos e hipótesis

Estudio 1

Este estudio tuvo como objetivo examinar, en adultos jóvenes tras la pandemia de COVID-19: (i) si los factores de vulnerabilidad psicológica (neuroticismo y estrés percibido) y los biomarcadores del eje HPA (HC y HDHEA) se asociaban con las SMCs; y (ii) si dichos biomarcadores moderaban la relación entre estos factores de vulnerabilidad y las SMCs. Estos objetivos se desarrollan en el Capítulo III.

Se esperaba que mayores niveles de neuroticismo (Könen & Karbach, 2020; Sutin et al., 2020) y de estrés percibido (Molina-Rodriguez et al., 2016) se asociaran con mayores SMCs, dado que los fallos cognitivos subjetivos se relacionan más estrechamente con características de personalidad y procesos vinculados al estrés que con el rendimiento cognitivo objetivo. La evidencia indica que el neuroticismo se asocia consistentemente con un mayor número de SMCs (Sutin et al., 2020), y que el estrés percibido contribuye sustancialmente a las SMCs en adultos jóvenes (Molina-Rodriguez et al., 2016). Dada la evidencia mixta respecto a los marcadores endocrinos y la cognición subjetiva en adultos jóvenes, las asociaciones que implicaban medidas endocrinas basadas en cabello, incluyendo su posible papel moderador, se examinaron de manera exploratoria.

Estudio 2

El estudio examinó (i) si rasgos de personalidad como la evitación del daño y la autodirección se asociaban con la sintomatología prefrontal autopercibida, y (ii) si la inflexibilidad psicológica mediaba estas asociaciones en adultos jóvenes. Estos objetivos se desarrollan en el Capítulo IV.

Se esperaba que una mayor evitación del daño y una menor autodirección se asociaran con mayor sintomatología prefrontal. Esta expectativa se fundamenta en evidencia que vincula niveles elevados de evitación del daño con mayor reactividad emocional, preocupación anticipatoria, sensibilidad al estrés y alteraciones en la implicación de los sistemas reguladores prefrontales, procesos que pueden intensificar los fallos cognitivos percibidos (Gabrys et al., 2018; Hu et al., 2016; Zhong et al., 2024). Por otra parte, niveles bajos de autodirección se han asociado con peor autorregulación,

impulsividad, disfunción ejecutiva y menor control metacognitivo en poblaciones no clínicas (Pedrero-Pérez & Ruiz-Sánchez de León, 2013; Ruiz-Sánchez de León et al., 2014). Además, la combinación de alta evitación del daño y baja autodirección se ha identificado como un fuerte predictor de quejas cognitivas cotidianas (Pedrero-Pérez et al., 2013), respaldando su conceptualización como configuraciones de personalidad relacionadas con la vulnerabilidad que influyen en el funcionamiento ejecutivo percibido.

Asimismo, se planteó la hipótesis de que la inflexibilidad psicológica mediaría estas relaciones, de modo que mayor evitación al daño y menor autodirección predecirían mayor inflexibilidad, la cual a su vez predeciría mayor disfunción ejecutiva percibida. Esta hipótesis se apoya en evidencia que indica que la inflexibilidad psicológica refleja una integración deficiente entre la reactividad emocional y el control ejecutivo, incluyendo menor flexibilidad cognitiva y menor capacidad de cambio atencional (Bond et al., 2006; Grant et al., 2022; Kashdan & Rottenberg, 2010), y que contribuye a dificultades cognitivas y regulatorias asociadas al estrés en diversas poblaciones (Doorley et al., 2020; Orouji et al., 2022)

Estudio 3

Los objetivos de este estudio fueron: (i) analizar si las condiciones de convivencia durante la movilidad académica en el contexto pospandémico se asocian con el funcionamiento psicológico (soledad y estrés percibido), biológico (HC y HRV) y cognitivo (WM, DM y PM) en adultos jóvenes; (ii) examinar la relación entre los indicadores fisiológicos de regulación del estrés (cortisol y HRV) y el rendimiento en memoria; y (iii) evaluar el papel moderador de la soledad en la asociación entre regulación fisiológica y rendimiento mnésico. Estos objetivos se desarrollan en el Capítulo V.

Basándonos en la hipótesis de amortiguación social (Cohen & McKay, 1984) y en evidencia previa que vincula el aislamiento social y la disrupción contextual con malestar emocional, desregulación fisiológica y alteraciones cognitivas (Groarke et al., 2020; Hopf et al., 2022; Li & Wang, 2020; Newby et al., 2020), se planteó la hipótesis de que los individuos condiciones de convivencia más socialmente restringidas mostrarían experimentaban mayor percepción de soledad, una regulación fisiológica menos adaptativa, reflejada en niveles más elevados de cortisol y menor HRV y peor rendimiento

objetivo en memoria. Además, se hipotetizó que una regulación fisiológica menos adaptativa, se asociaría con peor rendimiento mnésico. Finalmente, se esperaba que la soledad moderara estas asociaciones, de modo que las relaciones negativas más intensas entre desregulación fisiológica y resultados de memoria se observaran en individuos con mayores niveles de soledad percibida.

Estudio 4

Este estudio examinó la movilidad académica en estudiantes evaluados en distintas fases de la movilidad (inicio vs. final de la estancia), (i) comparando en ambos grupos, el estrés percibido y los índices de regulación fisiológica (endocrina y autonómica) y (ii) si los indicadores endocrinos y autonómicos de regulación se asociaban con el rendimiento objetivo en memoria (WM, DM y PM). Estos objetivos se abordan en el Capítulo VI.

A partir de hallazgos previos, se esperaba que los estudiantes evaluados en la fase final de estancia informaran menores niveles de estrés percibido que aquellos evaluados poco después de su llegada (English et al., 2020; Zhao, 2024). En consonancia con modelos psicobiológicos que vinculan la exposición crónica al estrés con la desregulación del eje HPA y del funcionamiento autonómico (Forte & Casagrande, 2025; Hellhammer et al., 2009), también se anticipó una menor activación fisiológica del estrés en la fase tardía, reflejada en niveles más bajos de cortisol salival y una regulación autonómica más adaptativa (mayor HRV).

Apoyándonos en evidencia que indica que la secreción de cortisol y la regulación autonómica influyen en el funcionamiento de la memoria, se esperaba que una mayor liberación de cortisol se asociaría con peor rendimiento en WM (Oei et al., 2006), mientras que niveles más altos de HRV mediada vagalmente se asociarían con mejor rendimiento mnésico (Forte & Casagrande, 2025). Dado que la evidencia que vincula directamente la liberación integrada de cortisol con el rendimiento en PM en adultos jóvenes es limitada, las expectativas relativas a esta asociación se trataron de forma exploratoria.

Estudio 5

El objetivo de este estudio fue analizar si la soledad percibida (y sus distintas dimensiones) predice la PM a través de las SMCs teniendo en cuenta la HRV en reposo en adultos jóvenes durante la movilidad académica. Este objetivo se explora en el Capítulo VII.

Basándonos en evidencia que indica que la soledad interfiere con el control atencional, los procesos de memoria y la eficiencia cognitiva (Bangee et al., 2014; Batallas et al., 2024; Ingram et al., 2021), y considerando que la PM depende en gran medida de la monitorización ejecutiva y la detección de claves (McDaniel & Einstein, 2000; Talbot et al., 2014), se esperaba que mayores niveles de soledad predijeran peor rendimiento en PM basada en eventos y en el tiempo. Por lo tanto, se hipotetizó que las SMCs mediarían esta asociación, reflejando el vínculo entre vulnerabilidad emocional y funcionamiento cognitivo percibido (Crespo-Sanmiguel et al., 2024; Heffner et al., 2022).

