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Social stress dynamics in complex systems. Neurocognitive and behavioural metrics

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Index

Abstract **1**

1. SECTION 1 – Theoretical foundations of stress regulation in complex contexts **2**

1.1. Understanding stress in contemporary organisational settings 2

1.1.1. From eustress to distress in high-pressure systems *6*

1.1.2. Acute vs. anticipatory stress *10*

1.1.3. Social-evaluative threat in remote and digital communication *13*

1.2. Human adaptation to high-complexity environments: a neurocognitive perspective 17

1.2.1. Cognitive Load, Executive Functions and Emotion Regulation *24*

1.2.2. Trait-level modulators: mindfulness, interoception, empathy *27*

1.2.3. Regulation vs. resistance: distinct dynamics of stress management *31*

1.3. Neural and behavioural correlates of stress 35

1.3.1. EEG frequency bands: indicators of cognitive and emotional states *40*

1.3.2. Autonomic activity: HRV, SCR, and arousal regulation in evaluative settings *43*

1.4. Toward an integrated framework 47

1.4.1. Feedback-driven adaptation and cognitive-emotional plasticity *53*

1.4.2. Multilevel integration of neural, autonomic, and behavioural responses *56*

1.4.3. Applications in organisational neuroscience and digital HR design *58*

1.4.4. From theoretical architecture to experimental validation: thesis's general aim *61*

2. SECTION 2 – Neurophysiological (EEG) response to social feedback in stressful situations **66**

2.1. Abstract 66

2.2. Introduction 67

2.3. Materials and methods 73

2.3.1. Sample *73*

2.3.2. Experiment procedure *74*

2.3.3. Behavioural data acquisition and processing *77*

2.3.4. Electrophysiological data acquisition and processing *78*

2.3.5. Statistical analysis *78*

2.4. Results 79

2.4.1. Behavioural results *79*

2.4.2. EEG results *81*

2.5. Discussion 85

2.6. Conclusion 90

3. SECTION 3 – Different types of social feedback can enhance or reduce performance, and induce or alleviate psychosocial stress: an exploratory study of the underlying neurophysiological mechanisms 92

3.1. Abstract 92

3.2. Introduction 93

3.3. Materials and methods 96

3.3.1. Sample *96*

3.3.2. Procedure *97*

3.3.3. EEG recording and reduction *100*

3.3.4. Statistical analysis *102*

3.4. Results 103

3.5. Discussion 106

3.6. Conclusion 111

3.7. Supplementary Material 113

4. SECTION 4 – Sensorimotor Simulation's Influence on Stress: EEG and Autonomic Responses in Digital Interviews 114

4.1. Abstract ... 114
4.2. Introduction ... 115
4.3. Materials and Methods ... 121
4.3.1. Hypotheses ... 121
4.3.2. Sample ... 123
4.3.3. Procedure ... 124
4.3.4. Behavioral Data Processing ... 127
4.3.5. EEG Data Acquisition and Processing ... 128
4.3.6. Autonomic Data Acquisition and Processing ... 130
4.3.7. Data Analysis ... 130
4.4. Results ... 131
4.4.1. Behavioural Results ... 131
4.4.2. EEG Results ... 133
4.4.3. Autonomic Results ... 139
4.5. Discussion ... 140
4.6. Conclusions ... 148
4.6.1. Proposals and Recommendations ... 149
5. SECTION 5 – General discussion and future directions ... 150
5.1. General Discussion ... 150
5.1.1. Adaptive psychophysiology of stress: a multilevel perspective ... 150
5.1.2. Social feedback valence and anticipatory cognitive-affective activation ... 155
5.1.3. Sensorimotor dynamics and cognitive load in digital stress scenarios ... 160
5.1.4. Toward an integrative neurocognitive model of stress adaptation ... 163
5.2. Implications and future directions ... 168
5.2.1. Methodological advances: multimodal, ecological, and comparative approaches ... 168

5.2.2. Contributions to the neuroscience of social and organizational adaptability..... 172

5.2.3. From neuroethics to neuro-inclusive design: rethinking digital assessment..... 175

5.2.4. Final remarks: human adaptability and neurocognitive plasticity in evaluation contexts 179

6. References..... 183

Personal publications..... 235

Papers under review 238

Conference contributions..... 239

Abstract

In increasingly digital and performance-driven environments, the ability to regulate cognitive and emotional responses under social evaluative pressure has become a central dimension of professional adaptability. This doctoral dissertation investigates the multilevel neurophysiological mechanisms underlying human stress regulation in socially demanding tasks, focusing on the interplay between social feedback, sensorimotor context, and anticipatory cognitive-affective activation. Across three experimental studies (N = 117 in total), participants engaged in ecologically realistic stress-induction tasks inspired by the Trier Social Stress Test, adapted to simulate digital job interviews. Using a multimodal recording setup – including electroencephalography (EEG), heart rate (HR), heart rate variability (HRV), skin conductance level (SCL), and skin conductance response (SCR) – the studies examined how feedback valence (positive, neutral, negative), ambiguity, and sensorimotor format (static vs. dynamic) shaped preparatory performance states and regulatory effort. The results reveal distinct neurophysiological signatures of stress adaptation: positive feedback enhanced delta and theta activity associated with internal elaboration; ambiguous or neutral feedback elevated beta activity and autonomic arousal, reflecting increased uncertainty processing; negative and aversive feedback produced either compensatory engagement or physiological withdrawal, depending on intensity and repetition. Furthermore, dynamic, video-based evaluative contexts elicited greater alpha desynchronization and gamma synchronization than static ones, indicating higher attentional and integrative processing demands. These findings support an integrative model of stress regulation that combines central, autonomic, behavioural, and sensorimotor components. The model accounts for the anticipatory nature of adaptation and highlights the role of social meaning, emotional clarity, and perceptual structure in modulating stress responses. The dissertation contributes to organisational neuroscience by reframing performance under pressure as a dynamic regulatory process, and to applied fields such as digital assessment design and neuro-inclusive human resource practices. In conclusion, this work advances a neurocognitive perspective on human adaptability in evaluative environments, advocating for assessment systems that are not only valid and efficient, but also cognitively accessible, emotionally attuned, and ethically responsive to individual differences in regulatory style and neurophysiological sensitivity.

1. SECTION 1 – Theoretical foundations of stress regulation in complex contexts

1.1. Understanding stress in contemporary organisational settings

The theoretical and experimental development of the concept of stress in organisational contexts has undergone, over the past thirty years, a paradigmatic evolution reflecting the increasing complexity of work dynamics and their interaction with neurocognitive constructs of adaptive regulation. From an essentially reactive conception, focused on the transient dysfunction generated by excessive environmental demands, the field has advanced toward a systemic understanding of stress as a phenomenon emerging from multilevel self-regulatory processes, involving the integration of neural networks, internal dynamic configurations, relational structures, and complex organisational dynamics (Fleshner et al., 2011; Khayrutdinov et al., 2020).

Current neurobiological theories of stress, particularly those based on the models of allostatic load and predictive brain theories, interpret stress not merely as dysfunction but as the prolonged and repeated activation of adaptive systems in response to structural uncertainty, evaluative ambiguity, and hyper-exposure to interpersonal dynamics. Under such conditions, frequently observed in contemporary organisations, persistent disruption of homeodynamic mechanisms governing the balance between activation, control, and recovery can be detected. The continuous requirement to optimise performance under multiple constraints – temporal, normative, social – generates a form of systemic stress that is not episodic but progressively stabilises as a long-term operational pattern, often internalised and normalised (Kim & Kim, 2023; McEwen & Stellar, 1993).

On the neurophysiological level, recent evidence has shown that chronic exposure to high-pressure work environments leads to significant modifications in the main cerebral networks involved in cognitive-affective regulation. In particular, the cortico-limbic circuit – including the amygdala, anterior insula (aINS), anterior cingulate cortex (ACC), precuneus

(PrCu), and dorsolateral and ventromedial Prefrontal Cortex (dlPFC, vmPFC) – exhibits a progressive functional decoupling, with hyperactivity of limbic structures and diminished capacity of the Prefrontal Cortex (PFC) to exert inhibitory control and top-down modulation. This imbalance undermines not only emotional regulation but also predictive accuracy and the ability to sustain a flexible state of vigilance (Hassamal, 2023; Wei et al., 2018).

Techniques such as Diffusion Tensor Imaging (DTI) have demonstrated that prolonged psychosocial strain may compromise the axial integrity of fronto-limbic fibres, negatively affecting the functional coherence of Decision-Making (DM) and self-regulatory processes (Gunatilake et al., 2025; Jindal et al., 2025). These morphostructural alterations are predictive of phenomena such as persistent irritability, tendencies toward social withdrawal, depletion of intrinsic motivation, and cognitive fatigue, delineating a neurobehavioral profile of adaptive vulnerability that precedes the manifestation of clinically significant symptoms (Koch et al., 2017).

From a cognitive perspective, current organisational conditions may be defined as *cognitively unstable environments*, marked by dense information flows, frequent interruptions of operational sequences (i.e. task switching), multiplicity of communication channels, and the absence of clear feedback. These characteristics impose continuous demands on higher Executive Functions (EFs) – particularly working memory updating, inhibitory control, and mental flexibility – which, when strained beyond sustainable thresholds, tend to decline, triggering a vicious cycle between operational disorganisation and perceived stress (Aithal & Satpathy, 2024; Balconi, Angioletti, et al., 2020).

On the psychosocial level, dynamics of continuous evaluation, performance management, and digital transparency have produced pervasive forms of latent evaluative exposure, which operate even in the absence of explicit feedback and induce anticipatory activations of the Hypothalamic-Pituitary-Adrenal Axis (HPA) (McEwen & Sapolsky, 1995; Miller et al., 2007). Such latent stress conditions are often linked to what the literature defines as *contextual normative ambiguity*: a condition in which organisational expectations are implicit, fluid, or contradictory, making self-regulation and the identification of stable reference parameters for action particularly challenging (Hillman et al., 2023; Monk & Ogolsky, 2019).

Moreover, it is now well established that stress does not remain confined to the individual experience but circulates within social systems through mechanisms of emotional co-regulation, empathic resonance, and behavioural alignment (Herrando & Constantinides, 2021). In highly interdependent groups, such as work teams, the dysregulation of one or more members may give rise to systemic dysfunction, known as *cumulative relational dissonance*, where individual coping strategies prove ineffective in the absence of a regulatory and supportive relational context. Recent studies employing wearable sensors and network analysis methods have shown that relational centrality predicts the degree of exposure to symbolic (reputational) stress, with significant repercussions on Heart Rate Variability (HRV) and attentional stability (Ji et al., 2024; Xue et al., 2022).

The most advanced theoretical perspectives ultimately situate stress within an *adaptive computational framework*, whereby the organism – and, by extension, the organisational actor – is continuously engaged in minimising the predictive error between internal expectations and environmental inputs (Friston, 2009; Krupnik, 2020). In this view, stress constitutes a signal of misalignment between the internal model and observed reality, the accumulation of which compromises the capacity to update generative inferences and leads to states of chronic alertness and behavioural rigidity.

Effective regulatory intervention, therefore, cannot be limited to conventional stress management strategies but must aim to promote inferential plasticity, cognitive flexibility, and the capacity to reinterpret stress-inducing stimuli in adaptive and generative terms (Clark, 2013; Friston, 2009).

A crucial aspect that guides the present thesis is the role of social feedback and communicative processes in shaping the anticipatory regulation of stress. Stressful performance contexts rarely emerge in isolation: they are embedded in a communicative framework, in which information about one's behavior is continuously exchanged, interpreted, and re-integrated into self-regulatory models. Feedback, whether explicit or implicit, positive or negative, clear or ambiguous, constitutes a powerful determinant of regulatory dynamics, influencing not only immediate affective appraisal but also the neurocognitive preparation for subsequent action (Cavalcanti et al., 2021; Karin et al., 2020; Thayer & Lane, 2000).

Theoretical accounts of adaptive regulation have emphasized that feedback does not simply operate as a post-hoc evaluation but as an anticipatory cue that orients attention, modulates motivational states, and biases expectancies. In line with predictive coding and active inference models, communicative signals can be conceived as *precision-weighted information* that reduces or increases uncertainty in social contexts, thereby recruiting large-scale neural networks involved in salience detection, executive control, and affective monitoring. This perspective positions feedback as a communicative mechanism that actively shapes the balance between top-down predictions and bottom-up signals during stress regulation (Brudner et al., 2022; Raftery & Bizer, 2009; Smith & Vale, 2006; Vanderhasselt et al., 2015).

Within this framework, feedback is not a homogeneous construct but a multidimensional one. Its valence (rewarding vs aversive), its clarity vs ambiguity (affirmative, neutral, or contradictory cues), and its mode of delivery (static vs dynamic, verbal vs multimodal) differentially engage neurophysiological mechanisms. Previous literature suggests that positive feedback may promote integrative processing through dopaminergic and fronto-parietal networks, while negative feedback may mobilize vigilance and error monitoring, enhancing occipito-temporal low-frequency oscillations and autonomic arousal (Balconi & Vanutelli, 2016; Brockner et al., 1987; Crivelli et al., 2023; Rawls et al., 2020; Somerville et al., 2010). Ambiguous or neutral feedback, on the other hand, imposes an interpretative cost, reflected in sustained beta-band activity and increased sympathetic activation, as the system attempts to resolve uncertainty and re-establish regulatory stability.

By explicitly linking communicative processes to regulatory dynamics, this thesis advances the view that the anticipatory window following feedback is a privileged period in which cognitive, affective, and physiological systems converge to prepare the organism for forthcoming performance demands. This conceptual stance directly informs the design and interpretation of the three empirical studies presented in Sections 2–4.

Within this theoretical and applied framework, the following subsections will provide a more detailed analysis. Subsection 1.1.1 will examine the conceptual transition from the dichotomous eustress-distress model to the logic of adaptive pressure gradients, concerning dynamic threshold and saturation models. Subsection 1.1.2 will explore the relationship

between stress, mental load, and the deterioration of EFs in cognitively dense environments. Finally, subsection 1.1.3 will focus on neurocognitive strategies of metacognitive and emotional regulation, with particular emphasis on resilience circuits and prospects for preventive intervention in highly complex organisational systems.

1.1.1. From eustress to distress in high-pressure systems

The traditional distinction between *eustress* and *distress*, introduced by Selye (1976) and subsequently disseminated through classical psychosocial models, represented an initial heuristic attempt to describe the biphasic nature of the stress response, acknowledging its potential adaptive as well as dysfunctional aspects. Within this dichotomous model, eustress is defined as a «*positive*» form of activation, associated with heightened motivation, increased vigilance, and optimised performance, whereas distress refers to a «*negative*» condition of dysfunctional activation, characterised by emotional overload, depletion of attentional resources, and impaired DM capacities (Selye, 1976). In particular, communicative and feedback dynamics have been increasingly recognised as decisive modulators of whether activation unfolds along an adaptive or maladaptive trajectory, underscoring the social embedding of stress regulation (Karin et al., 2020).

However, recent neuroscientific and psychophysiological findings have highlighted the limitations of such conceptual polarisation, demonstrating that the stress response cannot be linearly interpreted through a simple binary opposition. Rather, it emerges from the dynamic interaction among stimulus intensity, available cognitive resources, regulatory plasticity, and the socio-relational context (Field & Schuldberg, 2010; Veer et al., 2012). In highly complex organisational environments, the transition from a functional to a dysfunctional state is rarely abrupt or universally predictable; instead, it follows non-linear interindividual trajectories mediated by cognitive, affective, neuroendocrine, and metacognitive factors (Trouillet et al., 2016).

Contemporary research has therefore moved beyond the static and normative eustress/distress model, adopting more complex approaches grounded in continuum logics, vulnerability thresholds, and probabilistic computational models. The Yerkes-Dodson Law, frequently cited in the literature, provides an initial framework for understanding how the optimal level of activation varies as a function of task difficulty (Sosnowski & Brosnan, 2023; Yerkes & Dodson, 1908).

However, it has been further refined by more recent models, such as the Dynamic Integration Theory (DIT) (Labouvie-Vief, 2003; Labouvie-Vief et al., 2010), and more contemporary frameworks that incorporate emotional, motivational, and environmental variables into the prediction of transitions between functional and dysfunctional activation states. Within these models, the role of social feedback is increasingly emphasised as a factor capable of tipping the balance between adaptive engagement and maladaptive overload, particularly in contexts of evaluation and interpersonal negotiation (S. N. Brudner et al., 2016; Thayer & Lane, 2000).

In particular, control-theoretic approaches have conceptualised stress as the result of maladaptive regulation within dynamic feedback systems, where the accumulation of emotional load, attentional demands, and reward prediction errors disrupts homeostatic balance. For example, recent models based on *Proportional-Integral-Derivative* (PID) control describe how dysregulation in the interaction between arousal levels, affective signals, and motivational incentives may progressively alter the gain of Executive Control Network (ECN), especially under persistent strain (Howlett & Paulus, 2024; Quinn & Shields, 2023). Seen through this lens, feedback is not merely an evaluative signal but a regulatory input that alters system gain, influencing anticipatory adjustments and resilience thresholds. Seen through this lens, feedback is not merely an evaluative signal but a regulatory input that alters system gain, influencing anticipatory adjustments and resilience thresholds (Henderson et al., 2012).

Complementary to this, neurocomputational perspectives such as the *Triple-Network Model* emphasise the role of the Salience Network (SN) – particularly the insula (INS) and ACC – as a key dynamic modulator of the transitions between the Default Mode Network (DMN) and the frontoparietal ECN. Under conditions of high contextual ambiguity or

elevated motivational conflict, aberrant salience processing has been shown to trigger non-linear transitions toward dysfunctional activation states, marked by rigid, hypervigilant, and inefficient cognitive configurations (Hu et al., 2021; Labouvie-Vief et al., 2010; Schimmelpfennig et al., 2023). Ambiguity in communicative feedback, as frequently observed in organisational and digital contexts, can therefore act as a salient perturbation that destabilises network transitions, pushing the system beyond adaptive thresholds (Bennett et al., 1990; Raftery & Bizer, 2009).

From a neurophysiological perspective, the hypothesis of the inverted U-curve has evolved into models of non-linear transition that describe the cumulative effect of chronic stress on the responsiveness of the central nervous system (Yi et al., 2025). Longitudinal studies employing functional Magnetic Resonance Imaging (fMRI) and endocrine measures (cortisol, ACTH) have demonstrated that the same level of activation, initially associated with increased concentration, precision, and motivation, under conditions of persistence or intensification, may become disorganizing, leading to a functional collapse of executive capacities and the emergence of maladaptive behavioural rigidity (Rampino et al., 2019; Weldon et al., 2015).

A crucial element of this transition is represented by the *saturation of regulatory capacity*, namely the point at which the cognitive, motivational, and physiological resources required to sustain a functional activation state are exhausted or rendered ineffective. This threshold is neither fixed nor generalizable but depends on multiple factors: temperamental traits (e.g., neuroticism, emotional lability), metacognitive resources, endocrine profile, history of early-life stress exposure, quality of social support, and perceived sense of agency (Canli et al., 2005; Taylor, 2011). Importantly, the communicative environment – whether supportive, neutral, or threatening – can accelerate or delay the reaching of this threshold, making feedback a pivotal contextual determinant of regulatory sustainability (Balconi & Fronda, 2022; Kalisch et al., 2015).

In organisational contexts, the challenge lies in the fact that many stress-inducing conditions are neither acute nor explicitly identifiable, but rather manifest in subclinical, cumulative, and latent forms. Workers are often immersed in a continuous flow of micro-stressors – fluctuating deadlines, simultaneous communicative demands, role ambiguity,

reputational pressures – which, when considered individually, do not exceed the critical threshold, but in aggregate generate a high latent pressure load that is difficult to monitor and even more challenging to self-regulate (Cooper & Cartwright, 2018).

Furthermore, the subjective value attributed to stress-inducing stimuli must be considered. Two individuals exposed to the same situation, such as a negative performance review, may react in radically different ways: one may activate cognitive restructuring strategies and adaptive improvement (*eustress response*), while the other may develop rumination, avoidance, and hyperreactive limbic activation (*distress response*). This has led to a reassessment of the concept of primary appraisal as a central mechanism in the stress response, now reinterpreted in light of affective neuroscience and emotional metacognition (Balconi & Rovelli, 2024; Lazarus & Smith, 1988). Primary appraisal, in this revised sense, operates as a communicative filter, mediating how feedback signals are decoded, emotionally weighted, and integrated into regulatory models.

An emerging component in the literature is the concept of *adaptive reactive stress*, that is, a form of temporary, sustainable, and cognitively modulated activation that enables individuals to enhance their efficiency in solving complex tasks, provided it is accompanied by effective regulatory processes, a sense of internal control, and clear goal structuring. Although physiologically similar to pathological stress, this form is distinguished by its reversibility, the presence of *recovery windows* (periods of autonomously induced recovery), and the absence of chronic neuronal sensitisation phenomena (Friedman & Robbins, 2021; Schwabe & Wolf, 2011). In this context, feedback plays a defining role: timely, precise, and transparent communicative signals can transform reactive stress into a platform for learning and adaptive recalibration rather than a pathway toward maladaptive rigidity.

Ultimately, overcoming the eustress/distress dichotomy implies a reconceptualization of *organizational risk assessment*: it is not sufficient to monitor manifest fatigue or burnout conditions; rather, it is necessary to identify early signals of adaptive saturation and intervene on the environmental, cognitive, and intersubjective dynamics that facilitate or hinder the effective integration of stress as a transformative resource. The objective is not to eliminate stress but to render it processable and adaptively useful, through the promotion of contexts

that support tolerance of uncertainty, sense of agency, communicative transparency, and co-regulation of workloads. In this respect, communicative structures and feedback practices represent not peripheral factors but central levers of organisational design, capable of sustaining adaptive thresholds and preventing maladaptive escalation.

In light of the above, it becomes evident that stress, within contemporary organisational systems, can no longer be interpreted in dichotomous or normative terms, but rather as a continuous gradient of neurocognitive pressure that evolves dynamically as a function of individual regulatory plasticity and the structural properties of the context. This implies that any activation state, even when initially adaptive, may deteriorate into a dysfunctional condition if not supported by adequate resources for monitoring, modulation, and recovery.

However, for adaptive pressure to remain within functional thresholds, it is necessary that central cognitive resources – particularly those involved in ECN – remain operational and sufficiently integrated. In environments characterised by high informational density and operational hyperfragmentation, such as those typical of current work configurations, EFs are particularly vulnerable to progressive wear, selective deterioration, and cumulative inefficiency.

The next section (1.1.2) will therefore examine the phenomenon of acute versus anticipatory stress, clarifying how preparatory and reactive regulatory modes operate under evaluative pressure and how these dynamics influence subsequent executive functioning.

1.1.2. Acute vs. anticipatory stress

The understanding of regulatory processes in the management of work-related stress cannot be separated from a thorough analysis of the emotional and metacognitive competences involved in the individual's adaptive response. While EFs represent the operational arm of behavioural control, it is the ability to intentionally regulate internal states – affective, cognitive, and bodily – that determines the quality and sustainability of performance in high-pressure contexts. From this perspective, emotional regulation and metacognition emerge as higher-order cognitive

resources, indispensable for maintaining adaptive coherence and preventing functional collapse in cognitively dense systems.

Emotional regulation is defined as the set of processes through which individuals monitor, evaluate, and modify the intensity and direction of their affective responses to achieve internal and external goals (Gross, 1998). It includes automatic and voluntary strategies, implicit and explicit, reactive and proactive, which are activated depending on the context and the availability of cognitive resources. Numerous neuroscientific findings indicate that emotional regulation primarily involves the vmPFC, orbitofrontal cortex (OFC), ACC, amygdala, and aINS, in a dynamic circuit integrating cognitive evaluation, affective salience, interoceptive awareness, and voluntary control (Gross, 1998).

Effective emotional regulation enables not only the containment of dysfunctional reactive responses (e.g., limbic hyperactivation, rumination, avoidance) but also the sustaining of intentionality in action, the promotion of adaptive flexibility, and the reduction of executive load (McRae et al., 2012; Ochsner & Gross, 2005). Under high-pressure organisational conditions, this competence proves essential for preserving the balance between control and openness, precision and creativity, perseverance and recalibration (Kalisch et al., 2015; Tugade & Fredrickson, 2004). Conversely, deficits in emotional regulation – often unrecognised due to the absence of immediate clinical symptoms – constitute vulnerability factors for adaptive exhaustion, metacognitive deterioration, and DM rigidity (Shields et al., 2016).

Alongside emotional regulation, a central role in neurocognitive resilience is played by metacognition, understood as the ability to observe and monitor one's mental functioning, reflect on internal states, recognise the limits of one's judgment, and intentionally modify the cognitive strategies employed (Flavell, 1979; Nelson, 1990). It constitutes the basis of strategic control, that is the capacity not only to act within the environmental context but also to act upon one's mode of acting within that context (Fleming et al., 2010; Veenman et al., 2006). From a neurofunctional perspective, metacognition is associated with the activity of the anterolateral prefrontal cortex, the PrCu, and the frontal pole, regions involved in self-reflection, conflict monitoring, and inference on mental states (Fleming & Dolan, 2012; Vaccaro & Fleming, 2018).

In highly complex organisational environments, metacognition enables the distinction between automatic reactivity and intentional action, the reframing of erroneous evaluations, the anticipation of the effects of one's decisions, and the selection of adaptive strategies based on contextual variability (Veenman et al., 2006). Moreover, it serves as a mediator between self-perception and emotional regulation: a metacognitively competent individual is better able to recognise signals of latent stress, identify emerging dysfunctional patterns, and act promptly to interrupt spirals of operational deterioration (Spada et al., 2008).

Recent theoretical models have proposed an integrated view of emotional regulation and metacognition as a self-regulatory system with hierarchical architecture, in which strategic control is exercised across multiple levels of representation: from interoceptive sensory monitoring to cognitive restructuring, to the reconfiguration of motivational priorities. From this perspective, resilience is not conceived as a stable trait but as a dynamic process of cognitive-affective adaptation mediated by flexible metarepresentations, allowing individuals to maintain internal coherence even under conditions of systemic perturbation (Critchley & Garfinkel, 2017; Sterling, 2012).

These dynamics take on particular significance in organisational systems with high symbolic and intersubjective density, where stress is not merely operational load but also dissonance between personal values and implicit norms. In such environments, metacognitive regulation enables the neutralisation of behavioural default tendencies, preventing the passive automatization of responses and promoting the deliberate construction of strategic pathways congruent with one's resources, limits, and objectives (Frith, 2012).

Empirical applications of this construct in work contexts are growing. Interventions focused on strengthening metacognition – through interoceptive awareness training, emotional labelling protocols, guided reflective practices, neurophysiological biofeedback, and dialogic supervision – have shown positive effects on stress regulation, complex DM capacity, the quality of critical thinking, and organisational resilience (Critchley et al., 2004; Mehling et al., 2012; Vago & Silbersweig, 2012).

In summary, emotional regulation and metacognition constitute two fundamental pillars for maintaining functional adaptation in high-pressure contexts, enabling individuals not only to withstand stress but to transform it into a lever for learning, recalibration, and strategic growth. They represent, within an advanced vision of work psychology, not mere individual competences but true neurocognitive modulators of operational resilience, whose valorisation today constitutes a priority in the design of sustainable organisational ecosystems.

In light of this evidence, it becomes clear that affective and metacognitive regulation capacities not only constitute auxiliary resources but represent central components of an adaptive cognitive architecture, necessary to effectively confront the neurocognitive and emotional demands posed by contemporary organisational contexts. Their role becomes even more crucial as individuals are exposed to prolonged evaluative pressures, interactive contexts with high symbolic ambiguity, and DM burdens characterised by reputational risks and high-intensity relational dynamics.

The following section (1.1.3) will extend this analysis by focusing on the specific context of social-evaluative threat, particularly in face-to-face and digitally mediated environments, where communicative dynamics further modulate anticipatory and reactive stress responses.

1.1.3. Social-evaluative threat in remote and digital communication

EFs represent the cornerstone of adaptive behaviour in complex environments, as they constitute the neurocognitive substrate through which individuals can plan actions, maintain goals, inhibit automatic responses, update working memory, and monitor the outcomes of their behaviour (Diamond, 2013). These abilities are particularly critical in contemporary organisational contexts, characterised by multitasking, simultaneous management of asynchronous communication channels, implicit evaluative pressure, and operational flexibility (Balconi, Angioletti, et al., 2020; Chan et al., 2021). However, due to their strategic relevance, EFs are also among the most vulnerable cognitive systems to hyperactivation induced by chronic stress.

Prolonged exposure to stress-inducing conditions selectively and cumulatively reduces the efficiency of executive processes. The most recent empirical evidence, derived from longitudinal studies employing fMRI and DTI, indicates that chronic stress compromises the structural and functional integrity of the PFC, the ACC, and the PrCu, resulting in reduced connectivity within the Central Executive Network (CEN) and altered dynamic synchronisation between the SN and the DMN. This neural misalignment leads to a progressive loss of coherence between goal representation, environmental context, and manifested behaviour, fostering a disorganised, reactive, and cognitively inefficient operational mode (Chan et al., 2021; Liston et al., 2009; McEwen & Morrison, 2013).

At the neuroendocrine level, the prolonged activation of the HPA axis, in response to evaluative or unpredictable stimuli typical of high-demand work contexts, leads to chronic release of glucocorticoids (cortisol), which exert neurotoxic effects on brain regions involved in executive regulation. Alterations in the hippocampus (HC) and PFC, confirmed by autopsy and neuroimaging studies, manifest as reduced synaptic efficiency, diminished neuronal plasticity, and impaired fronto-striatal dopaminergic transmission. Observable phenomena resulting from these changes include the inability to maintain intentional states, increased inattentional errors, and the emergence of automated, rigidly defensive behaviours, poorly sensitive to environmental feedback (Lei et al., 2025; Lupien et al., 2009; Bruce S. McEwen, 2007).

From a theoretical perspective, the *Dual Mechanisms of Control Model* provides an important framework for interpreting the effect of stress on EFs. According to this model, the cognitive system operates through two regulatory modes: (i) *proactive control*, which involves the active maintenance of goal representations and the anticipatory preparation of responses, and (ii) *reactive control*, which is activated only in the presence of critical stimuli. Prolonged stress, as confirmed by behavioural and neurophysiological studies, inhibits proactive control in favour of a more economical but less efficient reactive mode, with repercussions for planning, cognitive flexibility, and the capacity to integrate complex information (Braver, 2012; Lupien et al., 2009).

Within this shift, communicative and feedback processes assume a central role. Empirical findings suggest that clear, consistent, and positively valenced feedback can partially sustain proactive control by reinforcing goal representations and reducing interpretative uncertainty, thereby mitigating the drift toward reactive and short-sighted processing (Garrison et al., 2013; Wang et al., 2016). Conversely, ambiguous or negatively framed feedback has been shown to accelerate the collapse of proactive control, amplifying reliance on reactive modes that prioritise immediate threat avoidance over strategic integration. From a predictive coding perspective, feedback signals act as precision cues that either stabilise anticipatory models or destabilise them, depending on their epistemic clarity and affective valence. In organisational and evaluative contexts, where individuals must continuously anticipate expectations and outcomes, the form in which feedback is delivered thus directly shapes the trajectory of executive functioning under pressure. This perspective highlights feedback not as an accessory component of performance evaluation, but as a structural determinant of executive sustainability, capable of influencing whether EFs remain flexibly proactive or regress into fragmented reactivity.

Operationally, in cognitively dense contexts – defined as environments characterised by high informational entropy, low predictability margins, elevated task overlap, and attentional competition – EFs are subjected to continuous load, preventing resource recovery and promoting the onset of cognitive overload states (Frömer & Shenhav, 2022; Lavie et al., 2004). In such contexts, individuals experience increasing difficulty filtering irrelevant stimuli, managing the alternation between simultaneous tasks, and maintaining coherence between initial intentions and actions effectively performed. This phenomenon, known as *cognitive fragmentation*, constitutes a robust predictor of inefficiency, reduced productivity, and increased risk of critical errors, particularly in roles of strategic responsibility or in socially sensitive environments (Braff & Geyer, 1990).

The impairment of EFs under conditions of elevated stress also has measurable effects on DM processes. Reinforcement learning computational models indicate that under stress, there is reduced depth of the deliberative cycle, heightened sensitivity to negative emotional signals, accelerated decision times (*decision urgency*), and contraction of the temporal horizon *(temporal*

myopia) (Huys et al., 2016; Lempert et al., 2012; Starcke & Brand, 2012). Individuals tend to adopt heuristic decision strategies aimed at minimising short-term uncertainty, which, however, may prove dysfunctional in the medium to long term (Porcelli & Delgado, 2009; Raio & Phelps, 2014).

Another critical area concerns the interaction between EFs and motivational self-regulation. Under conditions of prolonged stress, cognitive resource depletion is often accompanied by a loss of intrinsic orientation, a reduction in the sense of agency, and a disintegration of the connection between personal goals and the reference context. This dissociation produces a form of *functional cognitive apathy*, wherein individuals formally maintain operability but lack the internal regulatory drive necessary to ensure coherence, precision, and the strategic finalisation of their actions (Nigg, 2017).

The systemic effect of such impairments is amplified within groups and organisations. When multiple individuals operate under prolonged stress and executive inefficiency, cascading effects are observed at the level of social interaction, interindividual coordination, and operational cohesion. Phenomena such as collective decision fatigue, conflict escalation, and the spread of defensive cognitive patterns represent recurrent manifestations of a system that, deprived of the capacity for cognitive self-regulation, enters a regressive and dysfunctional trajectory (Arnsten, 2009, 2015; Pruessner et al., 2005).

To counteract this drift, it is necessary to design cognitively sustainable work environments capable of supporting executive recovery, stabilising informational flows, segmenting tasks, and providing access to metacognitive regulatory resources (Bruce S. McEwen & Morrison, 2013). Evidence-based interventions, such as attentional training, cognitive task structuring, process-based feedback, and practices aimed at reducing cognitive clutter, have been shown to be effective in reestablishing the balance between load and control, thereby preserving executive functionality even under conditions of high pressure (Luu & Tucker, 2001; Shenhav et al., 2016).

However, while EFs are central to behavioural management, they do not operate in isolation. Their effectiveness largely depends on the individual's capacity to consciously and

intentionally modulate affective and motivational states. In this respect, emotional regulation and metacognition constitute crucial factors for ensuring strategic adaptation and resilience within highly complex organisational systems.

Concluding, this subsection has demonstrated that the stress response cannot be interpreted solely in terms of intensity of activation or temporal configuration but must also be situated within the communicative and relational context in which evaluation takes place. Building on the discussion of eustress and distress (Section 1.1.1) and on the distinction between acute and anticipatory stress dynamics (Section 1.1.2), it becomes evident that communicative environments—whether direct, mediated, supportive, or ambiguous—act as decisive modulators of regulatory outcomes. In particular, the shift toward digitalised and asynchronous forms of evaluation highlights how communicative form, timing, and transparency can either preserve adaptive anticipatory regulation or accelerate the collapse into dysfunctional reactivity. Such dynamics reveal that the sustainability of adaptation in organisational systems depends not only on the intrinsic resources of the individual but also on the epistemic quality and affective valence of the feedback received. The following section (1.2) will therefore introduce contemporary theoretical and neuroscientific models of neurocognitive adaptation and allostatic regulation, offering a systemic framework to interpret how cognitive load, executive vulnerability, and interindividual plasticity are continuously recalibrated by communicative and evaluative feedback within complex, high-pressure environments.

1.2. Human adaptation to high-complexity environments: a neurocognitive perspective

Human adaptation in high-complexity environments – especially within contemporary organisational ecosystems – emerges from the coordinated activation of advanced neurocognitive systems, whose dynamic interplay sustains both homeostatic regulation and the preservation of functional efficacy under conditions of systemic demand (Ashmos et al., 2000). Within this framework, adaptation is not conceived as mere resistance to perturbation or as a

transient return to homeostasis. Instead, it represents a complex self-regulatory and metacognitive process, characterised by the modulation of arousal states, the strategic allocation of cognitive resources, and the deliberate reconfiguration of self-representational schemas and environmental appraisal mechanisms. The construct of neurocognitive adaptation is grounded in the assumption that the human mind functions as an anticipatory and contextually attuned system, rather than as an isolated or merely reactive entity. Adaptive functioning entails the proactive generation of predictive models, the ongoing evaluation of stimulus-model congruence, and the dynamic updating of cognitive and behavioural strategies in response to environmental flux. In contexts marked by high volatility and informational density, the agent's operational viability hinges on the capacity to integrate salient novelties, suppress irrelevant or redundant inputs, inhibit automatic behavioural routines, and flexibly reorient goals in real time. These processes necessitate the coordinated engagement of specialised neural substrates embedded within hierarchically structured and functionally distributed large-scale brain networks (Bidet-Caulet et al., 2012; Bornkessel-Schlesewsky et al., 2022; Luczak & Kubo, 2022).

Specifically, adaptation is supported by three principal neurofunctional systems (Friedman & Robbins, 2021; Krönke et al., 2020): (i) the CEN, comprising the dlPFC and the posterior parietal cortex (PPC), responsible for executive regulation, the maintenance of intentional sets, and the monitoring of goal-directed behaviour; (ii) the SN, including the aINS, the ACC, the right PFC (rPFC) and the supramarginal gyrus (SMG), implicated in the detection of behaviourally relevant stimuli and the adaptive switching between functional modalities; and (iii) the DMN, involving the PrCu, medial Prefrontal Cortex (mPFC), the Posterior Cingulate Cortex (PCC), the HC and the posterior middle temporal gyrus (pMTG), associated with self-referential processing, autobiographical projection, and metacognitive regulation.

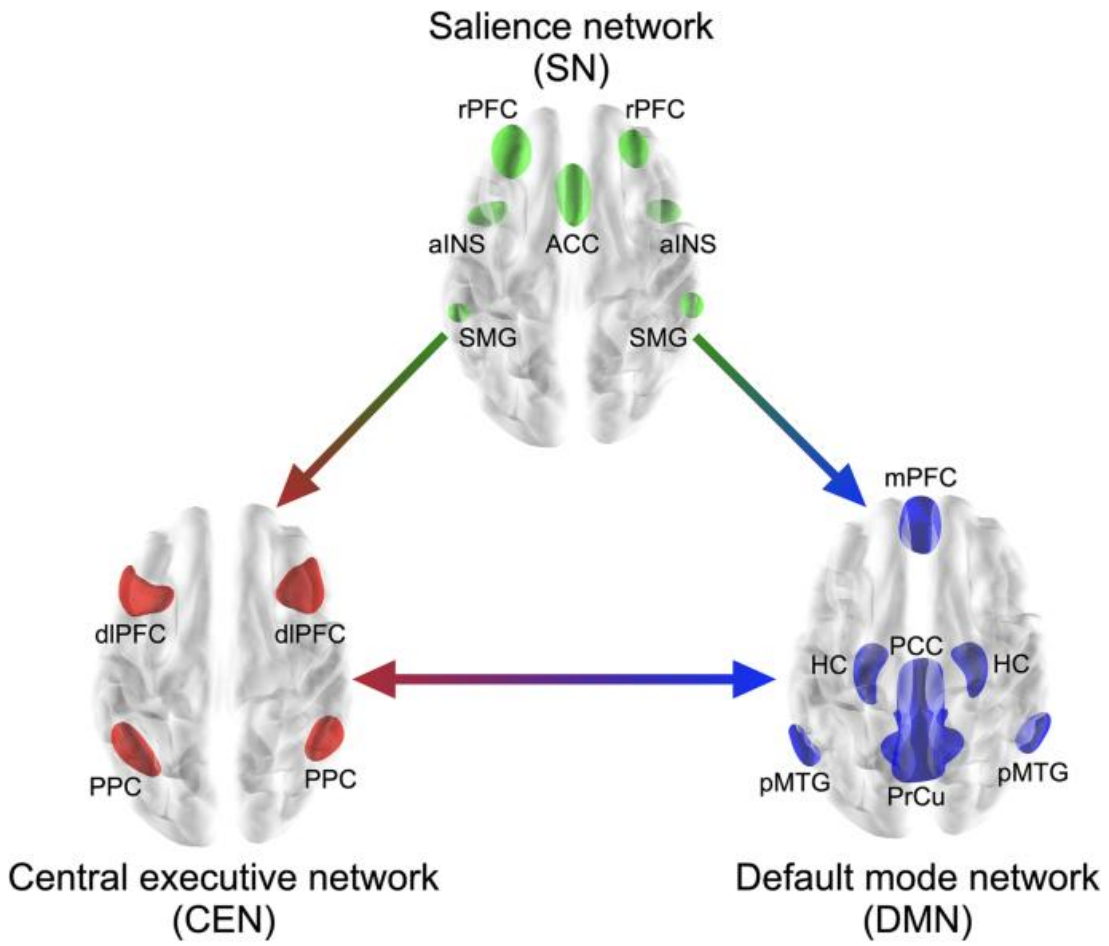

Figure 1.1. *Triple network model.* The anti-correlated relationship between the Central Executive Network (CEN; red regions) and Default Mode Network (DMN; blue regions), which are regulated by the Salience Network (SN; green regions) (source: Seo et al. 2025)[1].

A further implication of this tripartite organisation is that adaptation in high-complexity environments cannot be reduced to the activation of isolated circuits but must be understood as a dynamic negotiation between communicative inputs, predictive expectations, and

[1] rPFC rostral prefrontal cortex, ACC anterior cingulate cortex, aINS anterior insula, SMG supramarginal gyrus, dlPFC dorsolateral prefrontal cortex, PPC posterior parietal cortex, mPFC medial prefrontal cortex, HC hippocampus, PCC posterior cingulate cortex, pMTG posterior middle temporal gyrus, PrCu precuneus.

regulatory resources. In particular, social and evaluative feedback emerges as a central driver of cross-network reconfiguration, shaping the degree to which the CEN, SN, and DMN cooperate or compete in sustaining goal-directed behaviour (Henderson et al., 2012; Howlett & Paulus, 2024; Sterling, 2012). Positive or supportive feedback, for instance, tends to enhance CEN–DMN integration by reinforcing self-representational coherence and stabilising attentional sets, whereas negative or ambiguous feedback often increases SN dominance, leading to heightened salience attribution, hypervigilance, and accelerated depletion of executive control. Thus, communicative signals do not simply accompany adaptation but actively re-weight the balance among large-scale networks, determining whether stress will be channelled into flexible regulation or devolve into maladaptive rigidity (Bennett et al., 1990; Raftery & Bizer, 2009).