En consonancia con los modelos de integración neurovisceral, también se esperaba que la HRV en reposo moderara la mediación previamente mencionada, de modo que el impacto negativo de la soledad sobre la PM a través de las SMCs fuera más intenso en individuos con menor HRV (Thayer & Lane, 2009; Forte et al., 2019). Finalmente, dado el aumento de las demandas psicosociales asociadas a estudiar en el extranjero, se anticipó que los efectos previamente mencionados serían más pronunciados en estudiantes internacionales en comparación con sus pares no desplazados (Greischel et al., 2018; Sawir et al., 2008).

Metodología

A continuación, se presenta una descripción integrada de la metodología incluyendo los participantes, el procedimiento, así como de las variables evaluadas e instrumentos empleados en los cinco estudios que componen la presente Tesis Doctoral.

Participantes

En esta Tesis Doctoral, tres de los estudios (Capítulos 3, 5 y 6) se desarrollaron íntegramente en el Laboratorio de Neurociencia Social Cognitiva de la Universitat de València (España). Los estudios expuestos en los capítulos 4 y 7, por su parte, se llevaron a cabo en colaboración con instituciones universitarias de Ecuador, manteniendo en todo momento procedimientos estandarizados y criterios homogéneos de selección de la

muestra. Concretamente, el estudio correspondiente al Capítulo 4 se realizó en universidades públicas y privadas de la ciudad de Loja (Ecuador), mediante la administración supervisada de cuestionarios en instalaciones universitarias. Finalmente, el último estudio (capítulo 7) fue fruto de una colaboración entre el Laboratorio de Neurociencia Social Cognitiva de la Universitat de València (para la evaluación del grupo en movilidad internacional) y la Universidad Internacional del Ecuador (para la evaluación del grupo control en el país de origen), garantizando la comparabilidad metodológica entre sedes en el marco de la estancia académica internacional.

Respecto a la población evaluada, los cinco estudios incluyeron adultos jóvenes universitarios con edades comprendidas entre 18 y 35 años. Todos los participantes eran hablantes nativos de español

En el estudio 1, la muestra final estuvo compuesta por 69 voluntarios sanos (6 hombres y 63 mujeres), con una edad media de M = 23.45; DT = 3.53, reclutados en la Universitat de València. Todos los participantes fueron seleccionados tras un cribado telefónico que evaluó criterios de inclusión/exclusión relacionados con salud general y factores con potencial impacto sobre el eje HPA y el rendimiento cognitivo.

El estudio 2 incluyó 501 estudiantes universitarios (284 hombres y 217 mujeres), con una edad media de M = 21.00; DT = 2.62, reclutados en universidades públicas y privadas de Loja (Ecuador). La selección se realizó mediante muestreo por conveniencia, y la participación se basó en voluntariedad y consentimiento informado.

El estudio 3 contó con 45 estudiantes con una media de edad de M = 25.6; DT = 3.107, reclutados en la Universitat de València. En este estudio, los grupos se establecieron en función de la situación residencial y de movilidad internacional durante los ocho meses previos al estudio: los integrantes de un grupo vivían solos tras experimentar cambios en el núcleo familiar y el desplazamiento internacional (Alone Group; n = 23) y los del otro grupo que vivían en su país de origen sin cambio del núcleo familiar (Not Alone Group; n = 22).

El estudio 4 incluyó 74 estudiantes participantes en un programa de intercambio académico internacional, distribuidos en dos grupos independientes: estudiantes evaluados durante el primer mes en el extranjero (Initial Adaptation Phase; n = 33) y

estudiantes evaluados al final de una estancia de cuatro meses (Final Adaptation Phase; n = 41). Las edades oscilaron entre 18 y 27 años, con una distribución de sexo similar entre grupos.

El último estudio 5 contó con una muestra de 83 estudiantes ecuatorianos distribuidos en un grupo en movilidad internacional (Study Abroad; n = 40) y un grupo que permanecía en su país de origen (Home-Based; n = 43), con edades entre 18 y 27 años (M = 19.98; EE = 0.44).

De manera general, en los estudios se aplicaron criterios de exclusión homogéneos, que incluyeron: la presencia de trastornos cardiovasculares o neuroendocrinos; antecedentes neurológicos o psiquiátricos (p. ej., esquizofrenia, trastorno bipolar, discapacidad intelectual o antecedentes de accidente cerebrovascular); problemas graves de visión o audición, o cualquier enfermedad asociada a alteraciones del sistema nervioso; consumo o abuso de alcohol u otras sustancias; y tabaquismo superior a 10 cigarrillos por día.

Procedimiento

Los cinco estudios siguieron diseños transversales o comparativos entre grupos independientes, con sesiones únicas de evaluación cuya duración osciló entre 60 y 120 minutos.

El Estudio 1 fue diseñado para examinar la asociación entre estrés percibido y vulnerabilidad afectiva (neuroticismo) con las SMCs, considerando además biomarcadores crónicos del eje HPA (cortisol y DHEA) medidos en cabello. Para ello, los participantes acudieron a una sesión única de aproximadamente 2 horas en la Universitat de València, realizada durante el periodo en el que persistían medidas preventivas post-pandémicas (p. ej., mascarillas, limitaciones de eventos y movilidad). El día anterior se indicaron recomendaciones estándar para minimizar interferencias fisiológicas (evitar ejercicio intenso 24 h antes; abstenerse de comer, fumar o consumir estimulantes al menos 2 h antes). Tras la firma del consentimiento informado, los participantes completaron cuestionarios estandarizados y un cuestionario sociodemográfico. Al final de la sesión se extrajeron tres mechones de pelo del vértex posterior con proximidad al cuero cabelludo, siguiendo recomendaciones de recogida y

conservación ampliamente utilizadas en investigación psicobiológica (Stalder & Kirschbaum, 2012).

El Estudio 2 tuvo como objetivo analizar el vínculo entre rasgos de personalidad (evitación del daño y autodirección), inflexibilidad psicológica y sintomatología prefrontal autopercibida en población universitaria. Para ello, los estudiantes completaron una administración supervisada de cuestionarios en instalaciones universitarias (duración aproximada 30–35 minutos).

El Estudio 3 se diseñó para estudiar las implicaciones de la soledad percibida y las condiciones de convivencia en indicadores psicológicos, biomarcadores (cortisol en cabello y HRV) y rendimiento en memoria. Los participantes acudieron a una sesión única de 55–60 minutos en la Universitat de València, bajo medidas preventivas vigentes. Previamente se indicaron recomendaciones similares (evitar estimulantes, tabaco y comida 2 h antes; evitar ejercicio intenso 24 h). El protocolo comenzó con una fase de habituación (10 minutos) para asegurar adaptación al entorno y estabilización fisiológica, durante la cual se colocó una banda torácica para registro cardiaco y se instruyó a los participantes a respirar con normalidad. A continuación, se realizó una serie de tareas de de memoria inmediata (20 minutos) y una fase posterior en la que se completaron cuestionarios y componentes diferidos de las pruebas cognitivas. Al finalizar la sesión se utilizó el mismo procedimiento de recolección de cabello que en el Estudio 1. El registro cardiovascular fue continuo durante toda la sesión.

En los Estudios 4 y 5, centrados en la adaptación a la movilidad académica, el grupo en movilidad fue evaluado en el laboratorio de la Universitat de València, mientras que el grupo sin movilidad fue evaluado en espacios habilitados en su universidad de origen (Ecuador), replicando el mismo procedimiento experimental. Todos los participantes completaron una única sesión experimental de aproximadamente 90 minutos. En el Estudio 4 se compararon dos grupos de estudiantes evaluados en distintas fases de su estancia académica mientras que en el Estudio 5 se incluyó un grupo control de estudiantes no desplazados.

El protocolo experimental se estructuró en tres fases secuenciales: (a) una fase de habituación de 10 minutos, durante la cual se colocó el sistema de registro fisiológico y se obtuvo la muestra salivar basal; (b) una fase de evaluación neuropsicológica de

aproximadamente 30 minutos, con registro continuo de la HRV para estimar la reactividad autonómica durante la demanda cognitiva; y (c) una fase de recuperación, en la que se administraron los cuestionarios psicológicos y se mantuvo el registro de HRV, finalizando con la recogida de una tercera muestra de saliva. La recogida de cortisol salivar (tres muestras mediante tubos tipo Salivette®) se realizó únicamente en las sesiones experimentales llevadas a cabo en Valencia. Las muestras de saliva fueron analizadas mediante técnicas de inmunoensayo (ELISA), siguiendo los procedimientos estandarizados en investigación psicobiológica.

Todos los estudios se realizaron de acuerdo con la Declaración de Helsinki y contaron con las aprobaciones éticas correspondientes: 1) OB_16_2025_UIDE_AF; 2) 1034878

Variables

Variables psicológicas

La soledad percibida se evaluó en los Estudios 3, 4 y 5 mediante la adaptación española de la escala UCLA Loneliness Scale (Russell et al., 1980; Vázquez & Jiménez, 1994). En el Estudio 5 se utilizaron las 3 dimensiones (aislamiento, conectividad relacional y soledad rasgo) propuesto en trabajos psicométricos recientes (Bottaro et al., 2023), calculándose medias por subescala y para el total.

El estrés percibido se midió en los Estudios 1, 3 y 4 con la Escala de Estrés Percibido (PSS) en su versión abreviada de 4 ítems (PSS-4), derivada de la escala original (Cohen et al., 1985) y validada en población española (Remor, 2006; Vallejo et al., 2018). El instrumento valora el grado en que las situaciones vitales se perciben como impredecibles o sobrecargantes durante el último mes.

El neuroticismo se evaluó en el Estudio 1 mediante la subescala correspondiente del NEO Inventario de cinco Factores (NEO-FFI; Costa & McCrae, 1992; adaptación española: Costa & McCrae, 1999), que cuantifica tendencia estable a experimentar afecto negativo mediante 12 ítems con respuesta Likert (1–5).

Los rasgos de personalidad Evitación del Daño y Autodirección se midieron en el Estudio 2 con la versión abreviada española del Inventario de Temperamento y Carácter

de 67-item (TCI-R-67; Cloninger, 1999; adaptación abreviada: Pedrero, 2009), centrando el análisis en dichas dimensiones por su relevancia para la autorregulación.

En el Estudio 3, la sintomatología depresiva se midió con la versión española del Inventario de Depresión de Beck (BDI-II; Beck et al., 1996; adaptación española: Perdig, 2003), instrumento de 21 ítems que evalúa síntomas cognitivos, somáticos y conductuales.

La inflexibilidad psicológica se evaluó en el Estudio 2 con el cuestionario de Aceptación y Acción (AAQ-II; Bond et al., 2011; adaptación española: Ruiz et al., 2013), un instrumento de 7 ítems (1–7) ampliamente utilizado para operacionalizar rigidez experiencial y evitación.

Variables cognitivas

La evaluación cognitiva integró medidas subjetivas y objetivas, con especial atención a sistemas de memoria relevantes en la vida cotidiana y el rendimiento académico.

Las SMCs se evaluaron en los Estudios 1, 3 y 5 mediante la versión española del cuestionario de Fallos de Memoria en la Vida Cotidiana MFE-30 (Sunderland et al., 1984 adaptación española: Lozoya-Delgado et al., 2012). Este instrumento consta de 30 ítems con formato Likert (0–4), donde puntuaciones más altas indican mayor frecuencia de fallos cotidianos.

La sintomatología prefrontal autopercibida se evaluó en el Estudio 2 mediante el Inventario de Síntomas Prefrontales (ISP; Ruiz et al., 2012), que estima dificultades en control ejecutivo, conducta social y regulación emocional a través de 46 ítems (0–4).

La WM se evaluó en los Estudios 3 y 4 mediante el Digit Span Test de la Wechsler Memory Scale-III (Wechsler, 1997), usando los subtest Forward y Backward, asociados a procesos atencionales/almacenamiento y componente ejecutivo, respectivamente (Conklin et al., 2000).

La DM se evaluó en los Estudios 3 y 4 con el Free and Cued Selective Reminding Test (FCSRT; Grober & Buschke, 1987; adaptación española: Labos et al., 2008). En el

Estudio 3 se calculó un índice de retención siguiendo propuestas previas para estimación del mantenimiento mnésico (Hidalgo et al., 2016), mientras que en el Estudio 4 se analizaron medidas de recuerdo inmediato y diferido (30 minutos).

La PM se evaluó con instrumentos ecológicos, semi-naturalistas. En el Estudio 3 se emplearon subtest del Rivermead Behavioral Memory Test (RBMT; Wilson et al., 1985), obteniéndose una puntuación total de PM a partir de varias tareas (pertenencia, cita, ruta y mensaje). En los Estudios 4 y 5 se utilizó el Royal Prince Alfred Prospective Memory Test (RPA-ProMem; Radford et al., 2011), diferenciando PM basada en eventos y basada en tiempo (Blondelle et al., 2020). En el Estudio 5 se incluyeron tanto tareas a corto plazo como a largo plazo (p. ej., envío de WhatsApp al llegar a casa; correo electrónico dos semanas después), siguiendo los criterios de puntuación estandarizados de la prueba.

Variables biológicas

El eje HPA se estudió mediante biomarcadores en saliva y en cabello. Concretamente, en el Estudio 4 se recogieron muestras de cortisol salivar con tubos de tipo Salivette® (Sarstedt), y las concentraciones se determinaron mediante ELISA (Salimetrics), siguiendo procedimientos estandarizados de almacenamiento, centrifugación y análisis.

En el Estudio 1 se analizaron HC y HDHEA, focalizando en los 4 cm proximales como índice de exposición acumulada durante aproximadamente cuatro meses, asumiendo un crecimiento medio de 1 cm/mes (Russell et al., 2012; Stalder & Kirschbaum, 2012). Las muestras fueron procesadas en el laboratorio del Prof. Kirschbaum (Technische Universität Dresden) mediante UPLC–MS/MS, siguiendo el protocolo de Wang et al. (2019). En el Estudio 3 se utilizó el mismo procedimiento de análisis de cortisol en cabello, con extracción en el vértex posterior y análisis en condiciones equivalentes (Stalder & Kirschbaum, 2012; Wang et al., 2019).

La HRV se evaluó en los Estudios 3, 4 y 5 como indicador de regulación autonómica y resiliencia fisiológica. Concretamente, en el Estudio 3 se empleó un dispositivo Polar RS800cx (muestreo 1000 Hz), y los registros se analizaron con Kubios, con corrección de artefactos y extracción de segmentos centrales conforme a

recomendaciones clásicas (Task Force, 1996). El índice principal fue RMSSD, considerado un marcador robusto de actividad vagal (Kleiger et al., 2005; Thayer & Lane, 2000), además de presentar menor sensibilidad a la respiración que ciertos parámetros de frecuencia (Hill & Siebenbrock, 2009).

En los Estudios 4 y 5 se registró la actividad cardiaca con el dispositivo VU-AMS (de Geus et al., 1995) y se calculó el índice RMSSD en los 5 minutos centrales de los diferentes periodos (habituación, tarea y recuperación). En el Estudio 4 se estimó, además, una medida de reactividad y recuperación autonómica a partir de cambios entre fases, mientras que en el Estudio 5 se consideró la HRV en reposo como índice de diferencias individuales estables en regulación autonómica.