From the standpoint of predictive brain theories, feedback can be conceptualised as an epistemic anchor that modulates the precision weighting of prediction errors within hierarchical models. When feedback is reliable, clearly valenced, and contextually interpretable, it reduces inferential uncertainty, allowing the system to maintain proactive control while flexibly updating goals. By contrast, imprecise, inconsistent, or ambiguous feedback inflates prediction error volatility, destabilising inferential hierarchies and biasing the system toward reactive control. This shift manifests neurofunctionally as a contraction of CEN recruitment, overactivation of salience-driven circuits, and dysregulated coupling with limbic structures. In high-density organisational contexts, where the frequency and multiplicity of feedback exchanges are elevated, this epistemic dimension becomes decisive: adaptation is sustained not by the mere availability of resources but by the communicative quality of evaluative inputs (Blader et al., 2025; Nieminen & Carless, 2023).

At a more applied level, this perspective underscores that the resilience of adaptive functioning in contemporary organisational ecosystems depends as much on the communicative ecology as on individual neurocognitive resources. Environments saturated with fragmented, contradictory, or algorithmically generated feedback create conditions of chronic salience hyperactivation and attentional fragmentation, increasing the risk of maladaptive transitions even in otherwise resilient individuals. Conversely, systems that provide structured, transparent, and temporally calibrated feedback foster conditions that stabilise

network dynamics, preserve executive continuity, and support reflective regulation. Adaptation, in this sense, is co-constructed: it is not only the property of an individual brain but the emergent outcome of brain–environment coupling mediated through communicative exchanges.

Finally, this integrative account provides the conceptual bridge to the empirical sections that follow. By framing feedback as both a neurocomputational perturbation and a communicative event, the model specifies three regulatory dimensions that will be systematically examined: (i) the valence of feedback and its capacity to mobilise differential cortical–autonomic configurations; (ii) the ambiguity of feedback and its interpretative costs for anticipatory regulation; and (iii) the form of feedback, contrasting static versus dynamic communicative modalities in shaping attentional and emotional engagement. These dimensions provide not only testable hypotheses but also a unifying framework that ensures continuity between theoretical constructs and experimental design, clarifying how large-scale network models of adaptation translate into operational mechanisms observable in real-world organisational and evaluative contexts.

Furthermore, adaptation capacity emerges from the flexibility with which these networks activate and inhibit one another, thereby maintaining a functional balance among external stimulation, cognitive control, and internal integration. Dysfunctional adaptation arises when this network-level flexibility is disrupted: predominant DMN activity is associated with maladaptive introspection, perseverative cognition, and DM paralysis; SN hyperactivation may induce states of hyperarousal, threat sensitivity, and affective over-reactivity; whereas reduced CEN engagement compromises executive continuity, strategic foresight, and goal-directed behaviour (Alvarez et al., 2015; Makovac et al., 2020; Menon & Uddin, 2010).

This dynamic architecture of adaptation is theoretically supported by computational models grounded in the predictive brain framework (Gilbert et al., 2022; Harris et al., 2023; Robinson et al., 2013), which conceptualises the cognitive system as a hierarchical inferential apparatus aimed at minimising predictive error. Within this perspective, adaptation to stress corresponds to the capacity to efficiently update internal models in response to incoherent environmental signals, thereby avoiding both the rigid maintenance of obsolete schemas and

the instability generated by excessive inferential volatility (Paulus et al., 2009). Such balance is enabled by synaptic plasticity, dopaminergic regulation, and the metacognitive capacity to observe one's mental operations as intentional objects.

Nevertheless, the sustainability of this equilibrium is limited. Under conditions of continuous stimulation, prolonged mental workload, and persistent social pressure, a progressive increase in allostatic load may occur (i.e., the cumulative regulatory cost required to maintain internal stability).

The allostatic model, initially proposed by Sterling and Eyer (1988) and later expanded by McEwen (2007), describes this phenomenon as the gradual depletion of neuroendocrine, cognitive, and emotional resources, ultimately leading to systemic dysregulation. This load is not solely physiological; it also encompasses cognitive and symbolic dimensions, manifesting in heightened informational noise, a contraction of reflective capacities, and diminished availability of resources for managing risk, complexity, and uncertainty (Booth et al., 2015; Ganzel et al., 2010).

In parallel, recent theoretical developments have underscored the crucial role of the interaction between neuroplasticity and metacognition in modulating adaptive processes. While neuroplasticity ensures the physical reconfiguration of neural circuits in response to experience, metacognition enables the intentional restructuring of cognitive strategies through reflective activity directed not at the external world, but at internal mental processes themselves. The synergy between these two levels – neural and metarepresentational – constitutes a necessary condition for truly sustainable regulation: neither purely automatic nor entirely volitional, but guided by internal schemas that are flexible, coherent, and open to updating (Gazerani, 2025).

The efficiency of adaptation also depends on the quality of intermodal integration among cognitive, affective, and bodily signals. The capacity to perceive, represent, and modulate internal states – commonly referred to in the literature as *conscious interoception* – is a fundamental prerequisite for the functional allocation of regulatory resources. The insular cortices, limbic system, and mPFC operate jointly to construct an internal map of the self,

which in turn informs DM, modulates emotional arousal, and sustains congruence between the corporeal and intentional self (Craig, 2009; Simmons et al., 2013; Wang et al., 2019).

In light of these considerations, neurocognitive adaptation should not be conceived as a unitary or generalised construct, but rather as a constellation of distributed processes characterised by interindividual variability. These processes are influenced by dispositional traits (e.g., mindfulness, empathy, openness to experience), learning histories, environmental conditions, and strategies of either active or passive regulation. Consequently, the analysis of adaptation to stress in cognitively saturated environments requires a decomposition of its structural and functional components, capable of distinguishing flexible adaptive trajectories from defensive, rigid, or dysfunctional patterns.

The following three paragraphs will provide a systematic examination of the principal dimensions through which neurocognitive adaptation unfolds: (i) paragraph 1.2.1 will explore the interrelation among cognitive load, EFs, and emotional regulation, highlighting the co-determination between informational overload, executive vulnerability, and affective stability; (ii) paragraph 1.2.2 will analyse the role of trait-level modulators such as mindfulness, conscious interoception, and empathy, explaining how these dispositional resources influence adaptation in preventive, reflective, and transformative ways; (iii) finally, paragraph 1.2.3 will focus on the distinction between adaptive regulation and passive resistance to stress, clarifying the functional, neurocognitive, and operational implications of two fundamentally divergent dynamics, often conflated yet critical to the long-term sustainability of individual functioning.

These conceptual articulations will serve to construct an integrated model of neurocognitive adaptation mechanisms, one that may be employed both to interpret observable variability in individual stress responses and to inform the development of «neuro-compatible» interventions aimed at promoting plastic, reflective, and strategically sustainable functioning.

1.2.1. Cognitive Load, Executive Functions and Emotion Regulation

The first foundational axis of neurocognitive adaptation within high-complexity organisational environments involves the dynamic interplay among Cognitive Load (CL), EFs, and Emotion Regulation (ER) processes. Although conceptually distinguishable, these three domains are intrinsically interconnected at both functional and neuroanatomical levels, constituting an integrated regulatory system that enables the individual to maintain behavioural efficacy and internal stability under conditions of elevated environmental and task-related demands. This triadic system operates as the core interface through which adaptive responses are orchestrated in cognitively taxing contexts. The modulation of CL, the flexible deployment of EFs (such as inhibition, working memory, and cognitive flexibility), and the regulation of affective arousal are not only reciprocally influential but also synergistically engaged in preserving goal-directed behaviour and mitigating maladaptive stress responses (Buhle et al., 2014; Hermann et al., 2014; Okon-Singer et al., 2015).

CL can be operationally defined as the cumulative demand exerted on the cognitive architecture during task execution, particularly concerning the availability and allocation of attentional and working memory resources. In contexts characterised by high informational density and low environmental predictability, the cognitive system is required to simultaneously encode, integrate, and prioritise multiple streams of stimuli, dynamically update internal representations, and preserve coherence between operative goals and shifting contextual constraints. When such demands exceed processing capacity, cognitive overload ensues, manifesting in the accelerated depletion of working memory reserves, diminished sustained attention, and marked decrements in DM performance, typically reflected in increased response latency, reduced accuracy, and impaired strategic consistency (Balconi & Rovelli, 2024; Zucchelli et al., 2025).

EFs – particularly the core components of inhibitory control, cognitive flexibility (*shifting*), and working memory updating – represent the central set of cognitive control processes that enable individuals to efficiently regulate CL. These mechanisms support the

selective encoding of task-relevant information, the suppression of distractors, and the adaptive revision of goals and strategies in response to changing environmental feedback. Despite their pivotal regulatory role, EFs are characterised by intrinsic capacity limitations and marked vulnerability to affective interference. Converging neuroscientific evidence indicates that heightened activity within limbic structures – most notably the amygdala and broader nodes of the salience network – can exert a top-down disruptive influence on the functional integrity of the dlPFC, a key hub of executive regulation. This antagonistic interaction compromises the deployment of executive resources under conditions of maximal cognitive demand, leading to diminished regulatory precision, reduced cognitive flexibility, and increased susceptibility to maladaptive responses (Datta & Arnsten, 2019; Miyake et al., 2000).

Within this neurocognitive framework, Emotion Regulation (ER) emerges as a critical modulatory function in the preservation of executive performance under conditions of stress and elevated cognitive load. The ability to volitionally attenuate the intensity, duration, and impact of affective responses, particularly through cognitively mediated strategies such as reappraisal or mindful acceptance, plays a central role in sustaining the functionality of executive systems. In addition to these meaning-based regulatory strategies, attentional deployment mechanisms such as distraction constitute a complementary class of ER processes, operating primarily through the redirection of cognitive resources away from affectively salient stimuli toward neutral or task-relevant information. Empirical neuroimaging data consistently show that individuals with higher levels of emotional regulatory competence exhibit increased activation in prefrontal control regions (e.g., dlPFC, vmPFC) and attenuated reactivity in limbic structures, notably the amygdala, during the execution of cognitively demanding tasks not only during reappraisal but also during distraction-based regulation, which has been associated with enhanced engagement of lateral prefrontal and parietal attentional control networks (Etkin et al., 2011; Ochsner et al., 2002).

The integrated model of adaptive efficiency posits that sustainable performance in informationally dense and dynamically unstable environments is not solely a function of the absolute availability of executive resources, but rather of the quality of their dynamic coordination and their resilience to affective perturbation. When CL surpasses the threshold of

functional tolerance in the absence of adequate ER, the system is prone to executive degradation, manifesting as disorganisation of goal-directed behaviour, impaired decisional clarity, and a breakdown in the alignment between intentionality and enacted action plans. These dysfunctions compromise both immediate performance outcomes and the long-term integrity of self-regulatory processes (Etkin et al., 2011; Ochsner et al., 2002).

Converging evidence from dual-task paradigms, fMRI, and EEG studies indicates that, under conditions of elevated CL, affective ER acts as a neurofunctional buffer that preserves the integrity of the CEN and mitigates the disruptive intrusion of emotionally irrelevant stimuli. This regulatory buffering effect is supported by the co-activation of key prefrontal regions, particularly the dlPFC and the ACC, whose joint engagement reflects a functional integration between cognitive control and affective modulation systems. In contrast, a prevailing activation of limbic-affective circuits – specifically the aINS and the amygdala – under high-load conditions is consistently associated with failures in emotion-cognition integration, leading to regulatory collapse, increased behavioural impulsivity, and decreased performance reliability (Dillen et al., 2009; Etkin et al., 2011).

Beyond intra-individual processes, the interaction among CL, EFs, and ER exerts systemic effects within organisational ecosystems. When informational architectures are poorly calibrated to the cognitive constraints of human agents – whether through excessive task complexity, continuous multitasking demands, or chronically evaluative and affectively dysregulating work cultures – the result is a progressive deterioration of performance quality, characterized by elevated error rates, procedural overregulation, and a decoupling between strategic objectives and operational implementation (Madore & Wagner, 2019).

Conversely, organisational environments that proactively support affective regulation, institutionalise cognitively restorative pauses, and structure tasks into temporally and cognitively tractable units foster conditions conducive to neurofunctional sustainability. Such environments promote more stable executive functioning, enhance task engagement, and reduce the psychophysiological burden associated with chronic regulatory effort, thereby optimising both individual performance and collective efficiency over time (Keng et al., 2011; Woods et al., 2018).

Ultimately, a comprehensive understanding of the interplay between CL, EFs, and ER necessitates the integration of metacognitive awareness as a higher-order modulatory construct. Metacognition enables individuals to monitor, evaluate, and strategically regulate their cognitive and affective states, thereby facilitating the early detection of overload conditions and the intentional adjustment of task-related strategies. In this perspective, regulation transcends its role as a reactive or compensatory function, becoming instead a reflective process of endogenous governance. Such metacognitive operations are essential for preserving operational plasticity and ensuring adaptive flexibility, particularly under conditions of sustained pressure and fluctuating environmental demands.

In light of these considerations, it becomes clear that adaptive success in cognitively demanding environments cannot be attributed exclusively to the quantitative intensity of external stimulation or the objective complexity of task requirements. Rather, it critically depends on the efficiency, synchronicity, and reflexivity with which the cognitive-affective system self-regulates in response to internal and external perturbations. Accordingly, adaptive functioning is best understood as an emergent property of integrative regulatory processes – executive, emotional, and metacognitive – that operate in concert to preserve functional coherence and behavioural efficacy.

The following section (1.2.2) will examine the contribution of stable dispositional modulators – specifically mindfulness, interoceptive awareness, and empathic attunement – in modulating subjective experiences of CL and in facilitating more flexible, sustainable, and intentional adaptive responses across complex operational settings.

1.2.2. Trait-level modulators: mindfulness, interoception, empathy

Neurocognitive adaptation to complex environments is not uniquely the product of reactive adjustments to external contingencies. It is the result of a more profound interplay between situational demands and stable dispositional configurations that influence the baseline functioning of cognitive and affective systems. Among these stable traits, specific dispositional

variables have emerged as fundamental modulators of stress sensitivity, regulatory coherence, and long-term functional integrity under pressure. These variables do not operate in isolation but interact with neurocognitive systems to support the maintenance of adaptive capacity under sustained or escalating cognitive and emotional load. Three dimensions, in particular – mindfulness, interoception, and empathy – have been identified as core pillars of this dispositional modulation, each contributing to the refinement of regulatory processes through distinct yet converging mechanisms.

Mindfulness refers to the tendency to maintain present-centred, intentional, and non-reactive awareness of mental and somatic states (Balconi et al., 2019; Crivelli, Fronda, & Balconi, 2019). As a dispositional resource, mindfulness enhances the capacity for attentional stability and self-observation, allowing the individual to monitor and adjust internal dynamics without becoming affectively entangled in them. This quality becomes particularly relevant in high-load contexts, where rapid fluctuations in task demands and emotional salience require continuous reorientation of attention and goal structures. Individuals with elevated levels of mindfulness demonstrate a greater capacity to attenuate the escalation of stress reactivity, preserve prefrontal engagement, and access higher-order control functions even when the regulatory system is under duress (Sinha et al., 2016; Taren et al., 2017). Mindfulness thus contributes not only to the attenuation of maladaptive arousal but also to the stabilisation of executive functioning through mechanisms of internal decentring and cognitive reframing. In addition, mindfulness supports a metacognitive stance that is essential for adaptive functioning in complex environments. This includes the ability to monitor one's regulatory strategies, detect the early onset of overload, and modify cognitive operations accordingly. By fostering a detached yet intentional relation to internal experience, mindfulness enables the individual to maintain operational flexibility, reduce perseveration, and avoid rigid behavioural patterns. This regulatory posture does not merely suppress stress responses but enables their real-time modulation, limiting the accumulation of neurophysiological strain and promoting a more efficient allocation of limited cognitive resources. The impact of mindfulness on self-regulatory functioning is thus both preventive and transformative, reinforcing the agent's ability to act

with strategic coherence under fluctuating internal and external conditions (Guendelman et al., 2017; Kilpatrick et al., 2011).

A second foundational trait is *interoception*, which concerns the ability to consciously perceive, monitor, and interpret internal bodily signals (Gibson, 2019). While visceral afference occurs continuously and automatically, interoception introduces a level of awareness that allows these signals to be cognitively elaborated and used as inputs for regulatory action. This includes the perception of cardiac activity, respiratory rhythms, muscular tension, and other autonomic fluctuations that signal the state of the organism's internal environment. Conscious interoception enables the detection of subtle physiological changes that may precede overt signs of stress or cognitive degradation, acting as an early warning system for regulatory imbalance (Balconi & Angioletti, 2023b; Gibson, 2019; Schulz & Vögele, 2015).

Moreover, interoception supports the alignment between bodily activation and mental representation, allowing for the dynamic coordination of sensorimotor, emotional, and cognitive domains. It is involved in the construction of self-related experience, in the attribution of salience to environmental stimuli, and the calibration of emotional intensity (Balconi & Angioletti, 2021a). Through these functions, interoception contributes to the fine-tuning of regulatory responses, adjusting the amplitude and duration of adaptive reactions in proportion to actual internal needs rather than external pressures alone. This capacity to integrate bottom-up sensory data with top-down evaluative processes reinforces the coherence of the individual's responses and reduces the risk of disproportionate or poorly modulated behaviours. Furthermore, interoception plays a central role in maintaining the continuity of the self, particularly under disruptive conditions that may threaten internal integration. It supports the preservation of identity-related consistency by ensuring that internal states remain accessible, interpretable, and regulable within the framework of intentional action (Balconi & Angioletti, 2021b).

Empathy constitutes the third major dispositional modulator, with particular relevance in environments where interpersonal complexity and relational intensity are high. Unlike automatic emotional contagion, which may result in affective overload, regulated empathy allows for recognising and interpreting others' emotional states without affective fusion. It

involves both the simulation of another's experience and the active modulation of one's affective resonance, preserving the distinction between self and other while facilitating co-regulation in social interactions (Lamm & Majdandžić, 2015; Rameson et al., 2012).

This regulatory dimension of empathy is essential in professional and organisational settings where interpersonal evaluation, role negotiation, and emotional contagion are frequent and intense. Individuals with well-developed empathic regulation are better equipped to handle charged situations effectively without compromising their regulatory integrity. They can respond to others' emotional cues with appropriateness and attunement, while maintaining clarity of intention and behavioural stability (Angioletti & Balconi, 2020; Balconi & Canavesio, 2016; Bennett, 2001).

From a neurocognitive perspective, empathy involves the coordinated engagement of systems responsible for sensorimotor mirroring, emotional appraisal, and reflective control. This allows for continuous monitoring of the relational field and modulation of one's own affective states in relation to it. Empathy, in this sense, does not merely facilitate social connection; it protects the cognitive-affective system from the destabilising effects of interpersonal overload, supporting functional integrity in contexts of high relational density.

Taken together, mindfulness, interoception, and empathy represent three interrelated dispositional dimensions that modulate adaptive functioning across distinct levels of regulation. Mindfulness enhances metacognitive observation and attentional stability; interoception provides a somatic foundation for emotional and cognitive control; empathy ensures relational modulation and protects against affective contagion. The co-presence and dynamic interplay of these traits foster regulatory flexibility, support strategic variability, and increase resilience under complex and prolonged demands. They constitute not ancillary skills, but fundamental components of the neurocognitive architecture of adaptation.

The following section (1.2.3) will further elaborate on this framework by introducing a conceptual distinction critical to the understanding of adaptive trajectories under pressure: the differentiation between regulation and resistance to stress. These two dynamics, often

conflated, reflect profoundly different neurocognitive organisations and imply divergent implications for long-term sustainability in complex environments.

1.2.3. Regulation vs. resistance: distinct dynamics of stress management

Within the framework of neurocognitive adaptation to stress, a crucial theoretical and functional distinction – often overlooked or conflated in applied literature – concerns the difference between regulation and resistance (Geuens et al., 2018). While both strategies manifest as responses aimed at preserving individual functioning under environmental pressure, they are grounded in radically different neurocognitive architectures, with distinct evolutionary trajectories, psychophysiological implications, and cognitive costs.

Stress regulation can be defined as an intentional, dynamic, and flexible process aimed at modulating internal activation in accordance with goals, context, and subjective awareness of affective and cognitive states. It entails the use of adaptive top-down strategies, the active engagement of prefrontal structures (dlPFC, vmPFC, ACC), and integrated functioning across cognitive, affective, and interoceptive circuits (Poppelaars et al., 2018). Regulation enables the inhibition of dysfunctional automatic responses, cognitive reappraisal of the stimulus, adjustment of expectations, and ultimately, the restoration of an operational state congruent with environmental demands (Dillen et al., 2009; Gross, 2015).

By contrast, *stress resistance* reflects a defensive configuration in which the individual passively contains the impact of stress through avoidance, emotional suppression, cognitive denial, or behavioural overcompensation. Resistance is grounded in bottom-up, often automatic strategies that recruit subcortical circuits (amygdala, striatum, periaqueductal grey) and involve a decoupling between subjective awareness and physiological state (Geuens et al., 2018; Yurchuk & Lyashch, 2024). While resistance may prove functional in the short term, particularly in high-urgency or survival contexts, over time it engenders behavioural rigidity, vulnerability to regulatory depletion, and diminished cognitive plasticity.

This distinction between stress regulation and resistance is not merely conceptual but is also reflected in measurable neuroendocrine and autonomic dynamics. Individuals who predominantly rely on regulatory strategies tend to exhibit more adaptive physiological profiles, characterised by higher HRV, lower baseline levels of cortisol, and more rapid autonomic and neuroendocrine recovery following acute stress exposure. These markers reflect a system capable of flexibly modulating arousal, activating appropriate responses to environmental demands, and returning efficiently to homeostatic balance once the challenge has been resolved (Jentsch & Wolf, 2020; Williams et al., 2015).

In contrast, resistance-based profiles are typically associated with a sustained activation of the HPA axis and a dominance of sympathetic autonomic activity that is both tonic and insufficiently counterbalanced (Chen et al., 2017; Karin et al., 2020). This physiological configuration results in delayed recovery trajectories, increased metabolic expenditure, and reduced parasympathetic re-engagement, all of which contribute to a chronic state of hyperarousal. Although such profiles may remain clinically silent or appear functional in the short term – often interpreted as signs of resilience or «grit» – they tend to deteriorate over time, leading to cumulative dysregulation across neurovisceral and cognitive domains. This trajectory, while outwardly effective in initial stages, progressively undermines executive efficiency, emotional balance, and immune functioning, ultimately increasing vulnerability to burnout, affective disorders, and somatic symptomatology (Dahlman et al., 2021; Vente et al., 2015).

At the cognitive-behavioural level, the divergence between regulation and resistance is equally pronounced. Regulatory profiles are characterised by greater cognitive flexibility, the capacity to adapt problem-solving strategies in light of changing task demands, and the ability to reformulate goals in response to emerging constraints. DM processes within regulatory functioning are guided by mental models that remain open to updating, allowing for the ongoing calibration of intentions, expectations, and actions. This dynamic adjustment promotes decisional coherence, reduces perseverative errors, and supports sustained goal-directed behaviour even in unstable or unpredictable environments (Draheim et al., 2022; Musslick & Cohen, 2021).

Conversely, resistance-oriented profiles tend to rely on rigid behavioural patterns and low tolerance for ambiguity. Under pressure, individuals adopting this mode of functioning often resort to procedural overcontrol and stereotyped routines, privileging stability over adaptability. Over time, this strategy may become counterproductive, leading to cognitive inflexibility, reduced creativity in problem-solving, and a progressive misalignment between operative behaviours and contextual requirements. In more severe cases, the chronic use of resistance mechanisms can result in motivational detachment, loss of engagement, and disengagement from both tasks and interpersonal dynamics (Leon et al., 2015; Salvi et al., 2023; Saraiva & Nogueiro, 2025).

From a metacognitive perspective, regulation entails active self-monitoring, awareness of one's cognitive and emotional limits, and the use of corrective strategies to adjust performance when needed. This includes the capacity to detect early signs of overload, recognise when strategies are no longer effective, and deliberately seek support or modify one's approach. In contrast, resistance is frequently associated with low levels of insight into one's functioning, a tendency to overestimate one's self-regulatory capabilities, and a reduced inclination to acknowledge vulnerability or rely on external resources (David et al., 2012; Fischer & Fleming, 2024; Wang et al., 2024).

In organisational settings, recognising the distinction between regulation and resistance is essential for the development of truly effective strategies for prevention, training, and intervention. Systems that reward vulnerability suppression, emotional overcontrol, and denial of limitations tend to foster resistant profiles – superficially productive but potentially dysfunctional. Conversely, environments that value reflexivity, situational awareness, and transformative learning promote the emergence of regulatory profiles that are more sustainable and generative.

In conclusion, regulation and resistance do not merely represent different coping strategies, but rather two radically distinct ways of inhabiting pressure, reflecting different neurocognitive architectures and subjective positions. Understanding this distinction – and promoting reflective and intentional regulation – is a necessary condition for any initiative

aimed at supporting health, performance, and neurofunctional sustainability in cognitively and relationally demanding environments.

In summary, Section 1.2 has delved into the complexity and multidimensionality of the neurocognitive mechanisms supporting adaptation, offering a comprehensive theoretical model that integrates cognitive, affective, interoceptive, and metarepresentational processes. The literature has demonstrated that adaptive efficiency in high-pressure contexts does not depend solely on stress tolerance, but rather on the flexibility with which individuals can modulate, restructure, and integrate their internal responses considering environmental demands.

Paragraph 1.2.1 highlighted the need for dynamic balance among CL, EFa, and ER, emphasising how the «fragility» of any one component may compromise the entire operational system. Paragraph 1.2.2 focused on the strategic role of dispositional modulators – mindfulness, interoception, and empathy – in predisposing individuals to resilience and mediating adaptive trajectories. Finally, paragraph 1.2.3 introduced a clear theoretical distinction between adaptive regulation and defensive resistance, clarifying their neurofunctional bases, long-term outcomes, and operational implications in complex systems.

These three dimensions converge to define neurocognitive adaptation not as a reactive function, but as an intentional and self-reflective process – one that requires synaptic plasticity, functional integration, and metacognitive awareness. Within this framework, stress is not an «enemy to be eliminated», but a transformative vector capable, if effectively regulated, of triggering processes of learning, restructuring, and consolidation of self-regulatory competencies.

However, to fully understand the dynamics of such regulation, it is necessary to examine how stress manifests at the neural and behavioural levels – that is, its neurophysiological, expressive, and performance-related correlates as measurable through rigorous experimental protocols. Bridging the theoretical and empirical domains thus requires further articulation capable of connecting cognitive and affective models of adaptation with neuroscientific evidence related to stress response.

Section 1.3 will be dedicated to this critical transition. It will present key neuroscientific findings on cortical and subcortical activation under stress, with particular attention to variations in fronto-limbic network activity, neuroendocrine modulation, physiological synchronisation, and behavioural patterns observed under high evaluative or cognitive pressure. The goal will be to construct an empirical foundation upon which subsequent experimental analyses can be built, delineating the neurofunctional and psychophysiological coordinates of the adaptive stress response.

1.3. Neural and behavioural correlates of stress

As outlined in the preceding sections, the theoretical analysis of neurocognitive mechanisms underlying adaptive functioning highlights the necessity of grounding functional models in empirically verifiable indicators capable of capturing the manifestation of stress in both neural and behavioural dimensions. While conceptual frameworks provide essential interpretive scaffolding, developing robust, operationalizable models of adaptation requires integrating physiological, neurofunctional, and behavioural evidence that can be systematically measured and critically compared across individuals and contexts.

In this perspective, the present section is dedicated to the delineation and systematisation of the principal empirical correlates of stress, with a focus on modalities that are particularly informative in high-demand environments characterised by elevated CL or strong evaluative pressure. Specifically, the analysis will centre on three major domains of investigation: (i) electrophysiological (EEG) parameters, including frequency band modulation and event-related dynamics; (ii) indices of autonomic nervous system activation, such as HRV, skin conductance (SC), and respiratory patterns; and (iii) overt behavioural markers, including performance metrics, response variability, and expressive reactivity.

Together, these levels of analysis provide a multidimensional framework for assessing stress-related phenomena in ecologically valid contexts, offering critical insight into the dynamic interplay between brain function, physiological regulation, and adaptive behaviour.

Indeed, stress cannot be adequately assessed through self-report instruments or subjective accounts of distress alone. While introspective measures offer valuable information on perceived burden, they fail to encompass the full complexity of stress as a multi-systemic phenomenon (Ghasemi et al., 2024). Stress manifests through the coordinated activation of diverse physiological subsystems, cortical oscillatory patterns, subcortical dynamics, and observable changes in behavioural regulation. These manifestations reflect the integrated functioning of SN, arousal modulation mechanisms, ECN, and automatic response circuits determined by evolutionary adaptive priorities (Hultman et al., 2016; Stoliker et al., 2024).

The neurobehavioral perspective offers a privileged access point to these dynamics, enabling the observation of stress responses across multiple timescales and levels of analysis. Through this approach, it becomes possible to examine the temporal structure of regulatory fluctuations, interindividual variability in reactivity and recovery, and the systemic organisation of adaptive and maladaptive trajectories. By integrating neurophysiological, autonomic, and behavioural data, the neurobehavioral model provides a comprehensive analytical framework for identifying patterns of regulation, compensation, and breakdown in cognitively and socially demanding environments. This multimodal lens is essential not only for understanding how stress operates but also for delineating its impact on performance, DM, and long-term functional integrity.

At the neural level, stress engages specific and differentiated circuits whose activation patterns vary as a function of the nature of the stressor, the temporal characteristics of exposure, and the availability of cognitive and regulatory resources (Causse et al., 2022; Navarro-Nolasco et al., 2025). The cortical component of the stress response predominantly involves frontal regions, including the dlPFC, vmPFC, and ACC, as well as posterior areas such as the PCC, aINS, and PrCu. These regions are critically implicated in the cognitive appraisal of situational threat, the top-down modulation of arousal states, and the metacognitive monitoring of internal experiences. Their coordinated activation supports the integration of contextual information, the evaluation of relevance, and the initiation of regulatory strategies adapted to environmental contingencies (Kredlow et al., 2022; Limbachia et al., 2021).

At the subcortical level, key structures such as the amygdala, HC, hypothalamus, and ventral striatum contribute to the encoding of emotional salience, the consolidation of associative memory, and the modulation of neuroendocrine responses. The amygdala plays a central role in the rapid detection and prioritisation of affectively charged stimuli (Pessoa & Adolphs, 2010), while the HC contributes to contextual encoding and the comparison of current inputs with past experiences (Smith & Bulkin, 2014). The hypothalamus, as a major effector node, orchestrates neuroendocrine outputs via the HPA axis, regulating the secretion of glucocorticoids and coordinating systemic responses to perceived threat (Kinlein & Karatsoreos, 2019; Smith & Vale, 2006). The ventral striatum participates in the evaluation of motivational salience and reward prediction, and its dysregulation under stress has been associated with alterations in goal-directed behaviour and affective reactivity (Pool et al., 2021; Tottenham & Galván, 2016).

The coordinated yet often asynchronous activation of cortical and subcortical regions involved in stress regulation gives rise to measurable oscillatory phenomena at the electrophysiological level, particularly as observed through EEG. Oscillatory activity across distinct frequency bands – including delta, theta, alpha, beta and gamma – serves as a dynamic index of neurocognitive functioning, offering sensitive markers of cognitive load, affective arousal, vigilance, and attentional control (Balconi & Angioletti, 2021c). Changes in spectral power and functional coherence within and between these bands reflect ongoing processes of neural reorganisation and adaptive regulation. These indices are increasingly recognised as robust EEG signatures capable of capturing transient disruptions as well as sustained stress responses. Moreover, the temporal evolution of EEG oscillations allows for the identification of inflexion points – critical thresholds at which regulatory mechanisms begin to fail, and compensatory strategies become inefficient, rigid, or maladaptive (Chikhi et al., 2022; Helfrich & Knight, 2016; Lundqvist et al., 2011; Tan et al., 2024).

In parallel, stress-induced alterations at the level of peripheral neurophysiology – particularly within the autonomic nervous system (ANS) – offer complementary insights into the somatovisceral dimension of the stress response. These alterations are typically captured through measures such as HRV, skin conductance response (SCR), and respiratory or pupillary

dynamics. Such parameters, while indirect, provide highly sensitive markers of sympathetic-parasympathetic balance, vagal inhibitory tone, and systemic recovery efficiency (Huang et al., 2022; Mackersie & Calderon-Moultrie, 2016; Yu et al., 2024). Specifically, reductions in HRV, elevations in tonic electrodermal activity (skin conductance level, SCL), and high-amplitude phasic responses are consistently associated with heightened arousal, impaired autonomic flexibility, and elevated perceived stress (Yu et al., 2024). The patterns of autonomic dysregulation observed under these conditions often mirror those of central dysfunction, particularly in cases where sustained sympathetic activation is not counterbalanced by parasympathetic restoration mechanisms.

When EEG and autonomic indices are recorded simultaneously and interpreted within rigorously controlled experimental designs, they allow for a multilayered reconstruction of the stress response (Allegretta et al., 2024; Balconi et al., 2019; Balconi & Angioletti, 2021c; Sistiaga et al., 2025). This integrated framework enables the concurrent monitoring of cortical oscillatory dynamics, subcortical modulation, somatic regulation, and behavioural expression. Such multimodal integration constitutes the foundation of contemporary neurofunctional assessment paradigms, increasingly applied across educational, organisational, and clinical contexts to distinguish between efficient adaptation, fragile compensation, and emerging dysregulation. By linking neural markers with systemic and observable outputs, this approach improves both the precision and ecological validity of stress diagnostics.

From a behavioural perspective, stress gives rise to quantifiable disruptions across a wide range of cognitive and motor domains, manifesting in performance variability, strategic disorganisation, and diminished adaptive coherence. Among the most frequently observed impairments are increased intra-individual variability in reaction times (RTs), inconsistent deployment of executive strategies, reduced flexibility in DM processes, and compromised planning in goal-directed tasks (Hendry et al., 2024). These manifestations signal a reduction in the functional stability of higher-order cognitive operations, often resulting from overload, emotional interference, or regulatory fragmentation. In contexts characterised by evaluative pressure, social exposure, or high cognitive stakes, additional behavioural phenomena tend to emerge, including excessive self-monitoring of motor and cognitive output, postural inhibition

(freezing), indecisiveness, and a generalised reduction in behavioural flexibility. These patterns are not merely symptomatic but reflect underlying dysregulations within the broader neurocognitive architecture of adaptation (Herpen et al., 2022). Hypervigilance and procedural overcontrol, in particular, indicate a compensatory attempt to maintain task performance despite impaired integrative capacity, often at the cost of fluidity, spontaneity, and efficiency (Stahl et al., 2015). Critically, such behavioural markers acquire diagnostic value when interpreted in conjunction with neurophysiological measures. The triangulation of behavioural data with EEG indices and autonomic parameters enables the identification of latent dynamics that are not accessible through observation alone (Balconi, Gatti, et al., 2018; Balconi & Angioletti, 2024; Balconi & Fronda, 2022). This includes fluctuations in attentional engagement, breakdowns in executive integration, or affect-driven biases in DM. When synchronised across levels of analysis, behavioural indices do not merely serve a s endpoints or surface-level outcomes; rather, they become integral components of a systemic model of stress regulation, capable of capturing the real-time evolution, compensation attempts, and eventual failure or recovery of adaptive mechanisms under strain (Angioletti et al., 2025).

Ultimately, the analysis of neural and behavioural correlates of stress allows for the abandonment of reductive, one-dimensional conceptions of the phenomenon, revealing its intrinsically dynamic, stratified, and modular organisation.

Stress, as anticipated, is not a unitary state, but a processual condition emerging from the interplay among central and peripheral systems, mediated by individual dispositions and contextual constraints (Bendezú et al., 2016). This multidimensional perspective enables not only a more comprehensive understanding of adaptive functioning but also the early detection of vulnerability trajectories and the identification of predictive neurophysiological markers associated with resilience or progressive dysregulation. Such an approach opens the possibility of transitioning from descriptive assessment to functional diagnosis, grounded in objective and quantifiable indices.

In pursuit of this goal, the following paragraphs will examine two primary lines of investigation that constitute the empirical core of the present section. Paragraph 1.3.1 will be dedicated to the in-depth analysis of EEG frequency bands as indicators of cognitive and

emotional state. Particular attention will be given to spectral power modulations and topographic variations observed under stress-inducing conditions, to clarify how oscillatory activity reflects ongoing shifts in attentional, executive, and affective processes.

Paragraph 1.3.2 will turn to the evaluation of autonomic indices of arousal regulation, focusing on HRV and SCR as sensitive markers of sympathovagal balance and systemic flexibility in high-pressure contexts, especially those involving cognitive overload or social evaluation. By articulating these two empirical domains, the section aims to integrate the theoretical framework of neurocognitive adaptation with concrete physiological and behavioural evidence.

1.3.1. EEG frequency bands: indicators of cognitive and emotional states

Within the field of neurophysiological stress research, EEG analysis represents a preferred methodological approach for investigating the temporal architecture of neural dynamics involved in adaptive functioning. Unlike static neuroimaging modalities, EEG captures fast-occurring electrophysiological changes, offering direct access to the unfolding of neural events that support stress regulation. This regulation is not a linear or discrete process, but rather a rhythmic and recursive modulation of neural activity, reflected in specific oscillatory signatures across frequency bands that dynamically encode and influence the trajectories of cognitive and affective operations (Aftanas et al., 2001; Klimesch et al., 2007).

EEG frequency bands are not to be understood as mere correlates of discrete mental states; they represent oscillatory regimes of population-level neural synchrony, whose power and coherence reflect ongoing negotiations between bottom-up reactivity, top-down regulatory control, and the contextual salience of environmental inputs (Klimesch, 1999).

Under stress-inducing conditions – be they cognitively overloading or emotionally charged – oscillatory activity undergoes state-dependent reorganisation, reflecting the system's attempt to preserve or re-establish functional equilibrium through selective synchronisation across large-scale neural networks (Başar & Güntekin, 2013; Rogala et al., 2021).

Delta oscillations (0.5–4 Hz), the slowest cortical rhythms, are classically associated with deep sleep and unconscious processing. However, in awake states – particularly under sustained regulatory strain, emotional saturation, or mental fatigue – delta activity may emerge as a marker of cumulative burden on cognitive-affective systems. Increases in delta power, especially over prefrontal and frontocentral regions, have been observed in association with motivational withdrawal, decreased vigilance, and early signs of regulatory collapse (Başar & Güntekin, 2013). Functionally, delta oscillations are thought to support global inhibitory processes, neural downscaling, and the modulation of subcortical arousal inputs (Nácher et al., 2013). Their presence during stress may indicate either an effortful compensatory slowing of neural processing or a transitional state toward dysregulation, particularly when coupled with reduced higher-frequency synchrony. Delta rhythms should therefore be interpreted within a broader oscillatory context, where their significance depends on co-occurring activity in other bands.

Theta oscillations (4–8 Hz), with maximal expression in fronto-medial cortical areas, have been linked to conflict monitoring, executive regulation, and outcome evaluation. Increases in theta power – particularly in the ACC – have been consistently observed in tasks involving uncertainty, evaluative threat, and performance monitoring (Tang et al., 2021). These increases are interpreted as markers of central regulatory engagement, indexing the system's effort to resolve dissonances between predicted and actual outcomes. However, excessive and sustained theta augmentation may indicate a shift toward maladaptive cognitive rumination, reduced strategic efficiency, and increased risk of affective perseveration, especially in prolonged or unresolved stress contexts (Klimesch et al., 2007).

Alpha oscillations (8–12 Hz), often misconstrued as passive indicators of rest, are fundamental to the gating of information and the selective inhibition of irrelevant inputs. Under stress, desynchronization of alpha rhythms – particularly in frontal and parietal regions – may signal heightened vigilance or affective dysregulation (Klimesch, 2012). Notably, lateralized alpha desynchronization patterns have been associated with dispositional vulnerability (Katmah et al., 2021; Klimesch, 1999). Indeed, left-sided alpha suppression is often linked to anxious hyperactivation, while bilaterally attenuated alpha is suggestive of diffuse regulatory breakdown and reduced affective containment. It is thus critical to

distinguish adaptive alpha suppression, which facilitates attentional deployment, from disorganised alpha desynchronization indicative of hyperreactivity or compromised control (Aftanas et al., 2001).

Beta oscillations (13–30 Hz) are traditionally associated with motor planning, sustained attention, and maintenance of task goals. Under stress, elevated beta power – particularly over frontal and central sites – has been observed in contexts requiring sustained vigilance, such as performance under public scrutiny or time pressure (Townsend et al., 2022). However, beta increases do not uniformly reflect adaptive control: in individuals employing rigid or overcontrolled coping styles, beta augmentation has been linked to compensatory hyperregulation, associated with elevated energetic cost, reduced cognitive flexibility, and higher error probability. In such cases, beta activity may represent an electrophysiological correlate of maladaptive executive overcommitment – a pattern of hyperadaptation in which equilibrium is maintained at the expense of functional plasticity (Başar-Eroglu et al., 1996; Chikhi et al., 2022).

Gamma oscillations (>30 Hz), although less frequently reported in stress literature, are gaining empirical support as markers of integrative cognitive-affective processing (Rieder et al., 2011). Gamma increases have been associated with heightened metacognitive access, intermodal integration, and conscious regulation of arousal, especially in individuals trained in contemplative practices or interoceptive techniques. Regional increases in gamma power, particularly in the INS and PrCu, appear to reflect the system's capacity to engage higher-order reflective processing during emotionally challenging conditions, suggesting a role for gamma activity in transitions from reactive to self-regulated modes of functioning (Herrmann et al., 2004; Miltner et al., 1999; Rieder et al., 2011).