Resultados principales

El primer estudio se centró en analizar la relación entre el estrés percibido, el neuroticismo y las SMCs en jóvenes durante el período postpandemia, así como el papel modulador de biomarcadores endocrinos crónicos del eje HPA. Los resultados mostraron que tanto el estrés percibido como el neuroticismo se asociaron con un mayor número de SMCs, indicando que la vulnerabilidad emocional, tanto a nivel estado (estrés percibido) como rasgo (neuroticismo), influye en la autoevaluación del funcionamiento cognitivo. Aunque los biomarcadores hormonales (HC y HDHEA) no se relacionaron directamente con las SMCs, sí actuaron como moduladores de la relación negativa entre las variables psicológicas y la percepción de la memoria, lo que sugiere que la fisiología del estrés condiciona la expresión de la vulnerabilidad psicológica más que determinar directamente el malestar cognitivo.

El segundo estudio amplió este enfoque al analizar cómo ciertos rasgos de personalidad (evitación del daño y autodirección) se relacionan con la sintomatología prefrontal percibida, considerando la inflexibilidad psicológica como un mecanismo mediador. Los resultados indicaron que una mayor evitación del daño y una menor autodirección se asocian con más dificultades percibidas en el control ejecutivo y emocional, y que esta relación se explica parcialmente por un estilo rígido de afrontamiento y regulación interna. Este estudio aporta evidencia de que sintomatología prefrontal percibida no depende únicamente de factores externos de estrés, sino también

de la forma en que las personas regulan sus experiencias internas y se adaptan a las demandas del entorno.

El tercer estudio examinó el impacto de la soledad y de las condiciones de convivencia durante el período postpandemia sobre indicadores psicológicos, fisiológicos y de rendimiento cognitivo. Los resultados mostraron que vivir solo en un país extranjero y con menor contacto presencial se asocia con mayor soledad, niveles ligeramente superiores de cortisol crónico y peor rendimiento en WM y PM. Además, la soledad moduló la relación entre cortisol y MP, indicando que el impacto fisiológico del estrés sobre la cognición es mayor en individuos con mayor percepción de soledad. Estos hallazgos refuerzan la importancia del contexto social como un factor clave en la vulnerabilidad cognitiva, incluso en poblaciones jóvenes y sanas.

El cuarto estudio abordó la adaptación al estudio en el extranjero como un contexto natural de estrés prolongado, comparando estudiantes evaluados al inicio de su estancia con estudiantes evaluados tras varios meses de adaptación. Los resultados mostraron una disminución del estrés percibido en la fase más avanzada de adaptación, aunque sin cambios claros en los indicadores fisiológicos. A nivel cognitivo, los estudiantes que se encontraban en una fase más avanzada de su movilidad internacional presentaron un mejor rendimiento en DM diferida y en PM basada en el tiempo. Este patrón sugiere que una mayor exposición al contexto de destino podría facilitar una adaptación progresiva al entorno, promoviendo procesos más eficientes de consolidación de la información y autorregulación cognitiva. Asimismo, se observó que mayores niveles de cortisol total se asociaron con un mejor rendimiento en WM y en recuerdo diferido de DM en ambos grupos, mientras que una mayor HRV se relacionó con un mejor desempeño en pm basada en eventos, apoyando una visión no lineal y específica por dominio de la relación entre activación fisiológica y cognición.

El quinto estudio integró los componentes psicológicos, sociales y fisiológicos al analizar cómo la soledad afecta el rendimiento en PM a través de las SMCs, y cómo la regulación autonómica actúa como un factor modulador de esta relación. Los resultados mostraron que la soledad rasgo se asocia con más SMCs y que, en estudiantes internacionales con baja regulación fisiológica, estas quejas predicen peor rendimiento en PM.

Discusión general

De forma integrada, los resultados de la presente Tesis Doctoral apuntan a dos patrones interpretativos principales. El primero corresponde a una vía de vulnerabilidad psicológica, en la que el estrés percibido, el neuroticismo, la soledad y la inflexibilidad psicológica incrementan la monitorización negativa del propio funcionamiento cognitivo y favorecen la aparición de quejas subjetivas y dificultades percibidas. El segundo patrón responde a una vía de modulación fisiológica, en la que los sistemas endocrino y autonómico no determinan de forma directa el rendimiento cognitivo, pero sí condicionan cuándo y en qué medida la vulnerabilidad psicológica se traduce en consecuencias cognitivas objetivas.

En este marco, puede proponerse un modelo biopsicosocial de vulnerabilidad y adaptación cognitiva en adultos jóvenes. A lo largo de los estudios, se observa que las SMCs y la percepción de sintomatología prefrontal no deben entenderse exclusivamente como indicadores de déficit, sino como fenómenos psicobiológicos que emergen de la interacción entre disposiciones emocionales, procesos regulatorios y contexto social. Especialmente en contextos de transición prolongada o inestabilidad como el período pospandémico o la movilidad académica internacional, estos procesos pueden intensificarse y hacerse más visibles.

La integración de indicadores endocrinos y autonómicos junto con variables de personalidad, evaluación del estrés, soledad y condiciones de convivencia ha permitido identificar mecanismos interrelacionados que contribuyen al funcionamiento cognitivo durante períodos de cambio social. Los hallazgos sugieren que no todos los individuos responden de la misma manera a estos contextos: aquellos con mayor vulnerabilidad disposicional (por ejemplo, neuroticismo, alta evitación del daño, baja autodirección o soledad rasgo) y menor capacidad regulatoria (por ejemplo, baja HRV) tienden a presentar mayores dificultades en la percepción de su funcionamiento cognitivo y, bajo determinadas condiciones, costes objetivos en dominios específicos como la PM, particularmente sensible a las demandas de autorregulación y control auto-iniciado.

En este sentido, la PM emerge como un dominio particularmente sensible a estos procesos. A diferencia de otros sistemas mnésicos, la PM requiere mantener intenciones futuras activas, detectar claves relevantes en el entorno e iniciar acciones de forma auto-

dirigida, lo que implica una elevada demanda de control ejecutivo y autorregulación. Esta característica la convierte en un indicador especialmente vulnerable en contextos de disrupción rutinaria, carga emocional sostenida o exigencias adaptativas prolongadas.

Asimismo, los resultados subrayan que la contribución fisiológica a la cognición en adultos jóvenes parece ser más moduladora que determinante. La regulación autonómica y endocrina no mostró efectos directos consistentes sobre el rendimiento mnésico, pero sí interactuó con variables psicológicas, configurando un gradiente de vulnerabilidad–resiliencia dependiente del contexto. Esto refuerza la idea de que la adaptación cognitiva en la juventud temprana es un proceso dinámico, sensible tanto a disposiciones individuales como a las demandas situacionales.

En conjunto, esta Tesis Doctoral contribuye a una comprensión más amplia del funcionamiento cognitivo en adultos jóvenes, destacando que las quejas subjetivas cognitivas y las variaciones en el rendimiento deben interpretarse dentro de un marco adaptativo y contextual. Estos hallazgos tienen implicaciones relevantes para el diseño de estrategias preventivas e intervenciones orientadas a fortalecer la regulación emocional, la flexibilidad psicológica, la conexión social y la resiliencia fisiológica en poblaciones jóvenes expuestas a entornos de cambio, incertidumbre y movilidad.

Limitaciones

A pesar de sus aportaciones, esta investigación presenta limitaciones que deben ser consideradas. En primer lugar, la mayoría de los diseños fueron transversales o se basaron en comparaciones entre grupos independientes, lo que limita la inferencia causal y la posibilidad de analizar cambios intraindividuales a lo largo del tiempo. Estudios longitudinales que sigan a los participantes antes, durante y después de transiciones relevantes permitirían modelar con mayor precisión las trayectorias dinámicas de adaptación.

En segundo lugar, en algunos estudios el tamaño muestral y el desequilibrio por sexo/género restringieron la posibilidad de analizar de manera sistemática posibles diferencias asociadas a estas variables, a pesar de que la literatura sugiere que pueden influir en la evaluación del estrés, la actividad endocrina y la regulación autonómica.

Futuros trabajos con muestras más amplias y equilibradas permitirían examinar moderadores individuales con mayor robustez.

Asimismo, aunque se incluyeron medidas fisiológicas relevantes, la evaluación fue puntual y limitada. Diseños con muestreo fisiológico ambulatorio podrían capturar con mayor precisión la dinámica regulatoria en contextos cotidianos. Finalmente, aunque las medidas subjetivas fueron centrales para los objetivos planteados, la incorporación de baterías neurocognitivas más amplias o de marcadores biológicos adicionales podría enriquecer la comprensión de los mecanismos implicados.

Líneas futuras de investigación

Las futuras investigaciones deberían ampliar este marco mediante diseños longitudinales que permitan modelar de forma causal los procesos de vulnerabilidad y resiliencia durante transiciones significativas como la movilidad académica. Asimismo, estudios experimentales o de intervención dirigidos a potenciar la flexibilidad psicológica, la conexión social o la regulación autonómica podrían esclarecer si la modificación de estos procesos se traduce en mejoras objetivas y subjetivas del funcionamiento cognitivo.

Además, la incorporación de evaluaciones ecológicas momentáneas y monitorización fisiológica ambulatoria permitiría examinar el acoplamiento temporal entre estados emocionales, regulación fisiológica y desempeño cognitivo en situaciones reales. Finalmente, integrar otros marcadores neurobiológicos o inflamatorios podría contribuir a profundizar en la comprensión de los mecanismos que vinculan vulnerabilidad psicosocial y resultados cognitivos en la juventud.

Conclusiones

Las principales conclusiones alcanzadas en la presente Tesis Doctoral se presentan a continuación:

1. Mayores niveles de estrés percibido y de neuroticismo se asocian con más SMCs en adultos jóvenes en el contexto pospandémico.
2. Los marcadores fisiológicos crónicos de estrés (HC y HDHEA) no predicen directamente las SMCs, pero influyen en las condiciones bajo las cuales la

vulnerabilidad psicológica se relaciona con el funcionamiento cognitivo subjetivo en adultos jóvenes en el contexto pospandémico.

3. Un perfil de personalidad caracterizado por alta evitación del daño y baja autodirección se asocia con mayor sintomatología prefrontal autopercibida
4. La inflexibilidad psicológica media la relación entre los rasgos de personalidad y la sintomatología prefrontal autopercibida, actuando como un posible mecanismo central en esta asociación.
5. Vivir solo en el extranjero y estar separado del entorno familiar habitual se asoció con mayores niveles de soledad percibida; sin embargo, no se observaron diferencias significativas en cortisol en cabello ni en HRV. En el ámbito cognitivo, este grupo mostró un peor rendimiento en memoria objetiva, especialmente en WM y PM, pero no en DM.
6. Los indicadores fisiológicos de estrés (cortisol y HRV) no mostraron asociaciones directas consistentes con el rendimiento en memoria, lo que sugiere que su contribución a los resultados cognitivos en adultos jóvenes es modesta y dependiente del contexto.
7. La soledad moderó la asociación entre los indicadores fisiológicos de estrés y el rendimiento en memoria, observándose esta interacción específicamente en PM y principalmente en niveles moderados y altos de soledad.
8. El estrés percibido varió durante la movilidad académica, con niveles más bajos en fases más avanzadas del período, mientras que los indicadores endocrinos y autonómicos no mostraron diferencias consistentes. Esto sugiere una disociación parcial entre las respuestas subjetivas y fisiológicas al estrés.
9. Los indicadores endocrinos y autonómicos se asociaron de manera selectiva con el rendimiento en memoria: los niveles de cortisol se relacionaron con resultados en DM y WM, mientras que la reactividad de la HRV mostró asociaciones modestas y específicas con la PM.
10. Mayor soledad predice un peor rendimiento en MP basada en eventos, a través de mayores puntuaciones de SMCs cuando la HRV en reposo es más baja, únicamente en estudiantes en movilidad académica, lo que resalta la importancia de la flexibilidad autonómica en la vulnerabilidad cognitiva durante procesos de transición prolongado.

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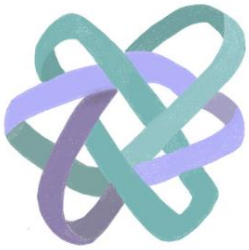

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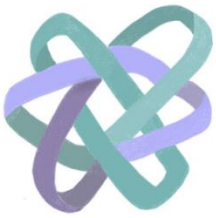
SUPPLEMENTARY DATA



Supplementary data

Supplementary data Chapter V

Covid-19 related questionnaires

Individual Coronavirus Experience

The information in this questionnaire is completely confidential. Its purpose is to gather general information related to the coronavirus. Please answer honestly.

1. Have you experienced symptoms related to the coronavirus? Please select only one of the following options:
    - Yes__No___
2. If your answer is yes, have you received a confirmed diagnosis of coronavirus? Please select only one of the following options:
    - Yes__No___
3. If your answer is yes, have you been hospitalized? Please select only one of the following options:
    - Yes__No___
4. If your answer is yes, where were you hospitalized? Please select only one of the following options:
    - In the ICU____On a regular Ward___
5. If your answer was yes, how many days were you hospitalized? Please write your response here:_____
6. Do you currently have any lingering effects related to coronavirus? Please select only one of the following options:
    - Yes__No___

7. If your answer is yes, what are these lingering effects? Please write your response here: Have any family members or friends contracted coronavirus? Please select only one of the following options:

    - Yes__No___

8. If your answer is yes, where did they contract it? Please select only one of the following options:

    - ____At home
    - ____In the hospital (less than 2 weeks)
    - ____In the hospital (more than 2 weeks)

9. Have any family members or friends died due to coronavirus? Please select only one of the following options:

    - Yes__No___

10. In the past year, how sad or depressed have you felt? Please select only one of the following options: with 1 being "Not at all" and 5 being "Very much"

    __1___ 2___3___4_____5

11. In the past year, how anxious have you felt? Please select only one of the following options: with 1 being "Not at all" and 5 being "Very much"

    __1___ 2___3___4_____5

12. In the past year, have you felt hopeless about the future? Please select only one of the following options:

    - Yes__No___

13. If your answer is yes, how hopeless do you feel? Please select only one of the following options: with 1 being "Not at all" and 5 being "Very much"

    __1___ 2___3___4_____5

14. In the past two weeks, how sad or depressed have you felt? Please select only one of the following options: with 1 being "Not at all" and 5 being "Very much"

    __1___ 2___3___4_____5

15. Have you changed your living situation in the past year? Please select only one of the following options:

    - Yes__No___

16. If your answer is yes, who were you living with before? Please select only one of the following options:

    ___Alone

    ___With family or close relatives

    ___With roommates

    ___Alone with children

    ___Alone with a partner or spouse

    ___With a partner or spouse and children

17. Who do you currently live with? Please select only one of the following options:

    ___Alone

    ___With family or close relatives

    ___With roommates

    ___Alone with children

    ___Alone with a partner or spouse

    ___With a partner or spouse and children

18. Number of people living in the household (including you) Please write your response here:_____

19. Have you experienced any stressful events as an indirect consequence of the coronavirus? For example...

Please check the relevant options:

____Breakup of your romantic relationship

____Parents' separation

____Dropped out of studies

____Job loss

____Other:

Social contact

Nationality: _____

Mobility - residence

• Have you had to move from your usual residence in the past year? Yes ( ) No ( )

If your answer is yes, please specify the type of move you made:

country ( ) city ( ) apartment/flat/student residence ( ) other ( ) _____

*If the response is country or city, is there a time zone difference? Specify (number of hours): _____

• Have you had to leave your family residence in the past year? Yes ( ) No ( )

If yes, please specify the reason:

Studies ( ) Work ( ) Other ( ) _____

Family contact

• In the past year, have you regularly had face-to-face contact with your family?