Beyond spectral power, EEG coherence and functional connectivity metrics provide a more detailed index of the brain's regulatory organisation under stress (Balconi et al., 2009; Balconi, Venturella, et al., 2020; Balconi & Angioletti, 2023a). For instance, increased fronto-parietal theta coherence is generally interpreted as a marker of adaptive network integration supporting executive control and flexibility (Tan et al., 2024). In contrast, excessive or rigid synchrony – particularly involving limbic-prefrontal circuits – has been observed in individuals

exposed to chronic stress, often reflecting reduced strategic variability and impaired top-down modulation. Multisite EEG analyses thus extend the interpretive power of frequency band analysis by revealing network-level properties of coordination, compensation, or dysregulation (Arnsten, 2009).

Crucially, EEG frequency band dynamics do not yield universal or context-independent biomarkers of stress. Rather, they produce complex, multivariate profiles that must be interpreted in relation to task parameters, individual predispositions, and available regulatory resources. The functional significance of any given oscillatory pattern – adaptive, compensatory, or dysfunctional – depends on its integration with peripheral physiological indices, behavioural outcomes, and self-reported states. Considering these considerations, EEG analysis should be regarded not merely as a diagnostic instrument, but as a dynamic tool for mapping adaptation as an evolving process. When integrated with ecologically valid task paradigms and multimodal physiological protocols, the monitoring of oscillatory activity enables early detection of vulnerability profiles, rigid regulatory patterns, adaptive breakdowns, and, importantly, emerging markers of resilience and neurofunctional plasticity.

The following paragraph (1.3.2) will extend this integrated perspective by examining the role of autonomic neurophysiological indices – specifically HRV and SCR – as complementary and synchronous parameters to EEG activity, useful for evaluating the quality of the regulatory system in evaluative and cognitively saturated environments.

1.3.2. Autonomic activity: HRV, SCR, and arousal regulation in evaluative settings

In the context of neurophysiological investigations of stress, the ANS activity constitutes a critical component of the psychophysiological response repertoire. The ANS functions as a bidirectional interface between internal visceral states and externally oriented behaviour, translating cognitive-affective demands into somatovisceral adjustments aimed at maintaining homeodynamic stability. Among the most informative indices of autonomic functioning, HRV and SCR have emerged as reliable, temporally sensitive markers of arousal regulation (Ernst,

2017; Kim et al., 2018; Zahn, Wenzel, et al., 2016). These measures capture short-latency fluctuations in sympathetic and parasympathetic tone, allowing for the dynamic monitoring of stress-related reactivity and recovery processes in response to cognitively demanding or socially salient stimuli (Mee et al., 2020; Vinberg et al., 2022).

In particular, evaluative stress paradigms – characterised by social exposure, performance uncertainty, and the anticipation of external judgment – represent ecologically valid conditions for eliciting autonomic activation patterns (Laborde & Mosley, 2016). Such contexts trigger evolutionarily conserved defence-alert systems, leading to acute increases in sympathetic arousal, vagal withdrawal, and sustained electrodermal activation. While these responses are adaptive in acutely bounded episodes, they become maladaptive when prolonged in the absence of affective processing, post-task deactivation, or top-down modulation.

Under such conditions, persistent arousal contributes to the accumulation of allostatic load and progressive erosion of regulatory capacity (Ernst, 2017; Zahn, Adams, et al., 2016; Zahn, Wenzel, et al., 2016).

HRV, particularly in the high-frequency domain (HF-HRV), reflects the capacity of the parasympathetic branch, mediated by the vagus nerve, to regulate cardiac activity in response to environmental demands. Elevated HRV is interpreted as a biomarker of neurovisceral flexibility and adaptive efficiency, supporting behavioural inhibition, ER, attentional reallocation, and executive functioning. Conversely, diminished HRV is consistently associated with reduced self-regulatory resources, increased affective vulnerability, and heightened risk for both psychiatric and cardiovascular dysregulation. Importantly, HRV does not merely index the magnitude of parasympathetic output but also encodes the capacity of the central-autonomic axis to modulate arousal in a context-sensitive and anticipatory manner (Grol & Raedt, 2020; Kim et al., 2018; Wang et al., 2023).

From a theoretical standpoint, polyvagal theory conceptualises HRV as a neurobiological substrate of adaptive social engagement, linking cardiac regulation with higher-order cognitive and relational capacities. In this framework, vagal tone mediates the organism's ability to transition from defensive states to affiliative engagement, modulating the balance between self-

preservative vigilance and prosocial openness. HRV thus assumes the dual role of being both an output of autonomic regulation and an input into neurocognitive systems governing emotional responsiveness and interpersonal behaviour (Gitler et al., 2025; Pham et al., 2021; Zammuto et al., 2021).

SCR, by contrast, is a direct index of sympathetic activation, reflecting phasic changes in eccrine sweat gland activity under conditions of heightened salience or emotional arousal. SCR exhibits high temporal sensitivity to stimulus onset and is particularly reactive to social-evaluative threats, including public performance, interpersonal conflict, and negative feedback. Its amplitude and latency are closely linked to amygdaloid activation and affective salience attribution, making it a privileged marker of reactive arousal (Klucken et al., 2015; Laine et al., 2009; Vinberg et al., 2022). While HRV captures the tonic regulatory landscape and resilience potential of the organism, SCR maps the immediacy and intensity of its phasic engagement with emotionally significant stimuli.

When assessed jointly, HRV and SCR provide a biphasic model of autonomic adaptation: HRV as a marker of parasympathetic withdrawal and re-engagement capacity, SCR as a measure of sympathetic activation threshold and sensitivity. An adaptive profile is characterised by high HRV and modulated SCR, indicative of a system capable of proportionate engagement and efficient deactivation. In contrast, maladaptive profiles typically show low HRV with elevated or tonic SCR, reflecting sustained hyperarousal, poor autonomic flexibility, and an increased risk of regulatory collapse under sustained evaluative load.

These physiological patterns are not merely theoretical constructs but exhibit strong correlations with observable behavioural outcomes in organisational, academic, and high-pressure decision-making settings. Individuals exhibiting maladaptive autonomic profiles tend to display greater performance inconsistency, heightened behavioural inhibition, reduced initiative, and lower tolerance for uncertainty (Chalmers et al., 2014; Schneider & Schwerdtfeger, 2020). In contrast, those with efficient regulatory patterns demonstrate enhanced cognitive flexibility, strategic adaptability, and the ability to maintain engagement in socially evaluative conditions (Laborde et al., 2017).

Emerging evidence further suggests that autonomic regulation cannot be reduced to an intrapersonal phenomenon. Recent hyperscanning studies have documented interpersonal physiological synchrony – defined as the temporal coordination of HRV or electrodermal activity across interacting individuals – as a key predictor of dyadic trust, emotional stability, and collaborative performance (Balconi & Vanutelli, 2017a; Ernst, 2017). Such findings underscore the intersubjective nature of stress, revealing that arousal regulation is not solely individual but embedded within relational dynamics, co-regulated through embodied cues and reciprocal physiological attunement.

In conclusion, the integrative assessment of HRV and SCR offers a powerful framework for analysing affective regulation and autonomic adaptation under stress from a multilevel, temporally resolved, and ecologically grounded perspective. When interpreted in conjunction with EEG-derived markers of neural activation and behavioural indicators of self-regulation, these measures contribute to the construction of a comprehensive profile of stress response. This profile enables the identification of individual trajectories of resilience or vulnerability, informs early-stage intervention strategies, and supports the design of adaptive environments that facilitate physiological recovery and regulatory plasticity.

This integrated perspective supports not only a more precise and predictive description of stress vulnerability but also a more advanced mapping of neurocognitive adaptation trajectories. It is instrumental for identifying early signs of dysfunction, protective factors, and potential leverage points for regulatory intervention.

To address this need for synthesis, Section 1.4 will be devoted to the development of a multilevel theoretical model capable of connecting neurophysiological, cognitive, and behavioural evidence within a unified and dynamic framework. Specifically, it will address: (i) the principles of integration among neural activity, autonomic signals, and observable conduct (1.4.1); (ii) the role of feedback and cognitive-emotional plasticity in adaptive regulation processes (1.4.2); (iii) the theoretical and practical implications for the field of organizational neuroscience and the digital design of human resources, with attention to evaluative environments and adaptive technologies (1.4.3).

This final section will conclude the theoretical block of the dissertation and lay the foundation for the subsequent empirical section, grounded in validated and integrated experimental protocols.

1.4. Toward an integrated framework

The discussion of neurocognitive mechanisms of adaptation (Section 1.2) and their neural, autonomic, and behavioural correlates (Section 1.3) has highlighted the multilayered, stratified, and dynamically integrated nature of the stress response. If stress is conceived as an emergent condition resulting from a dissonance between environmental demands and available resources, then effective adaptation is never the product of a single system or parameter. Rather, it is the outcome of a transmodal orchestration of cognitive, affective, somatic, and metacognitive processes in continuous exchange with the structural features of the context.

From this perspective, there emerges the necessity to formulate an integrated theoretical framework capable of transcending the methodological fragmentation that characterises much of the scientific literature and of capturing the full complexity of adaptive phenomena in human cognitive systems. Such a framework is not conceived as a static synthesis but instead as a generative structure able to articulate: (i) the interactions between central and peripheral neurofunctional levels; (ii) the interplay of stable dispositional traits and situational variables; (iii) the plasticity of regulatory responses as a function of feedback; (iv) and the epistemological and applied implications within digitalised organisational systems.

At the core of this model is the conceptualisation of *human stress adaptation*, particularly within evaluative or cognitively demanding contexts, as a dynamic, emergent process governed by the continuous negotiation between opposing functional poles. The individual is not passively subjected to environmental pressures but actively regulates their position along key regulatory axes: between physiological activation and homeostatic recovery, between executive control and receptive openness, and between the maintenance of internal coherence and responsiveness to external task demands. This dialectical regulation is not static but unfolds

over time as a function of both dispositional traits and situational contingencies, giving rise to adaptive trajectories that can range from flexible engagement to rigid compensation or breakdown.

Neural activity, as indexed by the modulation of EEG frequency bands and the functional architecture of large-scale brain networks, particularly the CEN, the SN, and the DMN, constitutes the foundational substrate of the adaptive regulatory system. Through the coordinated interaction of these systems, the brain can integrate perceptual, emotional, decisional, and metacognitive components into coherent responses to environmental demands. This integrative function supports the flexible deployment of cognitive control, affective modulation, and strategic realignment under pressure.

In parallel, autonomic activity reflects the embodied correlate of adaptation, operationalising the organism's capacity to regulate arousal and physiological variability following situational salience. Indices such as HRV and SCR serve as sensitive markers of the system's ability to sustain regulatory flexibility and generate proportionate reactivity to affectively or cognitively relevant stimuli. Together, these two domains – central neural and peripheral autonomic – constitute a dual-channel architecture through which the adaptive process is instantiated and expressed.

Critically, the functional significance of these activations does not lie in the isolated interpretation of single metrics, but rather in the systemic configurations and dynamic couplings they form. It is through the temporal convergence, synchrony, or dissonance between EEG and autonomic signals that the trajectory of adaptation becomes intelligible, whether flexible or rigid, reflective or reactive, integrative or fragmenting. These multimodal patterns serve as process-level indicators of the organism's regulatory mode and its capacity to engage with the environment in a sustainable and resilient manner.

Moreover, the behavioural dimension, frequently underrepresented in favour of physiological metrics, must be reconceptualised as the terminal expression of adaptive synthesis. It is through behavioural output that the cumulative effects of neurophysiological regulation are externalised, encompassing patterns of choice, interpersonal attunement, and the enactment

of agency. Behaviour thus operates not merely as a consequence, but as a diagnostic expression of the systemic coherence, or incoherence, of the adaptive response.

A second foundational component of the proposed framework concerns the transformative function of feedback within regulatory dynamics. Broadly construed – whether evaluative, performative, or contextual – feedback should not be regarded as a mere external stimulus, but as a semantically rich informational input about the self-in-context. It functions as a signal capable of eliciting processes of cognitive-affective reappraisal, regulatory recalibration, and restructuring of operative schemas by environmental contingencies. In this perspective, adaptive functioning is not limited to arousal modulation but entails the continuous updating of internal predictive models, the revaluation of motivational goal hierarchies, and the reorganisation of cognitive-emotional priorities in response to evolving task and relational conditions.

Such transformation presupposes a high degree of cognitive-emotional plasticity, defined as the system's capacity to transition fluidly between states, to flexibly regulate the amplitude and direction of activation, and to dynamically reconceptualise context-relevant decision parameters. At the neurofunctional level, this plasticity is instantiated through mechanisms such as synaptic remodelling, attentional reallocation, metacognitive self-monitoring, and interoceptive integration. These mechanisms constitute the biological and functional vectors through which the individual reorganises and reorients adaptive strategies. In the absence of such plasticity, stress responses tend to crystallise into stereotyped configurations, increasing energetic cost, diminishing regulatory efficiency, and reducing the capacity for innovation or resilience.

The third axis of the model concerns its translational and applicative implications, particularly in the domains of organisational neuroscience and human performance design in digitally mediated contexts. Contemporary work environments exert unprecedented demands on the neurocognitive regulatory system. These environments call for equally innovative tools capable of detecting, supporting, and cultivating adaptive competencies beyond traditional behavioural or productivity-based metrics. Within this scenario, the implementation of a neuro-integrated framework enables a redefinition of assessment paradigms, introducing

multimodal indicators – neurophysiological, autonomic, and behavioural – as early markers of sustainable engagement, latent vulnerability, or adaptive breakdown.

Moreover, such a framework enables the conception of neuro-compatible work systems: operational architectures that align technological infrastructures with human neurocognitive rhythms, regulatory needs, and plasticity potentials. These environments are not merely *reactive* but *proactively adaptive*, characterised by feedback ecosystems that support cognitive recovery, attunement, and self-regulation. In this context, applied neuroscience transcends the descriptive function of «stress measurement» to contribute normatively to the co-design of cognitively sustainable and ethically grounded organisational ecologies.

The theoretical model proposed here does not aim to reduce the complexity of adaptive functioning to a unidimensional logic. Rather, it offers a dynamic and multilevel conceptual matrix through which adaptation can be observed, analysed, and optimised via the reciprocal interaction among neurobiological systems, regulatory strategies, and sociocultural environments. The development of an integrated neurocognitive model of adaptation to stress (Rovelli & Balconi, 2025) – capable of capturing the systemic, situated, and stratified nature of adaptive regulation – constitutes not only an epistemological frontier but also an urgent translational priority. The objective is not simplification, but the generation of conceptual and methodological tools capable of guiding the interpretation, evaluation, and enhancement of human adaptive capacity in high-density cognitive-affective environments.

Three-Axis theoretical model

Axis I. Multilevel integration of adaptive systems - Objective: explain adaptation as an emergent phenomenon arising from the coordinated dynamics of central, autonomic, and behavioural systems.

Systemic level	Key components	Functions in adaptation
Central Neural System	EEG frequency bands; large-scale networks (CEN, SN, DMN)	Integration of perceptual, emotional, decisional, and metacognitive inputs; cognitive control under pressure
Autonomic Nervous System	HRV, SCR, arousal modulation	Embodied regulation of stress response; flexibility in physiological activation
Behavioural output	Choice patterns, interpersonal attunement, agency enactment	Expression and externalisation of systemic coherence (or dysfunction)
Emergent property	Systemic regulatory mode	Determined by synchrony/convergence between neural and autonomic signals

Core Principle: adaptation is a dynamic, multi-system process that must be analysed through cross-modal coupling, not isolated metrics.

Axis II. Feedback-driven regulation and plasticity - Objective: reframe feedback as a functional vector for cognitive-affective transformation and strategic adaptation.

Functional element	Mechanisms	Adaptive contribution
Feedback	Evaluative, performative, contextual cues	Semantic input for reappraisal and strategic recalibration
Cognitive-emotional plasticity	Synaptic remodelling, attentional shifting, metacognition, interoception	Enables updating of internal models, goal hierarchies, and decision schemas
Adaptive dysregulation	Crystallisation of stress responses into rigid configurations	Reduced efficiency, higher energetic cost, impaired resilience

Core Principle: plasticity is not a by-product of regulation, but the primary enabler of adaptive transformation in uncertain and evaluative contexts.

Axis III. Translational and Ecological Implications - Objective: extend the model toward applied domains, particularly within digitally mediated organisational systems.

Application domain	Neurocognitive target	Strategic outcome
Organisational neuroscience	Multimodal markers (EEG, HRV, behaviour) as early indicators	Sustainable engagement, vulnerability detection, breakdown prevention
Human Performance Design	Neuro-compatible work environments	Alignment of workflows with neurocognitive rhythms and recovery needs
Assessment paradigms	Beyond productivity: systemic coherence, regulatory health	Holistic, anticipatory HR systems and ethical co-design of digital ecologies

Core Principle: applied neuroscience must shift from measurement to co-design, shaping ecosystems that are functionally aligned with human adaptation needs.

The sections that follow will articulate this integrated framework along three fundamental trajectories. Paragraph 1.4.1 will be dedicated to the multilevel integration of neural, autonomic, and behavioural responses, to clarify how emergent adaptation cannot be interpreted in isolation from any single system but must be read as a dynamic pattern reflecting the organism–subject's functional configuration. Paragraph 1.4.2 will explore the concept of feedback-driven adaptation, focusing on how cognitive and emotional plasticity constitutes a core regulatory function that enables individuals to update predictive models, redefine priorities, and maintain strategic coherence in rapidly changing environments. Paragraph 1.4.3 will address the practical and design implications of the integrated framework, with particular reference to organisational neuroscience and the adaptive design of human resource systems in digital environments, proposing avenues of scientific and professional application capable of combining neurocognitive sustainability, evaluative innovation, and integrated regulation architectures.

This articulation will provide the theoretical and operational foundations for the transition to the empirical section of the thesis, where the principles discussed thus far will be tested through rigorous experimental protocols and multimodal observational tools.

1.4.1. Feedback-driven adaptation and cognitive-emotional plasticity

Within a multilevel framework of neurocognitive adaptation, feedback must be conceptualised not as a peripheral response to behavioural output, but as a central computational event that actively modulates cognitive, affective, and motivational trajectories. At the neurofunctional level, feedback does not merely reinforce or inhibit executive sequences; rather, it constitutes a high-salience perturbation signal capable of eliciting substantial recalibrations in internal predictive models (Brudner et al., 2016).

From the standpoint of predictive coding theories, the brain is inherently structured to generate probabilistic hypotheses regarding environmental contingencies. Every act of perception, DM, or behavioural output is preceded by an anticipatory model – the prior – whose validity is continuously revised through the processing of sensory data. The resulting prediction error, defined as the discrepancy between expected and actual input, constitutes the fundamental driver of regulatory learning (Walsh et al., 2020; Wilke et al., 2013).

Crucially, however, the efficacy of this process depends not solely on the magnitude of the prediction error, but on the system's estimated precision of the feedback signal, its epistemic reliability and affective salience (Romy Frömer et al., 2021; Sprevak & Smith, 2023).

Cognitive-affective plasticity, within this model, is defined as the system's capacity to flexibly update internal representations in response to prediction error while preserving functional coherence. This capacity is governed by a cortico-subcortical architecture comprising fronto-cingulate circuits (e.g., dlPFC, ACC), mesocortical dopaminergic pathways encoding salience and novelty, and fronto-striatal loops implicated in reinforcement learning and outcome monitoring (Garrison et al., 2013). In conditions of evaluative stress, adaptive functioning depends on the dynamic modulation between cognitive stability and restructuring

flexibility, balancing the preservation of internal coherence with responsiveness to disconfirmatory input (Gabrys et al., 2019).

This regulatory plasticity, however, is inherently susceptible to interference. Individuals exposed to chronic or repeated stress often exhibit attenuated neurocomputational sensitivity to feedback, characterised by diminished prediction error processing, reduced top-down prefrontal modulation, and exaggerated limbic reactivity. Such profiles manifest as impaired regulatory updating, wherein corrective signals are either dismissed, distorted, or assimilated into rigid defensive schemas (e.g., denial, minimisation, pseudo-adaptation), thus limiting the system's capacity for transformation (McEwen & Morrison, 2013; Oliveira et al., 2013).

At this juncture, the affective dimension of feedback assumes central importance. The informational efficacy of a feedback signal is determined not only by its objective content but by its perceived emotional valence, the degree of experienced identity threat, and the individual's metacognitive resources for tolerating dissonance. Affective metacognition – the capacity to monitor, interpret, and regulate emotional responses to feedback – represents a critical prerequisite for transforming affect-laden perturbations into opportunities for adaptive reorganisation. This process is subserved by a network involving the vmPFC, aINS, and posterior midline structures such as the PrCu, supporting reflective awareness and self-referential processing (Kolloff et al., 2025; Luo & Liu, 2023; Sato & Loewen, 2018).

The broader evaluative context plays a pivotal modulatory role. In high-density informational environments – typical of digitalised, asynchronous, or algorithmically mediated settings – feedback often becomes ambiguous, non-contingent, or excessively frequent. These conditions generate a state of evaluative noise, wherein the system's capacity to discriminate informative from spurious signals is compromised. The consequent hyperactivation of dopaminergic alerting systems, combined with reduced signal precision, produces a blunted regulatory response: either desensitisation and avoidance, or compulsive overprocessing without effective integration (Bennett et al., 1990; Ward et al., 2015).

To enable feedback to exert its full regulatory potential, it must be delivered under conditions that preserve its salience while allowing for integration. Three critical conditions are

required: (i) *epistemic clarity* – the feedback must be interpretable within the system's operational schemas and consistent with its internal metrics for self-assessment; (ii) *regulatory anchoring* – the individual must retain sufficient cognitive and emotional stability to tolerate and assimilate informational perturbations; (iii) *metacognitive openness* – there must be an accessible window for reflective evaluation of the feedback's implications, enabling strategic restructuring of goals and priorities (Callender et al., 2016; Lipnevich et al., 2023; Nieminen & Carless, 2023).

These three axes define the boundary conditions under which feedback functions not as evaluative judgment but as an epistemically structured catalyst for model updating.

Ultimately, regulatory adaptation is inherently feedback-mediated, contingent upon the system's ability to encode the signal, modulate its affective reverberations, and enact internal reorganisations without destabilisation. Feedback thus constitutes a central vector for modulating neurocognitive plasticity, guiding action trajectories, and facilitating transitions between regulatory states (Kockel et al., 2010). The subsequent section (1.4.3) will articulate how these theoretical mechanisms may be operationalised within applied domains, such as organisational neuroscience and digital human resource design, to develop neuroadaptive systems, feedback-informed interfaces, and cognitively sustainable work environments.

In this respect, the theoretical argument developed here provides not only a mechanistic account of feedback processing, but also a direct orientation for the empirical programme of the dissertation. By conceptualising feedback as a communicative perturbation signal that recalibrates predictive models, the framework delineates the precise dimensions that will be operationalised in the experimental sections. Specifically, three aspects are of critical relevance:

First, valence determines whether the perturbation is processed as rewarding or threatening, with consequences for fronto-parietal integration versus occipito-temporal vigilance, as will be empirically tested in Section 2. Second, ambiguity and neutrality modulate the epistemic precision of the feedback signal, imposing interpretative costs that recruit beta-band activity and autonomic regulation; this constitutes the central hypothesis of Section 3. Third, the form of communication – static versus dynamic, image-based versus multimodal –

defines the degree of attentional mobilisation and affective resonance elicited by the feedback, an issue examined in Section 4.

By articulating feedback in terms of its valence, ambiguity, and communicative form, the present framework thus establishes the guiding thread that links the predictive coding account of stress regulation to the design of the empirical studies. This explicit continuity ensures that the transition from theory to experimentation is not merely illustrative, but logically necessary: the experimental sections can be read as progressive operationalisations of the theoretical claim that adaptation under evaluative stress is fundamentally feedback-mediated.

1.4.2. Multilevel integration of neural, autonomic, and behavioural responses

To construct a scientifically valid and operationally applicable model of neurocognitive adaptation to stress in high-demand environments, it is necessary to adopt a multilevel integrative perspective that accounts for the coordinated interaction among central neural dynamics, autonomic regulation, and behavioural expression. Adaptation, in this framework, is not understood as a static property or the output of a single system, but more accurately as an emergent, temporally structured process arising from the functional coupling of distributed physiological and cognitive subsystems. The level of integration achieved across these subsystems determines the efficiency, sustainability, and resilience of the stress response (Zink et al., 2021).

From a neurophysiological standpoint, current evidence supports the view that effective adaptation to environmental demands relies on the dynamic interaction among large-scale brain networks, particularly the CEN, the SN, and the DMN (Geng et al., 2024). Regulatory efficiency is not conferred by the activation of individual regions per se, but by the system's capacity to ensure flexible transitions among these networks in accordance with contextual requirements. Dysregulation frequently reflects maladaptive network configurations – such as excessive SN engagement associated with heightened vigilance, or impaired CEN recruitment during complex DM – rather than focal neural deficits (Blader et al., 2025; Hartley & Phelps,

2012; Nitschke & Bartz, 2023). Thus, neuroadaptive performance is determined by the functional integration and reciprocal modulation of network activity over time.

At the level of autonomic regulation, HRV and SCR have emerged as core indices of the system's capacity to manage arousal under pressure. As mentioned in the previous paragraph, HRV reflects parasympathetic modulation of cardiac output and is associated with inhibitory control, homeodynamic flexibility, and recovery efficiency (Kim et al., 2018). SCR, mediated by sympathetic activation of eccrine sweat glands, provides a sensitive index of phasic arousal in response to salient or socially evaluative stimuli (Le et al., 2019). The concurrent analysis of HRV and SCR allows for a precise characterisation of the autonomic profile associated with regulatory success or failure. Adaptive responses are marked by high-frequency HRV coupled with context-appropriate SCR reactivity, indicating a well-modulated autonomic system capable of activating and deactivating in a temporally contingent manner. In contrast, maladaptive patterns – characterised by reduced HRV and sustained or excessive SCR – are indicative of chronic activation states, diminished vagal flexibility, and increased physiological costs (Berntson & Cacioppo, 2004; Chalmers et al., 2014; Fiskum et al., 2018; Friedman, 2007). It is important to highlight that autonomic activity is not peripheral to central regulation but is functionally embedded within cortico-subcortical circuits. Regions such as the aINS, ACC, and vmPFC serve as integration hubs for interoceptive signalling, autonomic feedback, and affective modulation (Kittleson et al., 2024; Namkung et al., 2017). Consequently, the coherence between cortical oscillatory patterns (e.g., alpha and theta dynamics) and autonomic output provides a more accurate index of regulatory quality than either domain considered in isolation.

Behavioural parameters constitute the third essential component of the adaptive system. Observable responses – such as postural control, motor variability, decisional latency, and interactional synchrony – are not merely outputs, but integral expressions of the system's operational state. Behaviour functions both as a product of underlying regulatory activity and as a recursive modulator through which environmental feedback is incorporated into ongoing adaptation. Incongruence between behavioural performance and physiological activation (e.g., externally coherent behaviour with covert sympathetic overactivation) frequently reflects

compensatory regulation, wherein cognitive resources are mobilised to maintain surface-level functioning at the cost of longer-term adaptability (Avancini et al., 2024; Gunten et al., 2018).

The methodological implication of this framework is the necessity of synchronised, multimodal data acquisition and temporally aligned analysis. Only through the concurrent assessment of EEG activity, autonomic dynamics, and behavioural performance can meaningful regulatory configurations be identified – such as coherent adaptive profiles (e.g., network synchrony, flexible vagal tone, behavioural congruence), effortful compensation (e.g., elevated cortical arousal with reduced HRV and increased motor control), or latent vulnerability (e.g., alpha desynchronisation, tonic sympathetic activation, behavioural rigidity).

In conclusion, multilevel integration represents a fundamental criterion for the scientific investigation of stress adaptation in ecologically valid contexts. It enables a comprehensive understanding of regulatory mechanisms and supports the identification of differential trajectories of resilience, compensation, or disorganisation. The subsequent section (1.4.3) will therefore examine the applied implications of this framework, with particular attention to how principles of feedback-informed regulation can be operationalised within organisational neuroscience and digital human-resource design to promote sustainable performance and neurocognitive well-being.

1.4.3. Applications in organisational neuroscience and digital HR design

The development of an integrated neurocognitive framework for adaptation to stress, as articulated in the preceding sections, provides a theoretically robust yet operationally translatable model. Its primary epistemological value lies not in theoretical self-referentiality but in its potential to inform the design of evaluation systems, regulatory infrastructures, and work environments that are neurocognitively compatible with the constraints and affordances of human functioning. In this regard, applied neuroscience – and specifically the emerging domain of organisational neuroscience – may serve not only as a measurement apparatus, but as a generative approach for the reconfiguration of complex organisational ecosystems.

Contemporary organisational systems often remain anchored to performance-driven and evaluative paradigms that insufficiently account for the physiological, emotional, and cognitive dynamics underpinning adaptive regulation. Such configurations frequently engender a structural misalignment between system-level demands and individual regulatory capacities, culminating in chronic evaluative stress, maladaptive compensatory patterns, progressive deterioration of metacognitive control, and a loss of subjective agency (Balconi, 2021; Balconi & Angioletti, 2021c). The integration of neurocognitive models within human resource systems offers a means of re-engineering these architectures, thereby promoting operational environments that support rather than deplete cognitive-affective plasticity (Balconi, Nava, et al., 2020; Balconi & Angioletti, 2021b).

One of the most immediate translational applications lies in the design of cognitively sustainable work environments, where the organisation of informational density, temporal pacing of tasks, and feedback loops is aligned with the neurofunctional dynamics of attention, regulation, and recovery. This entails a paradigmatic shift from linear, productivity-centred logics to cyclically structured regulatory models that incorporate phases of activation, restitution, task decomposition, bio-behavioural synchronisation, and guided metacognitive reflection. While models from dynamic neuroergonomics provide foundational frameworks for understanding human-technology interactions, their real-time adaptability and ecological validity are enhanced only when integrated with physiological (e.g., HRV, EEG) and metacognitive markers (Balconi, Angioletti, et al., 2020).

A second critical application pertains to the development of adaptive feedback systems, structured around principles of timing sensitivity, salience modulation, and cross-modal integration. Feedback that is asynchronous, depersonalised, or informationally saturated places excessive strain on regulatory mechanisms, reducing the system's capacity for effective updating and potentially inducing withdrawal, rigidity, or compensatory hyperregulation. Conversely, feedback systems that incorporate physiological inputs, derived from autonomic and neural indices and contextualised within reflective digital interfaces, can act as secondary regulatory devices. Such systems not only inform performance but actively scaffold processes of adaptive learning and internal model reorganisation (Cavalcanti et al., 2021; Sun et al., 2023; Villagrán

et al., 2023). These methodological advances converge within the paradigm of *Digital HR Design*: the construction of intelligent ecosystems for human resource management grounded in principles of neurocompatibility, plasticity, and sustainability (Mondal & Das, 2023). The integration of emergent technologies – such as wearable biotrackers, neuroadaptive algorithms, and multimodal behavioural analytics – permits the implementation of predictive systems capable of identifying latent dysregulation patterns, monitoring vulnerability trajectories, and activating personalised metacognitive scaffolds.

The implications of such systems extend well beyond risk mitigation or burnout prevention; they facilitate a fundamental epistemological reframing of the concept of the human resource. No longer conceptualised as a disembodied cognitive executor, the human resource is redefined as a multilevel regulatory entity, embedded within metabolic, attentional, affective, and neuroplastic constraints. Designing environments that respect this complexity constitutes a prerequisite for ensuring long-term sustainability in cognitively saturated work systems.

In parallel, organisational neuroscience enables the development of next-generation evaluation models capable of incorporating non-observable or latent dimensions – such as regulatory efficiency, decisional flexibility, and affective-metacognitive competence – into composite predictive indices. These models can be applied to talent identification, adaptive training pathways, leadership development, and strategic workforce planning. Rather than simply supplementing existing evaluative metrics, they function as translational interfaces between neurophysiological data and organisational decision-making, contributing to the epistemological evolution of work design itself.

In conclusion, the application of the integrated neurocognitive framework to the domains of organisational neuroscience and digital HR design does not represent a mere translational exercise, but rather an ontological redefinition of the human-system interaction. This reconceptualisation constitutes the foundational premise for the empirical section of the present dissertation, wherein the theoretical constructs developed thus far will be subjected to systematic examination through multimodal experimental protocols, neurophysiological

measurement, and applied models of adaptive regulation, plasticity, and operational sustainability.

1.4.4. From theoretical architecture to experimental validation: thesis's general aim

The first section of this dissertation has presented a progressively articulated and theoretically integrated model of neurocognitive adaptation to stress, with a specific focus on high-complexity contexts marked by organisational demands, evaluative pressure, and cognitive oversaturation. Drawing upon recent advances in cognitive, effective, and social neuroscience, it has been argued that human adaptation cannot be adequately conceptualised as a linear or homeostatic adjustment mechanism. Rather, it constitutes a dynamic, stratified, and context-sensitive process, characterised by neurofunctional plasticity and the continuous modulation of interdependent systems.

This model emphasises that adaptation emerges from the coordinated regulation of neural oscillatory patterns, autonomic reactivity, emotional states, and behavioural expressions – each contributing to the real-time calibration of the individual – environment relationship. Such a perspective rejects reductive or modular accounts in favour of a systemic and ecologically grounded understanding of adaptive functioning. In doing so, it lays the conceptual foundation for the empirical investigations that follow, aimed at capturing the complexity of stress regulation through multimodal neurophysiological and behavioural indices.

The first section of this dissertation has provided a structured and multilayered conceptual foundation for the investigation of neurocognitive adaptation to stress in complex, high-demand environments. Section 1.1 reconstructed the historical and theoretical evolution of the stress construct through a systemic lens, critically re-examining the traditional dichotomy between eustress and distress. In doing so, it introduced a functional reinterpretation of stress as a regulatory phenomenon, emphasizing the role of executive functioning, affective modulation, and metacognitive competence in sustaining performance under pressure. Section 1.2 deepened the analysis by exploring the neurocognitive mechanisms that support adaptive

regulation. Particular attention was devoted to the interaction between CL, emotional dynamics, and dispositional traits – such as mindfulness, interoceptive awareness, and empathic attunement – as determinants of regulatory efficiency. The distinction between intentional, flexible regulation and rigid, defensive resistance was highlighted as a critical dimension of adaptive functioning. Section 1.3 focused on the empirical correlates of stress responses, examining central (EEG-based) neural activity, autonomic nervous system modulation (HRV, SCR), and behavioural outputs as complementary and temporally coupled indices of regulatory quality. This section underscored the necessity of a multimodal and synchronised interpretative approach, capable of bridging disciplinary silos and capturing the complexity of adaptation as a process distributed across neural, physiological, and behavioural levels. Section 1.4 culminated in the proposal of an integrated theoretical framework, informed by contemporary models of predictive coding, embodied cognition, and cognitive-affective self-regulation. Adaptation was conceptualised as an emergent property of the dynamic interaction among functional neural networks (CEN, SN, DMN), autonomic flexibility, and context-sensitive behavioural schemas. Central to this framework is the transformative role of feedback in enabling regulatory plasticity, as well as the translational implications of the model for applied domains such as organisational neuroscience and digital human systems design. Taken together, these four sections establish the epistemological and methodological premises for the empirical investigations that follow, grounding the subsequent sections in a coherent, multidimensional theory of adaptive regulation in cognitively and socially saturated environments.

This first part of the dissertation has thus accomplished a dual objective. On the one hand, it has delineated a coherent and empirically informed theoretical model for interpreting stress responses within high-complexity systems; on the other, it has established a robust epistemological and conceptual foundation for guiding the experimental validation of the proposed hypotheses. The transition from theoretical formulation to empirical investigation now becomes an essential step for assessing both the internal validity and the translational potential of the model, through the systematic collection and multimodal analysis of neurophysiological and behavioural data under rigorously controlled experimental conditions.

At the core of this transition lies the central claim that adaptive responses to evaluative stress are not produced in isolation but emerge from a multilevel regulatory architecture continuously shaped by communicative dynamics. In particular, the anticipatory window following the reception of social feedback is conceptualised as a privileged regulatory phase, in which communicative signals exert their modulatory impact on attention, affective states, and preparatory behaviour. Feedback is thus framed as a communicative mechanism – varying in valence, clarity, and expressive form – that actively reorganises the balance between cortical oscillations, autonomic reactivity, and behavioural readiness. By situating feedback as the communicative hinge of adaptation, the dissertation establishes a direct bridge between the theoretical model and its empirical validation.

The second part of the dissertation is entirely dedicated to the empirical validation of the regulatory adaptation model, operationalised through the implementation of three methodologically independent yet theoretically integrated studies. These investigations are based on multimodal protocols that combine central (EEG), peripheral (ANS), and behavioural measures, in order to examine specific dimensions of the framework – namely, the dynamics of social feedback, the role of adaptive plasticity, and the modulatory impact of environmental structure – within evaluative, cognitively saturated, and socially salient experimental settings.

More specifically, Section 2 addresses the valence of social feedback (positive, negative, neutral), testing how rewarding versus aversive cues recalibrates oscillatory activity, autonomic responses, and performance strategies under stress. Section 3 examines the regulatory costs of ambiguity, adopting a repeated-exposure design with graded conditions to capture how neutral or non-affirmative signals impose interpretative demands, and how trajectories of adaptive recalibration unfold over time. Section 4 investigates the form of communication, contrasting static image-based scenarios with dynamic avatar-mediated interactions, in order to probe the impact of interactivity and immersion on attentional engagement, emotional mobilisation, and the ecological validity of digitally mediated evaluative environments. Together, these three studies map the regulatory landscape of stress adaptation across naturalistic, repeated, and digital contexts, providing convergent evidence that communicative structures decisively shape anticipatory regulation. Section 2 presents the first experimental study, aimed at investigating

the differential impact of three types of social feedback (positive, negative, and neutral) on electrophysiological responses – specifically in the alpha and theta bands – autonomic indices of arousal regulation (HRV, SCR), and behavioural performance measures in a sample of young adult participants. The study is designed to identify neurobehavioral configurations associated with distinct regulatory strategies and to explore the degree of integration between large-scale cortical networks and autonomic reactivity in the real-time management of socially mediated stress. Section 3 extends the empirical investigation by adopting a repeated-exposure design to examine the temporal dynamics of adaptive regulation. Participants are exposed to repeated and systematically varied sequences of socially stressful interactions, allowing for the observation of within-subject fluctuations over time. The objective of this study is to identify neurophysiological and behavioural markers of regulatory recalibration and to capture trajectories of learning or degradation in cognitive-emotional plasticity under cumulative pressure. This approach enables a more comprehensive analysis of how regulatory strategies consolidate, shift, or collapse in response to recurring evaluative demands, thereby providing critical insight into the sustainability of adaptive functioning. Section 4, finally, addresses a frontier context of high translational relevance: the simulation of evaluative scenarios in digitally mediated environments. In this study, participants are assigned to one of two experimental conditions: a static evaluative simulation presented through static images, and a dynamic, interactive simulation mediated by a responsive digital avatar. The aim is to investigate how levels of interactivity and immersion influence neurophysiological stress responses – specifically EEG patterns and autonomic reactivity – and to assess the ecological validity of digital interfaces for the elicitation and modulation of evaluative pressure. This study lays the methodological groundwork for neuroscientifically informed applications in personnel selection, performance training, and digital human-resource interaction. Taken together, the three experimental studies presented in Sections 2, 3, and 4 delineate a coherent and strategically articulated empirical trajectory. Each study isolates and tests distinct components of the theoretical framework – feedback reactivity, regulatory plasticity, and environmental mediation – while contributing original evidence to the understanding of human stress adaptation across naturalistic, repeated, and digitally augmented settings. In doing so, this

second part of the dissertation not only seeks to validate the model of integrated regulatory adaptation but also to inform the development of next-generation evaluative systems that are neurofunctionally sustainable, cognitively transparent, and aligned with the demands of an increasingly digitalised social world.

To sum up, the central thread of the thesis can thus be summarized as follows: adaptive responses to performance-related stress emerge from a multilevel regulatory architecture in which cortical oscillations, autonomic markers, and behavioural adjustments are dynamically tuned by the communicative properties of feedback. The emphasis is placed not merely on the immediate reactivity to evaluation but on the anticipatory preparation that unfolds once feedback has been processed. The three empirical studies provide complementary perspectives on this architecture: the first isolates the role of feedback valence in modulating neural and behavioral adaptation; the second examines how ambiguity and neutrality of feedback impose distinctive regulatory demands; and the third explores how the form of communication – static versus dynamic feedback – shapes attentional and affective engagement.

2. SECTION 2 – Neurophysiological (EEG) response to social feedback in stressful situations[2]

2.1. Abstract

The relationship between external feedback and cognitive and neurophysiological performance has been extensively investigated in social neuroscience. However, few studies have considered the role of positive and negative external social feedback on electroencephalographic (EEG) and moderate stress response. 26 healthy adults underwent a moderately stressful job interview consisting of a modified version of the Trier Social Stress Test. After each preparation, feedback was provided by an external committee, ranging from positive to negative with increasing impact on subjects. Stress response was measured by analysing response times (RTs) during the speech phase, while cognitive performance was assessed using a Stroop-like Task before and after the test. Results indicate that RTs used to deliver the final speeches with negative feedback were significantly lower compared to those used for the initial speech with positive feedback. Moreover, a generalised improvement in Stroop-like task performance was observed in the post-SST compared to the pre-SST. Consistent with behavioural results, EEG data indicated greater delta, theta, and alpha band responses in right prefrontal and left central areas, and for delta and theta bands, also in parietal areas in response to positive feedback compared to aversive-neutral feedback, highlighting greater cognitive effort required by the former. Conversely, an increase in these bands in right and left temporal and left occipital areas was observed following negative and aversive feedback, indicative of an adaptive response to stress and emotion-regulatory processes. These findings suggest that negative social feedback in moderately stressful and non-critical conditions could contribute to improving individual cognitive performance.