Yes ( )No ( )

• On average (weekly), how much time do you spend communicating with your family?

_____ hours

What communication method do you use to connect with them?

( ) Telephone

( ) Skype, Zoom, or similar

( ) WhatsApp, Text Messages, or similar

( ) Other: _____

Contact with friends

• In the past year, have you regularly had face-to-face contact with your friends?

Yes ( )No ( )

• On average (weekly), how much time do you spend communicating with friends from your previous residence (friends from your place of origin)? _____ hours

What communication method do you use to connect with them?

( ) Telephone

( ) Skype, Zoom, or similar

( ) WhatsApp, Text Messages, or similar

( ) Other: _____

• On average (weekly), how much time do you spend contacting friends from your current residence (new friends)? _____ hours

What communication method do you use to connect with them?

( ) Telephone

( ) Skype, Zoom, or similar

( ) WhatsApp, Text Messages, or similar

( ) Other: _____

Covid-19 related results

Supplementary Table 1: Group Comparisons with T-Tests or Chi-Square Tests on Main COVID-Related Conditions.

Covid-19 Information	AG	NAG	*p*
Having contracted COVID-19			
Yes (%)	2(8.7%)	1(4.5%)	0.577
No (%)	21(91.3%)	21(95.5%)	
Been hospitalized for COVID-19	-	-	-
Yes (%)	23 (100%)	22(100%)	
No (%)			
Having a **family member who died from COVID-19 disease**			
Yes (%)	5(21.7%)	2(9.1%)	0.242
No (%)	18(78.3%)	20(90.9%)	
In the past year, how sad or depressed have you felt?	M=2.783 Ds=1.380	M=1.546 Ds=1.299	0.556
In the past year, how anxious have you felt?	M=2.261 Ds=1.214	M=2.272 Ds=1.202	0.097
In the past year, have you felt hopeless about the future?			
Yes (%)	14(60.9%)	12(54.5%)	0.668
No (%)	9(39.1%)	10(45.5%)	
In the past two weeks, how sad or depressed have you felt?	M=2.261 Ds=1.214	M=2.272 Ds=1.202	0.974

Sex-controlled results report

Supplementary Table 2. Sample characteristics. Mean values (M), Standard Deviations (SD), and Student's *t*-test values.

	AG (n=23)		**NAG (n=22)**		***F [1,42]***	***p***
	M	SD	M	SD		
Sociodemographic characteristics						
Age (years)	25.696	2.721	25.500	3.529	0.148	0.702
Years in the education system	17.220	1.929	16.59	3.389	0.686	0.412
Alcohol consumption (Num. of drinks per week)	1.914	2.466	1.909	1.716	0.009	0.995
Cigarette consumption (Num. of cigarettes per week)	0.174	0.491	0.727	2.251	1.425	0.239
Psychological/affective characteristics						
Loneliness	38.087	9.657	30.636	5.169	10.110	0.003*
Perceived stress	6.565	3.883	5.773	3.436	0.422	0.520
Depression	13.478	10.962	9.818	8.958	1.338	0.254
SMC test score**s**	29.522	17.170	20.182	14.575	3.845	0.057
biomarkers						
cortisol	0.8052	0.3536	0.5158	0.2673	5.257	0.030*

Abbreviations: AG, Alone Group; NAG, Not Alone Group; Subjective Memory Complaints, SMCs. *$p < 0.05$.

Supplementary Table 3. Sample's Social interaction characteristics (weekly).

Social interaction characteristics	**AG (n=23)**	**NAG (n=22)**		***p***
Hours of communication with family	5.00 (4.112	7.864 (10.073)	1.561	0.218
Hours of communication with friends	6.348 (4.579)	6.636 (6.184)	0.029	0.865

Abbreviations: AG, Alone Group; NAG, Not Alone Group.

Supplementary Table 4. Mean values and standard deviations (SD) for memory outcomes and statistics of group comparisons with one-way ANOVAs.

	AG N=23		NAG N=22		*F* [1,42]	*p*
	Mean	S.D.	Mean	S.D.		
Working Memory	4.435	1.674	7.091	1.377	19.06	0.000
Declarative Memory	262.032	39.185	245.212	33.857	2.237	0.142
Prospective Memory	20.826	1.267	21.636	1.049	5.156	0.028

Abbreviations: AG, Alone Group; NAG, Not Alone Group. *$p < 0.05$.

Differences in HRV during cognitive task.

Analyses of the HRV response pattern during memory tasks, focusing on the RMSSD. No significant differences were found between periods (p=0.281). In addition, no significant effects of the Group factor (F[1,38]= 2,275, p=0.140) or the Group x Period interaction (F[2,76]= 1.115, p=0.228) were found.

Correlations

Supplementary Table 5. Correlations between biomarkers and memory outcomes.

	WMI	DMI	PMI
CORTISOL	0.662	0.556	0.799
RMSSD-MEMORY	0.821	0.095	0.927

Supplementary Table 6. Adjusted moderation analyses with cortisol as a predictor and memory as a dependent variable for different values of loneliness.

Dependent variable: working memory						
ΔR^2 interaction = 0.0013 F=0.0641, df (1,2)=1, 25 p=0.8023						
LLCI= -0.3180ULCI= 0.4071						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	-1.0870	1.2865	-0.8449	0.4062	-3.7366	1.5627
34.000	-0.7751	1.0291	-0.7532	0.4584	-2.8945	1.3443
43.760	-0.3403	2.3015	-0.1478	0.8837	-5.0804	4.3999
Dependent variable: declarative memory						
ΔR^2 interaction = 0.0135 F=0.3778, df(1,2)=1, 26 p=0.5441						

LLCI= -6.4013 ULCI= 11.8623						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	4.1534	32.237	0.1288	0.8985	-62.1136	70.4204
34.000	23.267	24.232	0.9602	0.9602	-26.5435	73.0778
43.760	49.917	56.436	0.8845	0.8845	-66.0931	165.9273
Dependent variable: Prospective memory						
ΔR^2 interaction = 0.3114 *F*= 17.4037, df (1,2) = 1, 26 *p*= 0.0003 **LLCI= -0.6313 ULCI= 0.3345**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	**1.7759**	**0.7357**	**2.4140**	**0.0231**	**0.2637**	**3.2881**
34.000	**-1.1845**	**0.5530**	**-2.1421**	**0.0417**	**-2.3212**	**-0.0478**
43.760	**-5.3121**	**1.2879**	**-4.1248**	**0.0003**	**-7.9595**	**-2.6648**

Supplementary Table 7. Adjusted moderation analyses with HRV as a predictor and memory as a dependent variable for different values of loneliness.