Keyword: social feedback, EEG, stressful interview, SST, Stroop

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2.2. Introduction

In social neuroscience, the interplay between social feedback and stress reactivity is crucial for understanding how the brain regulates social environments and copes with challenges. This interaction assumes a significant role in shaping behavioural responses and adapting to variable environmental circumstances (Petzold et al., 2010). As Maier and Watkins (2010) have highlighted, exhibiting an improvement in cognitive functioning in response to stress is a crucial skill for human resilience. Contexts such as sports competitions, academic exams, job interviews, and artistic performances emerge as paradigmatic examples in which the pressures of stress can either hinder performance or, conversely, catalyse determination in the pursuit of set objectives (Henderson et al., 2012). In the current context, understanding how stress responses affect performance is crucial. Specifically, the examination of stressor controllability and the effects of social feedback emerge as pivotal elements within the neuroscientific landscape (Dickerson et al., 2004; Dickerson & Kemeny, 2004).

Controllability represents a fundamental aspect in studying stress response, particularly within the context of learned helplessness. Previous research suggests that the influence of stress on cognitive functions is linked to individual responses to stressors: moderate and controllable responses tend to promote optimal performance, whereas extreme responses – both positive and negative – tend to compromise performance (Balconi et al., 2019; Crivelli, Fronda, Venturella, et al., 2019).

Concerning *social feedback*, the literature unanimously acknowledges its primary importance for humans, highlighting how interaction and communication within social contexts are closely linked to the development of significant human competencies, such as language progression, assimilation of social norms (Zhang et al., 2023), formation of social bonds (E. G. Brudner et al., 2022), individual resilience (Wan et al., 2022), as well as goal orientation and effective resolution of challenging social situations (Podsakoff & Farh, 1989). Furthermore, in scientific research, it has been highlighted how positive feedback is associated with a sense of approval and social support (Peifer et al., 2020), contributing to stress reduction.

Conversely, negative feedback can evoke feelings of inadequacy or threat, increasing in stress response. In this context, it is important to consider the implications of the social feedback on stress and brain functioning and psychological well-being. The impact of social feedback, whether positive or negative, on neurophysiological and cerebral substrates extends through a network of neural connections that modulate the individual's subjective perception and cognitive-emotional processing such as limbic regions and the dorsal and orbital prefrontal cortex (Balconi & Angioletti, 2023c; Balconi & Vanutelli, 2017a), as well as brain regions typically associated with salience, such as the dorsal anterior cingulate cortex, insula, inferior frontal gyrus, frontal pole, and the supplementary motor area (Molen et al., 2017). This complex network of neurobiological and neurochemical signals also intersects with mechanisms of homeostatic regulation and neural plasticity, delineating an adaptation and response framework to complex environmental contexts (Molicki, 2023). Furthermore, research indicates that prolonged exposure to stressors can detrimentally impact neuroplasticity, thereby diminishing the brain's inherent capability to undergo adaptive alterations in reaction to environmental stimuli (Radley et al., 2015).

More specifically, in the present work within in the wider scope of investigating social feedback, particular attention is directed towards *external evaluative* social feedback and its stress response. Indeed, to better understand the effects of their choices and facilitate regulatory mechanisms, individuals require external feedback (Crivelli et al., 2023).

According to a recent interpretation provided by Peters and colleagues (2024), evaluative social feedback is defined as the set of evaluations expressed toward an individual during social interaction. This form of feedback is characterised by its polarity, which may be positive or negative, its anticipation, which may be expected or unexpected, and its contextual relevance, which can vary based on the interlocutor's perception and its significance within the considered interactive context. Additionally, this feedback can be expressed and conveyed through various communication channels, including verbal communication (Zandbagleh et al., 2022), implicit modalities (such as in the cyberball task, Achterberg et al., 2016), gestures and facial expressions (Pfabigan et al., 2019), among others. The significance of evaluative social feedback appears to be linked to its involvement in shaping neural responses related to reward and threat

perception. Particularly, considering negative social feedback initially, a form of external evaluation that can be perceived as critical or adverse (Anderson, 2017), it can be argued that it activates various brain regions involved in processing social information and regulating emotions (Vanderhasselt et al., 2015), including the ventral anterior cingulate cortex/medial prefrontal cortex (Somerville et al., 2010), the right anterior insula, the right supplementary motor area (SMA)/pre-SMA, the right fusiform/inferior temporal gyrus, the bilateral temporoparietal junction, and posterior superior temporal sulcus (Gozzi et al., 2017). Additionally, negative feedback, as mentioned before, can elicit feelings of inadequacy or threat (Brockner et al., 1987; Kredlow et al., 2022), triggering an increase in stress response by activating brain regions involved in threat perception such as the amygdala and ventromedial prefrontal cortex (Wheeler & Fellows, 2008). This activation can lead to the release of stress-related hormones, including cortisol (Gu et al., 2020). Instead, from the electrophysiological (EEG) point of view, the feeling of *social disconnection* that may result from negative feedback is associated with reduced delta band activation (Jin et al., 2019). Conversely, still considering negative feedback, when facing critical situations, increased activation of the theta band is observed in temporal and occipital areas (Billeke et al., 2014; Cristofori et al., 2013; Orgo et al., 2015). However, despite the tendency to associate negative feedback with an adverse connotation, the crucial role played by the negativity bias in modulating human emotional and cognitive responses must be acknowledged (Unkelbach et al., 2020). Scientific literature highlights how feedback carrying a negative valence may contribute to enhancing individual cognitive performance (Balconi et al., 2019; Crivelli, Fronda, Venturella, et al., 2019).

On the other hand, the neural mechanisms of reward in the human brain, involving structures such as the mesolimbic dopaminergic system and regions implicated in social cognition, such as the ventromedial prefrontal cortex (vmPFC), the dorsomedial prefrontal cortex (dmPFC), as well as the medial temporal lobe, demonstrate a particular vulnerability to socially rewarding stimuli (Alcaro et al., 2007; Berridge & Kringelbach, 2015; Crawford et al., 2020). The activation of this neural network extends beyond mere responses to material stimuli and encompasses positive social interactions.

Moreover, positive feedback is associated, as mentioned above, with social support (Peifer et al., 2020), contributing to stress reduction by activating cortical regions linked to gratification and well-being, such as the rostral anterior cingulate cortex (rACC), the posterior cingulate and the right superior frontal gyrus (Mies et al., 2011). These processes, as elucidated in the literature, may correlate with increased delta and theta band activity in specific brain regions. Among these, the right frontal cortex, implicated in emotion regulation, social cognition, and internal state monitoring, is noteworthy (Christie & Tata, 2009; Harmony, 2013; Gennady G. Knyazev, 2007). Literature, in this context, emphasises the role of the right PFC (Fp2 electrode), whose activity has been associated with the elaboration of positive emotional stimuli (Adrian et al., 2017).

Moreover, positive social feedback can function as positive reinforcement, enhancing motivation to engage in specific behaviours. From an EEG perspective, this may be associated with increased theta band activity in the frontal brain areas involved in active learning and, particularly, in the left central regions (C3 electrode), which is representative of motor execution networks (Yordanova et al., 2024). Generally, these regions are indeed implicated in the planning and execution of motivational actions (Algermissen et al., 2021; Domic-Siede et al., 2021), as well as in processes of control and behavioural adaptation (Cavanagh & Frank, 2014; Cavanagh & Shackman, 2015). Furthermore, receiving positive social feedback may necessitate processing social information concerning the evaluation of one's performance, typically engaging the parietal regions of the brain responsible for sensory information perception and processing (Gottlieb, 2007). These regions – together with the left parietal area (P3) and the central-parietal area (Pz) – are involved in the processing of reward, motivation, and positive reinforcement (Wisniewski et al., 2015).

Literature has also highlighted how desynchronization of the alpha band in the occipito-temporal region may be associated with the modulation of brain activity during the feedback processing process (Codispoti et al., 2023). The alpha band is often considered an indicator of brain inactivity or relative rest state, and its desynchronization has been correlated with processes of attention, perception, and generalised sensory integration (Klimesch, 2012).

Finally, regarding the role of beta and gamma, the literature provides less consistent results, and only a few studies have focused on analysing these bands in relation to social feedback (Mishra et al., 2022; Yang et al., 2020).

Furthermore, research on social evaluative feedback and controllability has so far focused on investigating how external factors can influence information processing, such as how individuals integrate social evaluative feedback based on their expectations or personality traits (Peters et al., 2024). Previous studies have also delved into investigating the activation of the hypothalamic-pituitary-adrenal axis (Andrews et al., 2007), or exclusively focused on cognitive performance (Henderson et al., 2012), or explored cortisol levels and autonomic responses alongside psychometric measures (Dawans et al., 2011). However, to the best of our knowledge, no study has explored the combined impact of these factors on stress, EEG response, and cognitive performance. Hence, this study aims to investigate how positive and negative social feedback may modulate behavioural and EEG responses, as well as to examine stress response and adaptation, construed as recently proposed by Rodeback and colleagues (2020), as the process whereby individuals under moderately stressful conditions learn to respond to a stressor and adjust the allocation of attentional resources to successfully achieve their intentions.

To examine this aspect, a commonly utilised task is the Trier Social Stress Test (Allen et al., 2017), which exposes participants to a panel of judges who observe and evaluate their performance in a stressful situation. In our study, a sample of healthy young adults underwent a modified version of this task, the Social Stress Test (SST). Participants prepared and presented five discourses on various topics and received feedback ranging from positive to negative. Stress response was measured by analysing RTs during the speech phase following the feedback presentation.

It is relevant to emphasise that the stressors used in our study were purposefully moderate in intensity. Moderate stressors were selected to emulate the challenges individuals typically face in their everyday routines, thereby augmenting the applicability of our results to real-life contexts. Moreover, moderate stressors facilitate a controlled yet ecologically valid exploration of physiological and psychological reactions to stress, avoiding excessive distress while eliciting

discernible responses. This methodology guarantees the capture of reliable stress reactions without unduly burdening participants or transgressing ethical research standards.

Cognitive performance was assessed using standard executive function tasks (e.g. Stroop Task, Stroop, 1935) before and after the test. EEG data were recorded to understand the effects of feedback on neurocognitive performance.

Given these premises, we hypothesise, firstly, an improved behavioural performance in terms of RTs, response accuracy, and number of omitted responses in both congruent and incongruent stimuli during the Stroop task in the post-SST phase compared to the pre-SST phase. Indeed, in line with previous research, while low or high levels of subjective stress have been associated with increased interference in the Stroop task, a moderate level of subjective stress has been linked to reduced interference and facilitation of cognitive conflict resolution processes, leading to enhanced Stroop performance (Henderson et al., 2012).

Secondly, we also hypothesise a decrease in RTs during the speech phase following negative feedback compared to positive feedback. This can be attributed to the engagement in processing positive feedback by the prefrontal and central areas involved in cognitive control, planning, and self-assessment (Friedman & Robbins, 2021). Activation of these areas requires increased cognitive effort, consequently resulting in increased processing times, unlike negative feedback, which may benefit from and be modulated by attentional and emotional bias.

Indeed, studies delving into the effects of the negativity bias on performance have demonstrated that, from a neurocognitive perspective, there may be a reduction in reaction times required (RTs) to process information and respond adaptively to moderately stressful situations (Balconi, Crivelli, et al., 2018). This hypothesis, taking into account the moderately arousing nature of the task, aligns with the assertions made in the preceding paragraph and is strengthened by previous studies highlighting how moderate and controllable activations tend to foster optimal performances (Balconi et al., 2019; Crivelli, Fronda, Venturella, et al., 2019).

Furthermore, the literature highlights the anterior cingulate cortex among the frontal areas as being involved in error monitoring and behavioural correction (Magno et al., 2006).

Receiving negative social feedback can enhance activity in this region, which could enhance awareness during subsequent discourse phases, leading to a reduction in RTs.

Finally, for EEG data, we hypothesise an increase in delta and theta activity in the right frontal regions, the left central cortical regions, and parietal regions of the brain in response to positive feedback compared to negative feedback. Conversely, considering the processing of negative feedback, we hypothesise a decrease in alpha band activity in the fronto-polar area and an increase in the temporal region. This hypothesis is supported by previous research (Aftanas et al., 2001; Bacigalupo & Luck, 2022; Gallina et al., 2023) suggesting that when the brain is processing negative feedback, there is increased activation and processing of sensory information related to such feedback in temporal regions, while simultaneously, there may be a decrease in activity in the frontal region associated with cognitive control and emotional processing.

In addition, we considered the beta and gamma bands in an exploratory approach. The beta band, although primarily associated with motor control and certain cognitive processes, has a less clear role in the context of feedback processing. Therefore, we included beta activity in our analysis to explore its potential involvement and to identify any novel patterns related to the cognitive and emotional mechanisms of feedback. On the other hand, the gamma band is linked to high-level information processing and sensory binding. We considered gamma activity in an exploratory manner to investigate its possible role in feedback processing, aiming to uncover further insights that might enhance our understanding of neural responses to feedback.

2.3. Materials and methods

2.3.1. Sample

A total of 16 females and 10 males (M_{age} = 23.038, SD_{age} = 1.455, age range: 22-28) participated at the experiment. The inclusion criteria comprised individuals aged between 20 and 30 years

with normal or corrected visual and auditory acuity. Conversely, the exclusion criteria were designed to exclude individuals exhibiting clinically significant distress or burnout symptoms, a history of neurological or psychiatric disorders, ongoing therapy with psychoactive substances potentially affecting cognition, and those who had experienced major stressful life events in the preceding six months. Additionally, participants were required to complete the Italian version of the Perceived Stress Scale-10 (PSS-10; Cohen et al., 1983) to ascertain low stress levels in the thirty days before their involvement in the study. This stringent screening process aimed to ensure a sample population devoid of confounding factors that could potentially bias the study's outcomes or compromise its integrity. All participants provided written informed consent without any form of remuneration. All participants provided written informed consent without compensation. The study was approved by the Ethics Committee of the Department of Psychology (approval code: 2021 PhD-TD), Catholic University of The Sacred Heart, Milan, Italy, and was conducted in adherence to the guidelines outlined in the Declaration of Helsinki (2013) and according to the General Data Protection Regulation - Reg. UE 2016/679 and its ethical guidelines.

2.3.2. Experiment procedure

The experiment was conducted in a controlled setting, with participants directed to sit in front of a workstation comprising a monitor and a mouse, positioned about 80 centimetres away from the screen. Participants were explicitly informed that they would take part in an experimental procedure lasting approximately 40 minutes, primarily involving participation in a video interview aimed at competing for a prestigious job position. They were assured that the interview was a simulation and not a real job application. Furthermore, they were told they would be competing with a specific number of candidates for a single position, under the assessment of a designated evaluation committee. After obtaining signed informed consent, EEG electrodes were applied to the participants' scalps to record resting-state brain activity, both with eyes open and closed.

Following the initial phase, the pre-test assessment was initiated, during which participants were asked to complete a task similar to the Stroop test (Stim2 software, Compumedics Neuroscan, Charlotte, NC). In this task, participants were presented with four colour-related words - the Italian words for yellow, blue, green, and red - written in one of the four colors and were asked to indicate congruent or incongruent associations between colour and word by pressing one of two different response buttons.

Each participant later engaged in the production of five different speeches (Discourse, D1-5). These speeches were structured into four phases: (i) reading the request (Request, REQ1-5), (ii) speech preparation (Preparation phase, Pp1-5), (iii) exposure to audiovisual feedback from the examining committee (F1-5); and finally, (iv) speech presentation (Speech Phase, Sp1-5). During these phases, participants were tasked with creating a situation congruent with the given request, having full autonomy in selecting and formulating the contents of their speech.

REQs became progressively more demanding and challenging. Similarly, during D1-5, the valence of feedback was gradually manipulated from positive to negative, resulting in variations in the reactions of the evaluating committee (friendliness, neutrality, boredom, impatience, dislike).

External judges rigorously examined and evaluated the audiovisual feedback presented in this research to confirm their coherence and reliability in producing the desired experimental outcomes, with particular attention to the consistency and reliability of the desired results and to induce moderate stress. Upon completion of the experimental phase, in the post-test assessment, participants were asked to repeat the Stroop-like task. The experimental procedure lasted approximately 40 minutes (Figure 2.1).

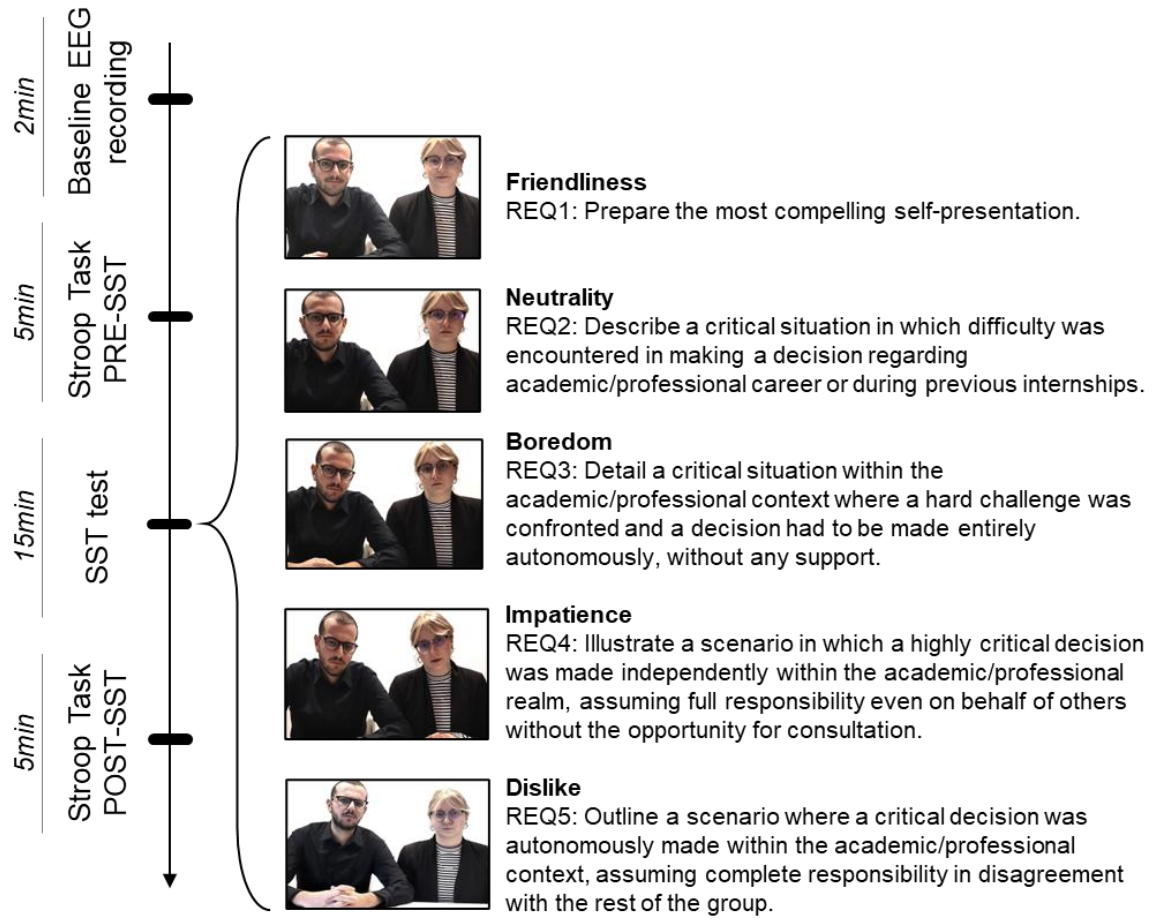


Figure 2.1. *Experimental Procedure and feedback during Social Stress Test (SST).* The figure illustrates the experimental setup and corresponding feedback during the SST. The upper section shows the experimental timeline, beginning with a baseline EEG recording for 2 minutes, followed by a 5-minute Stroop Task (PRE-SST), a 15-minute SST, and concluding with another 5-minute Stroop Task (POST-SST). The lower section details the discourse requests and feedback during the SST. Five specific requests (REQ1 to REQ5) are listed, each requiring participants to describe or illustrate various critical decision-making scenarios in academic or professional contexts. The feedback for each request is categorized as "friendliness," "neutrality," "boredom," "impatience," and "dislike," with corresponding video captures depicting the evaluating committee's facial expressions.

2.3.3. Behavioural data acquisition and processing

Two sets of behavioural data were collected to examine the effects of external evaluative social feedback on neurocognitive response, cognitive function, and stress response.

In the first set of data, an automated approach was utilised to measure the RTs to the stimuli of each discourse to determine the stress response. To evaluate the appropriateness of each speech as well as the content's coherence and relevance, objective and qualitative criteria were used. Analysis did not include discourses that did not match productivity criteria, such as those that were incoherent, lacked content, or included off-topic or inconsistent subjects. This meticulous procedure guaranteed content consistency among the five discourses under analysis, facilitating an impartial assessment of performance resulting from the stimuli.

The second set of data aimed to explore cognitive performance and assess executive functions (MacLeod, 1992) before and after the test. This was done through a computerised Stroop-like task utilising Stim2 software (Compumedics Neuroscan, Charlotte, NC), recognised as the gold standard for evaluating general executive ability (N. P. Friedman et al., 2008). Participants were presented with four colour-related words – yellow, blue, green, and red in Italian – written in one of those four colours and were tasked with indicating congruent versus incongruent colour-word associations by pressing one of two response buttons. Stimuli were randomised and presented for 300 ms, with an inter-trial interval of 1500 ms and a response window of 1000 ms, totalling 160 trials. Data on overall accuracy index (Acci-tot; calculated as the ratio of the number of correct responses to the total number of responses), accuracy index for incongruent stimuli (Acci-I), accuracy index for congruent stimuli (Acci-C), mean of overall RTs (RTs-tot), RTs for incongruent stimuli (RTs-I), RTs for congruent stimuli (RTs-C), Total errors (Error-tot), Total omission (Omiss-tot) were collected.

2.3.4. Electrophysiological data acquisition and processing

EEG data for the baseline and the Sp1-5 were collected using an 18-channel DC amplifier (SYNAMPS) and NEUROSCAN 4.2 software, with Ag/AgCl electrodes positioned according to the 10/20 system and referenced to the earlobes (Klem et al., 1999). Data were sampled at 1000 Hz, with 0.01-250 Hz input filter and a 50 Hz notch filter. Electrode impedance was monitored to ensure it remained below 5 kΩ. Data underwent offline processing, including IIR bandpass filtering (0.1–50 Hz, 48 dB/octave) using Vision Analyser2 software (Brain Products GmbH, Gilching, Germany) and correction with an ICA-based algorithm (Jung et al., 2000) after EOG correction and visual inspection.

For the next statistical analysis, all electrodes (AFz, Fp1, F7, F3, Fz, F4, F8, Fp2, T7, C3, Cz, C4, T8, P3, Pz, P4, O1, O2) were used. To maintain the integrity of the EEG data, the data were then divided into epochs using a 2000 ms window. The fast Fourier transform was then applied to artifact-free segments to compute condition-specific power spectral density (PSD) at 0.5 Hz resolution and a Hamming window. For every phase, the average PSD for the principal EEG frequency bands (delta: 0.5–3.5 Hz; theta: 4–7.5 Hz; alpha: 8–12.5 Hz; beta: 13–30 Hz; and gamma: 30.5–50 Hz) was then collected. Additionally, all task-related data were adjusted to each participant's eyes-open baseline.

2.3.5. Statistical analysis

Repeated measures ANOVAs (analysis of variance, IBM SPSS 29, IBM Corp., Chicago, IL, USA) were applied to behavioural and EEG.

For behavioural SST data, a repeated measures ANOVA with Speech (5: Sp1, Sp2, Sp3, Sp4, Sp5) as the within-subject factor was applied to the behavioural RTs scores.

Furthermore, eight repeated measures ANOVAs with Assessment phase (2: pre-SST, post-SST) as within-subject independent variable were applied to the following behavioural Stroop-like task scores considered as dependent variables: Stroop-like accuracy index, accuracy index for

incongruent stimuli, accuracy index for congruent stimuli, Stroop-like RTs score, RTs for incongruent stimuli, RTs for congruent stimuli, Total errors, Total omission.

Subsequently, for EEG data, five repeated measures ANOVAs considering Electrode (18) and Speech Phase (5) as within-subject independent variables were carried out for the five different frequency bands (delta, theta, alpha, beta, and gamma).

When necessary, degrees of freedom for each ANOVA test were adjusted using the Greenhouse-Geisser epsilon. After that, significant interactions were investigated using pairwise comparisons to assess simple effects, and potential biases arising from multiple comparisons were addressed by using the Bonferroni correction. This approach controls the family-wise error rate, ensuring that the likelihood of type I errors across our analyses is minimised. The results section includes these corrected p-values to reflect the stringent criteria applied. Eta squared (η2) indices were used to measure the size of statistically significant effects, with a significance level of $\alpha = 0.05$. Previous analysis showed no statistically significant main or interaction effects concerning gender; hence this variable was not included in any further analyses.

2.4. Results

2.4.1. Behavioural results

Considering the analysis performed on the behavioural SST score, a significant main effect was found for the RTs ($F_{(2.62, 65.61)} = 7.802$, $p \leq .001$, $\eta^2 = .238$) with higher mean for the RTs in Sp_1 compared to the RTs in Sp_4 ($p = .002$), and in Sp_5 ($p = .009$) (Figure 2.2).

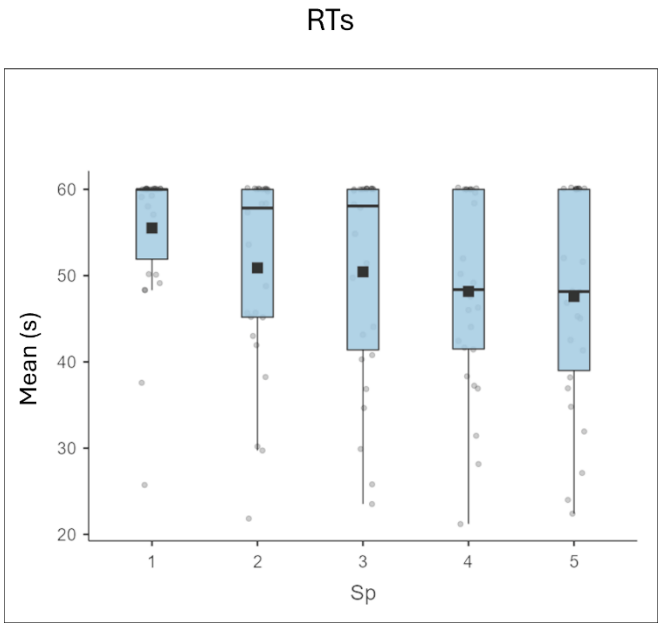


Figure 2.2 *Reaction Times (RTs) Analysis Across Different Speech phases* (Sp). Boxplot illustrating the distribution of mean RTs (in seconds) for the five different speeches. Each boxplot shows the median (horizontal line), interquartile range (box), and each single-subject values (dots). The black squares indicate the mean RTs for each Sp.

Furthermore, considering the behavioural Stroop-like score analysis, a significant main effect was found for the Assessment phase for all the dependent variables considered.

A significant main effect was found for the Stroop-like Acc_i-tot ($F_{(1, 25)} = 51.960$, $p \leq .001$, $\eta^2 = .675$), for the Acc_i-I ($F_{(1, 25)} = 28.053$, $p \leq .001$, $\eta^2 = .529$), and for the Acc_i-C ($F_{(1, 25)} = 25.971$, $p \leq .001$, $\eta^2 = .510$), with higher mean for the Post-SST compared to the Pre-SST (Figure 2.3a).

Instead, a significant main effect was observed for the Stroop-like RTs-tot ($F_{(1, 25)} = 10.502$, $p = .003$, $\eta^2 = .296$), RTs-I ($F_{(1, 25)} = 9.160$, $p = .006$, $\eta^2 = .268$), and RTs-C ($F_{(1, 25)} = 6.992$, $p = .014$, $\eta^2 = .219$), with a lower mean for the Post-SST compared to the Pre-SST (Figure 2.3b).

Finally, a significant main effect was observed for Error-tot ($F_{(1, 25)} = 51.960$, $p \leq .001$, $\eta^2 = .675$) and Omiss-tot ($F_{(1, 25)} = 10.281$, $p = .004$, $\eta^2 = .291$), with a lower mean for the Post-SST compared to the Pre-SST.

No other significant differences were found in the behavioural data.

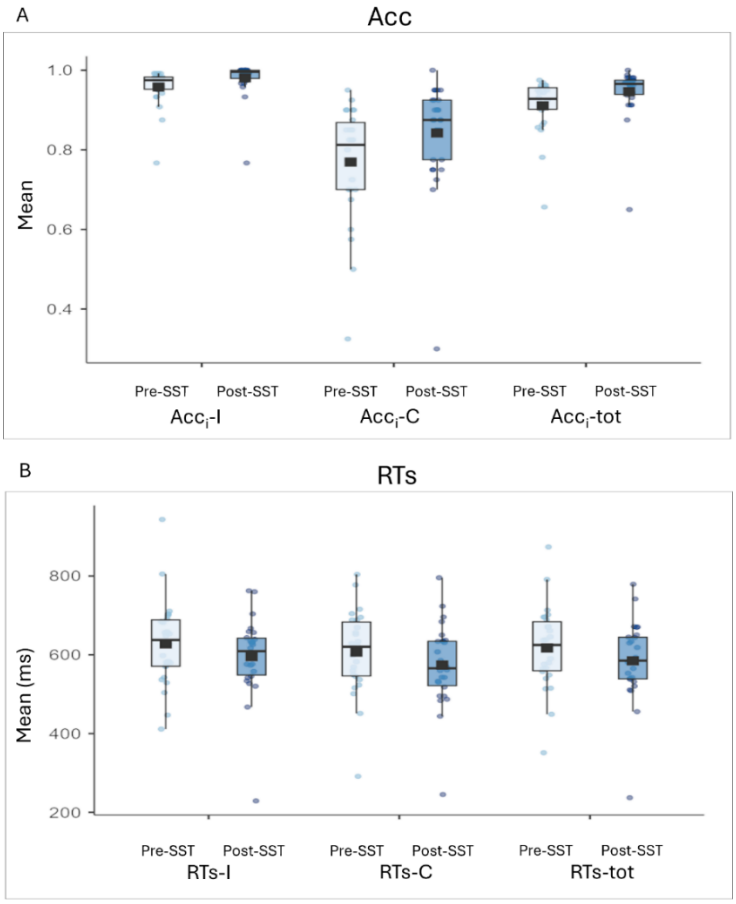
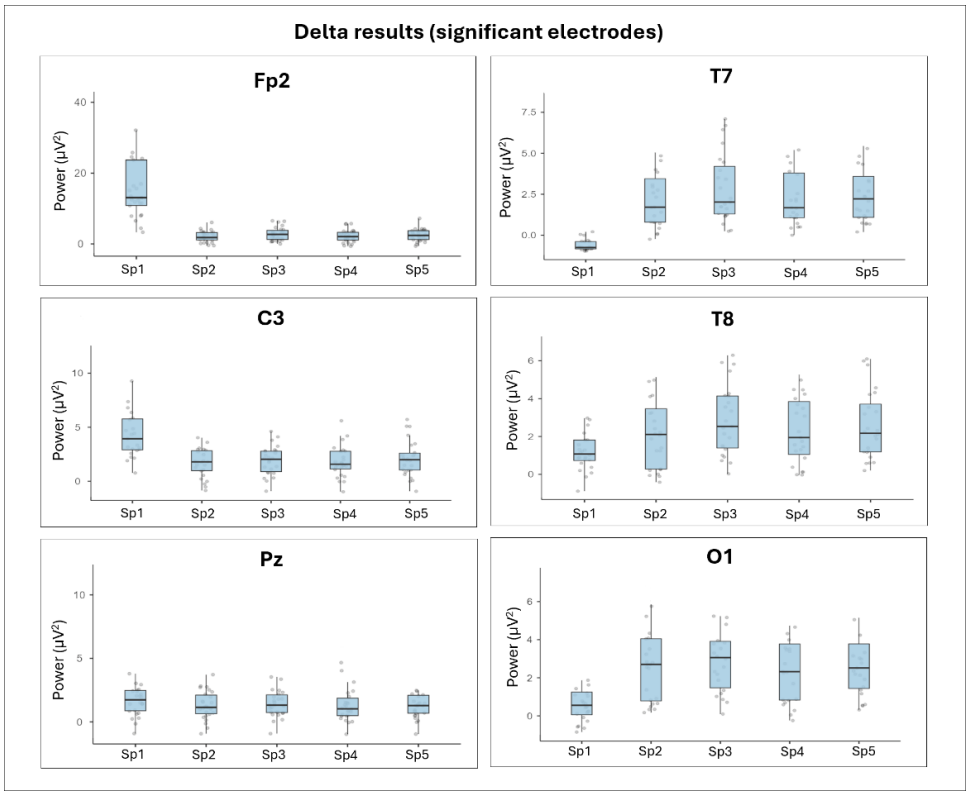


Figure 2.3. *Boxplots of Cognitive Performance Before and After the SST.* (**A**) Accuracy (Acc). The boxplots display mean accuracy in incongruent (Acc$_i$-I), congruent (Acc$_i$-C), and total (Acc$_i$-tot) conditions before (Pre-SST) and after (Post-SST) the Social Stress Test (SST). (**B**) The boxplots represent mean reaction times in milliseconds for incongruent (RTs-I), congruent (RTs-C), and total (RTs-tot) conditions. Each boxplot shows the median (horizontal line), interquartile range (box), and each single-subject values (dots). The black squares indicate the mean value for each result considered.

2.4.2. EEG results

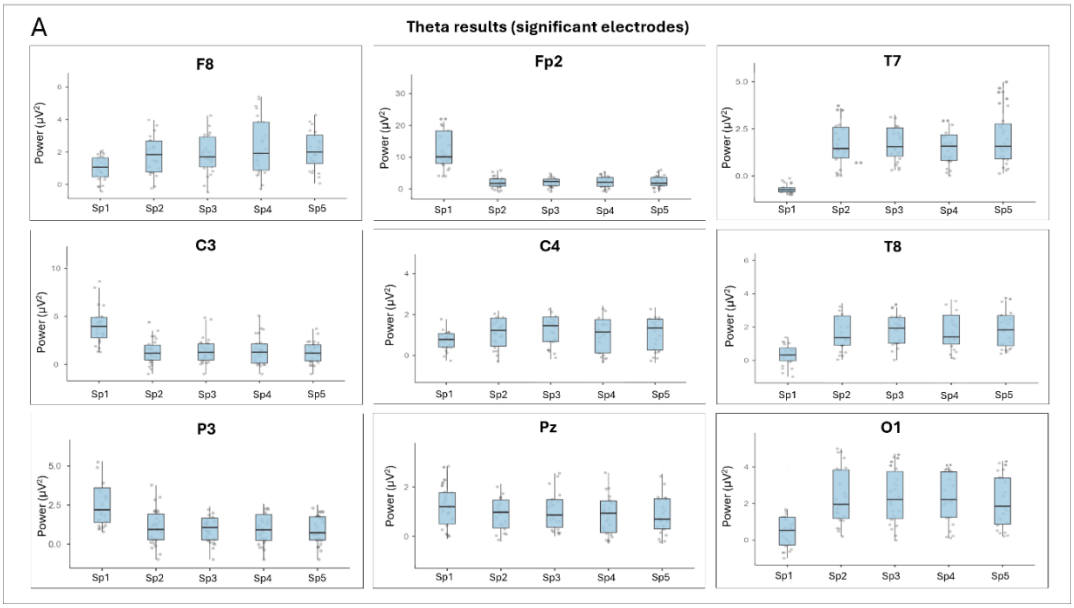
The ANOVAs performed on the different frequency bands (delta, theta, alpha, beta, and gamma) are reported.

Delta band. For delta band, a significant interaction effect was revealed for Electrode × Speech Phase ($F_{(68, 1224)}$ = 17.041, p ≤.001, η^2 =.486) (Figure 2.4a). Significant pairwise comparisons revealed lower mean values in Fp2 for the Sp_2 (p ≤*.001*), Sp_3 (p ≤*.001*), Sp_4 (p ≤*.001*), Sp_5 (p ≤*.001*) compared to the Sp_1; and in C3 for the Sp_2 (p =.002), Sp_3 (p =.003), Sp_4 (p =.012), Sp_5 (p =.011) compared to the Sp_1. Significant pairwise comparisons revealed also lower mean values in Pz for the Sp_3 (p =*.037*) compared to the Sp_1. Instead, pairwise comparisons revealed higher mean values in T7 for the Sp_2 (p ≤.001), Sp_3 (p ≤.001), Sp_4 (p ≤.001), Sp_5 (p ≤.001) compared to the Sp_1. Furthermore, higher mean values were found in T8 for the Sp_3 (p =.003), Sp_4 (p =.012), Sp_5 (p =.011), compared to the Sp_1. Finally, higher mean values were also found in O1 for the Sp_2 (p =.025), Sp_4 (p =.033), Sp_5 (p =.017), compared to the Sp_1. In the supplementary figure 2.1, boxplots relating to the delta band are presented.



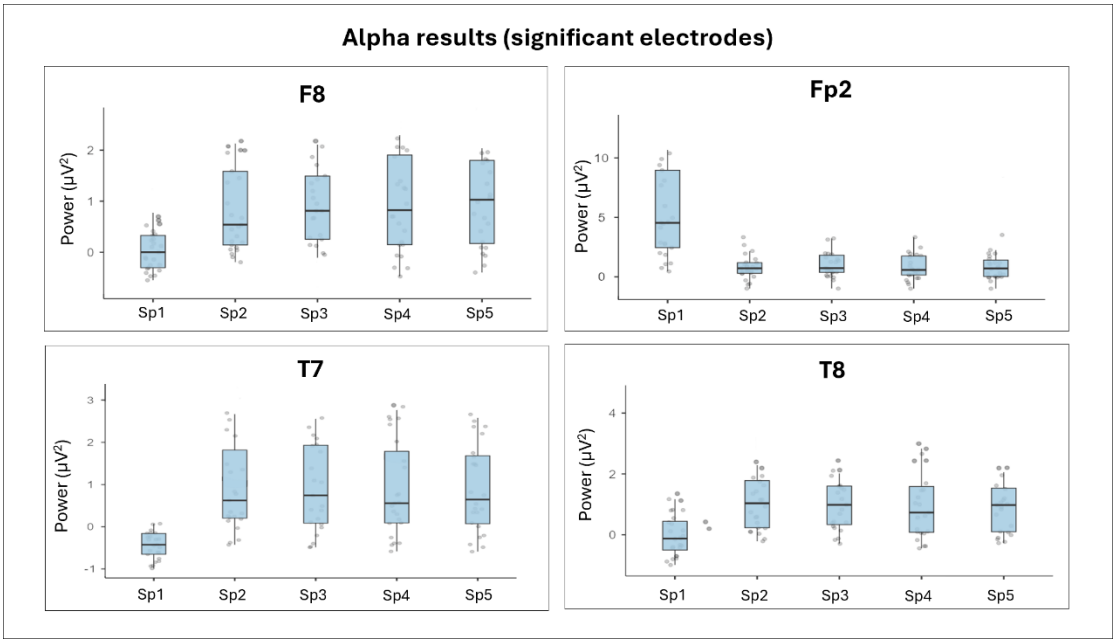
Supplementary figure 2.1. For each represented electrode (Fp2, T7, C3, T8, Pz, O1), boxplots illustrating the distribution of mean delta values for the five different speeches. Each boxplot shows the median (horizontal line), interquartile range (box), and each single-subject values (dots).

Theta band. For theta band, a significant interaction effect was revealed for Electrode × Speech Phase ($F_{(68,\ 1000)}$ = 18.210, p ≤.001, η^2 =.503) (Figure 2.4b). Significant pairwise comparisons revealed lower mean values in Fp2 for the Sp_2 (p =.001), Sp_3 (p =.001), Sp_4 (p =.001), Sp_5 (p =.001) compared to the Sp_1; in C3 for the Sp_2 (p =.001), Sp_3 (p =.002), Sp_4 (p =.007), Sp_5 (p =.002) compared to the Sp_1; and in P3 for the Sp_2 (p =.005), Sp_3 (p =.005), Sp_4 (p =.042), Sp_5 (p =.008) compared to the Sp_1. Significant pairwise comparisons revealed lower mean values also in Pz for the Sp_2 (p =.002), Sp_3 (p =.032), Sp_5 (p =.025) compared to the Sp_1. Instead, pairwise comparisons revealed higher mean values in F8 for the Sp_2 (p =.010), Sp_3 (p ≤.001), Sp_4 (p =.011), Sp_5 (p ≤.001) compared to the Sp_1; in T7 for the Sp_2 (p ≤.001), Sp_3 (p ≤.001), Sp_4 (p ≤.001), Sp_5 (p ≤.001) compared to the Sp_1; in T8 for the Sp_2 (p ≤.001), Sp_3 (p ≤.001), Sp_4 (p =.002), Sp_5 (p ≤.001), compared to the Sp_1; and in O1 for the Sp_2 (p =.002), Sp_3 (p =.002), Sp_4 (p =.001), Sp_5 (p =.002). Finally, higher mean values were found in C4 for the Sp_3 (p =.012) and Sp_5 (p =.025), compared to the Sp_1. In the supplementary figure 2.2, boxplots relating to the theta band are presented.



Supplementary figure 2.2 For each represented electrode (F8, Fp2, T7, C3, C4, T8, P3, Pz, O1), boxplots illustrating the distribution of mean theta values for the five different speeches. Each boxplot shows the median (horizontal line), interquartile range (box), and each single-subject values (dots).

Alpha band. For alpha band, a significant interaction effect was revealed for Electrode × Speech Phase ($F_{(68,\ 1224)}$ = 7.111, p ≤.001, η^2 =.283) (Figure 2.4c). Significant pairwise comparisons revealed lower mean values in Fp2 for the Sp_2 (p ≤.001), Sp_3 (p ≤.001), Sp_4 (p ≤.001), Sp_5 (p ≤.001) compared to the Sp_1. Instead, pairwise comparisons revealed higher mean values in F8 for the Sp_2 (≤.001), Sp_3 (p ≤.001), Sp_4 (p ≤.001), Sp_5 (p =.001) compared to the Sp_1; in T7 for the Sp_2 (p =.002), Sp_3 (p =.002), Sp_4 (p =.003), Sp_5 (p =.002) compared to the Sp_1; and in T8 for the Sp_2 (p ≤.001), Sp_3 (p ≤.001), Sp_4 (p =.006), Sp_5 (p ≤.001), compared to the Sp_1. In the supplementary figure 2.3, boxplots relating to the alpha band are presented.