Dependent variable: Working Memory						
ΔR^2 interaction = 0.0279 *F*=1.8300, df (1,2)= 1, 35 *p*= 0.1848 **LLCI= -0.1128 ULCI= 0.5636**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	-0.2651	2.0237	-0.1310	0.8965	-4.3736	3.8434
34.000	1.5378	1.3927	1.1041	0.2771	-1.2897	4.3652
41.280	3.1784	1.7507	1.8155	0.0780	-0.3758	6.7326
Dependent variable: Declarative Memory						
ΔR^2 interaction = 0.0066 F=0.2589, df (1,2)= 1,36 *p*= 0.6140 **LLCI= -9.6030 ULCI= 5.7509**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	66.7569	46.6978	1.4296	0.1615	-27.9521	161.4659
34.000	51.3484	32.6643	1.5720	0.1247	-14.8989	117.5958
41.280	37.3267	40.5867	0.9197	0.3639	-44.9883	119.6418
Dependent variable: Prospective Memory						
ΔR^2 interaction = 0.0064 *F*=0.2851, df (1,2) = 1, 36 *p* =0.5967 **LLCI= -0.2847 ULCI= 0.1688**						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	1.1925	1.394	0.8554	0.3980	-1.6348	4.0197
34.000	0.7098	0.975	0.7279	0.4714	-1.2678	2.6874
41.280	0.2706	1.2116	0.2234	0.8245	-2.1867	2.7279

Results of biomarker analysis without logarithm transformation

Supplementary Table 8. Sample characteristics. Mean values (M), Standard Deviations (SD), and Student's *t*-test values.

	AG		NAG		*t [gl]*	*p*
	M	SD	M	SD		
Sociodemographic characteristics						
Cortisol	9.6937	12.880	3.8292	3.8292	1.946(19,412)	0.066

Differences in HRV during cognitive task.

Analyses of the HRV response pattern during memory tasks. Regarding the RMSSD, the Period factor reached statistical significance (F[2,78]=13.025, $p<0.001$), reflecting lower values during the immediate memory tasks than during the post-immediate memory task period ($p<0.001$) and the pre-task period ($p<0.001$). No significant differences were found between pre-task vs post-immediate memory tasks ($p=0.478$). In addition, no significant effects of the Group factor (F[1,39]= 2,342, $p=0.134$) or the Group x Period interaction (F[2,78]= 1.200, $p=0.295$) were found.

Correlations

Supplementary Table 9. Correlations between biomarkers and memory outcomes.

	WMI	DMI	PMI
CORTISOL	0.591	0.652	0.809
RMSSD-MEMORY	0.674	0.172	0.489

Supplementary Table 10. Adjusted moderation analyses with cortisol as a predictor and memory as a dependent variable for different values of loneliness.

Dependent variable: working memory
ΔR^2 interaction = 0.0010 F=0.0472, df (1,2)=1, 26 p=0.8296
LLCI= -0.0253 ULCI= 0.0313

Loneliness	Effect	SE	*t*	*p*	LLCI	ULCI
27.000	-0.0496	0.0715	-0.6927	0.4947	-0.1966	0.0975
34.000	-0.0286	0.0453	-0.6303	0.5340	-0.1218	0.0646
43.760	0.0007	0.1700	-0.0040	0.9969	-0.3487	0.3500
Dependent variable: declarative memory						
ΔR^2 interaction = 0.0262 F=0.7548, df(1,2)=1, 27 *p*=0.3926						
LLCI= -0.3942 ULCI= 0.9732						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	-0.9834	1.7302	-0.5684	0.5745	-4.5336	2.5668
34.000	1.0431	1.0558	0.9880	0.3319	-1.1233	3.2095
43.760	3.8685	4.0814	0.9479	0.3516	-4.5060	12.2430
Dependent variable: Prospective memory						
ΔR^2 interaction = 0.2173 *F*= 9.0852, df (1,2) = 1, 27 *p*= 0.0055						
LLCI= -0.0452 ULCI=- 0.0086						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
27.000	**0.117**	**0.0463**	**2.5354**	**0.0173**	**0.0224**	**0.2123**
34.000	**-0.0707**	**0.0282**	**-2.5040**	**0.0186**	**-0.1287**	**-0.0128**
43.760	**-0.3330**	**0.1092**	**-3.0496**	**0.0051**	**-0.5570**	**-0.1089**

Supplementary Table 11. Adjusted moderation analyses with HRV as a predictor and memory as a dependent variable for different values of loneliness.

Dependent variable: Working Memory						
ΔR^2 interaction = 0.0364 *F*=2.2238, df (1,2)= 1, 36 *p*= 0.1446						
LLCI= -0.0013 ULCI= 0.0083						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	-0.0064	0.0318	-0.2020	0.8410	-0.0709	0.0580
34.000	0.0216	0.0227	0.9526	0.3472	-0.0244	0.0676
41.280	0.0471	0.0261	1.8089	0.0788	-0.0057	0.1000
Dependent variable: Declarative Memory						
ΔR^2 interaction = 0.0089 F=0.3518, df (1,2)= 1,37 *p*= 0.5567						
LLCI= -0.1349 ULCI= 0.738						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	0.9287	0.7048	1.3176	0.1957	-0.4995	2.3569
34.000	0.6843	0.5111	1.3389	0.1888	-0.3513	1.7200
41.280	0.4620	0.5847	0.7900	0.4345	-0.7228	1.6467
Dependent variable: Prospective Memory						
ΔR^2 interaction = 0.0032 *F*=0.1413, df (1,2) = 1, 37 *p* =0.7092						
LLCI= -0.0037 ULCI= 0.0026						
Loneliness	**Effect**	**SE**	***t***	***p***	**LLCI**	**ULCI**
26.000	0.0220	0.0212	1.0391	0.3055	-0.0209	0.0650
34.000	0.0174	0.0154	1.1300	0.2658	-0.0138	0.0485

41.280	0.0131	0.0176	0.7467	0.4600	-0.0225	0.0488

Supplementary data Chapter VII

Moderated mediation analysis of Isolation on PM through SMCs considering the influence of HRV

Supplementary Tables 1 (total sample), 2 (SA group) and3 (HB group) present the results of the moderated mediation analyses testing whether the effect of isolation on PM operates indirectly through SMCs and whether this indirect path is moderated by resting-state HRV.

Across all samples, isolation was positively associated with SMCs, particularly in the HB group (B = 0.54, p = 0.001) and in the total sample (B = 0.31, p = 0.014), but not in the SA (B = 0.24, p = 0.183).

For event-based PM, the direct and indirect effects of isolation were nonsignificant in all groups. For time-based PM, neither direct, indirect, nor interaction effects were significant across any sample. The indices of moderated mediation were nonsignificant in all analyses, as all bootstrap CIs included zero.

Overall, these results suggest that SMCs partially reflect the impact of isolation, but do not mediate its relationship with PM performance, nor is this association significantly moderated by HRV.

Supplementary Table 12. Moderated mediation analysis results: isolation on PM through SMCs in total sample.

Interaction	Coefficient (B)	SE	*p*	95% CI [LL, UL]
Event-based PM				
isolation → SMCs (path a)	0.3137	0.1245	0.014	[0.0648, 0.5625]
isolation → Event-based PM (c′)	0.0435	0.1434	0.763	[−0.2435, 0.3304]
SMCs → Event-based PM	−0.1500	0.1380	0.281	[−0.4261, 0.1261]
HRV→ Event-based PM	−0.1040	0.1270	0.416	[−0.3582, 0.1502]
SMCs × HRV→ Event-based PM	0.0609	0.1357	0.655	[−0.2106, 0.3324]
Moderated Mediation total index	0.0191	0.0454	—	[−0.0663, 0.1224]
Time-based PM				

isolation → time-based PM (c′)	0.0129	0.1453	0.930	[−0.2778, 0.3035]
SMCs → time-based PM	−0.0581	0.1398	0.679	[−0.3378, 0.2216]
HRV→ time-based PM	−0.0536	0.1287	0.679	[−0.3111, 0.2040]
SMCs × HRV→ Time-based PM	−0.0953	0.1374	0.491	[−0.3703, 0.1797]
Índice de mediación moderada	−0.0299	0.0480	—	[−0.1335, 0.0602]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals (CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect

Supplementary Table 13. Moderated mediation analysis results: isolation on PM through SMCs in abroad student's sample.

Effect type	**B**	**SE**	***p***	**95% CI [LL, UL]**
Event-based PM				
isolation → SMCs (path a)	0.2388	0.1740	0.183	[−0.12, 0.60]
isolation → Event-based PM (c′)	0.0312	0.1790	0.863	[−0.34, 0.40]
SMCs → Event-based PM	−0.2479	0.2062	0.243	[−0.68, 0.18]
HRV→ Event-based PM	0.0259	0.2064	0.902	[−0.40, 0.46]
SMCs × HRV→ Event-based PM	0.5316	0.2357	0.035	[0.04, 1.02]
Index of moderated mediation	0.1269	0.1028	—	[−0.06, 0.35]
Time-based PM				
isolation → time-based PM (c′)	0.0387	0.1683	0.820	[−0.31, 0.39]
SMCs → time-based PM	0.0756	0.1939	0.701	[−0.33, 0.48]
HRV→ time-based PM	−0.1705	0.1941	0.390	[−0.57, 0.23]
SMCs × HRV→ Time-based PM	−0.0606	0.2216	0.787	[−0.52, 0.40]
Index of moderated mediation	−0.0145	0.0730	—	[−0.19, 0.10]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals

(CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect

Supplementary Table 3. Moderated mediation analysis results: isolation on PM through SMCs in home based sample.

Effect type	B	SE	p	95% CI [LL, UL]
Event-based PM				
isolation → SMCs (path a)	0.3724	0.1795	0.045	[0.01, 0.74]
isolation → Event-based PM (c′)	0.1868	0.2270	0.416	[−0.28, 0.65]
SMCs → Event-based PM	−0.2307	0.1972	0.250	[−0.63, 0.17]
HRV→ Event-based PM	−0.1217	0.1687	0.476	[−0.46, 0.22]
SMCs × HRV→ Event-based PM	−0.1294	0.1868	0.493	[−0.51, 0.25]
Index of moderated mediation	−0.0482	0.0889	—	[−0.27, 0.09]
Time-based PM				
isolation → time-based PM (c′)	−0.0460	0.2368	0.847	[−0.53, 0.44]
SMCs → time-based PM	−0.1492	0.2057	0.474	[−0.57, 0.27]
HRV→ time-based PM	−0.0314	0.1760	0.860	[−0.39, 0.33]
SMCs × HRV→ Time-based PM	−0.1071	0.1949	0.586	[−0.50, 0.29]
Index of moderated mediation	−0.0399	0.0880	—	[−0.22, 0.17]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals (CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect

Moderated mediation analysis of Relational Connectedness on PM through SMCs considering the influence of HRV

Supplementary Tables 4 (total sample), 5 (SA group) and 6 (BH group) display the moderated mediation results examining whether the effect of relational connectedness (RC) on PM operates indirectly through SMCs and whether this indirect path is moderated by HRV.

Across samples, RC was a significant positive predictor of SMCs, especially in the total group (B = 0.41, p = 0.001) and HB group (B = 0.54, p = 0.001), indicating that greater relational connectedness was associated with higher reported memory complaints.

However, direct and indirect effects of RC on PM were nonsignificant across all groups.

No significant effects were found for time-based PM in any sample. Additionally, the indices of moderated mediation were nonsignificant in all models (all 95% CIs included zero).

Supplementary Table 14. Moderated mediation analysis results: RC on PM through SMCs in total sample.

Effect type	B	SE	*p*	95% CI [LL, UL]
Event-based PM				
RC → SMCs (path a)	0.4114	0.1228	0.001	[0.17, 0.66]
RC → Event-based PM (c′)	0.2105	0.1539	0.177	[−0.10, 0.52]
SMCs → Event-based PM	−0.2174	0.1418	0.130	[−0.50, 0.07]
HRV→ Event-based PM	−0.1178	0.1250	0.350	[−0.37, 0.13]
SMCs × HRV→ Event-based PM	0.0114	0.1382	0.935	[−0.27, 0.29]
Index of moderated mediation	0.0047	0.0549	—	[−0.10, 0.12]
Time-based PM				
RC→ time-based PM (c′)	0.0079	0.1583	0.960	[−0.31, 0.32]
SMCs → time-based PM	−0.0572	0.1458	0.696	[−0.35, 0.23]
HRV→ time-based PM	−0.0549	0.1286	0.671	[−0.31, 0.20]
SMCs × HRV→ Time-based PM	−0.0955	0.1421	0.504	[−0.38, 0.19]
Index of moderated mediation	−0.0393	0.0682	—	[−0.19, 0.09]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals (CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect

Supplementary Table 15. Moderated mediation analysis results: RC on PM through SMCs in study abroad sample.

Effect type	B	SE	*p*	95% CI [LL, UL]
Event-based PM				
RC → SMCs (path a)	0.1553	0.2154	0.478	[−0.29, 0.60]
RC → Event-based PM (c′)	0.2224	0.1979	0.274	[−0.19, 0.63]
SMCs → Event-based PM	−0.2649	0.1933	0.185	[−0.67, 0.14]
HRV→ Event-based PM	0.0235	0.1961	0.906	[−0.38, 0.43]
SMCs × HRV→ Event-based PM	0.5152	0.2258	0.033	[0.05, 0.98]
Index of moderated mediation	0.0800	0.1203	—	[−0.12, 0.36]
Time-based PM				
RC→ time-based PM (c′)	0.1208	0.1899	0.532	[−0.27, 0.52]
SMCs → time-based PM	0.0737	0.1855	0.695	[−0.31, 0.46]
HRV→ time-based PM	−0.1771	0.1882	0.357	[−0.57, 0.21]
SMCs × HRV→ Time-based PM	−0.0745	0.2167	0.735	[−0.53, 0.38]
Index of moderated mediation	−0.0116	0.0728	—	[−0.19, 0.13]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals (CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect

Supplementary Table 16. Moderated mediation analysis results: RC on PM through SMCs in home based sample.

Effect type	B	SE	p	95% CI [LL, UL]
Event-based PM				
RC → SMCs (path a)	0.5414	0.1483	0.001	[0.24, 0.84]
RC → Event-based PM (c′)	0.3623	0.2426	0.145	[−0.13, 0.86]
SMCs → Event-based PM	−0.3735	0.2249	0.106	[−0.83, 0.08]
HRV→ Event-based PM	−0.1455	0.1648	0.384	[−0.48, 0.19]

SMCs × HRV→ Event-based PM	−0.2223	0.1973	0.268	[−0.62, 0.18]
Index of moderated mediation	−0.1203	0.1108	—	[−0.38, 0.09]
Time-based PM				
RC→ time-based PM (c′)	0.0281	0.2590	0.914	[−0.50, 0.55]
SMCs → time-based PM	−0.1812	0.2400	0.456	[−0.67, 0.31]
HRV→ time-based PM	−0.0302	0.1760	0.865	[−0.39, 0.33]
SMCs × HRV→ Time-based PM	−0.1314	0.2106	0.537	[−0.56, 0.30]
Index of moderated mediation	−0.0711	0.1350	—	[−0.31, 0.23]

Abbreviations: SMCs, Subjective memory complaints; PM, Prospective Memory; LLCI, Lower limit confidence interval; ULCI, Upper limit confidence interval; SE, standard error. The confidence intervals (CIs) were calculated using bootstrap resampling procedures. An indirect effect is considered statistically significant if the CI does not include zero, indicating a meaningful mediation effect