Supplementary figure 3. For each represented electrode (F8. Fp2, T7, T8), boxplots illustrating the distribution of mean alpha values for the five different speeches. Each boxplot shows the median (horizontal line), interquartile range (box), and each single-subject values (dots).

Beta and Gamma band. No significant differences were found for the ANOVAs performed on the EEG Sp data for beta and gamma band.

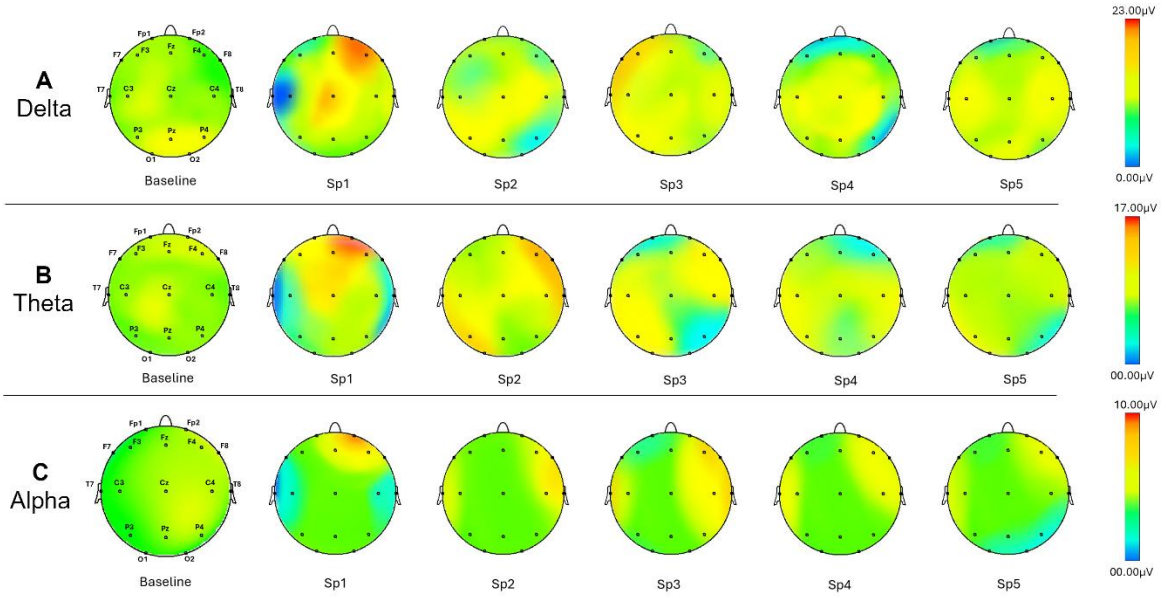


Figure 2.4. *EEG results.* The topographic EEG maps display the PSD for delta, theta, and alpha band recorded during the baseline and each Speech phase. Each map illustrates the voltage (µV) distribution across the scalp, with warmer colours indicating higher PSD activity levels. The baseline map also includes electrode positions according to the international 10-20 system.

2.5. Discussion

This study aimed to investigate the effects of exposure to external social feedback, both positive and negative, in moderately stressful contexts, on behavioural responses (RTs employed to deliver speeches), cognitive performance (RTs, accuracy, errors, and omissions in the Stroop Task), and the neurophysiological stress response (analysis of EEG frequency bands). Indeed, despite the literature having already explored the impact of positive or negative feedback on individual aspects of behaviour, personality, or biology (Andrews et al., 2007; Dawans et al., 2011; Henderson et al., 2012; Peters et al., 2024), research adopting an integrative approach considering both behavioural and neurophysiological effects of exposure to evaluative social judgments remains limited.

Firstly, consistent with our hypotheses, the behavioural outcomes of the SST reveal that the RTs utilized for delivering the final two speeches (Sp4 – impatience; Sp5 – dislike) are significantly lower in comparison to those utilized for delivering the initial speech (Sp1 – friendliness). This observation is substantiated by various emerging interpretative frameworks in the literature, which emphasize how a decrease in RTs subsequent to exposure to external negative evaluative social feedback, as opposed to positive feedback, can be elucidated, as delineated in the introductory sections, within the framework of negativity bias (Unkelbach et al., 2020). When an individual is subjected to negative social feedback, it may elicit defensive emotional reactions (Niemann et al., 2014), initiating a mechanism of swift adaptation aimed at rectifying behaviour or mitigating the adverse repercussions of critical evaluation. This behavioural phenomenon can culminate in heightened vigilance and reactivity (Raftery & Bizer, 2009), thereby manifesting in reduced RTs in subsequent analogous contexts, concomitant with the augmentation of stimulus controllability. Conversely, positive social feedback, while potentially associated with positive reinforcement, can be construed as validation of behaviours that conform to social norms (Zhang et al., 2023), thereby diminishing the imperative for immediate adjustments and attenuating the prominence of cognitive and behavioural resources. Nevertheless, it is pertinent to note that no significant diminutions in RTs were discerned in exposures subsequent to comparatively neutral feedback, notwithstanding their socially aversive implications (Sp2 – neutrality, Sp3 – boredom), indicative of a general pronounced «plateau effect» related to emotional valence associated with such feedback.

Secondly, parallel to what was observed previously, the behavioural outcomes concerning the Stroop-like Task reveal a significant enhancement in performance in the post-SST phase compared to the pre-SST phase, across all considered variables, with a generalisation effect. Indeed, the fluctuation in cognitive performance in response to varying levels of stress is a complex phenomenon involving various neurobiological, psychological, and behavioural factors, for which the literature presents no unanimous direction. However, there is a certain consistency in considering that the stress response occurring in uncontrollable and critical stress conditions is fundamentally different from the response that may manifest in moderate stress

conditions (Venkatesh & Ram, 2015). Indeed, under conditions of intense stress, the stress response is predominantly mediated through the hypothalamic-pituitary-adrenal (HPA) axis, with significant release of cortisol and other stress-related neurotransmitters, which may exert suppressive effects on cognitive functions, particularly on memory, attention, and decision-making abilities (Herman et al., 2016). In situations of excessive stress, the brain may experience a sort of *overload*, leading to a reduction in cognitive resources available for complex tasks, such as the Stroop task. In such cases, the literature highlights how the Stroop Task may exhibit decreased accuracy, accompanied by higher RTs and a significant increase in the number of errors and omissions (Conway et al., 2013). This decline can be attributed to dysfunction in selective attention and inhibition capacities, which are fundamental for task completion.

Conversely, under moderately stressful conditions, the stress response tends to be more adaptive (i.e., eustress), which can lead to optimization of cognitive performance (Henderson et al., 2012). This type of stress, when appropriately managed, can trigger an enhancement in executive functions, problem-solving abilities, vigilance, motivation, and concentration capacities, thereby contributing to an overall performance improvement. These considerations align with the findings of the present study, where reduced RTs, a decrease in the number of errors and omissions, and an increase in overall accuracy were observed following exposure to a moderately stressful task.

Thirdly, once again the EEG results confirm and provide a more detailed insight into what emerged at the behavioural level. Indeed, an increase in delta and theta band power was observed in the right prefrontal (Fp2) and left central (C3) areas following presentations subsequent to positive feedback compared to presentations following negative and aversive-neutral feedback. Specifically, the right prefrontal areas are generally implicated in cognitive planning, action control, impulse control, and the ability to regulate one's own emotions and behaviours (N. P. Friedman & Robbins, 2021). Increased Delta activation in these regions has been associated with heightened response planning, also related to the modulation by social expectancy mechanisms, resulting in increased allocation of attentional resources (Harmony, 2013). Particularly, literature highlights how positive feedback, as mentioned in the

introductory paragraph, may be associated with a sense of gratification and motivation, influencing learning and future behaviour (Algermissen et al., 2021; Domic-Siede et al., 2021). According to recent contributions, increased delta band activation in right prefrontal regions indicates involvement in behaviour reinforcement processes and attributing value to positive experiences, requiring greater cognitive effort (Cavanagh, 2015; Gennady G. Knyazev, 2012).

Regarding theta, its increase in prefrontal areas has been linked to working memory and, specifically, the processing of visuospatial information requiring high cognitive effort and access to autobiographical memories. Conversely, its decrease in these areas has been correlated with adaptive regulation of negative emotions and evaluation of emotionally salient stimuli (Heinbockel et al., 2021; Schönfeld & Wojtecki, 2019), consistent with our results. As previously indicated, the behavioural results of the SST demonstrated that RTs for presenting the first discourse were significantly lower compared to RTs for presenting the last two discourses. A decrease in delta and theta activation in these areas following negative feedback might therefore indicate both increased processing of information related to positive feedback, ultimately resulting in an increase in Sp1 RTs, and adaptive response to negative stimuli in moderately stressful contexts, as supported by the decrease in RTs in discourses following the first one.

Contrary to prefrontal areas, in the right fronto-temporal areas (F8, T8), literature suggests that an increase in theta is associated with emotional adaptation processes and stress regulation (Güntekin et al., 2017; Marox et al., 2001). In this context, temporal areas may exhibit a broader generalization effect. An increase in delta and theta activity occurred indiscriminately in right and left temporal areas (T7, T8) following negative feedback, although delta activation in the right temporal area was less generalized compared to theta activation and significant only after exposure to negative and aversive feedback, not following neutral feedback (Sp2). The increase in delta and theta waves in bilateral temporal regions can be interpreted as an adaptive response to stress, reflecting deep cognitive processing and emotional regulation aimed at effectively managing adverse situations (Merino et al., 2021; Seo et al., 2025; Thompson & Thompson, 2007).

Delta and theta activity in the left central areas has been associated with social information processing and emotional regulation processes involved in evaluating and responding to social feedback (G.G. Knyazev et al., 2009; Lapomarda et al., 2022). Following negative social feedback in critical situations, there should be a specific increase in theta band in left central areas (C3) implicated in processing these stimuli (Rawls et al., 2020; Saffari et al., 2023). However, negative feedback in moderately stressful and non-critical contexts could define a decrease in theta wave activity in this region (Vanhollebeke et al., 2022). This could indicate a shift towards a more superficial processing mode or activation of other cognitive resources to cope with stress. This adaptive response could thus be interpreted as a form of emotional regulation or cognitive adaptation to the stressful situation. For example, a reduction in delta and theta wave activity following negative feedback could allow greater focus on the cognitive resources needed to deal with the situation, such as searching for coping strategies.

An increase in delta and theta band power following positive feedback compared to negative and aversive-neutral feedback was also found in parietal areas (P3, Pz); while a decrease in these bands in this condition was found in the left occipital area (O1). In this case, the literature seems to be less consistent. The left occipital area, in particular, seems to be involved in reduced vigilance states, without a specific direction in the literature regarding its relation to the processing of negative and aversive social feedback. The increase in delta and theta band power in parietal areas (P3 and Pz) in response to positive feedback may instead reflect reward processing, learning, and motivation. Receiving positive social feedback, as anticipated in the introduction, may require complex processing and integration of social information regarding self-performance evaluation (Gottlieb, 2007), with consequent sustained cognitive resource allocation, reflecting the behavioural results and the increase in RTs in this condition.

In addition, the results regarding the alpha band, commonly associated with brain inactivity or relative rest state, further reinforced the previous conclusions and are in line with previous research (Aftanas et al., 2001; Bacigalupo & Luck, 2022; Gallina et al., 2023) showing that, during the processing of negative feedback, the brain exhibits increased activation and processing of sensory information related to that feedback in temporal regions. At the same time, there is a potential reduction in activity in the frontal region associated with cognitive

control and emotional regulation. Recent research (Codispoti et al., 2023; Gratton, 2018) confirms the role of controllability, highlighting how the power of the alpha band is suppressed in temporal areas when processing new incoming stimuli is necessary, while it is increased to maintain and defend existing cognitive representations while simultaneously managing different sources of information or concurrent processing streams. In addition, it has also been emphasized, in line with our results, how stimuli with adverse valence (e.g., painful stimuli; threatening stimuli) lead to greater suppression of alpha activity in this area (Balderston et al., 2017; Li et al., 2020) compared to non-negative stimuli. However, it is important to consider how these studies suggest that alpha activity varies with the motivational significance of stimuli rather than their hedonic content (i.e., their valence), making further research integration necessary for a deeper understanding of what emerged from this study.

2.6. Conclusion

In conclusion, it can be stated that understanding cognitive dynamics in stressful situations and the role of moderators are crucial in delineating the effects of context on cognitive performance, as highlighted in the context of the Stroop Task. This research supports, in line with previous studies (Balconi et al., 2019; Crivelli, Fronda, & Balconi, 2019), that negative-valence feedback may contribute, under moderately stressful conditions, to enhancing individual cognitive performance. This phenomenon can be interpreted as a stimulus for improvement and refinement of one's abilities. In other words, while the comfort of praise may lead to stagnation, negative critical feedback can provide the necessary impetus to hone skills, especially when combined, as mentioned in previous paragraphs, with exposure to moderate stress factors (Henderson et al., 2012).

This study has significantly contributed to the understanding of the subject matter through rigorous data analysis and appropriate neuroscientific methods for the research purpose. However, it is important to note the limitations arising from the small sample size used in the study. Limitations regarding sample size may have influenced the generalizability

of the results, limiting the representativeness of the reference population. Therefore, it is recommended that future studies consider expanding the sample to increase external validity and enhance the reliability of the results obtained. In this context we recognize that, among the limitations present in this study, there is also the absence of a control group to account for potential practice effects. Due to logistical constraints and the preliminary nature of this research, it was not possible to include a control group. To further mitigate concerns regarding practice effects, we propose that subsequent investigations could implement a between-subjects design, where different groups are exposed to either the stress manipulation or a neutral condition. This approach would help disentangle the specific impacts of stress and social feedback from mere practice effects. Additionally, utilising alternative versions of the Stroop task with varied stimuli would ensure that any improvements in performance are not simply due to familiarity with the task. By addressing these design considerations, future research can more accurately elucidate the contributions of social feedback and stress on cognitive control and task performance. Additionally, it is important to show how externally evaluated social feedback is interpreted by individuals differently based on personality traits. For example, individuals who are more socially critical tend to react more strongly to negative feedback, leading to increased activation in brain regions involved in social evaluation, such as the prefrontal cortex. Furthermore, context and type of feedback can modulate neural and behavioural responses, and feedback provided by figures recognised as authoritative has different effects compared to peer feedback.

In summary, the interaction between feedback and stress responses is a complex phenomenon involving a wide range of neural and neurophysiological mechanisms. Understanding these processes is important for developing effective strategies for stress management and promoting a social environment conducive to mental and emotional well-being.

3. SECTION 3 – Different types of social feedback can enhance or reduce performance, and induce or alleviate psychosocial stress: an exploratory study of the underlying neurophysiological mechanisms[3]

3.1. Abstract

Purpose: Social feedback plays a pivotal role in human interactions, significantly impacting emotional and cognitive processes. This study explored the effect of affectively-connoted social feedback on anticipatory anxiety and adaptive psychophysiological correlates of performance in a psychosocial stress-induction task. *Methods:* Thirty-nine healthy adults prepared and presented five discourses, each associated with different social feedback valences. To assess the impact of social feedback on stress responses, electroencephalography (EEG), heart rate (HR), and electrodermal activity (SCL) were collected during the preparation phases of each discourse. *Results:* HR and SCL were significantly lower in the annoyed and bored feedback conditions (AF and BF) compared to no and neutral feedback (NoF and NF). Furthermore, EEG data showed higher gamma band activity in the posterior region of interest compared to frontal and central areas, and progressively increased from NoF to positive feedback (PF), NF, and BF conditions, peaking before declining in the AF condition. Similarly, beta band activity was higher in central and posterior regions compared to the frontal area and increased from NoF to NF before decreasing in BF and AF conditions. *Conclusions:* These findings highlight how social feedback modulates stress and performance, underscoring the significance of feedback valence in adaptive stress modulation with implications for neuroethics and practice. They underscore the responsibility to design interventions and technologies that leverage feedback to enhance well-being without exacerbating negative psychosocial environments.

Keywords: Stress; Social feedback; Assessment; EEG; Autonomic activity; Performance

[3] This paper can be found at the following bibliographic reference: Crivelli D., Rovelli K., Balconi M. (2025). Different Types of Social Feedback can Enhance or Reduce Performance, and Induce or Alleviate Psychosocial Stress: An Exploratory Study of the Underlying Neurophysiological Mechanisms. Adaptive Human Behavior and Physiology, 11(3), https://doi.org/10.1007/s40750-025-00257-6

3.2. Introduction

In designing methods to assess individual sensitivity and responsivity to psychosocial stress with real-world predictive validity, social feedback is frequently used as a key stressor. Positive feedback reduces stress by fostering approval and social support (Peifer et al., 2020), while negative feedback triggers stress through feelings of inadequacy or threat (Gozzi et al., 2017). The effects of social feedback on stress responses are mediated by specific neural and physiological mechanisms, which are also influenced by the type of stressor and the timing of its anticipation (Paridon et al., 2017; Vassilopoulos, 2008). These dynamics highlight the importance of clarifying the key concepts of stress and anticipatory anxiety to establish a clear theoretical foundation for this study. Stress has been classically theorised as the non-specific physiological and psychological response of an organism to stimuli that, due to their intensity or duration, elicit adaptive mechanisms aimed at re-establishing homeostasis (Selye, 1976). This response encompasses a complex interplay of neuroendocrine, autonomic, and behavioural processes designed to manage demands that challenge the individual's capacity for coping (Bruce S. McEwen, 2007; Selye, 1976). In this framework, stress represents a state of heightened arousal triggered by internal or external stressors that are appraised as exceeding the individual's resources for effective adaptation (Hobfoll, 2002). Conversely, anticipatory anxiety refers to the pre-emptive state of emotional and physiological hyperactivation that arises in anticipation of a potentially adverse or stressful event (Grupe & Nitschke, 2013). This phenomenon is characterised by a convergence of cognitive processes, such as persistent worry, and physiological manifestations, including somatic tension and heightened autonomic arousal (Chua et al., 1999).

Also, social feedback impacts brain functioning via neural networks modulating situated perception and appraisal, as well as cognitive-emotional processing, involving regions such as the limbic system, prefrontal cortex, anterior cingulate cortex, and insula (Balconi & Vanutelli, 2017b; Molen et al., 2017; Peters et al., 2024). This network plays a role in adapting to environmental contexts and the challenges that they impose through homeostatic regulation and neural plasticity.

Much research has focused on the effects of evaluative social feedback on neural responses related to reward and threat. Evaluative feedback, if perceived as critical or adverse, engages brain regions involved in processing social information and regulating emotions, like the anterior cingulate and prefrontal cortices, insula, temporoparietal junction, and amygdala (Gozzi et al., 2017; Peters et al., 2024; Wheeler & Fellows, 2008). Negative feedback is linked to altered EEG patterns, such as reduced delta band and increased theta activity (Cristofori et al., 2013; Jin et al., 2019). Emerging evidence suggests that the absence of feedback or neutral feedback also carries significant implications for neural and physiological stress responses. These forms of feedback act as stress-inducing stimuli by fostering uncertainty and ambiguity, activating prefrontal and limbic structures associated with cognitive control and emotional regulation. For instance, the anterior cingulate cortex (ACC) and insula are particularly engaged during the processing of ambiguous stimuli, reflecting increased efforts to resolve uncertainty and predict outcomes (Craig, 2009; Shackman et al., 2010). Neutral or absent feedback deprives individuals of the evaluative cues needed to calibrate their behaviour or emotional state, potentially leading to heightened activation of stress-related neural circuits. This aligns with the Social Self-Preservation Theory (Dickerson et al., 2004), which posits that ambiguous or unresponsive social interactions may represent a threat to the self, eliciting stress responses comparable to those triggered by overtly negative feedback. Furthermore, studies on variations of the Trier Social Stress Test indicate that neutral feedback, while not overtly negative, can elicit cortisol responses and autonomic activation similar to those observed under conditions of social rejection, underscoring the role of uncertainty as a potent stressor (Goodman et al., 2017). Finally, positive feedback, conversely, activates reward systems involving the dopaminergic pathways and prefrontal/medial-temporal cortex, crucial for social cognition processes (Crawford et al., 2020). Positive feedback has been shown to reduce stress levels by activating cortical regions associated with gratification and well-being, such as the rostral anterior cingulate cortex (rACC), the posterior cingulate, and the right superior frontal gyrus (Mies et al., 2011). This activation is linked to increased delta and theta oscillations, particularly in the right frontal cortex due to its role in emotion regulation, social cognition, and internal state monitoring (Christie & Tata, 2009; Gennady G. Knyazev, 2007).

However, the effects of evaluative social feedback in complex communicative interactions, particularly its influence on anticipatory anxiety and psychophysiological correlates of communication planning, remain understudied. Psychosocial stressors like social feedback induce alterations in large-scale brain networks, particularly the Salience and Central Executive Networks (Oort et al., 2017), affecting higher-order cognitive processing crucial for strategic planning of behaviour and communication. These shifts can be monitored through EEG, with theta, beta, and gamma rhythms providing insights into stress-induced modulation of cognitive control and emotion regulation (Balconi, Acconito, et al., 2023; Balconi & Crivelli, 2010; Başar-Eroglu et al., 1996; Crivelli et al., 2023; Engel & Fries, 2010; Kaiser & Lutzenberger, 2003; Korotkova et al., 2018; Wróbel, 2000). Additionally, the neurovisceral integration model (Thayer & Lane, 2000) suggests that cardiovascular activity (heart rate - HR, heart rate variability - HRV) and arousal (e.g., as marked by skin conductance levels - SCL) reflect self-regulation managing the stress response and its effect on higher cognitive-affective processes. Negative feedback decreases parasympathetic activity, lowering HRV and increasing stress, while positive feedback enhances sympathetic arousal through changes in SCL (Kouchaki & Wareham, 2015; Petrocchi & Cheli, 2019).

Building upon these foundations, this study aimed to investigate how social feedback, varying in emotional and motivational valence, modulates anticipatory anxiety and psychophysiological correlates in a realistic psychosocial stress-induction task. To achieve this, we used a modified version of the Trier Social Stress Test (TSST), called the Social Stress Test (Allegretta et al., 2024; Angioletti et al., 2025; Balconi et al., 2024a, 2024b; Balconi & Rovelli, 2024). Unlike the TSST, which focuses solely on negative feedback, the SST required participants to prepare and deliver five speeches, each followed by social feedback with positive, neutral, or negative valences. We examined how progressively stressful feedback influenced neurofunctional and autonomic activity during speech preparation in a simulated job screening, measured through electroencephalography (EEG), heart rate (HR), and skin conductance levels (SCL).

Despite the exploratory nature of the study, we expected to observe autonomic markers of sustained stress responses (increased HR and SCL) throughout the task, indicating its stress-

inducing potential. We also anticipated heightened electrophysiological markers of information processing and integration for task preparation, reflected in increasing gamma EEG activity as feedback became more stressful. In response to neutral feedback, which lacks clear social-emotional cues, we expected elevated beta activity due to the need for additional cognitive resources to interpret the ambiguity. Finally, based on previous findings that stressors reduce theta activity (Balconi et al., 2024b), we hypothesised that repeated exposure to social feedback might lead to decreased theta oscillations, indicating reduced cognitive capacity under stress.

3.3. Materials and methods

3.3.1. Sample

Thirty-nine volunteers took part to the study (22 women, 17 men; age range: 20-29, M_{age} = 23.08, SD_{age} = 1.67; education range: 13-18, M_{edu} = 16.08, SD_{edu} = 1.21). Participants were recruited via consecutive and snowball sampling and received no compensation for taking part in the study. Inclusion criteria were: age >18; normal or corrected-to-normal sight and hearing. Exclusion criteria were: history of neurological or psychiatric disorders; current active therapies based on psychoactive drugs that could alter electrophysiological signals or affect cognitive functioning; illness or conditions of clinical instability during the last 72 hours before the experimental session; clinically-relevant levels of distress or signs of burnout syndrome; exposure to stressful life events during the last 6 months before the experimental session.

A priori power analysis was conducted to determine the minimum sample size required to test the study hypothesis (G*Power version 3.1.9.6, Faul et al., 2007). Since no shared rules are available for computing power analyses in case of statistical approaches using mixed effect modelling with random effects, such as in our case, to estimate the minimum sample size sufficient to observe reliable effects we based such calculation on an ANOVA model including a within-subject factor with 5 levels, which - among the available options - is the most similar one in terms of its rationale. Consistently, in assessing the outcome of our mixed effect models

and significance of the fixed factors, we used Type III Sum of Squares F-tests. Given the premises above, results indicated the required sample size to achieve 80% power for detecting medium effects (f =.25), at a significance criterion of α =.05, was N = 21. Assuming attrition equal to 30%, the estimate for the minimum sample size increases to 27 cases. Thus, we consider the obtained sample size of N = 39 adequate to test the study hypotheses.

The study was approved by the Ethics Committee of the Department of Psychology, Catholic University of The Sacred Heart, Milan, Italy, and was conducted in adherence to the guidelines outlined in the Declaration of Helsinki (2013) and according to the GDPR - Reg. UE 2016/679 and its ethical guidelines. All participants gave their written informed consent to participate in the study.

3.3.2. Procedure

Participants were seated comfortably in a dimly lighted room in front of an LCD monitor (distance ≈ 80 cm) and, after sensor placement, underwent a period of accommodation. Then, collection of physiological data was started and, after recording of an eyes-open resting-state baseline (duration: 2 minutes), participants were introduced to the experimental task and were fully informed that they would be engaging in a simulated and fictitious interview. During the week before the planned experimental sessions, participants were asked to fill the Perceived Stress Scale.

3.3.2.1. Experimental task: the Social Stress Test

A web-based experiment management platform (Qualtrics XM platform; Qualtrics LLC, Provo, UT, USA) was employed for the SST, to evaluate the individual skills in stress regulation (SR) – defined as the ability to effectively manage physiological and psychological stress reactions (Crum et al., 2020; P. G. Williams et al., 2009) – and in stress tolerance (ST), defined as the ability to respond promptly and appropriately to sustained and/or more intense stress

conditions (Fleshner et al., 2011; Khayrutdinov et al., 2020), when facing psychosocial stressors and presented with social feedback.

Going down to specifics, the task required participants to prepare and deliver five speeches on specific self-referred topics under time constraints. Also, the task was given a realistic, engaging, and socially-laden frame by providing participants with the following scenario: "*Imagine yourself in a competitive screening process for an internship or job role that holds significant importance to you. The organization's representative reveals that only one position is vacant, and there are 23 other candidates vying for it. Your next step involves facing a selection interview, during which you'll encounter a panel of examiners. You must ready yourself to prepare and present various speeches*"

For each speech, participants were allotted two minutes for the Preparation phase and one minute for the Speech phase. Participants were advised to minimize their preparation time, as penalties were applied to their performance scores based on the duration of the preparation phase. This design makes the preparation phase critical in terms of emotional regulation and ST for several reasons. In fact, time pressure limits the amount of information participants can process and organize during preparation, necessitating rapid adaptation and immediate decision-making, which can be stressful and require substantial emotional regulation. Additionally, awareness that extended preparation time will incur penalties may further heighten stress and anxiety, as participants must balance adequate preparation with adhering to time limits. Due to such reasons, we here opted to focus the analyses of behavioural, electroencephalographic, and autonomic data on the preparation phase.

Moreover, the circumstances for delivering the speeches became progressively more demanding and stressful. Each speech was, indeed, associated with social feedback from the simulated expert panel, which varied in terms of emotional valence and affective intensity from a positive and accommodating feedback where the verbal and non-verbal communication of the examining committee conveyed acceptance and friendliness, to a neutral one where verbal and non-verbal cues were limited and aspecific (not conveying nor approval nor disagreement), to a boredom one where the verbal and non-verbal communication conveyed lack of interest and slight impatience, up to an annoyed one connoted by clear signs of irritation and

displeasure. Such feedbacks were provided in the form of videos. Each video used in the study was between 14 to 17 seconds long, featuring a panel of two individuals (one male, one female).

To ensure technical consistency, the videos were processed using DaVinci Resolve and Adobe Premiere Pro to standardize resolution (1920x1080), frame rate, bitrate, and format (H.264 to MP4, 16:9 aspect ratio). Audio levels were normalized, and audio compression was standardized (AAC) using Audacity. In addition, external judges (N = 3) blindly evaluated the social feedback stimuli to ensure consistency and reliability in eliciting the intended experimental outcomes. Inter-rater reliability was investigated by computing intra-class correlation (ICC) coefficients based on judges ratings for arousal, pleasantness, and discomfort induced by the video stimuli. ICC was, respectively, equal to.93,.97, and.99 for arousal, pleasantness, and discomfort ratings (quantified via 10-point Likert scales). The participants' post-test reports indicated a correlation between the specificity of the videos and their escalating stress levels, underscoring the significant impact of the increasing emotional content on their psychophysiological responses. Additionally, the heightened intensity of negative emotions portrayed in the videos was associated with greater induced stress.

Behavioural scores for stress regulation and tolerance were derived from participants' performance during the most critical phase of the interview, the speech preparation. Specifically, a 1-to-5 point Stress Regulation score (SRs) was assigned based on the time taken to prepare each speech under varying conditions. Independent judges systematically assessed the quality of the delivered speeches to identify and rate inadequate performances. This process ensured that low preparation times were not misinterpreted as indicators of high performance if the actual speech was irrelevant or insufficient. Stress Tolerance scores (STs), also ranging from 1 to 5, were computed to capture participants' ability to manage heightened stress levels induced by progressively increasing challenges and social pressure. A total performance score (SSTtot) was finally computed as the mean between SRs and STs scores. Further details on the task structure, materials, and score calculations can be found in Balconi and colleagues (Balconi et al., 2024b).

3.3.2.2. Psychometric testing

Tonic levels of perceived stress were measured via the Perceived Stress Scale – PSS (S. Cohen et al., 1983). The PSS is constituted by 10 items, scored on 0-to-4 Likert scales, and is deemed a quick and reliable tool in basic and applied research on stress and coping skills (Monroe, 2008).

3.3.3. EEG recording and reduction

EEG activity at rest and during the experimental task was recorded using a SynAmps DC amplifier (Compumedics Neuroscan, Charlotte, USA) and the NeuroScan software. The recoding montage included 17 electrode sites (Fp1, Fp2, F7, F8, F3, Fz, F4, T7, T8, C3, Cz, C4, P3, Pz, P4, O1, O2; 10-10 International System). Electrophysiological signals were collected via Ag/AgCl sintered electrodes referred to linked earlobes. In addition, eye movements and blinks were monitored via vertical EOG. Data were sampled at 1000 Hz, with 0.01-250 Hz input filter and a 50 Hz notch filter. Electrode impedance was monitored to ensure it remained below 5 kΩ.

EEG signals were processed offline with Vision Analyzer2 software (Brain Products GmbH, Gilching, Germany). The processing pipeline included IIR bandpass filtering (0.1-50 Hz, slope: 48 dB/oct) and automated ocular correction via ICA algorithm. After visual inspection of the corrected signals and manual rejection of residual ocular, muscular or movement artifacts, EEG data were segmented according to the resting-state and experimental task conditions. Power spectra of the EEG signals were computed based on artifact free segments using the Fast Fourier Transform (FFT) algorithm (Hamming window, resolution: 0.5 Hz), extracting power spectral density (PSD) values for frequency components of the standard EEG bands (Delta, 0.5–3.5 Hz; Theta, 4–7.5 Hz; Alpha, 8–12.5 Hz; Beta, 13–30 Hz; and Gamma, 30.5–50 Hz; Sanei & Chambers, 2007). Mean PSD values for the standard EEG bands in the Frontal, Central-temporal, an Parieto-occipital region of Interest (RoI) were

calculated for the eyes-open resting-state baseline and the Preparation phases of each task step to derive average PSD profiles values for such conditions.

Finally, task-related variations in EEG power values were computed as follows:

$$TR_{PSD} = ((PSD_{task}\text{-}PSD_{open\text{-}bl})/PSD_{open\text{-}bl})$$

where TR_{PSD} represents task-related variations in EEG power values for each frequency band and each RoI, PSD_{task} represents EEG power values during the task conditions for each frequency band and each RoI, and $PSD_{open\text{-}bl}$ represents EEG power values in eye-open baseline for each frequency band and each RoI.

2.2.4 Autonomic data recording and processing

To assess task-related autonomic activity variations connoting the discourse preparation phase, we utilised a wireless Biofeedback2000-Xpert system (Schuhfried GmbH, Modling, Austria). A multi-purpose sensor connected to the MULTI module of the recording system was placed over the distal phalanx of the second finger of the participant's non-dominant hand. Such sensor allows for capturing both cardiovascular and electrodermal biosignals. Namely, heart rate (HR) and skin conductance level (SCL) data were sampled with SR = 40 Hz. Also, hand movements were tracked using the inbuilt accelerometers in order to remove potential artefacts during signal processing.

In data processing, data were visually inspected offline to reject artefacts and then segmented based on the data collection phases (baseline and task conditions). Average condition-specific SCL and HR values were calculated starting from artifact-free segments. In addition, inter-beat-intervals were derived from HR data, and their condition-specific standard deviation (SDNN) was used as a measure of heart rate variability (HRV) to assess vagal influence on cardiovascular activity (Berntson et al., 2007; Mendes, 2009).

Finally, task-related variations in autonomic indices were computed as follows:

$$TR_{AI} = ((AI_{task}\text{-}AI_{open\text{-}bl})/AI_{open\text{-}bl})$$

Where TR_{AI} represents task-related changes in the autonomic measure (SCL, HR, or HRV), AI_{task} represents the autonomic activity during the task conditions for each measure, and $AI_{open\text{-}bl}$ represents the autonomic activity in eye-open baseline for each measure.

3.3.4. Statistical analysis

The potential effects of social feedback received during a speech on task-related PSD values (for Theta, Alpha, Beta, and Gamma bands across Frontal, Centro-temporal, and Parieto-occipital RoI) and task-related AI values (for SCL, HR, and HRV) marking the following discourse preparation phase have been tested using linear mixed-effects models. Statistical analyses have been run and checked using *jamovi* (version 2.4; The jamovi project, 2023) and the *GAMLj3* module (version 3.1.4). Social Feedback (5 levels: no previous feedback – NoF *vs.* positive feedback – PF *vs.* neutral feedback – NF *vs.* boredom feedback – BF *vs.* annoyed feedback – AF) has been included as fixed effect in the models, while PSS scores and SST scores has been included in the models as covariate to account for potential confounds concerning tonic perceived stress levels or individual performance. Models fitted for task-related PSD values included, as an additional fixed factor, even the RoI (3 levels: Frontal – Fr *vs.* Centro-temporal – CT *vs.* Parieto-occipital - PO). Subject has been used as a random effect to better control for individual differences between participants, while residuals were modelled via an autoregressive first-order structure to better account for potential autocorrelation confounds. In addition, a filter for outliers (cut-off: 4 SD above/below the average) was used to prevent confounds in model outcomes due to extreme deviations in modelled data. Assumptions for normality was checked by computing asymmetry and kurtosis values and looking whether such values were within standard ranges (± 1.5 for asymmetry and ± 3 for kurtosis). Yet, it is also

relevant to note that mixed-effects modelling as a statistical approach proved to be robust against deviation from normality (or other potential violations from assumptions), making it a valuable approach to investigate real complex datasets (Schielzeth et al., 2020).

The significance of terms for the fixed effect has been assessed by conditional F-tests; we will then report relative F and p values of the Type III Sum of Squares computations. Statistical significance threshold was set to $\alpha = 0.05$. Pair-wise comparisons used to explore simple effects were based on Tukey tests adjusting for multiple testing biases. Also, Cohen's d values were calculated and reported as a measure of effect size for statistically significant pair-wise comparisons. Effect sizes have been deemed as small when ≥ 0.2, medium when ≥ 0.5, and large when ≥ 0.8, in agreement with Cohen's norms (J. Cohen, 1988).

3.4. Results

The analysis of the TR_{PSD} values for the Gamma band showed significant main effects for the RoI ($F_{(2,516)} = 9.119$, $p < 0.001$) and for the Feedback ($F_{(4,516)} = 4.073$, $p = 0.003$) factors. Namely, gamma values was higher in the PO RoI than in the Fr ($p = 0.002$, $d = 0.44$; $EM_{PO} = 1.02$, 95% CI [0.80, 1.25]; $EM_{Fr} = 0.67$, 95% CI [0.44, 0.90]) and CT ($p = 0.014$, $d = 0.40$; $EM_{PO} = 1.02$, 95% CI [0.80, 1.25]; $EM_{CT} = 0.74$, 95% CI [0.51, 0.96]) ones. Also, gamma values showed a progressively increasing trend moving from the NoF condition to the PF, NF, and BF ones, where they reached their peak before the decrease connoting the AF condition (see *Figure 3.1a*). Also, pair-wise comparisons highlighted that gamma TR_{PSD} was significantly higher in the BF than in the NoF condition ($p < 0.001$, $d = 0.46$; $EM_{BF} = 1.08$, 95% CI [0.84, 1.32]; $EM_{NoF} = 0.62$, 95% CI [0.39, 0.86]) and AF Condition ($p < 0.001$, $d = 0.44$; $EM_{BF} = 1.08$, 95% CI [0.84, 1.32]; $EM_{AF} = 0.68$, 95% CI [0.45, 0.92]).

Consistently, even the analysis of the TR_{PSD} values for the Beta band showed significant main effects for the RoI ($F_{(2,519)} = 10.501$, $p < 0.001$) and Feedback ($F_{(4,519)} = 2.529$, $p = 0.040$) factors. Higher beta values was observed in the CT RoI ($p = 0.013$, $d = 0.44$; $EM_{CT} = 0.48$, 95% CI [0.33, 0.63]; $EM_{Fr} = 0.28$, 95% CI [0.13, 0.43]) and in the PO RoI ($p < 0.001$, $d = 0.67$; EM_{PO}

= 0.62, 95% CI [0.47, 0.76]; EM_{Fr} = 0.28, 95% CI [0.13, 0.43]) than in the Fr one. Beta values showed a progressively increasing trend moving from the NoF condition to the PF and NF one, where they reached their peak before the decrease connoting the BF and AF conditions (see *Figure 3.1b*). Again, pair-wise comparisons specifically highlighted that TR_{PSD} was higher in the NF condition than in the NoF one (p = 0.022, d = 0.38; EM_{NF} = 0.55, 95% CI [0.40, 0.70]; EM_{NoF} = 0.33, 95% CI [0.17, 0.48]).

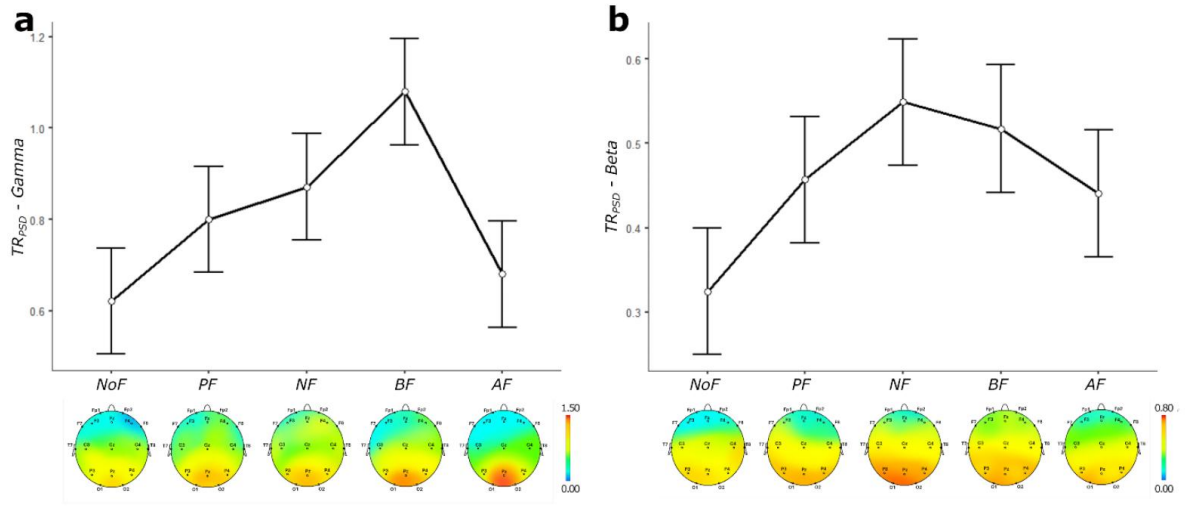


Figure 3.1 - EEG results. (a) Trend for gamma TRPSD values across different feedback conditions, paired with topographic EEG maps illustrating representative TRPSD distribution in the gamma band. (b) Trend for beta TRPSD values across different feedback conditions, paired with topographic EEG maps illustrating representative TRPSD distribution in the beta band. Bars in the trend plots represent ± 1 SE around the mean. Red colour in the topographic EEG maps denotes increased TRPSD values. Notes - TRPSD: task-related variations in EEG power values; NoF: no previous feedback; PF: positive feedback; NF: neutral feedback; BF: boredom feedback; AF: annoyed feedback.

Moving to autonomic measures, the models fitting TR_{AI} values for HR showed significant main effect for the Feedback factor ($F_{(4,152)}$ = 2.817, p = 0.027). Task-related HR modulations showed quite comparable values across the NoF, PF, NF, and BF conditions, with a decrease in the AF one where they reached the lowest values (see *Figure 3.2a*). Pair-wise comparisons highlighted that task-related variation of HR values were significantly lower in the AF than in the NoF

condition (p = 0.030, d = 0.57; EM_{AF} = 0.08, 95% CI [-0.03, 0.18]; EM_{NoF} = 0.24, 95% CI [0.14, 0.34]).

Furthermore, even the model fitting TR_{AI} for SCL highlighted a significant effect for the Feedback factor ($F_{(4,108)}$ = 2.569, p = 0.042) with, again, comparable values for the NoF, PF, and NF conditions and a progressive decrease in the BF and AF ones (see *Figure 3.2b*). Pair-wise comparisons highlighted significant differences between SCL values in the BF (p = 0.046, d = 0.35; EM_{BF} = 0.85, 95% CI [0.41, 1.29]; EM_{NF} = 1.29, 95% CI [0.86, 1.72]) and in the AF (p = 0.039, d = 0.45; EM_{AF} = 0.73, 95% CI [0.30, 1.17]; EM_{NF} = 1.29, 95% CI [0.86, 1.72]) conditions than in the NF one.

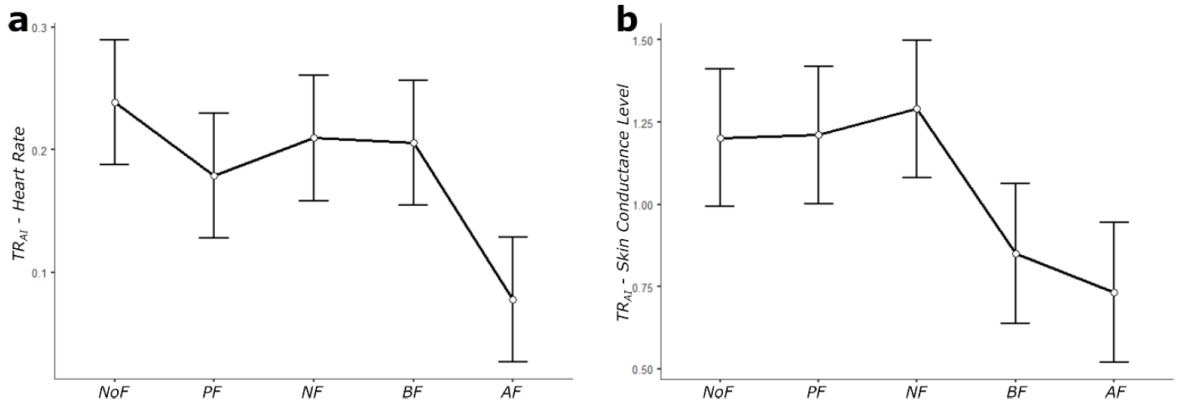


Figure 3.2 – Autonomic results. (a) Trend for Heart Rate TRAI values across different feedback conditions. (b) Trend for Skin Conductance Level TRAI values across different feedback conditions. Bars in the trend plots represent ± 1 SE around the mean. Notes - TRAI: task-related changes in autonomic measures; NoF: no previous feedback; PF: positive feedback; NF: neutral feedback; BF: boredom feedback; AF: annoyed feedback.

No other model highlighted statistically significant and relevant effects (see *Supplementary Materials* for further information on the outcomes of such models).

3.5. Discussion

This exploratory study investigated the effect of social feedback in a realistic psychosocial stress task, specifically focusing on its influence during the preparation phase of self-referred speeches in a simulated job interview. We examined neurofunctional and autonomic markers of anticipatory performance anxiety in response to feedback of varying emotional valence.

Our findings highlighted three key points: (i) gamma activity during speech preparation increased progressively across feedback conditions, peaking after boredom feedback; (ii) beta activity during speech preparation peaked after neutral feedback and then declined; (iii) HR and SCL values connoting the speech preparation phases showed stable modulations with no, positive, and neutral feedback, but differently diminished after boredom and annoyed feedback conditions.

As a first general point, it is essential to note that these modulations occurred during the speech preparation phase, after participants processed the feedback, and do not connote immediate exposure to the social feedback (i.e., the moment when they were watching the simulated expert panel feedback). This suggests that, given also the pressure towards performance that we tried to induce in participants, the effects we observed may reflect cognitive and behavioural adaptation of their cognitive and behavioural performance to the social cues they received. More specifically, the emerging pattern of physiological responses does not merely reflect the immediate reaction to an occurring social stimulus, but connote a phase of the task where participants were actively engaged in creating, planning, programming, and validating the content and form of their next upcoming speech. It is therefore plausible that their planning and preparation processes incorporated the feedback they had just received, allowing them to adapt to this new information in order to maintain or enhance the quality of their performance. From an evolutionary perspective, these findings may represent adaptive mechanisms that have evolved to optimize survival and social functioning in response to environmental challenges. Social feedback, indeed, serves as a critical cue in high-stakes situations, aiding in navigation of social hierarchies and enhancement of task performance. The

ability to effectively integrate feedback and adjust behaviour likely conferred significant advantages in ensuring social acceptance and group cohesion, essential for survival in ancestral environments. Yet, it also has to be noted that these adaptations also come with potential costs, such as the risk of chronic stress when faced with repeated social challenges. Linked to that, it is also relevant to note, as a second general remark, that the reported findings emerged while accounting for subjective tonic stress levels and for individual performance at the task. This suggest that the emerging physiological profiles do not depend on such subject variables and could be generalized across such individual factors.

Moving to the first main finding, we have observed that the modulation of the gamma band associated to the preparation of the self-referred speeches gradually increased moving from a starting condition with no previous feedback, to conditions where participants had previously received positive, neutral or boredom feedbacks on their presentation performance, peaking in such last condition and then decreasing after exposure to an adverse social feedback where the experts showed impatience and irritability.

According to the selectively distributed parallel processing gamma system hypothesis (Başar-Eroglu et al., 1996), gamma oscillations might be fundamental building blocks of the animal brain electrical activity, related to multiple functions and representing a universal code for central nervous system communication and information exchanges between neural structures. As such, they are deemed especially crucial for critical cognitive functions such as attentional processing, learning processes, formation and activation of mental representations, emotion perception and affective processing, and cognitive control of emotions (Harris & Gordon, 2015; Kaiser & Lutzenberger, 2003; Yang et al., 2020).

Building on such evidence base, we suggest that the observed increasing trends in the amount of gamma oscillations may mark the growing amount of resources dedicated to information integration for planning the requested speeches in conditions of increasingly challenging and stressful social feedback. Preparing the speech, indeed, requires participants to gather information from the social and physical context, recover information from memory, sketch-up a communication strategy, and integrate such different processes and their related outcomes for subsequent implementation of the prepared discourse. In an adaptive context,

such neural investment would have facilitated effective communication, a key component of social survival. However, this cognitive effort may also incur costs, such as increased mental strain or fatigue when feedback becomes excessively challenging, as observed with the peak response to boredom feedback. Such operations are, indeed, plausibly taxed by the affective and motivational valence of the feedback. Namely, the occurrence of a positive feedback on subjective performance do provide salient information, conveyed via social cues, that the participant may use to adjust following planning steps, reinforcing effective behaviour. Then, being subsequently exposed to neutral and then boredom feedbacks, the reinforcing effect fade away, while increasing distress take the scene. Growingly negative feedbacks prompts further adaptation of cognitive and behavioural processes in an attempt of maintaining good performance levels against adverse contextual factors, calling for greater control of affective experience. While we recognize that this interpretation needs further testing, we may speculate that the highest gamma values recorded following the social feedback conveying boredom in the experts, with respect to the initial condition, might mark resource investment in the attempt to plan a more effective and engaging speech to regain their attention. Partial support to this interpretation might derive from the localization finding. Indeed, gamma TR_{PSD} was the highest over parieto-occipital sites and modulations of such EEG rhythm in posterior and inferior parietal and occipital areas was associated to top-down activation of mental representations and maintenance of auditory and visual representations in working memory (Kaiser & Lutzenberger, 2003). Adapting to social feedbacks and preparing the following communication steps trying to make them more effective and engaging plausibly require imagery processes and re-activation of related mental representations. As a final note, while the observation of an inverted trend of gamma modulations following social feedback conveying annoyance and impatience was unexpected, we suggest it might mirror a sort of give-up response where no additional neural resources are devoted to further adapt the speech preparation process. We nonetheless acknowledge that this last interpretation, given currently available evidence and literature, is still speculative and is worth additional testing.

As for the second main finding, we have observed that the modulation of the beta band associated to the preparation of self-referred speeches was the greatest following the neutral

feedback condition, in particular with respect to a condition when clear adverse feedback was given and to when no previous feedback was available.

Beta oscillations are recognized as markers of cognitive workload, endogenous task-focused attention, and the top-down regulation of mental resources (Crivelli et al., 2023; Michalareas et al., 2016; Wróbel, 2000). In addition, coherently with the posterior localization here observed for the modulations of beta activity, the power of the EEG beta band over posterior sites has been found to positively correlate with perceived mental effort during challenging cognitive tasks (Balconi, Acconito, et al., 2023; Howells et al., 2010). Increased beta band power is also thought to reflect higher arousal levels needed to sustain attention during tasks. This is consistent with clinical observations where individuals with self-regulation and arousal management impairments, such as those with attention deficit hyperactivity disorder (ADHD), exhibit decreased beta band power and higher levels of effort (Howells et al., 2010).

Based on such premises, we suggest that the observed heightened beta activity in the preparation phase following the neutral feedback – together with the posterior localization of the global emerging beta responses – could depend on communication ambiguity of such experimental condition, specifically marking the increased cognitive load on attention orientation and mentalization mechanisms imposed by the lack of clearly connoted social cues from the experts panel. The ambiguous effect of neutral communication is widely known in facial expression research. Neutral expressions are, indeed, usually interpreted and responded to in different ways, due to lacking or potentially ambivalent information on the emotional state of the person or his/her relationship towards the inter-agent, and are processed by partly different neural structures than those commonly used to process emotional facial expressions (Fusar-Poli et al., 2009). We here posit that, in our case, the ambiguity of the message conveyed by the neutral feedback called for a top-down allocation of cognitive resources to central and temporal structures involved in social perception and cognition processes.

Consistently, even from an evolutionary perspective, neutral feedback may represent unexpectedly-salient social cues that require additional cognitive and attentional resources for interpretation. Emerging evidence suggests that the absence of feedback or neutral feedback

carries significant implications for neural and physiological stress responses. These forms of feedback act as stress-inducing stimuli by fostering uncertainty, activating prefrontal and limbic structures associated with cognitive control and emotional regulation. For instance, the anterior cingulate cortex and insula are particularly engaged during the processing of ambiguous stimuli, reflecting increased efforts to resolve uncertainty and predict outcomes (Craig, 2009; Shackman et al., 2010). The heightened beta activity observed could reflect these neural processes, marking increased vigilance and allocation of resources in key neural structures in response to such ambiguity – a mechanism likely advantageous in uncertain social interactions, where interpreting unclear cues may enhance adaptability and promote social survival. This also aligns with the Social Self-Preservation Theory (Dickerson et al., 2004), which posits that ambiguous or unresponsive social interactions may represent a threat to the self, eliciting responses comparable to those triggered by overtly negative feedback.

Finally, we have also observed quite consistent cardiovascular and electrodermal markers of stress across the first conditions connoted by absent, positive or neutral feedback, up to the boredom feedback condition for HR values, and a successive decrease of autonomic modulations following the annoyed feedback condition.

Such an autonomic profile is globally consistent with an increase of psycho-physiological arousal associated with the stress response (Rodrigues et al., 2015). Namely, the functional role attributed to the activation of sweet glands – mirrored by the rise of skin conductance measures – is linked to action preparation to face environmental challenges, while modulations of HR have been primarily linked to activation systems involved in responding to situational requests and environmental demands (Dawson et al., 2007; Fowles, 1980). Relevant to the present discussion, social feedback specifically has a known crucial role in modulating autonomic responses (Mestanik et al., 2015). Both negative and positive feedback were, indeed, found associated with increased physiological arousal, due to their relevance for regulatory and adaptation mechanisms (Kouchaki & Wareham, 2015; Petrocchi & Cheli, 2019). In the face of such consistent global profile of heightened anticipatory performance stress response, we have nonetheless to acknowledge the unexpectedness of the decrease of autonomic modulations following the annoyed feedback condition. In continuity with the above-noted remarks on a

similar effect for gamma oscillations – we suggest that the drop of anticipatory physiological arousal after being exposed to overly negative feedback from the impatient and annoyed experts might reflect a reactive decrease of sympathetic response or the prepotent intervention of parasympathetic self-regulatory mechanisms to ease focusing on the task in the most socially stressful condition. Taking into account even an evolutionary perspective, in ancestral environments, those physiological responses to social feedback would have facilitated immediate preparation for action in salient, challenging and/or threatening social scenarios. Yet, when the social environment became excessively adverse, disengagement could be a potential conservation strategy, highlighting an adaptive trade-off between resource investment and energy preservation. Again, we recognise the speculative nature of this interpretation and the importance of follow-up dedicated investigation with replication samples and additional control conditions.

3.6. Conclusion

To conclude, this exploratory study investigated the impact of social feedback on neurofunctional and autonomic responses during a simulated job interview task designed to induce psychosocial stress. Specifically, the study examined how feedback of varying emotional valence influenced anticipatory performance anxiety and neurofunctional correlates of participants' performance in planning and adapting goal-directed communication strategies to previous social feedback. The findings revealed that gamma activity increased progressively, peaking after participants received boredom feedback. In contrast, beta activity showed a different trend, peaking following neutral ambiguous feedback. Additionally, autonomic values during speech preparation showed a consistent activation profile for most of the task phases. These results indicate that specific types of social feedback may significantly influence anticipatory anxiety and higher cognitive-affective processes connoting participants' preparation to face task requirements, with distinct neurofunctional and autonomic patterns emerging in response to different feedback conditions.

Despite such first insights gained from this exploratory study, several limitations must be acknowledged. First, the sample size was still relatively small, limiting the generalizability of the findings. Replication studies with larger and more diverse samples are necessary to validate and extend our results. Additionally, future research should consider controlling for individual differences such as social anxiety and extraversion, which may significantly influence responses to social feedback and stress induction tasks. Moreover, some of the unexpected results discussed in previous sections are still speculative in nature. These interpretations would benefit from specific testing through dedicated follow-up studies to better understand the underlying mechanisms. Similarly, the lack of a significant modulation of the theta band as well as of evidence for interaction effects between experimental conditions and RoI, leaves open questions concerning the relative contribution of different cortical structures and mechanisms to the investigated processes. Another important aspect that was not addressed in this study is the subjective experience of participants regarding the stressfulness of the task and the perceived affective relevance of the social feedback. Incorporating self-reports in future research could provide a more comprehensive understanding of how social feedback affects perceived stress and performance anxiety. As a final note, we deem it relevant to point out potential neuroethical implications that might already be raised by present findings. The demonstrated ability of social feedback to modulate stress and performance raises ethical questions about its use in human interactions and technological applications. On one hand, leveraging feedback mechanisms could foster well-being and enhance performance in educational, occupational, and clinical contexts. On the other hand, misuse of feedback – whether through neglect or deliberate exploitation – could perpetuate psychosocial harm, undermining dignity and mental health. In an era increasingly defined by human-technology interactions, understanding the neurocognitive mechanisms of feedback is crucial for designing interventions and systems that respect individual autonomy while promoting resilience and empowerment. Future research should also explore broader socio-environmental dynamics, drawing on concepts such as meaningful work and eudaimonia, to ensure that social feedback fosters equitable and empowering conditions in both human and organizational systems.

3.7. Supplementary Material

Outcome of linear mixed-effects models that did not highlight relevant and statistically significant effects for the research questions

Fixed Effects Omnibus Tests					Random Components					
Delta					Delta					
	F	*df*	*df (res)*	*p*	*Groups*	*Name*	*Variance*	*SD*	*ICC*	*Phi*
PSS	0.865	1	36.0	0.358	*ID*	*(Intercept)*	0.156	0.395	0.368	0.0220
PF_RegResStress	0.294	1	36.0	0.591	*Residual*		0.267	0.517		
RoI	2.299	2	520.0	0.101						
Feedback_pre	2.201	4	520.0	0.068						
RoI ✻ Feedback_pre	0.811	8	520.0	0.593						
Theta					Theta					
	F	*df*	*df (res)*	*p*	*Groups*	*Name*	*Variance*	*SD*	*ICC*	*Phi*
PSS	0.00382	1	36.0	0.951	*ID*	*(Intercept)*	0.0986	0.314	0.358	0.00838
PF_RegResStress	0.43208	1	36.0	0.515	*Residual*		0.1769	0.421		
RoI	342.156	2	520.0	0.033						
Feedback_pre	0.61942	4	520.0	0.649						
RoI ✻ Feedback_pre	0.63179	8	520.0	0.751						
Alpha					Alpha					
	F	*df*	*df (res)*	*p*	*Groups*	*Name*	*Variance*	*SD*	*ICC*	*Phi*
PSS	0.00317	1	36.0	0.955	*ID*	*(Intercept)*	0.0616	0.248	0.288	0.256
PF_RegResStress	0.51784	1	36.0	0.476	*Residual*		0.1526	0.391		
RoI	1.614.325	2	522.0	< .001						
Feedback_pre	137.073	4	522.0	0.243						
RoI ✻ Feedback_pre	0.48273	8	522.0	0.869						
Fixed Effects Omnibus Tests					Fixed Effects Omnibus Tests					
	F	*df*	*df (res)*	*p*	*Groups*	*Name*	*Variance*	*SD*	*ICC*	*Phi*
PSS	0.0142	1	36.0	0.906	*SubjID*	*(Intercept)*	0.387	0.622	0.409	0.0935
PF_RegResStress	0.1106	1	36.0	0.741	*Residual*		0.560	0.748		
Feedback_pre	0.2895	4	143.0	0.884						

4. SECTION 4 – Sensorimotor Simulation's Influence on Stress: EEG and Autonomic Responses in Digital Interviews[4]

4.1. Abstract

This study explored the role of sensorimotor simulation in modulating the stress response in individuals exposed to stressful digital simulated interviews. 52 participants were assigned to two different versions of a Digital Social Stress Test: a simulated version with a dynamic–realistic examining committee (Dyn-DSST) and a version with a static examining committee (Stat-DSST). During interview preparation, behavioural indices reflecting stress regulation and resistance, response times, and electroencephalographic (EEG) and autonomic indices were collected. Higher regulation scores were found for the Stat-DSST group compared to the Dyn-DSST group, probably induced by the presence of limited external sensory input in time and space, perceived as less stressful. The EEG results revealed a distinct contribution of the low- and high-frequency bands for both groups. Dyn-DSST required greater cognitive regulation effort due to the presence of a continuous flow of information, which can enhance sensory and motor activation in the brain. The SCR increased in the Dyn-DSST group compared to the Stat-DSST group, reflecting greater emotional involvement in the Dyn-DSST group and reduced sensory stimulation in the static version. In conclusion, the results suggest that sensorimotor simulation impacts the stress response differently in dynamic interviews compared to static ones, with distinct profiles based on behavioural, EEG, and autonomic measures.

Keywords: stress management; sensorimotor simulation; EEG; autonomic indices; Social Stress Test; stressful interview; cognitive regulation effort; emotional involvement

[4] This paper can be found at the following bibliographic reference: Balconi, M., Angioletti, L., & Rovelli, K.* (2024). Sensorimotor Simulation's Influence on Stress: EEG and Autonomic Responses in Digital Interviews. Brain sciences, 14(6), 608. https://doi.org/10.3390/brainsci14060608

4.2. Introduction

The ability to work under stress and maintain optimal performance under pressure has been deemed a valuable marker of professional maturity and adaptability, as well as subject-specific emotional resilience, which, according to former authors, is essential to successfully face professional challenges and mitigate the risk of errors (Ötting et al., 2020).

In recent years, a significant transformation has occurred in the means by which academic or job interviews take place. Advancements in recruitment have become possible through deep digitalization processes, which have pervaded every aspect of the personnel selection process. In addition, modern organizations are increasingly recognizing that personnel who are capable of proactively regulating and resisting stress are often better able to maintain a consistent level of performance over time.

Stress regulation, defined as the ability to effectively manage physiological and psychological reactions to stress, maintaining a suitable balance in the medium term, plays a pivotal role in fostering neurocognitive efficiency (Crum et al., 2020; P. G. Williams et al., 2009). Neurocognitive efficiency can be defined as the brain's ability to perform optimally in functions such as attention, memory, and executive tasks, particularly under stress. It is characterized by effective information processing and stress regulation, enabling task completion with minimal errors and cognitive effort, and can be assessed through behavioural and neurophysiological measures (e.g., reaction times (RTs), electroencephalographic (EEG) frequency bands) (Crivelli, Fronda, Venturella, et al., 2019; Gur et al., 2010). It is particularly crucial when facing tasks or situations under time or psychological pressure. Stress regulation involves an awareness of one's emotional responses, as well as the ability to cope with challenges, without experiencing prolonged negative impacts on one's mental and physical health (Goldfarb et al., 2019). Moreover, people with greater stress management abilities exhibit a heightened capacity to cope with challenges and sustain optimal cognitive functioning, fostering a constructive mindset under uncertainty, with personal awareness and self-control becoming key aspects (Balconi & Crivelli, 2019).

Simultaneously, stress resistance, defined as the capacity to respond promptly and appropriately to more acute and intense stress conditions, further contributes to an individual's adaptability and performance under pressure (Fleshner et al., 2011; Khayrutdinov et al., 2020). It involves not only emotional and mental resilience but also readiness to address situations requiring a rapid and accurate response. Stress resistance implies the ability to maintain high performance in critical situations. In line with the literature, personal awareness (Geuens et al., 2018) and self-control (Boltivets et al., 2021) are key components of this capacity, enabling individuals to overcome acute stressors and contribute to a more resilient organizational culture (Jelača et al., 2022). Therefore, exploring stress regulation and resistance during preparation for a job interview may provide valuable insights into candidates' abilities to effectively regulate stress and address professional challenges.

Nonetheless, in this context, technology has radically reshaped the conventional job assessment process, transforming the traditional job interview into a virtual experience and, in some cases, an entirely remote experience (Vuchkovski et al., 2023). Digital simulations, however, can significantly influence the individual's sensorimotor experience (Adamovich et al., 2009), thus affecting their behavioural and neurophysiological responses to stress.

Specifically, as highlighted by previous studies (Ackerley et al., 2016; Uysal & Düger, 2020), sensorimotor integration refers to the process by which sensory information is combined with motor actions, enabling coordinated and adaptive responses to environmental stimuli.

In the context of stress regulation and resilience, this integration is of paramount importance for several reasons. Firstly, sensorimotor integration and simulation play a pivotal role in how individuals perceive and respond to stressors (Rodriguez & Kross, 2023). When a person encounters a stressful situation, such as a demanding digital interview, their sensory systems (e.g., visual and auditory) rapidly process environmental cues (Mate, 2022). These sensory inputs are then integrated with motor responses, which encompass not only physical actions but also electrophysiological (Choi et al., 2023; Melnik et al., 2017) and autonomic nervous system responses (e.g., changes in heart rate (HR) and skin conductance) (Nakane, 2022). Research has highlighted the significance of sensorimotor integration in various

contexts, including movement disorders, speech motor learning, and stress regulation (Abbruzzese & Berardelli, 2003; Sares et al., 2018; Shum et al., 2011).

Specifically, sensorimotor simulation, in virtual job interviews, as opposed to those conducted in person, distinguishes itself not only by the peculiarities inherent in interacting with the digital environment, which may restrict sensory perception (Kong et al., 2017), but also by eliciting a certain emotional detachment, leading to a distinct emotional and cognitive response compared to real-life situations (Ciaunica et al., 2022).

In general, the literature focusing on the neuroscientific analysis of the differences between face-to-face and remote interactive dynamics is extensive. Recent neuroscience studies have investigated how individuals react to face-to-face (FTF) versus remote computer-mediated (RCM) interview conditions (Balconi, Fronda, et al., 2022). The primary objective of these studies was to explore and clarify the impacts of the FTF vs. RCM modes on social dynamics within assessment interviews, specifically focusing on interpersonal relationships and inter-brain neural and psychophysiological synchronisation in the recruiter–candidate dyad (Balconi, Crivelli, et al., 2022; Balconi & Cassioli, 2022). From a neurophysiological standpoint, these studies highlighted higher indices (i.e., intra-brain and inter-brain connectivity indices, computed by the authors using the partial correlation coefficient Πij) in the electroencephalographic (EEG) delta and theta frequency bands in the FTF compared to the RCM condition, regardless of the role (i.e., recruiter or candidate). Regarding autonomic activity, an increase in the skin conductance level (SCL) was found in the FTF condition, interpreted as the arousal reaction to being directly exposed to judgment (Balconi, Crivelli, et al., 2022; Balconi & Cassioli, 2022).

The functional meaning and scalp localisation of the EEG frequency bands can provide insightful information about individuals' reactions to static versus dynamic conditions. A variation in slower EEG components may indicate greater attention to social processing and the regulation of interpersonal interaction and its affective correlates during the FTF condition compared to the RCM condition (Balconi, Crivelli, et al., 2022). Previous studies have also emphasized the role of theta activity at the scalp level as a contributor to emotional regulation

and internal attention and the processing of emotional information (Balconi & Lucchiari, 2006).

The literature shows that theta is activated by cognitive reward information and, in general, by negative or positive feedback, such as that provided by an examining committee (J. Wang et al., 2016). In addition, alpha band desynchronization has been associated with the modulation of attention processes (Huang & Sekuler, 2010). Finally, an increase in beta band power in parieto-occipital regions was linked to focused attention (Gola et al., 2013).

Similarly, the analysis of the autonomous nervous system's activity can provide valuable insights into an individual's peripheral reactions during a job interview. It serves as a representative measure of processes related to stress management, self-regulation, and social skills in various contexts, including organizational and professional spheres (Balconi & Salati, 2020; Zito et al., 2021). Notably, the aforementioned studies that have investigated psychological and physiological arousal in this context (Balconi, Crivelli, et al., 2022; Balconi & Cassioli, 2022), particularly concerning the stress response, focused on the two components of electrodermal activity (EDA): both the slow-varying tonic activity, commonly referred to as the skin conductance level (SCL), associated with arousal and the mental workload (Wiebe et al., 2010), and the phasic component, namely the skin conductance response (SCR), reflecting brief changes and serving as an indicator for the evaluation of emotional involvement and the significance attributed to various stimuli (Balconi & Bortolotti, 2012).

Such literature provides a significant overview of the neurophysiological and autonomic differences that exist between the FTF and RCM dynamics, highlighting how the adoption of a neuroscientific multimethod and multilevel approach, combining EEG frequency bands and autonomic data, has facilitated the investigation of the distinct brain-and-body responses of individuals under FTF and RCM conditions (Balconi, Fronda, et al., 2022). However, none of these studies have focused on entirely digital environments and the «medium» as a moderator of stress response regulation. The administration of digital interviews and assessments is now the preferred route for many international organizational entities. The digitization of these processes yields numerous benefits, including assessment standardization; nevertheless, digital assessments may induce a modification in the reciprocal directionality between interlocutors.

Specifically, sensorimotor simulation in digital job assessments takes on specific prerogatives depending on whether it is conducted in a wholly static condition or in dynamic conditions, where an individual/group X is recorded and individual Y observes the appearance of individual/group X on the screen (Troje, 2023).

Moreover, exploring the neural correlates of stress regulation in digital communication environments holds significance in comprehending the adaptive mechanisms behind human interaction in the digital era and in enhancing the design of digital platforms for communication and assessment objectives. Given these premises, in this study, a sample of healthy adults was divided into two groups, each subjected to a modified version of the Trier Social Stress Test (TSST; Allen et al., 2017), named the Social Stress Test (SST), specifically designed to assess individuals' behavioural, autonomic, and EEG stress responses to interview-style presentations conducted in two different modalities (static vs. dynamic digital stressful interview).

Former works have demonstrated that participants' EEG frequency bands reflect their individual responses to the TSST, with a significant increase observed in the delta band during the TSST, considered as mental effort, with a negative feeling (Barzegar et al., 2023). Conversely, a decrease was noted for the beta band and, to a lesser extent, for the theta and gamma oscillations, particularly in the frontal region, interpreted as indicating that a negative mood overcomes mental activity and places pressure on a person (Barzegar et al., 2023). However, to the best of our knowledge, no previous studies have compared individuals' behavioural and neuro- and psycho-physiological responses to modified versions of the TSST when delivered through a different medium.

In the current study, one part of the sample underwent a completely static digital version of the test, referred to here as the Static Social Stress Test (Stat-DSST); the other part of the sample underwent a dynamic version of the same test, referred to as the Dynamic Social Stress Test (Dyn-DSST). Both task versions required participants to prepare and present five interview-style presentations. In particular, the sequence entailed, for each of the five speeches, three distinct phases: (i) the reading of the assignment; (ii) the preparation of the discourse within a maximum timeframe of 120 s; (iii) the presentation of the discourse within a time

limit of 60 s. However, in the Stat-DSST version, the stimuli from the examining committee consisted of simple images of static people, devoid of sound and characterised solely by the emotional valence represented through facial expressions. In contrast, in the Dyn-DSST version, the committee was portrayed through realistic and simulated videos, which included – in addition to facial expressions similar to those in static images – non-verbal signs and a verbal request to the participants to provide the oral presentation.

Thus, through a multi-measurement methodological approach (Balconi et al., 2015), this study tested the behavioural, autonomic, and neurophysiological (EEG) responses of healthy individuals performing interview-style presentations conducted in two different modalities, dynamically versus statically (Dyn-DSST and Stat-DSST).

Specifically, as behavioural data, we measured the response times (RTs) during the preparation phase (i.e., the time needed for a participant to prepare an interview presentation), which were considered as a cognitive metric for the indirect evaluation of the performance, the psychophysiological stress, and the level of activation of the participants' nervous systems. As highlighted by earlier research, an increase in preparation time for a given performance may be considered an indicator of diminished performance and suboptimal stress regulation (Balconi & Vanutelli, 2016). This observation aligns with the understanding that prolonged preparation periods may signify heightened cognitive loads and inadequate coping mechanisms, thereby suggesting a potential detriment to overall performance outcomes (Ferrari, 2001). Based on the existing literature's evidence (Hatfield et al., 2020), by examining stress regulation and resistance in the preparation phase, it is possible to unveil the anticipatory mechanisms that shape individuals' abilities to effectively cope with stressors.

From the RTs recorded during the preparation phase, two behavioural indices reflecting stress regulation (Reg_{Stress}) and stress resistance (Res_{Stress}) were computed. As highlighted in the literature focused on high performance (e.g., in sports), it can be asserted that the preparation period leading up to a performance is crucial in evaluating stress management abilities. During this critical period, individuals engage in cognitive and emotional processes that significantly impact their subsequent performance (Paulus et al., 2009).

Moreover, autonomic and EEG indices were considered to obtain a comprehensive picture of individuals' stress management abilities in terms of the autonomic (arousal-related) and central (cortical-related) responses and provide multiple levels of explanation of the two experimental conditions (Balconi et al., 2015).

Through this methodological approach, this study aims to address a significant gap in the current literature on the neurophysiological and behavioural regulation of stress in digital environments. Specifically, it examines the effects of dynamic (Dyn-DSST) and static (Stat-DSST) sensorimotor simulations on stress responses during simulated digital interviews. By employing a multimodal neuroscientific methodology that integrates EEG data and autonomic activity measurements, this research seeks to provide a comprehensive understanding of the underlying neurophysiological sensorimotor mechanisms. This approach elucidates the cognitive and emotional engagement elicited by dynamic versus static simulations. The primary objective is to advance beyond existing theoretical contributions by directly comparing these two distinct simulation modalities. In fact, unlike traditional studies, which often focus on static or less interactive settings, or those conducted in person, this research introduces an innovative experimental framework that mirrors the dynamic nature of modern digital environments.

4.3. Materials and Methods

4.3.1. Hypotheses

Starting from the study aim and methodological considerations reported above, firstly, we hypothesize that the SST implemented through the static modality could have – even considering the presence of limited external sensory input in time and space – a minor cognitive and emotional impact on the individual, and this, in turn, would translate into lower cognitive costs and greater stress regulation and resistance (Reg_{Stress} and Res_{Stress} scores) in the Stat-DSST compared to the Dyn-DSST group. Meanwhile, the dynamic condition – which requires

participants to process not only verbal and/or written requests but also non-verbal and paraverbal components – could have a greater cognitive and emotional impact on participants, and this cost-demanding effect will translate into slightly lower behavioural performance in terms of the Reg_{Stress} and Res_{Stress} scores for the Dyn-DSST compared to the Stat-DSST group.

Secondly, for the behavioural data, we expect to find a positive relationship between the Reg_{Stress} and Res_{Stress} indices for both groups (Dyn-DSST and Stat-DSST). Indeed, as highlighted in the literature, effective stress management over extended periods and in the medium term, even in high-stakes contexts (Cicchetti & Rogosch, 2009; Hourani et al., 2020), can contribute to consolidating a «resilience reserve, activated during acute and intense events, allowing individuals to maintain stability and proactively address challenges.

Thirdly, regarding EEG data, since the literature suggests an increase in delta band power in stressful conditions with a negative feeling (Barzegar et al., 2023), we suppose that a decrease in delta band power might reflect better stress management abilities and the development of such a «resilience reserve» in even more stress-inducing conditions, such as the Dyn-DSST compared to Stat-DSST. The same trend is expected for the low-frequency bands (theta and alpha band desynchronization), supporting the hypothesis that a decrease in these frequency bands may indicate higher required attentional control over the situation in the Dyn-DSST compared to the Stat-DSST group.

Fourthly, we hypothesize a significant increase in the gamma band frequency in the Dyn-DSST compared to the Stat-DSST group. Gamma band activity correlates with advanced cognitive processes and information processing from the surrounding context (Ahn et al., 2018); thus, an increase in gamma power in the Dyn-DSST compared to the Stat-DSST group may suggest increased cognitive involvement in dynamic compared to static interviews. Furthermore, this hypothesis finds additional support in the literature, which underscores how constant flows of audiovisual information stimulate the sensory and motor activation of the brain, triggering an increase in cognitive demand (Gao et al., 2022).

Finally, regarding autonomic data, we expect a significant increase in the EDA indices in the Dyn-DSST compared to the Stat-DSST group. This hypothesis is supported by existing

evidence (Balconi, Crivelli, et al., 2022; Balconi & Cassioli, 2022); the simulated presence of the examination committee is likely to generate a more pronounced physiological response, deeply engaging the sensory stimulation and the emotional and social dimensions of judgment exposure.

4.3.2. Sample

A total of 52 healthy adults were selected as participants for this study (M_{age} = 25.25, SD_{age} = 3.435, age range: 22–35, N_{male} = 17, N_{female} = 35). They were recruited through a convenience sampling approach. The inclusion criteria were an age ranging from 22 to 35 years and normal or corrected visual and auditory acuity. Exclusion criteria were defined to prevent the participation of individuals showing clinically significant signs of distress and/or burnout. Further exclusion criteria included a history of neurological or psychiatric illnesses, current therapy with psychoactive substances potentially influencing decision-making or cognition, and major stressful life events in the last 6 months. Furthermore, the participants were checked for their clinical profiles: no psychopathological elements were observed for the depression construct (tested by Beck's Depression Inventory II, total score equal to or less than 10; Sica & Ghisi, 2007).

The overall sample was randomly assigned to two subgroups balanced for age and gender. The first group, consisting of 26 individuals (M_{age} = 23.038, SD_{age} = 1.455, age range: 22–28, N_{male} = 10, N_{female} = 16), underwent the Dyn-DSST, while the second group (M_{age} = 27.462, SD_{age} = 3.432, age range: 22–35, N_{male} = 7, N_{female} = 19) underwent the Stat-DSST. To all participants, the Italian version of the Perceived Stress Scale 10 (PSS-10; (S. Cohen et al., 1983b)) was applied to exclude the presence of high stress levels during the thirty days preceding the tool's administration (total score equal to or less than 27). No differences in the PSS were observed between the two groups.

No participant received any form of monetary or other compensation for their participation in the study. All participants took part in the study voluntarily and provided written informed consent. This research obtained approval from the Ethics Committee of the

Department of Psychology, Catholic University of the Sacred Heart, Milan, Italy, and it was conducted in compliance with the Declaration of Helsinki (2013) and the GDPR—Reg. UE 2016/679 and its ethical guidelines.

4.3.3. Procedure

The participants were invited to a moderately illuminated room dedicated to the experiment, where they received the experiment's instructions and were asked to sign the informed consent form. The participants were fully informed that they would participate in a simulated and fictitious interview (and not a real job interview). They were told to imagine giving an interview during a selection test to access a stage or an ideal job position in front of an evaluation board.

Before the experiment, the participants were asked to sit and keep their feet firmly planted on the ground. Except for a computer positioned 100 cm away from the participant, on which the test was administered, all other personal technological devices (e.g., smartphones) were turned off to avoid interference with the EEG measurements. Following this preliminary introduction, the EEG and sensors for the detection of autonomic indices were applied to the participants. After recording the baseline conditions with closed and open eyes, a web-based experiment management platform (Qualtrics XM platform; Qualtrics LLC, Provo, UT, USA) was used for the DSST's administration. The task required the participants to prepare and present five different speeches, based on incrementally challenging requests.

The following instructions were given at the beginning of the task:

"Imagine being in a selection test to access an internship or a job position that you care about. The representative of the organization informs you that there is only one available spot and 23 candidates interested in the position. You are scheduled for a selection interview where there will be an examining committee. You will need to prepare and orally present various speeches".

The participants were fully informed that, for each discourse, the preparation phase had a maximum time of 120 s, and the speech phase had a maximum time of 60 s. To achieve the highest score, the participants were informed that they were required to prepare their speech in the shortest time possible.

One part of the sample underwent the Dyn-DSST version, while the other half underwent the Stat-DSST version. The Dyn-DSST was conducted in a realistic context, characterised by environmental conditions and stimuli that mirrored the dynamic nature of the setting. In this specific condition, the evaluation committee consisted of real individuals who were video-recorded, contributing to the authentic transmission of visual, auditory, motor, verbal, and non-verbal stimuli. This methodology favoured a more ecologically valid approach. Conversely, the Stat-DSST version involved an evaluation committee composed of static images through a designed reproduction, aimed at creating a sense of distance and separation from the participants. This methodological choice was implemented to explore the participants' responses to less immediate and more distant stimuli. In this context, static images played a key role in creating an assessment environment that differed from the immediate reality, allowing an analysis of the participants' cognitive abilities and emotional responses not in the face of real stimuli but in response to remote stimuli.

Furthermore, during the task, the reactions of the evaluation committee incorporating various emotional states were incrementally manipulated. The increase in complexity and the growing conditions of stress were deliberately induced through a dual approach: (i) the complexity of the content of the requests during the preparation phase was heightened (e.g., D1, optimal self-presentation; D5, decision-making in disagreement with the group); (ii) the negative intensity of the non-verbal communication from the evaluation committee to which each participant was exposed was escalated (e.g., variations in speech speed, emphasized pauses, greater expressive articulation, a rigid posture, and the more pronounced use of gestures and facial expressions). External judges carefully examined and evaluated the stimuli to ensure that they were consistent and reliable according to the intended objectives and outcomes of the experiment.

Table 1 shows the content of the speech requests and the corresponding evaluation board's emotional states for each discourse (Table 4.1). Figure 1 depicts the experimental procedure, which lasted approximately 45 min (Figure 4.1).

Table 4.1 Description of the speech requests and emotional states of the examining committee for each discourse.

Discourse	Speech Request	Evaluation Committee Emotional Display
1	"We ask you to prepare the best presentation of yourself."	Friendly
2	"We ask you to describe a critical situation in which you encountered difficulties in making a decision on your academic/professional career or during previous internships."	Neutral
3	"We ask you to describe a critical situation in the academic/professional context where you faced a hard challenge and you needed to take a decision completely alone, without having the support of anyone in making a decision."	Bored
4	"We ask you to describe a situation in which you found yourself taking a critical decision alone in the academic/professional context, by taking full responsibility of it and in complete disagreement with the rest of the group."	Growing manifestation of impatience
5	"We ask you to describe a situation in which you found yourself taking a critical decision alone in the academic/professional context, by taking full responsibility for it and in complete disagreement with the rest of the group."	Adverse

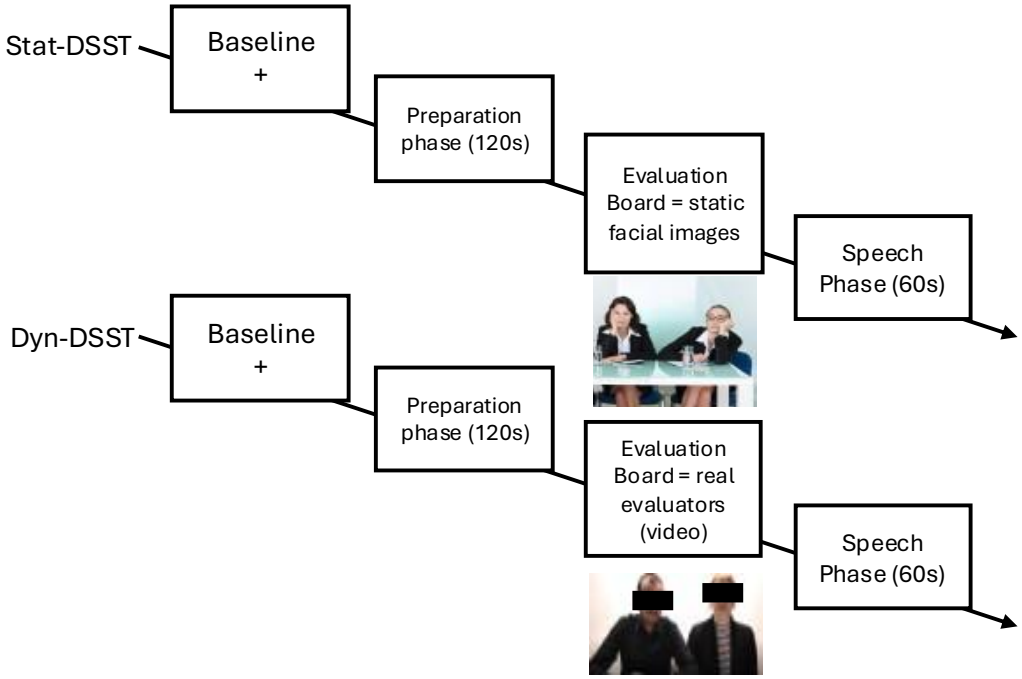


Figure 4.1. Graphical description of the experimental procedure. EEG and autonomic activity were monitored from the baseline throughout the task together with behavioral data recording.

4.3.4. Behavioral Data Processing

The performance of each participant was automatically recorded by the system, collecting RTs for the most critical phase of the interview (preparation phase) of every discourse, as an indirect measure of their performance. These data were subsequently processed offline to obtain the stress regulation and acute stress resistance scores (respectively, Reg_{Stress} score and Res_{Stress} score).

The experimenter employed both objective and qualitative criteria to assess the relevance, coherence, and appropriateness of each discourse. Any discursive production in which the content was deemed non-equivalent in terms of productivity – characterized by substance-lacking content, the inclusion of personal arguments unrelated to the task, and inconsistency with the requirements of each discourse – was excluded from the analysis. Through this process, the contents of the five analyzed discourses were deemed equivalent, allowing for an objectively comparable measure of performance derived from the preparation phase.

The scoring assignment (Table 4.2) was established through a thorough analysis of the normal distribution of the results obtained during a preliminary pilot test (N = 131). This pilot

test was conducted on a representative sample, comprising participants selected based on specific inclusion criteria analogous to those of the present study.

Specifically, for Reg_{Stress} score, a score from 1 to 5 was assigned based on each participant's performance in the preparation phase for each discourse based on the normal distribution reported in the table. A higher score indicated a better ability to regulate stress. For Res_{Stress} score, a score from 1 to 5 was assigned based on the absolute value difference between the averages of the preparation times for D4–D5, compared to the average, also expressed as an absolute value, and the overall preparation performance for the five discourses. A higher score indicated greater stress resistance. Subsequently, both scores, Reg_{Stress} score and Res_{Stress} score, were transformed into deciles.

Table 4.2. Scoring assignment based on the normal distribution of the results obtained during a preliminary pilot test.

Reg_{Stress} Assignment Score	*Value (s)*	ResStress (|s|) Assignment Score	Value
1	≥80	1	≥24
2	60 ÷ 80	2	18 ÷ 24
3	40 ÷ 60	3	12 ÷ 18
4	20 ÷ 40	4	6 ÷ 12
5	≤20	5	≤6

4.3.5. EEG Data Acquisition and Processing

After setting up the environment, the participants underwent an EEG assessment of the resting state. EEG data were collected with eyes both open and closed (120 s for each condition).

The EEG data related to the baseline and recordings during the test, further divided into the five different speeches and the preparation and execution phases, were acquired using an 18-channel DC amplifier (SYNAMPS system) with the support of the NEUROSCAN 4.2

acquisition software. An ElectroCap with Ag/AgCl electrodes was used for EEG recording, placed on 18 active sites of the scalp following the 10/20 electrode placement system (Klem et al., 1999), with reference to the earlobes.

In addition, two electrooculographic electrodes (EOG) were placed above and below the left eye of each participant to remain outside the visual field. Data were recorded at a sampling frequency of 1000 Hz and with a 50 Hz notch input filter. Before data collection, the electrode impedance was monitored for each subject, ensuring that it remained consistently below 5 kΩ.

Subsequently, data related to the eyes-open and eyes-closed resting states and related to the preparation phase of every discourse were processed offline (IIR bandpass filter 0.1–50 Hz, 48 db/octave) using the Vision Analyzer version 2.0 software (Brain Products GmbH, Gilching, Germany) and corrected by an ICA-based algorithm (Jung et al., 2000). After EOG correction and careful visual inspection, only segments free of muscle artifacts, eye artifacts, or interfering disturbances were considered. The data were epoched using a time window of 2000 ms. This approach ensured the integrity and quality of the collected EEG data. Artifact-free data were then used to calculate condition-specific power density spectra (PSD) using a Fast Fourier Transform (Hamming window, resolution: 0.5 Hz). The average PD for each band was extracted for each considered phase as follows: delta (0.5–3.5 Hz); theta (4–7.5 Hz); alpha (8–12.5 Hz); beta (13–30 Hz); and gamma (30.5–50 Hz).

For the statistical analysis, four regions of interest (ROIs) were derived from eight electrodes – frontal 1 (F1: F3; F7), frontal 2 (F2: F4; F8), temporo-parietal 1 (TP1: T7; P3), and temporo-parietal 2 (TP2: T8; P4) – covering the left and right frontal and temporoparietal neuroanatomical regions. Additionally, all task-related data were normalized to the eyes-open baseline of each participant using the following formula:

$$TR_{PSD} = ((PSD_{task} - PSD_{open\text{-}bl})/PSD_{open\text{-}bl})$$

4.3.6. Autonomic Data Acquisition and Processing

To continuously monitor the autonomic activity of each participant, the Biopac MP 150 system from Biopac Systems Inc. (USA) was employed. For ECG recording, two electrodes were placed on the lower wrist, with the positive pole on the left arm and the negative pole on the right arm. The ECG signal was sampled at 1000 Hz using the Biopac Acknowledge 3.7.1 software, following the manufacturer's instructions. To eliminate any motor and ocular artifacts, the signal underwent low-pass filtering at 35 Hz. Subsequently, the signal was converted into the HR, expressed in beats per minute (bpm), using predefined values for human rest. From these data, inter-beat interval values were derived and then converted into milliseconds, to calculate the heart rate variability (HRV).

Regarding the measurement of the electrodermal activity, two electrodes were placed on the palm of each participant's non-dominant hand, at the thenar and hypothenar reference points. The EDA signal was sampled at 1000 Hz and subjected to a low-pass filter at 10 Hz for artifact removal, to obtain the skin conductance level (SCL) values and skin conductance responses (SCR).

4.3.7. Data Analysis

For the behavioural data, two one-way ANOVAs were applied with the *group* (2: Dyn-DSST, Stat-DSST) as the independent variable and the Reg_{Stress} and Res_{Stress} scores as the dependent variables. Moreover, correlation analyses (Pearson correlation coefficients) were applied to explore the relation between the Reg_{Stress} and Res_{Stress} scores.

Subsequently, for the EEG results, five mixed repeated-measures ANOVAs considering the *group* (2: Dyn-DSST, Stat-DSST) as the between-subject independent variable and the *ROI* (4: F1, F2, TP1, TP2) and *discourse* (5) as the within-subject independent variables were carried out for the five different frequency bands (delta, theta, alpha, beta, and gamma).

Finally, for the autonomic data, four mixed repeated-measures ANOVAs with the *group* (2: Dyn-DSST, Stat-DSST) as a between-subject independent variable and *discourse* as a within-subject independent variable were applied to the following autonomic indices considered as dependent variables: SCR, SCL, HR, and HRV.

For all ANOVA tests, the degrees of freedom were corrected by the Greenhouse–Geisser epsilon when appropriate. Simple effects for significant interactions were further checked via pairwise comparisons, and Bonferroni correction was used to reduce multiple comparisons' potential biases. The size of the statistically significant effects was estimated by computing the eta-squared (η^2) indices. The threshold for statistical significance was set at $\alpha = 0.05$. For the statistical analysis, IBM SPSS 29 (IBM Corp., Chicago, IL, USA) was used. In a preliminary analysis, we tested for potential differences related to gender and no statistically significant main or interaction effects were found; thus, this variable was not included in the below-reported analyses.

4.4. Results

4.4.1. Behavioural Results

Considering the analysis performed on the Reg_{Stress} score, a significant main effect was found for the group ($F(1,50) = 4.188$, $p = 0.046$, $\eta 2 = 0.077$), with a higher mean for the Stat-DSST group compared to the Dyn-DSST group (Figure 4.2). No significant effects were found for the Res_{Stress} score.

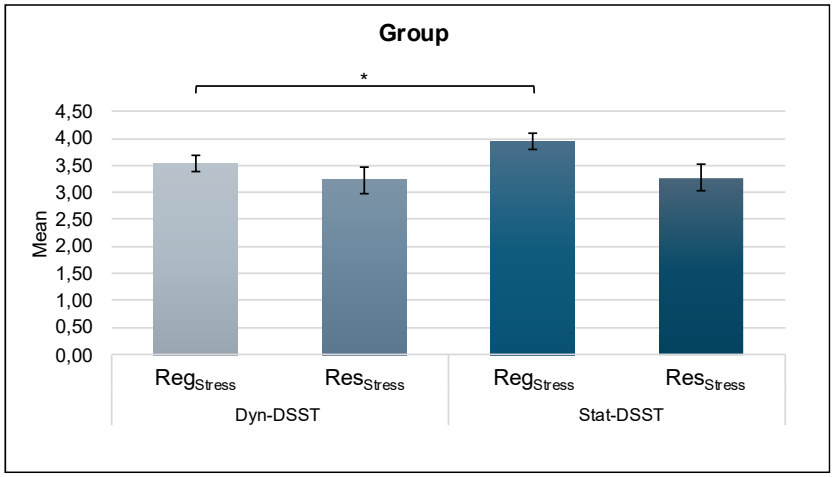


Figure 4.2. *Behavioural results*. The bar graph shows statistically significant differences in the behavioral stress scores (Reg_{Stress} score and Res_{Stress} score) for each group (Dyn-DSST and Stat-DSST). Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons.

4.4.1.1. Correlational Results between Behavioural Scores

The Pearson correlation analyses also revealed a positive correlation between the Reg_{Stress} and Res_{Stress} scores for the Dyn-DSST group ($r = 0.401$, $p = 0.042$) (Figure 4.3A). Similarly, in the Stat-DSST group, a positive correlation was observed between the Reg_{Stress} and Res_{Stress} scores ($r = 0.418$, $p = 0.033$) (Figure 4.3B).

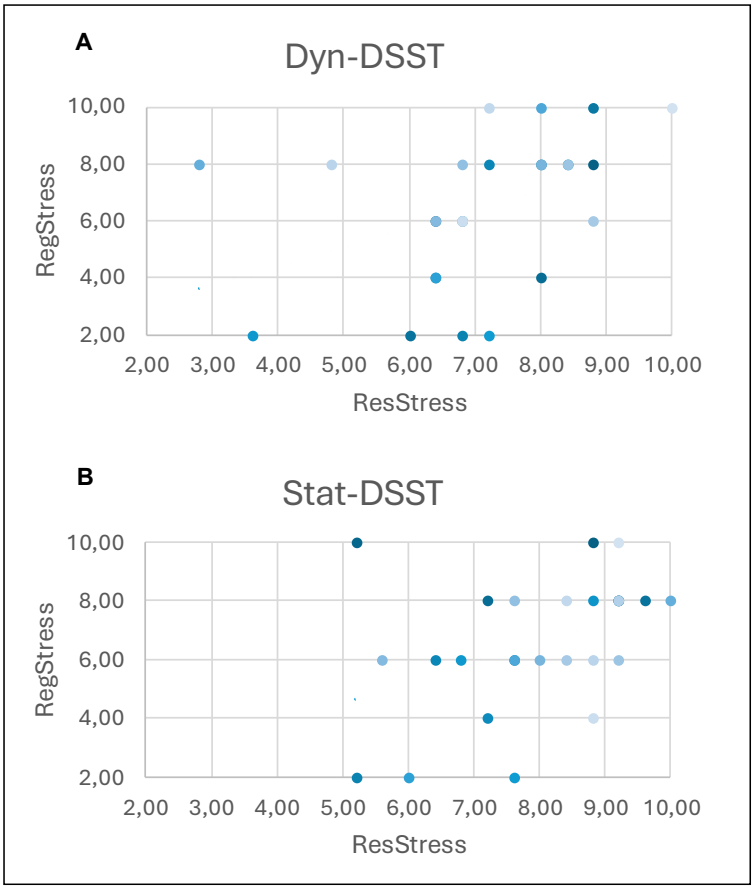


Figure 4.3. *Pearson correlations between behavioural scores.* (**A**) The scatter plots display a significant positive correlation between the Reg_{Stress} score and Res_{Stress} score in the Dyn-DSST group. (**B**) The scatter plots display a significant positive correlation between the Reg_{Stress} score and Res_{Stress} score in the Stat-DSST group.

4.4.2. EEG Results

The following sections show the results of the repeated-measures ANOVAs performed with the ROI (4: F1, F2, TP1, TP2) and *discourse* (5) as the independent within-subject factors and the *group* (2: Dyn-DSST, Stat-DSST) as a between-subject factor, for the different frequency bands (delta, theta, alpha, beta, and gamma).

4.4.2.1. Delta

For the delta band, a significant interaction effect was revealed for group × ROI × discourse ($F_{(4.2, 144)} = 2.606$, $p = 0.035$, $\eta^2 = 0.071$) (Figure 4.4).

Considering the comparison between the two groups, the significant pairwise comparisons revealed lower mean values for the Dyn-DSST group compared to the Stat-DSST group in TP1 ($p = 0.049$) as well as in TP2 ($p = 0.036$) during D2. Moreover, the Dyn-DSST group exhibited lower mean values than the Stat-DSST group in TP1 during D3 ($p = 0.030$) and in TP2 during D5 ($p = 0.001$). For the Dyn-DSST group, the pairwise comparisons revealed that D1 showed higher mean values than D2 ($p = 0.028$) and D3 ($p = 0.007$) in TP2. Finally, for the Stat-DSST group, lower mean values were observed for D3 than D5 in TP2 ($p = 0.002$).

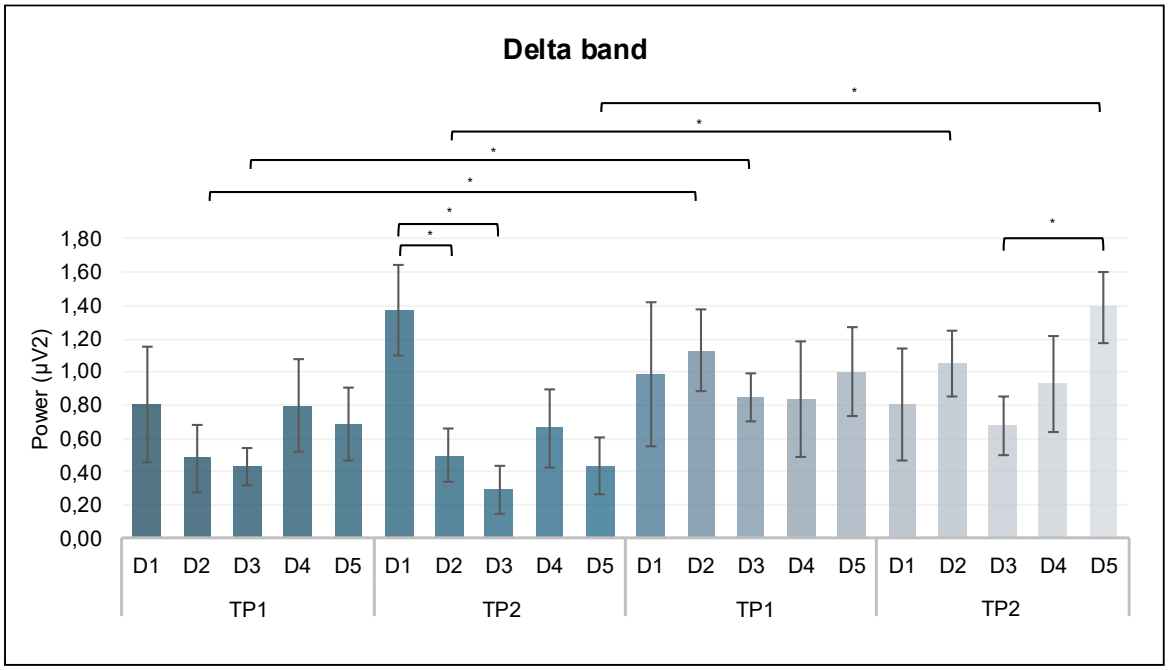


Figure 4.4. *EEG delta results.* The bar graph shows significant differences for the delta band in group × ROI × discourse. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons.

4.4.2.2. Theta

For the theta band, a significant interaction effect was revealed for *group* × *ROI* × *discourse* ($F_{(6, 199.4)} = 3.402$, $p = 0.003$, $\eta^2 = 0.093$) (Figure 4.5). Firstly, the pairwise comparisons showed that the mean values for the Dyn-DSST group were significantly lower than those for the Stat-DSST group during D2 ($p = 0.020$), as well as during D3 ($p = 0.018$), D4 ($p = 0.012$), and D5 ($p = 0.027$), in TP2. For the Dyn-DSST group, higher mean values were observed for D1 compared to D2 ($p = 0.001$), D3 ($p \leq 0.001$), and D4 ($p = 0.019$) in TP2. Furthermore, for the Stat-DSST group, the pairwise comparisons showed significantly higher activity for D5 than D3 ($p = 0.044$) in F2.

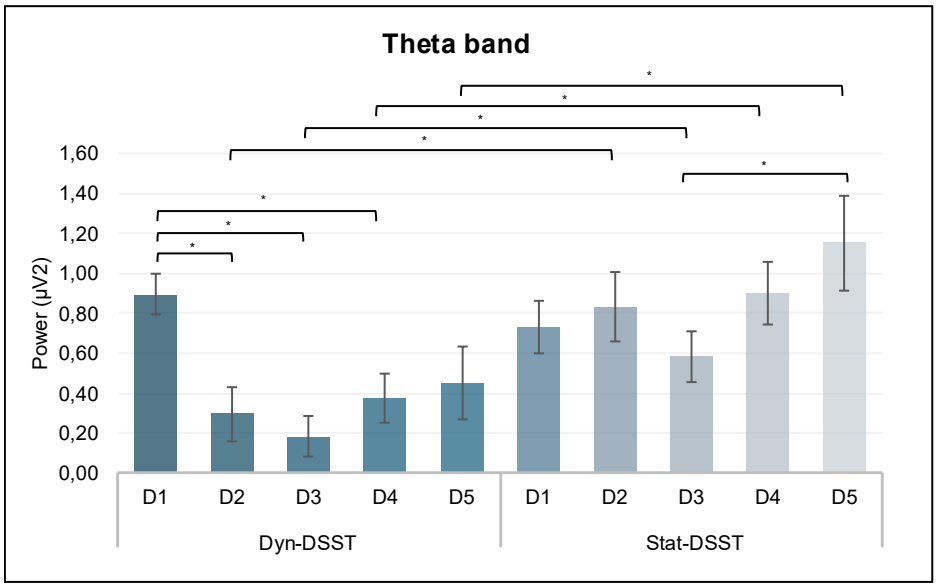


Figure 4.5. *EEG theta results.* The bar graph shows significant differences for the theta band in group × ROI × discourse. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons.

4.4.2.3. Alpha

For the alpha band, a significant interaction effect was also revealed for *group* × *ROI* × *discourse* ($F_{(4.164,\ 137.4)}$ = 2.479, p = *0.045*, η^2 = 0.070) (Figure 4.6).

Firstly, considering the comparison between the two groups concerning F1, the pairwise comparisons showed that the Dyn-DSST group exhibited decreased alpha activity compared to the Stat-DSST group in F1 during all of the discourses: D1 ($p \leq 0.001$), D2 ($p \leq 0.001$), D3 ($p \leq 0.001$), D4 ($p \leq 0.001$), and D5 ($p \leq 0.001$) (Figure 4.6A). Similar results were observed in the comparison between the two groups with reference to F2. The Dyn-DSST group exhibited decreased alpha activity compared to the Stat-DSST group in F1 during all of the discourses: D1 ($p \leq 0.001$), D2 ($p = 0.005$), D3 ($p = 0.009$), D4 ($p = 0.018$), and D5 ($p \leq 0.001$) (Figure 4.6B).

Considering TP1, the Dyn-DSST group showed decreased alpha activity compared to the Stat-DSST group during D1 ($p \leq 0.001$), D2 ($p = 0.001$), and D3 ($p = 0.005$) (Figure 4.6C). Lastly, similarly to the first two sets of results, concerning TP2, the Dyn-DSST group exhibited a decrease in alpha activity compared to the Stat-DSST group during all discourses: D1 ($p = 0.001$), D2 ($p \leq 0.001$), D3 ($p \leq 0.001$), D4 ($p \leq 0.001$), and D5 ($p = 0.003$) (Figure 4.6D).

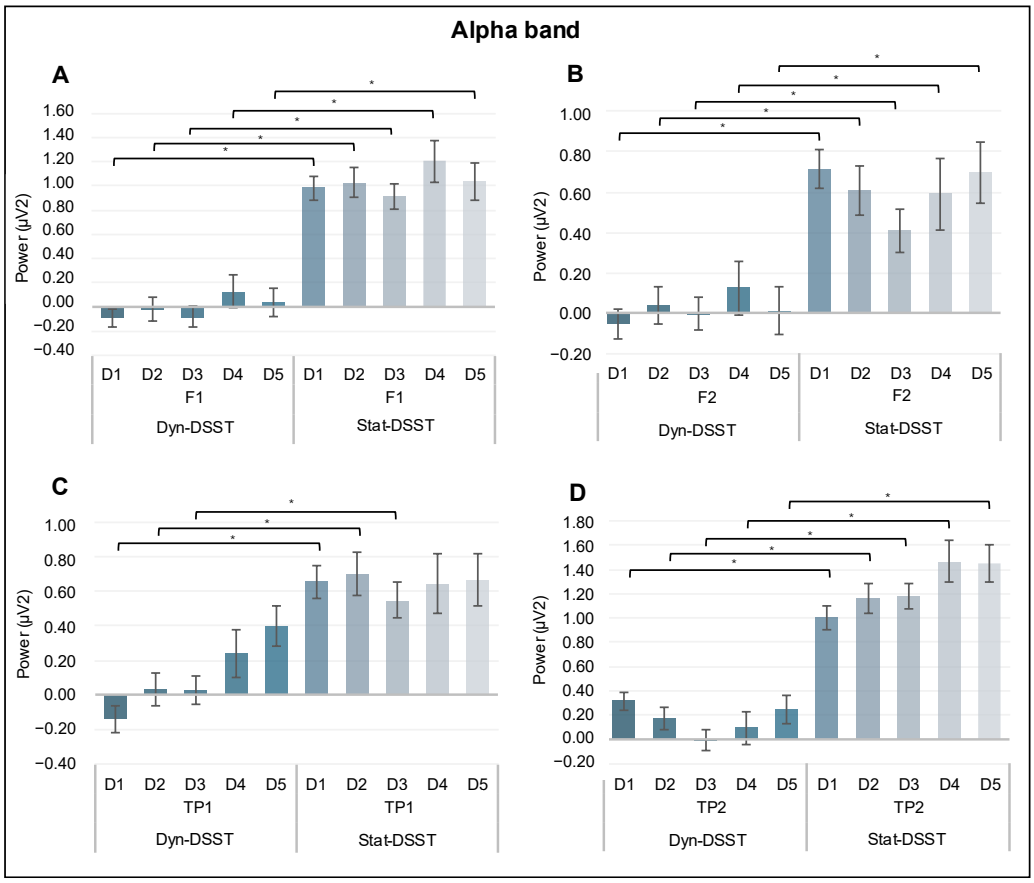


Figure 4.6. (**A–D**) *EEG alpha results.* The bar graph shows significant differences for the alpha band in group × ROI × discourse. (**A**) The bar graph displays the significant decrease in the alpha values in the Dyn-DSST compared to the Stat-DSST group for F1 during all discourses. (**B**) The bar graph displays the significant decrease in the alpha values in the Dyn-DSST compared to the Stat-DSST group for F2 during all discourses. (**C**) The bar graph displays the significant decrease in the alpha values in the Dyn-DSST compared to the Stat-DSST group for TP1 during D1, D2, and D3. (**D**) The bar graph displays the significant decrease in the alpha values in the Dyn-DSST compared to the Stat-DSST group for TP2 during all discourses. For all graphs, bars represent ± 1 standard error, and stars (*) mark statistically significant comparisons.

4.4.2.4. Beta

For the beta band, a significant interaction effect was revealed for *group* × *ROI* ($F_{(1.7, 56)}$ = 5.275, p = *0.011*, η^2 = 0.138) (Figure 4.7).

For the Dyn-DSST group, the pairwise comparisons revealed significantly lower mean values for F1 compared to TP1 (p = 0.025) and TP2 (p = 0.048). For the Stat-DSST group, the mean values for F1 were higher than for F2 (p = 0.016). Furthermore, within the Stat-DSST group, the pairwise comparisons showed significantly higher activity in F2 than in TP2 (p =.006).

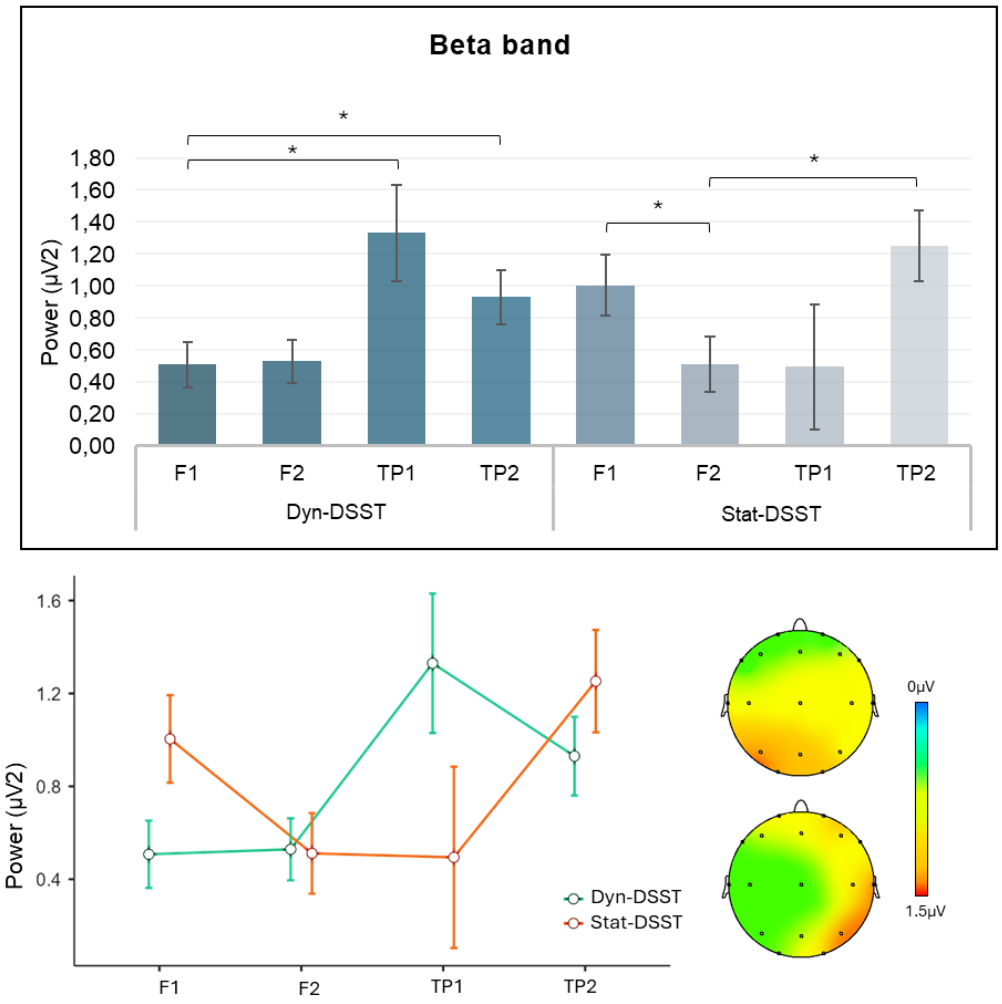


Figure 4.7. *EEG beta results.* The bar graph shows significant differences for the beta band in group × ROI. Bars represent ± 1 standard error and stars (*) mark statistically significant

comparisons. Each map illustrates the voltage (μV) distribution across the scalp, with warmer colours indicating higher PSD activity levels.

4.4.2.5. Gamma

For the gamma band, a significant main effect was revealed for the *group* ($F_{(1, 33)}$ = 8.258, p = 0.007, η^2 = 0.200), with higher mean values for the Dyn-DSST group compared to the Stat-DSST group (Figure 4.8).

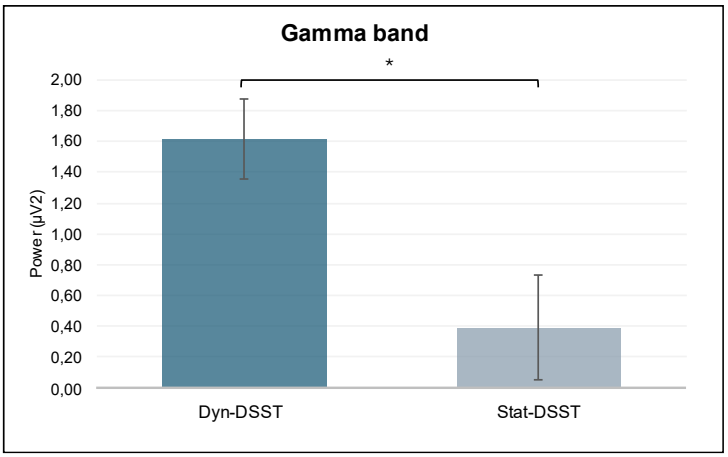


Figure 4.8. *EEG gamma results.* The bar graph shows significant differences for the gamma band in the group. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons.

4.4.3. Autonomic Results

For the SCR, a significant main effect was revealed for the *group* ($F_{(1, 31)}$ = 5.813, p = 0.022, η^2 = 0.158) (Figure 4.9), with higher mean values for the Dyn-DSST group compared to the Stat-DSST group.

No other significant results were found.

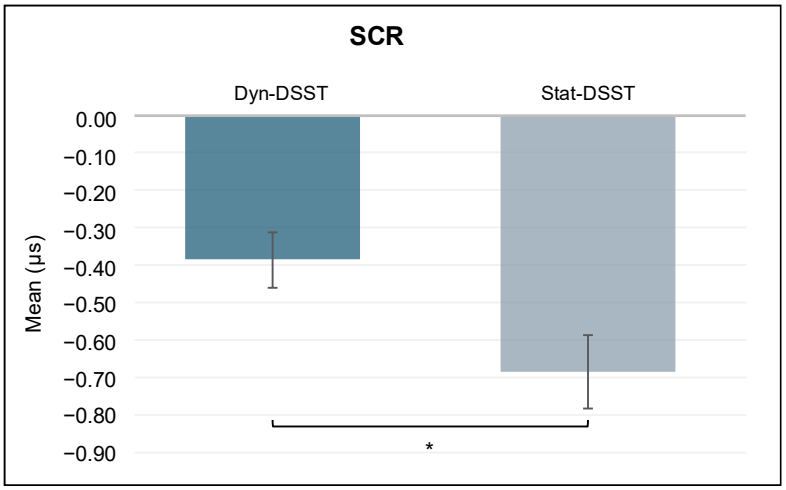


Figure 4.9. *Autonomic results.* The bar graph shows significant differences in the SCR for the group. Bars represent ± 1 standard error and stars (*) mark statistically significant comparisons.

4.5. Discussion

This study explored the behavioural, autonomic, and neurophysiological (EEG) responses of healthy individuals performing interview-style presentations conducted in two different modalities: a dynamic versus a static version (Dyn-DSST and Stat-DSST). During the interview preparation phase, RTs were collected and two behavioural indices expressing individuals' stress regulation and resistance abilities (Reg_{Stress} and Res_{Stress}) were computed. Moreover, EEG and autonomic indices were simultaneously recorded throughout the task, using a multi-measurement methodological approach (Balconi et al., 2015). Such an approach was exploited to provide multiple levels of explanation for the two experimental groups and to obtain a comprehensive picture of individuals' stress management abilities in terms of the autonomic (arousal-related) and central (cortical-related) responses.

The behavioural results suggested that the participants undergoing the static version (Stat-DSST group) exhibited higher behavioural performance in terms of Reg_{Stress} compared to the Dyn-DSST group, perhaps because the static condition was perceived as less stressful. However, in both groups, the more the individuals were able to regulate their stress, the more they could resist it even in conditions of acute stress.

Similarly, as hypothesized, the EEG findings displayed a distinct contribution of the low- and high-frequency bands for the two experimental groups, with a decrease in the delta, theta, and alpha band power in the Dyn-DSST compared to the Stat-DSST group. This result mirrored the need for greater cognitive regulation and control effort in the Dyn-DSST group. On the other hand, the significant increase in the gamma band power in the Dyn-DSST compared to the Stat-DSST group was interpreted as lower self-awareness in the static condition.

Finally, an increase in the SCR was observed in the Dyn-DSST compared to the Stat-DSST group, suggesting increased emotional engagement in the dynamic environment compared to the more static digital interaction.

These findings will be discussed below, considering the existing literature.

First, it was observed that there was a significant and positive correlation between the Reg_{Stress} and Res_{Stress} indices regardless of the experimental group (both in Dyn-DSST and Stat-DSST). Thus, individuals capable of effectively regulating their stress demonstrated greater resistance during the two stressful interview modalities, irrespective of the mode of interview administration.

Participants undergoing the static version (Stat-DSST group) exhibited higher behavioural performance in terms of Reg_{Stress} compared to the Dyn-DSST group. This evidence could be interpreted from the perspective of the perceived stress levels, suggesting that, in the static condition, there was a lower perception of stress compared to the dynamic condition. In particular, the static image of the committee could have limited the implicit motor activation associated with simulating interpersonal dynamics, resulting in a greater sense of control and predictability, ultimately leading to better overall stress response regulation and the reduced perception of issues derived from dynamic variables (Horvat et al., 2015). Conversely, in the Dyn-DSST group, the exposure to real-life simulation videos could heighten the stress response as the participants need to adapt to new information, non-verbal cues, and real-life movements, thus reducing the overall predictability of the stimuli.

Another potential interpretation of this effect could be the decreased awareness of stress-inducing stimuli in the static mode. This explanation is in line with former works suggesting that fully remote conditions could weaken empathy levels (Wellman et al., 2003) and work engagement (Bali & Liu, 2018) and ultimately affect social interactions at an emotional level (Balconi, Angioletti, et al., 2023). It is reasonable to suggest that the reduced sensation of «physical presence» caused by the static digital setting contributes to the decreased awareness of the stress levels. This perspective could be attributed to the perception of the other, which, due to the physical distance and mediated nature of digital communication, may induce a different representation of the context. Indeed, the perception of distance could contribute to a less threatening view of the evaluative context, thus influencing the overall perception of the stressful stimuli. In this way, the digital static medium could play a significant role in modulating psychological reactions, consequently impacting the stress regulation response.

Instead, for Res_{Stress}, no significant differences between the groups were observed. A possible reason for this lack of effect could be that behavioural measures do not always reflect healthy samples' performance (Crosswell & Lockwood, 2020) or the subthreshold stress management mechanisms with the same sensitivity as neuroscientific measures. Thus, the results obtained from the multimethod neuroscientific approach offer added value by not only highlighting but also illustrating and unravelling the implicit stress resistance of the individuals in the Dyn-DSST and Stat-DSST groups, which behavioural data alone may fail to capture.

This outcome suggests a strict link between the ability to manage stress and the ability to endure it during stressful conditions: the more individuals can regulate stress, the more they can resist it, even in conditions of acute stress. Indeed, according to Lazarus and Folkman's stress management theory (Biggs et al., 2017; Lazarus & Folkman, 1984), stress regulation may act as a mediator, influencing the perception of a situation and, consequently, stress resistance. We demonstrate that this relation is confirmed both in completely digitised static contexts and in digital dynamic interaction situations.

Considering the EEG results, first, a significant reduction in delta band power was found in the Dyn-DSST compared to the Stat-DSST group. This decrease was observed, in particular, in the temporo-parietal area and intensified with the increased complexity of the task, which

was consistent with a rise in negative emotional valence associated with the examining committee's verbal and non-verbal expressions.

Potential explanations for this phenomenon may be found in the connection between diminished delta power in the temporo-parietal area and an enhanced ability to regulate stress (Barzegar et al., 2023). Reduced delta band activation in the temporo-parietal region may indicate a greater need for regulatory effort, efficiency in cognitive processes, and better emotional control during stressful situations in the dynamic administration condition. This result could be considered an indicator of neurophysiological adaptation, suggesting that the realistic interview administration mode may lead to increased cognitive effort in participants, especially in the face of complex requests and negative emotional charges. These results could also be considered based on the recent literature, which highlights how digital simulations require continuous information processing and responses to external inputs in real time (Gao et al., 2022), involving the sensorimotor systems and an increasing cognitive load and brain activation in the lower temporo-parietal area (Pa & Hickok, 2008; Sarkheil et al., 2013).

Such an interpretation is consistent with the second set of significant results from our study. The results indicating a decrease in delta in the temporo-parietal regions that is more pronounced in the Dyn-DSST group at D2, D3, and D5 are consistent with the theta results. Indeed, similar patterns were observed for the theta band, with a decrease in the right temporo-parietal region's power in the Dyn-DSST compared to the Stat-DSST group in discourses D2, D3, D4, and D5. Furthermore, an additional set of significant results highlights that, within the Dyn-DSST group, a decrease in this band was observed in D2, D3, and D4 compared to D1. Overall, discourses with a greater focus on decision-making demands, which were more stressful and implied a negative evaluation by the committee (neutrality, boredom, impatience, aversion), may necessitate, especially in the dynamic exposure condition, additional regulatory effort and, accordingly, the greater employment of stress management resources.

Thirdly, mirroring the low-frequency patterns in the Dyn-DSST group, a significant increase in delta band power during a discourse characterized by higher demands and emotional complexity (D5) compared to a lower processing context (D3) was found for the Stat-DSST

group in the right temporo-parietal region. This trend was similarly identified in the theta band.

These findings not only reinforce the former findings observed for the Dyn-DSST, for which higher cognitive effort is needed, but also suggest that the low-frequency variations observed in the right temporo-parietal region regulate the adaptive response to stress differently based on whether the person is exposed to a dynamic or static condition. An interpretation of this phenomenon could be found in the context of remote communication, which might influence the subjective perception of emotional demands. Indeed, in a fully static and remote environment, the perceived demands may undergo differentiated filtration, attenuating the perception of the challenge associated with progressively complex requests. Future studies could deepen this evidence and test whether the physical distance may act as a mitigating factor, rendering the cognitive and emotional demands more manageable, even in the presence of an objectively more stressful condition.

Fourthly, the lower power of the alpha band in both the left and right frontal and temporo-parietal regions for the Dyn-DSST compared to the Stat-DSST group confirms the previously discussed results, according to which the dynamic condition requires greater cognitive effort and attentional regulation, compared to the static condition. In fact, due to the phenomenon of cortical idling, the lower presence of alpha waves corresponds to an increase in an individual's attentional engagement (Klimesch, 2012; Pfurtscheller & Silva, 1999). On the other hand, we also detected an increase in the beta band over specific ROIs for both experimental groups, perhaps suggesting the involvement of conscious attentional processes for both conditions. Since beta varies mainly in relation to attentional processes (Gola et al., 2013) and less directly in relation to stress regulation, the condition and type of speech do not seem to influence beta activation.

Finally, a significant increase in the gamma band power in the Dyn-DSST compared to the Stat-DSST group was found. These data align with theories associating the gamma band with advanced cognitive processes and the processing of information from the surrounding context. This finding could also be interpreted considering sensorimotor simulation, for which the increase in gamma power in the Dyn-DSST group may indicate higher cognitive

involvement, engagement, and interaction during dynamic simulations compared to job interviews conducted entirely remotely. Plausible interpretations of this result can be derived from the literature's evidence (Lou et al., 2017), suggesting a relationship between lower levels of gamma activity in the Stat-DSST group and reduced self-awareness. This connection could imply that the absence of a physical, real, or simulated presence might unfavourably influence individuals' awareness regarding their actions, the detection of demands, and the surrounding context.

Further support for the interpretation of the EEG findings, and particularly for the gamma band power, can be derived from the autonomic results, where an increase in the SCR is observed in the Dyn-DSST compared to the Stat-DSST group. This increase could be interpreted as a signal of heightened emotional responsivity (Balconi, Crivelli, et al., 2022; Balconi & Cassioli, 2022) in the dynamic environment compared to the more distant digital interaction, suggesting more pronounced emotional involvement in the former condition. In line with the literature, this result highlights the potential significance of the reduced sensorimotor simulation induced by static conditions on peripheral activation, representing involvement that is not only cognitive but also emotional (Davis et al., 2017; Wood et al., 2016).

To summarize, the comparison of these stressful interview conditions allowed us to identify their distinctive features: in the static condition, the participants displayed less cognitive effort and greater overall economy of resources and stress management, but there was also less awareness of the situation and less engagement by the «remote» condition; in the dynamic condition, the participants showed a greater sense of awareness and presence, along with emotional engagement related to the context of real perceived stress.

Which of these two conditions is more ideal for interviews in real-world settings? The answer relies on several potential expected outcomes, such as the degree of participation that we hope to observe in the person being interviewed and the cognitive and emotional «costs» that the person will have to bear to be essentially «present».

Rather than being related to the degree of stress derived from the interview modality, the differences observed in this study are mediated (as a mediator) by the different «perceptions» (and therefore by the perceived stress levels) induced by the two conditions.

Furthermore, the findings obtained in this study allow us to conclude that sensorimotor integration is closely related to both stress regulation and stress resilience mechanisms. Prior research has shown that effective sensorimotor integration enables individuals to rapidly process sensory information and execute appropriate motor responses, which can help to mitigate the impact of stressors (Mate, 2022; Shum et al., 2011).

The behavioural data from our study showed that the participants in the Stat-DSST group, who faced less demanding sensorimotor integration tasks, had better stress regulation, as indicated by their reduced RTs and higher regulation scores. Stress resilience, as an integral part of the stress response, is also influenced by sensorimotor integration. When individuals are exposed to dynamic and unpredictable environments, as simulated in the Dyn-DSST, their ability to integrate sensory inputs and coordinate motor responses becomes crucial (Rodriguez & Kross, 2023).

The increased cognitive load and emotional involvement observed in the Dyn-DSST group reflect the greater demands placed on their sensorimotor integration processes. This higher demand can deplete the cognitive resources more quickly, potentially compromising individuals' stress resilience. In contrast, in the Stat-DSST group, the reduced sensory input allowed for more efficient sensorimotor integration, preserving the participants' cognitive resources and improving their stress resilience.

In conclusion, this study provides preliminary evidence of a potential association between sensorimotor integration and both stress regulation and resilience. This association is indicated by the varied effects observed in both the dynamic and static digital interview conditions. Efficient sensorimotor integration may contribute to the ability to respond to stressors in a timely and appropriate manner, which in turn could potentially support both immediate stress management and the development of long-term stress resilience.

Limitations

To the best of our knowledge, this study constitutes the first effort to compare the multilevel effects of dynamic versus static interview modalities (with a modified version of the TSST); however, some limitations should be taken into consideration.

First, future studies must integrate both the preparation and speech phases, providing a comparison between the anticipatory and the actual stress regulation and resistance performance in a complete and integrated manner.

Secondly, the groups were not balanced in terms of the hormonal states of the female participants. In fact, in this study, we performed preliminary verbal verification to ascertain the presence of any potential hormonal alterations that could have influenced the participants' performance. This initial step was integral in attempting to control for biological variables that might confound the results. However, this approach has its limitations.

The reliance on verbal verification alone is insufficient to accurately assess hormonal fluctuations and their impacts. Therefore, a significant limitation of our study is the lack of comprehensive hormonal monitoring. This gap underscores the need for future research to incorporate detailed and systematic assessments of hormonal levels. Such evaluations should employ more rigorous methodologies, including biochemical analyses, to provide a clearer understanding of how hormonal fluctuations might affect participants' neurophysiological and psychological responses during stress-inducing tasks.

Thirdly, the analysis of the EEG cortical response was derived from limited ROIs, and a more detailed examination of this phenomenon is required, including a thorough investigation of the cortical localization of brain oscillations using, for example, neuroimaging methods like functional near-infrared spectroscopy, which has been shown in multiple prior studies to be an accurate means of data collection during interactive dynamics (Angioletti et al., 2019).

Creating a condition of real interaction with a two-way interactive exchange between inter-agents could be of further interest, using the hyperscanning paradigm, as presented in our previous studies, focusing on the neurophysiological synchronization between the individual

and the members of the examining committee (thus, with a multi-subject hyperscanning paradigm; Balconi & Fronda, 2020).

Finally, the role of high-frequency bands, particularly the gamma band, should be better explored in future studies, given that the current results suggest a possible reduction in self-awareness in the static condition compared to the dynamic one. In terms of practical applications, further in-depth analysis would prove useful and interesting since it would enable us to provide recommendations to institutions that regularly conduct interviews (e.g., universities or business organisations) regarding which settings are the most stimulating and which place candidates in the best position.

4.6. Conclusions

In conclusion, the present study investigated how sensorimotor simulation in job assessments represents a significant innovation in the field of personnel evaluation. It has delineated the behavioural, autonomic, and neurophysiological impacts of two distinct interview modalities: dynamic versus static (Dyn-DSST and Stat-DSST). Through a multimethod neuroscientific approach, individuals' stress regulation and resilience during these demanding circumstances were explored, examining how the interview format may influence their capacity to manage stressors. Furthermore, understanding how specific features of the virtual environment affect individuals' sensorimotor experiences and neurophysiological responses is crucial in devising effective stress management strategies during online evaluations and enhancing the validity and reliability of such tools in personnel selection.

The examination of stress responses in different interview settings holds implications for the refinement of interview methodologies and the enhancement of the overall experience for both interviewers and interviewees. The findings and subsequent discussion can enrich the broader discourse on stress psychology, offering nuanced insights into stress resilience within the specific realm of job interviews.

4.6.1. Proposals and Recommendations

To conclude, this article proposes several recommendations to advance the theoretical and practical understanding of stress management in digital environments.

Firstly, we suggest that future research should continue to utilize and refine multimodal neuroscientific methodologies, such as integrating EEG data with autonomic measures, to gain a more comprehensive understanding of the neurophysiological bases of stress responses. Secondly, we recommend that subsequent studies expand their scope to include a wider range of digital contexts and simulation modalities. This will allow for a better understanding of how different degrees and types of dynamic interaction influence stress and the cognitive load. Thirdly, we propose that organizations and institutions involved in personnel selection and training should adopt dynamic simulation tools that closely mirror real-world scenarios. This will enhance the ecological validity of assessments and training programs, thereby improving the accuracy of assessments and the effectiveness of stress management interventions. Fourthly, we suggest that autonomic index collection should be integrated into these simulations to provide real-time data on stress levels, enabling more immediate and personalized stress regulation strategies. Lastly, we strongly recommend the development of training programs aimed at enhancing individuals' cognitive and emotional regulation abilities in dynamic environments. These programs should incorporate evidence-based techniques to equip individuals with the skills necessary to effectively manage stress in high-pressure situations.

In conclusion, these practical recommendations highlight the importance of ongoing methodological innovations, broader contextual exploration, and the practical application of research findings to enhance stress management practices in digital environments.

5. SECTION 5 – General discussion and future directions

5.1. General Discussion

5.1.1. Adaptive psychophysiology of stress: a multilevel perspective

Stress adaptation is a fundamentally multilevel process, involving tightly coupled dynamics across cortical, subcortical, autonomic, and behavioural systems. Across the three empirical studies included in this dissertation (Sections 2, 3, and 4), participants were exposed to moderate psychosocial stressors embedded in simulated performance scenarios, during which neurophysiological (EEG), autonomic (HR, HRV, SCL, SCR), and behavioural (RTs, speech preparation) responses were recorded. These studies demonstrate that adaptation to social-evaluative stress is not linear but reflects a flexible, context-sensitive modulation of neural and peripheral systems in response to environmental demands. From a theoretical standpoint, these findings align with contemporary frameworks such as the *Neurovisceral Integration Model* (NIM) (R. Smith et al., 2017; Thayer & Lane, 2000), which posits that a network of brain structures – including the PFC, the ACC, the INS, and amygdala – coordinates central and autonomic activity to support adaptive regulation under challenge. This central network enables fine-tuned modulation of cardiac and electrodermal responses «in tandem» with higher-order executive and affective functions. The empirical evidence from our studies supports this view, illustrating how psychophysiological coherence emerges across EEG rhythms and autonomic indices in response to feedback valence and task demands.

In Section 2 (Study 1), the simulated job interview paradigm revealed that speech-phase RTs decreased progressively as participants received increasingly negative feedback, despite the absence of explicit time constraints. This behavioural marker – interpreted as an indicator of increased vigilance and effort mobilization – is consistent with the negativity bias literature and suggests a stress-induced shift toward reactive control strategies. At the neurophysiological level, participants displayed enhanced delta and theta power in right prefrontal (Fp2), central

(C3), and parietal (Pz) regions following positive feedback, likely reflecting increased cognitive engagement, social reward processing, and the recruitment of internal models of self-efficacy. Conversely, more aversive feedback conditions were associated with increased low-frequency activity in temporal and occipital regions (T7, T8, O1), suggestive of enhanced environmental scanning and sensory vigilance – consistent with threat monitoring circuits and bottom-up emotional reactivity. These findings resonate with the predictive coding framework (Gilbert et al., 2022; Sprevak & Smith, 2023), wherein the brain dynamically adjusts precision weighting across cortical hierarchies based on the expected affective volatility of the social environment.

The broader experimental framework outlined in Section 3 (Study 2) provided a more robust basis for examining the mechanisms underlying adaptive coupling. In this context, the task was specifically structured to isolate the anticipatory phase of stress, thereby capturing the temporal window in which participants prepared their verbal responses while concurrently integrating the social feedback previously received at the cognitive level. This study implemented an extended adaptation of the SST, incorporating a manipulation of feedback valence across five experimental conditions: absence of feedback (NoF), positive (PF), neutral (NF), boredom-inducing (BF), and annoyed (AF). Consistent with recent evidence on anticipatory stress responses (Grupe & Nitschke, 2013), participants exhibited a progressive increase in gamma-band activity – a neurophysiological marker associated with high-level cognitive integration and the dynamic updating of working memory – across conditions ranging from NoF to BF, followed by a marked decline under the AF condition. This non-linear modulation delineates a resource-allocation trajectory whereby individuals initially intensify cognitive engagement to recalibrate and sustain performance in ambiguous or disengaging contexts (such as boredom feedback) yet subsequently withdraw cognitive resources when confronted with overtly negative, affectively taxing feedback, indicative of a shift toward cognitive and motivational disengagement. Importantly, the spatial distribution of gamma-band effects – most pronounced over parieto-occipital regions – aligns with the functional involvement of posterior attentional networks, visual mental imagery, and the top-down maintenance of internal representations.

Concurrently, beta-band activity exhibited a progressive increase from NoF to NF, indicative of heightened cognitive load and sustained attentional engagement under conditions of social ambiguity. This pattern is consistent with recent theoretical accounts that conceptualize beta oscillations as an index of endogenous, task-related effort, particularly in contexts characterized by low predictability and the active interpretation of ambiguous social cues (Crivelli et al., 2023; Engel & Fries, 2010).

From a systems-level perspective, these spectral EEG modulations can be framed within the paradigm of allostatic regulation (McEwen & Stellar, 1993; Bruce S. McEwen, 1998, 2007), according to which central nervous system dynamics reflect not only reactive adjustments to immediate stressors but also proactive adaptations to anticipated environmental demands. Within this framework, feedback valence operates as a predictive cue signaling both social expectations and environmental stability, thereby shaping preparatory states at neural and autonomic levels. The concomitant autonomic markers observed in this study further substantiate this integrative interpretation.

Furthermore, in Section 3 (Study 2), both HR and SCL remained elevated across the initial feedback conditions (NoF, PF, NF), reflecting a state of sustained autonomic arousal. However, a pronounced reduction in both measures was observed under the AF condition, suggesting a threshold-like shift indicative of a transition from active regulatory engagement to physiological withdrawal or behavioral disengagement. This pattern aligns with predictions derived from polyvagal theory (Porges, 2007) and the Neurovisceral Integration Model (NIM), both of which posit that parasympathetic dominance may be reinstated as a strategic mechanism for energy conservation and affective disengagement when environmental challenges surpass adaptive thresholds.

In sum, the first two studies provide converging evidence that social stressors trigger a dynamic interplay of neurocognitive integration, autonomic arousal, and behavioural modulation, shaped by the nature of the feedback and its emotional-motivational properties.

The third empirical study (Section 4) introduced an additional and highly relevant dimension to the neurophysiological investigation of stress: the role of the sensorimotor

characteristics of the interactional context. The study examined how varying degrees of sensorimotor simulation within digital interview settings influence individuals' cognitive and emotional responses to socially induced stress. Participants were randomly assigned to one of two conditions: a Static Digital Social Stress Test (i.e. Stat-DSST), in which the examining committee was represented through emotion-expressive static images, or a Dynamic Digital SST (i.e. Dyn-DSST), in which participants interacted with video-based stimuli conveying more ecologically valid non-verbal and paraverbal feedback. The findings revealed distinct neurophysiological, autonomic, and behavioural patterns across the two conditions, indicating that the experience of stress was determined not only by the evaluative content, but also by the perceptual and bodily characteristics of the interactional environment.

From a behavioural standpoint, participants in the Stat-DSST group exhibited significantly higher stress regulation scores (RegStress), indicating greater control over speech preparation times. In contrast, the Dyn-DSST group showed increased RTs and greater variability under pressure, suggesting a heightened sensorimotor engagement cost. These results are consistent with theories of embodied cognition and sensorimotor simulation (Davis et al., 2017), which posit that social cognition is grounded in the simulation of others' actions, expressions, and bodily states. In dynamic, ecologically valid contexts, individuals recruit a broader set of perceptual and motor resources to interpret and respond to social cues. As a result, the cognitive cost of stress regulation increases when non-verbal dynamics are made more vivid and realistic – as was the case in the Dyn-DSST.

These behavioural distinctions were paralleled by marked differences in EEG activity. Across discourse phases, participants in the Dyn-DSST condition exhibited significantly lower delta, theta, and alpha power, particularly over frontal and temporo-parietal regions. Such desynchronization is commonly interpreted as an index of heightened cognitive effort, increased attentional allocation, and enhanced sensory integration. Reductions in delta and theta power have further been associated with the recruitment of top-down regulatory mechanisms under affective challenge (Barzegar et al., 2023; Knyazev, 2007), a pattern that aligns with the high interpersonal salience elicited by dynamic video-based stimuli. In contrast, gamma activity was significantly elevated in the Dyn-DSST group compared to the static

condition, most prominently over right frontal and temporo-parietal sites. This enhancement is typically regarded as reflecting processes of contextual integration, multisensory binding, and embodied predictive processing (Lou et al., 2017), which are particularly engaged in immersive, dynamic evaluative contexts.

The observed EEG dissociations are not only topographically specific but also theoretically coherent with predictive models of social cognition. In the *embodied predictive coding framework* (Venter, 2021), sensorimotor cues serve as evidence streams to test and update internal models of social contingencies. In dynamic contexts – such as the Dyn-DSST – participants must constantly revise their expectations based on subtle shifts in gaze, prosody, facial expression, and timing. This iterative revision process imposes a higher processing burden, manifesting in spectral signatures of increased effort and reduced inhibition (alpha), coupled with increased integrative synchrony (gamma). In contrast, the Stat-DSST group, exposed to low-variability, low-contingency input, experienced lower sensorimotor load and potentially greater subjective distance, yielding a profile of more efficient regulation but lower contextual immersion.

Autonomic indices further supported this interpretation. SCR, which reflect phasic emotional engagement and arousal, were significantly elevated in the Dyn-DSST group, despite the absence of substantive differences in task content between conditions. This finding indicates that sensorimotor realism, independent of explicit instructions or semantic feedback, can heighten physiological arousal and increase the cognitive-affective demands placed on the individual. Notably, no significant group differences emerged in HR or HRV, suggesting that the sensorimotor manipulation predominantly modulated sympathetic activation rather than parasympathetic withdrawal.

Collectively, the findings presented in Section 4 emphasize the embodied and ecological dimensions of stress regulation. Neurophysiological and behavioural responses to evaluative contexts are not solely driven by cognitive appraisal or the valence of presented content but are strongly influenced by the sensorimotor properties and perceptual fidelity of the environment. The greater the richness and contingency of the stimulus array, the more extensively the brain–body system engages in anticipatory adaptation, consistent with the demands encountered in

real-world settings. These results provide important empirical support for extending classical models of stress (Biggs et al., 2017; Lazarus & Folkman, 1984; Lupien et al., 2009; McEwen & Stellar, 1993; McEwen, 1998, 2007; McEwen & Sapolsky, 1995; McEwen & Morrison, 2013) toward ecologically oriented frameworks of neurocognitive regulation, particularly within digital and hybrid interactional environments.

In sum, the three studies collectively support the existence of a distributed, multilevel architecture of stress adaptation, wherein neurocognitive, autonomic, and behavioural systems operate in concert to respond not only to the informational content, but also to the sensory configuration of social challenges. These findings provide converging empirical evidence for the integration of theoretical frameworks such as the NIM, the *embodied predictive coding*, and the *Allostatic Load theory*. They further suggest that adaptive performance under stress is shaped not solely by internal resources, but by the dynamic interaction between the individual and the surrounding environment, mediated by affective, perceptual, and motor cues.

The implications of this integrated perspective on stress reactivity are examined in detail in the subsequent section (5.1.2), which addresses the emotional and motivational valence of social feedback and its influence on anticipatory cognitive and affective states, with particular emphasis on ambiguity, emotional salience, and preparatory control mechanisms.

5.1.2. Social feedback valence and anticipatory cognitive-affective activation

The emotional valence of social feedback plays a decisive role in shaping anticipatory cognitive-affective states, modulating both neural dynamics and performance readiness during preparation for socially evaluative tasks. Across the three experimental studies reported in this dissertation, a consistent and theoretically informative pattern emerged: the quality of prior social feedback – whether positive, neutral, or negative – systematically influenced participants' subsequent physiological reactivity, neural resource allocation, and behavioural control strategies. These findings offer converging support for integrative theories of emotion-

cognition interaction, and for models emphasizing the role of anticipatory affect in preparing the organism for adaptive behavioural responses under conditions of social scrutiny.

In the framework of the *Social Self-Preservation Theory* (Dickerson et al., 2004; Dickerson & Kemeny, 2004), social feedback – especially when evaluative or ambiguous – is conceptualized as an activator of self-relevant threat detection systems. Feedback that implies rejection, disapproval, or indifference is interpreted by the brain as a *cue of diminished social value*, thereby triggering defensive or compensatory mechanisms designed to restore status or mitigate rejection. The empirical data from Sections 2 and 3 are strongly consistent with this framework. In Section 2, for instance, increasingly negative feedback conditions (e.g., boredom, impatience, dislike) led to progressively reduced speech-phase RTs, suggestive of a behavioural mobilization effect, where participants engaged in faster, more reactive performance delivery, possibly to reduce exposure duration or to restore social acceptance. This behavioural trend may reflect the activation of defensive motivational systems, which promote rapid execution when threat-related cues are detected, even in the absence of overt danger.

In parallel, the EEG data from Section 2 revealed differential spectral profiles across feedback valence conditions. Positive feedback was associated with increased delta and theta power in prefrontal and parietal regions, patterns typically linked to reward processing, internal value updating, and cognitive elaboration of socially salient information. In contrast, negative and aversive feedback elicited increased low-frequency activity in temporal and occipital areas, consistent with emotion regulation, environmental scanning, and the modulation of visuo-affective processing streams (Başar & Güntekin, 2013; Güntekin et al., 2017; Knyazev, 2007). These regional shifts suggest that feedback valence directs attentional and regulatory resources toward distinct goals: elaboration and integration in the case of positive input; defensive reactivity and emotional vigilance in the case of negative stimuli.

However, perhaps the most conceptually informative findings concern neutral feedback, particularly as examined in Section 3. The condition of neutral feedback was operationalized as socially ambiguous: evaluative cues were present, but devoid of emotional expressivity or clear approval/disapproval content. Interestingly, this condition consistently evoked elevated beta-band activity, especially in central and posterior regions, compared to both the no-

feedback and negatively valenced conditions. Beta oscillations have been implicated in sustained attention, endogenous cognitive control, and mental workload (Balconi, Acconito, et al., 2023; Engel & Fries, 2010), and their amplification under NF may reflect the cognitive cost of ambiguity resolution. This interpretation is supported by models of uncertainty processing (Grupe & Nitschke, 2013), which posit that ambiguous social signals impose a unique demand on the brain's predictive coding machinery, requiring active hypothesis testing and enhanced executive effort.

This interpretation is further supported by the topographical EEG analyses: the observed enhancement of beta power within parietal and temporo-parietal ROIs is consistent with prior evidence associating these areas with mental state attribution, perspective-taking, and socio-perceptual integration (Carter & Huettel, 2013). Within the context of the SST paradigm, neutral feedback appears to engage participants in processes of introspective monitoring and social meaning inference, as they attempt to resolve the absence of clear evaluative cues. While negative feedback tends to elicit emotional reactivity and positive feedback may activate reinforcement-related systems, neutral feedback seems to promote a distinct mode of regulatory engagement, characterized by heightened cognitive control and sustained attentional vigilance in the absence of affective resolution.

This neurophysiological sensitivity to ambiguous feedback is not merely of theoretical interest; it represents a fundamental aspect of real-world social interactions, where explicit evaluations are frequently replaced by indirect or indeterminate signals. The brain's capacity to respond adaptively to such ambiguity can thus be considered a critical marker of anticipatory regulation, particularly within interpersonal and occupational contexts where decoding subtle feedback cues is essential for self-regulation and strategic behavioural planning.

The experimental design of Section 4 offers an essential extension to the understanding of how feedback valence and structure influence anticipatory states, by manipulating not only the content but also the expressive dynamics of evaluative feedback. Specifically, the study contrasted a static digital stress condition (Stat-DSST), in which feedback was presented via still images with emotional facial expressions, with a dynamic condition (Dyn-DSST), in which

feedback was delivered through full-motion video recordings of an evaluating committee conveying affective valence through both verbal and non-verbal cues.

Although the content of the feedback remained aligned across conditions (ranging from friendly to adverse emotional expressions), the emotional salience and perceptual richness of the dynamic stimuli led to a distinct increase in anticipatory cognitive-affective engagement, as evidenced by both EEG and autonomic indices. In particular, the Dyn-DSST condition elicited significantly reduced alpha-band power in frontal and temporo-parietal areas across all discourses, a well-established index of increased attentional demand and decreased cortical inhibition (Klimesch, 2012). This alpha desynchronization pattern, sustained during preparation phases, indicates that participants were engaged in more effortful and vigilant processing in anticipation of high-salience social evaluation.

Moreover, in line with the findings of Section 3, the anticipatory activation under emotional feedback was again modulated by the ambiguity and affective unpredictability of the context. For instance, in the Dyn-DSST condition, theta and delta band activity in temporo-parietal areas decreased progressively as the emotional complexity of the interview requests and committee expressions increased (from friendly to adverse), particularly during later discourses (D4, D5). These spectral dynamics have been interpreted as neural correlates of sustained regulatory effort, reflecting a prolonged engagement of top-down control networks in the presence of emotionally challenging and evaluatively uncertain stimuli (Barzegar et al., 2023). Such results align with the concept of anticipatory allostasis (Barrett et al., 2016), in which the brain prepares to meet predicted future demands through context-specific mobilization of cognitive and emotional resources.

From a motivational standpoint, these preparatory activations can be further contextualized within dual-process models of affective regulation (Ochsner & Gross, 2005; Pessoa & Adolphs, 2010), which distinguish between reactive emotion regulation (triggered by feedback exposure) and anticipatory affective control, which unfolds in the preparatory window preceding performance. The present studies – especially Sections 3 and 4 – provide clear evidence for the latter: even in the absence of immediate emotional input, previously experienced feedback valence continued to modulate preparatory states, shaping EEG dynamics

and peripheral arousal during the creation and internal rehearsal of upcoming performances. In the Dyn-DSST, this was particularly evident in gamma-band activity, which increased markedly in later discourses (D4–D5), likely reflecting high-order integrative processes involved in mental simulation, social cognition, and performance monitoring.

Importantly, this anticipatory modulation was not confined to the central nervous system. As shown in both Section 3 and 4, autonomic markers such as SCR and HR also showed valence-sensitive variations. While SCRs increased significantly in the Dyn-DSST group – particularly in response to emotionally intense committee displays – HR and SCL decreased under high aversive feedback (e.g., annoyed or impatient expressions), suggesting a non-linear response trajectory: initial feedback may activate sympathetic arousal and task engagement, while repeated exposure to aversive input may lead to withdrawal, cognitive disengagement, or conservation of resources (McEwen & Sapolsky, 1995; Porges, 2007).

These findings, taken together, point to a fine-grained, context-dependent coupling between the emotional content of feedback, the mode of its delivery (static vs. dynamic), and the anticipatory neurophysiological states that precede task performance. Positive feedback appears to foster elaborative cognitive integration and internalization, while ambiguous or neutral feedback elicits enhanced cognitive vigilance and uncertainty resolution effort. By contrast, overtly negative or aversive feedback, especially when delivered in a vivid and expressive format, can lead to either heightened engagement or disengagement, depending on the cumulative affective load and subjective perception of controllability.

This complexity highlights the necessity of considering both affective valence and communicative format in the analysis of feedback effects. It also sets the stage for the next section (5.1.3), which will explore how these anticipatory responses are further modulated by the sensorimotor structure of the evaluative context, and how cognitive load and embodied simulation dynamically interact to shape the brain's readiness for social performance under stress.

5.1.3. Sensorimotor dynamics and cognitive load in digital stress scenarios

A central contribution of the third empirical study (Section 4) lies in demonstrating that the sensorimotor configuration of an evaluative context – specifically, whether the social stimulus is presented in a static or dynamic form – affects not only emotional engagement but also cognitive load (CL), attentional regulation, and neurophysiological efficiency. These results provide robust empirical support for theoretical accounts proposing that the human brain operates not as a passive receiver of social cues, but as an active, embodied inference system that continuously simulates, anticipates, and responds to others' actions, expressions, and communicative intentions (Lehmann et al., 2024; Paolo & Jaegher, 2012; Standage et al., 2022).

In the dynamic digital interview condition (i.e. Dyn-DSST), participants encountered a continuous stream of verbal and non-verbal information, including facial expressions, gaze direction, prosodic contours, and subtle body movements – features that approximate naturalistic social interaction. This sustained flow of multimodal cues is likely to engage sensorimotor simulation processes, whereby observers internally model the perceived behaviour through their own perceptual and motor systems (Davis et al., 2017; Standage et al., 2022). While such mechanisms support the accurate decoding of others' mental and emotional states, they also heighten processing demands, particularly in contexts that are affectively complex or evaluatively ambiguous.

The EEG findings of Section 4 reflect this increased demand. Participants in the Dyn-DSST exhibited significantly lower alpha power across all four regions of interest (F1, F2, TP1, TP2) during all five discourses, compared to those in the Stat-DSST. Alpha desynchronization is widely regarded as a reliable index of active cortical engagement, reflecting the allocation of attention to task-relevant stimuli and the suppression of irrelevant or distracting input (Bacigalupo & Luck, 2022; Klimesch, 1999, 2012; Klimesch et al., 2007; Michalareas et al., 2016). This widespread reduction in alpha activity suggests that dynamic feedback environments recruit broader attentional networks, compelling participants to maintain

heightened vigilance and allocate greater neural resources to perceptual monitoring and social evaluation.

This interpretation is further supported by beta-band activity, which was higher in temporo-parietal than frontal regions, especially in the Dyn-DSST. Beta oscillations have been associated with task-focused attention, endogenous control, and the maintenance of cognitive sets under sustained demand (Gola et al., 2013; Townsend et al., 2022; Wróbel, 2000). Their topographic distribution in posterior regions is consistent with the notion that visual-spatial and social-perceptual integration processes are engaged more intensely in dynamic, sensorimotor-rich environments. Interestingly, the Stat-DSST group showed more localized and asymmetric beta patterns, suggesting a lower overall integration burden during the anticipatory phase.

Taken together, these results strongly support the idea that dynamic social environments elevate cognitive load through continuous demands on perceptual, attentional, and sensorimotor systems. Within the framework of Cognitive Load Theory (Lavie et al., 2004; Venter, 2021), such environments increase intrinsic load (complexity of the social task) as well as extraneous load (processing demands unrelated to the primary performance objective, such as interpreting nonverbal cues). However, in naturalistic settings, this extraneous load may be ecologically valid, reflecting real-world communicative demands that must be met for successful social interaction.

In this sense, the neural signature of the Dyn-DSST condition reflects not inefficiency, but rather a cost of realism: the brain engages more resources not because the environment is flawed, but because it approximates the sensorimotor dynamics of genuine interpersonal communication, which require constant predictive updating, emotion decoding, and goal-directed behavioural preparation.

The neurophysiological findings reported in Section 4 are further enriched by the autonomic data, which provide independent support for the interpretation that dynamic, sensorimotor-rich social stimuli impose higher emotional and cognitive demands. In particular, SCR – a sensitive index of sympathetic arousal and affective engagement – was significantly

higher in the Dyn-DSST condition compared to the Stat-DSST, even though both groups were exposed to structurally equivalent task demands. This finding suggests that the format of the social interaction, not simply its content, modulates emotional investment and arousal intensity.

The increase in SCR without a corresponding rise in HR or HRV may indicate a selective sympathetic activation pattern, potentially reflecting a more tonic attentional engagement rather than acute cardiovascular stress. Such patterns are commonly observed in emotionally engaging but non-threatening contexts, where cognitive and perceptual demands are high, yet overt threat appraisal remains moderate (Dawson et al., 2007; Thayer & Lane, 2000).

In real-world settings – such as interviews, evaluations, or high-stakes collaborative tasks – this profile may represent an adaptive neurovisceral configuration, optimizing vigilance without triggering a full-blown defensive physiological response.

Crucially, this interpretation is supported by the significant increase in gamma-band activity observed in the Dyn-DSST group. Gamma oscillations are considered a hallmark of high-order integrative processing, involved in cross-modal binding, working memory maintenance, and neurocognitive simulation of internally generated models (Engel & Fries, 2010; Kaiser & Lutzenberger, 2003). In social contexts, enhanced gamma power has been linked to mentalizing, social prediction, and self-referential simulation (Yang et al., 2020). The elevated gamma activity found in Section 4, therefore, likely reflects participants' internal construction of communicative strategies, active comparison with previous feedback, and preparation for expressive performance under conditions of social uncertainty.

Yet, this heightened gamma engagement is not without cost. Drawing on resource-based models of executive functioning (Diamond, 2013; Friedman et al., 2008; Langner & Eickhoff, 2013; Zink et al., 2021), it can be posited that sustained sensorimotor and cognitive activation in dynamic contexts may tax the individual's regulatory bandwidth, potentially leading to quicker fatigue, performance variability, or strategic disengagement over time. While the Dyn-DSST format elicited greater immersion and emotional authenticity, it also imposed a computational burden on attention, memory, and emotion regulation systems – burdens that,

if unmitigated, may reduce overall neurocognitive efficiency or resilience in prolonged evaluative settings.

The evidence presented in Section 4 highlights a central trade-off in human social cognition: while sensorimotor realism enhances ecological validity, affective salience, and interpersonal engagement, it simultaneously requires greater allocation of neural resources for simulation, prediction, and regulatory processes. By contrast, simplified or static interactions reduce processing demands and facilitate regulatory balance, yet often at the cost of interpersonal resonance, motivational relevance, and behavioural authenticity.

This trade-off has important implications for the development of digital assessment platforms, hybrid interview protocols, and virtual communication systems. A clearer understanding of the neurocognitive demands and affordances associated with different feedback structures can guide the design of interactional environments that balance ecological validity with the sustainability of cognitive and emotional effort, adapting feedback modalities to both the functional requirements of the task and the individual's regulatory capacities.

In summary, findings across behavioural, autonomic, and EEG measures indicate that sensorimotor dynamics directly influence cognitive load, attentional engagement, and emotional responsiveness during the anticipation of social performance. These results underscore the importance of integrating perceptual richness, affective valence, and task structure within a unified neurocognitive framework of human adaptability under stress. This integrative approach is developed further in the following section (5.1.4), where a synthetic model is proposed to consolidate the multilevel mechanisms of stress regulation observed across the three studies.

5.1.4. Toward an integrative neurocognitive model of stress adaptation

The empirical and theoretical analyses developed in the preceding sections converge on a central premise: stress adaptation in socially evaluative contexts arises from the coordinated interaction of multiple neurocognitive and physiological systems, dynamically modulated by contextual

cues, the valence of social feedback, and the perceptual richness of the environment. These systems encompass cortical networks supporting cognitive control and social cognition, subcortical and brainstem circuits governing autonomic regulation, and peripheral physiological pathways such as cardiac and electrodermal responses. The evidence presented across Sections 2, 3, and 4 consistently substantiates this view, indicating that adaptive performance under stress is not the product of a single regulatory mechanism, but rather the emergent property of a context-sensitive, integrated neurophysiological architecture.

To account for this complexity, the present dissertation proposes a model of multilevel adaptive regulation, in which central (EEG-derived), autonomic (HR, HRV, SCL, SCR), behavioural (reaction times, performance timing), and embodied perceptual (sensorimotor) processes operate in reciprocal coordination. This framework draws upon and extends three principal theoretical perspectives in affective neuroscience and cognitive psychophysiology: (i) the *Neurovisceral Integration Model* (NIM); (ii) the framework of *Allostasis and Predictive Regulation*; and (iii) the *Embodied Predictive Processing approach*.

As stated, the *NIM* (R. Smith et al., 2017; Thayer & Lane, 2000) emphasizes the role of a central autonomic network – comprising PFC, ACC, Ins, and amygdala – in maintaining homeostasis through integrated top-down and bottom-up regulation. Our findings corroborate this model by demonstrating that variations in social feedback valence are accompanied by parallel modulations in EEG rhythms (e.g., gamma, beta, theta), autonomic indices, and behavioural adaptation (e.g., reduced RTs, performance reorganization) during speech preparation.

The framework of *Allostasis and Predictive Regulation* (Barrett et al., 2016; Sterling, 2012; Sterling & Eyer, 1988) posits that the brain's core function is to anticipate and meet future demands by adjusting internal states in advance of environmental perturbations.

The findings – particularly those presented in Sections 3 and 4 – underscore the anticipatory dimension of stress adaptation. Feedback received during earlier phases of the task continued to modulate neural, autonomic, and behavioural responses in subsequent speech planning, indicating that participants maintained and updated internal models of the social

context to guide forthcoming performance. This was reflected in the sustained elevation of gamma- and beta-band activity, as well as in the non-linear modulation of SCL and HR across the different feedback conditions.

Finally, *Embodied Predictive Processing frameworks* (Clark, 2013; Friston, 2009) offer a synthetic view of perception, action, and affect as hierarchically organized, generative processes that minimize prediction error through motoric, attentional, or interoceptive adjustment. The sensorimotor findings of Section 4 – demonstrating increased cortical and electrodermal engagement under dynamic audiovisual feedback – provide direct empirical support for this view. Participants exposed to richly embodied, temporally continuous social cues engaged in sensorimotor simulation and prediction, as evidenced by greater alpha suppression and increased gamma synchronization, especially in temporo-parietal and prefrontal regions.

Crucially, these models converge on a shared assumption: adaptive regulation depends on system-level coherence, i.e., the capacity for different subsystems (cortical, autonomic, sensorimotor, behavioural) to co-regulate in synchrony in response to changing demands. The findings support this hypothesis, revealing that dysregulation or overactivation in one domain (e.g., heightened SCR or excessive gamma activity) is often accompanied by compensatory patterns in another (e.g., performance adjustment, reduced HR), consistent with resource reallocation or protective disengagement. This compensatory interplay was particularly evident in the shift from high arousal/high engagement patterns under ambiguous or boredom feedback to attenuated autonomic responses and cognitive disengagement under overtly negative social evaluation.

Thus, our integrative model views stress adaptation as an emergent process involving: (i) anticipatory updating of internal models; (ii) context-sensitive recruitment of attentional and executive systems; (iii) visceral-autonomic calibration; and (iv) sensorimotor engagement/disengagement loops, all dynamically regulated through a feedback-responsive coordination that prioritizes both short-term task performance and long-term resource preservation.

Within this integrative framework, stress adaptation is not conceived as a fixed trait or a linear function of resilience, but rather as a plastic, context-dependent capability emerging from the interplay of multiple dynamically coupled systems. The findings from this dissertation underscore that individual responses to social stressors are not uniformly maladaptive – even under moderate evaluative pressure. Rather, the organism exhibits a repertoire of regulatory strategies that vary based on perceived controllability, emotional valence, sensory richness, and anticipated task demands.

In particular, the results suggest that high engagement under emotionally ambiguous or evaluatively neutral feedback (e.g., elevated beta and gamma activity, increased SCR, faster RTs) may reflect an adaptive mobilization of resources, aimed at disambiguating social signals and preserving self-efficacy. In contrast, attenuated autonomic and cortical activation under sustained negative or rejecting feedback (e.g., decreased SCL and HR, reduced gamma power) may signal strategic disengagement, consistent with allostatic recalibration or emotionally protective withdrawal (Porges, 2007; McEwen, 1998). These adaptive shifts – while effective in the short term – could become maladaptive if chronically activated or poorly regulated, leading to phenomena such as emotional blunting, decision paralysis, or burnout.

This dynamic view of adaptive regulation has direct implications for the design of cognitive-behavioural training programs, human–machine interfaces, and digital assessment tools. For example:

- in personnel selection or evaluation, excessive reliance on emotionally neutral or static interfaces may fail to capture true regulatory capacity under ecologically valid stressors. The present data suggest that dynamic, sensorimotor-rich scenarios elicit more differentiated neurophysiological profiles and may better simulate real-world performance contexts;
- in resilience training or coaching, identifying individual patterns of EEG and autonomic responsivity to feedback could inform personalized interventions, targeting overactivation (e.g., excessive beta/gamma in high ambiguity) or under-engagement

(e.g., alpha dominance in high-stakes trials) through neurofeedback or adaptive stress inoculation protocols;

- in educational or therapeutic environments, modulating the valence and timing of social feedback could optimize attentional engagement and emotional safety. For instance, alternating affirming and ambiguous feedback may challenge attentional systems without tipping into threat-induced shutdown, thereby sustaining learning-relevant arousal levels.

Despite its promise, the model presented here must be interpreted in light of its methodological and conceptual boundaries. First, while the studies employed high-resolution EEG and autonomic measures, no direct imaging of subcortical structures (e.g., amygdala, basal ganglia, hypothalamus) was conducted. Therefore, the proposed central-autonomic loops remain theoretically inferred based on topographic cortical signals and peripheral indicators. Second, although stress adaptation was conceptualized as dynamic, the temporal dynamics of transitions between engagement and disengagement were not directly modelled, and may benefit from time-series, phase-based, or nonlinear analysis approaches in future work.

Finally, the model – while biologically grounded – does not preclude the role of psychosocial moderators such as personality traits, interpersonal schemas, cultural norms, or past experiences of rejection or reward. Such factors may alter how feedback is perceived, how internal models are updated, and which regulatory strategies are enacted under stress. Integrating individual difference measures, along with hyperscanning or dyadic paradigms, may further refine our understanding of interactive stress regulation in real-world settings.

In conclusion, the proposed model offers a multilevel, flexible, and ecologically attuned account of stress adaptation in socially evaluative contexts. It accommodates both engagement-based strategies (e.g., elaboration, simulation, prediction) and disengagement-based responses (e.g., withdrawal, resource conservation), positioning the individual as an active constructor of regulatory dynamics, rather than a passive recipient of stress. In the following section (5.2), we articulate how this model may guide future research and application, focusing on

methodological innovations, theoretical developments, and translational implications in digital assessment, organizational neuroscience, and neuro-inclusive design.

5.2. Implications and future directions

5.2.1. Methodological advances: multimodal, ecological, and comparative approaches

5.2.1.1. Integrative Experimental Design and Ecological Validity in Social Stress Research

One of the most salient methodological contributions of the present dissertation lies in the strategic integration of multimodal measures within ecologically structured paradigms, enabling a layered understanding of how individuals adapt to complex, socially embedded stressors. Across all three empirical studies, the experimental protocols were specifically designed to maximize both internal validity – through rigorous control of stimuli, timing, and recording parameters – and external validity, by simulating real-world conditions of performance pressure, social evaluation, and interpersonal uncertainty.

First, the use of converging physiological and neurophysiological signals (i.e. EEG, HR, HRV, SCL, and SCR) constituted a methodological advance that allowed for simultaneous capture of central and peripheral dynamics. Rather than relying solely on subjective reports or behavioural endpoints, the studies adopted a biopsychosocial perspective, operationalizing stress regulation through spectral EEG patterns (e.g., beta, gamma, theta power), autonomic modulation (e.g., phasic SCR variation, tonic HR change), and RTs–based behavioural proxies (e.g., preparation speed, speech latency). This multimodal triangulation provided a robust framework to test hypotheses derived from theoretical models such as the *NIM*, *Allostasis, and Embodied Predictive Processing*, grounding abstract constructs in empirically observable markers.

Second, the experimental designs privileged ecological plausibility by embedding the stressor within realistic communicative and professional scenarios – most notably, the simulated job interview context that was central to all three studies. This choice ensured that

the stress induction was not artificially imposed through impersonal stimuli (e.g., noise bursts, cognitive conflict tasks) but rather emerged from interpersonally meaningful demands such as self-presentation, impression management, and evaluative ambiguity. In doing so, the studies addressed longstanding concerns in the field of psychophysiological stress research, which has often been criticized for lacking generalizability due to overly reductive or decontextualized paradigms.

Moreover, the methodological refinement introduced in Section 4 – comparing static versus dynamic digital interfaces – represents a significant innovation in the direction of ecological comparison. By manipulating the sensorimotor richness and temporal continuity of the evaluative committee's feedback, the study enabled a more specific examination of how interaction modality shapes both cognitive-affective engagement and neurophysiological cost. Such a comparative design goes beyond binary stress/no-stress contrasts, offering insight into qualitative differences in regulatory profiles depending on how social stimuli are structured and delivered.

This level of experimental sensitivity was made possible by the adoption of parametric manipulation of social feedback across five gradations of valence (no feedback, positive, neutral, boredom, annoyed) in Section 3. The graded structure allowed for the observation of non-linear and non-monotonic response patterns, such as the inverted-U gamma activity or the decrease in autonomic arousal under high aversive load, which would have remained undetected in dichotomous feedback designs. These results underscore the importance of affective modelling, whereby the organism's adaptive strategies are not binary (e.g., engage vs. disengage) but are dynamically modulated across a continuum of social meaning and emotional tone.

Taken together, these methodological decisions demonstrate the feasibility and theoretical utility of implementing multimodal, ecologically grounded, and parametrically sensitive paradigms to study neurocognitive stress adaptation in contextually realistic settings. The next section will examine how these methodological foundations support comparative inference and open new directions for integrating cross-context and cross-population perspectives in future research.

5.2.1.2. Comparative Insight and Translation Toward Neuroecological Models

Beyond the integration of multiple physiological modalities and the careful modulation of ecological realism, another key methodological advance of the present work lies in its comparative logic, enabling inter-condition and inter-context analysis across studies. While each experiment was designed to test specific hypotheses – ranging from the impact of feedback valence (Sections 2 and 3) to the influence of sensorimotor structure (Section 4) – the shared task architecture and common data streams permitted a cumulative, cross-study analytical lens. This convergence makes it possible to observe how specific feedback characteristics (e.g., ambiguity, aversion) and presentation modalities (e.g., static vs. dynamic) interact with core regulatory systems across varying levels of stress induction.

Such comparative insight is particularly valuable in the context of translational research, where findings from controlled laboratory conditions must be generalizable to real-world organizational, clinical, or educational domains. The paradigm employed here, based on a digitally adapted SST, lends itself to modular extension and task customization, making it an ideal platform for comparative implementation across different populations (e.g., neurotypical vs. neurodivergent individuals), developmental stages (e.g., adolescence, aging), or occupational categories (e.g., healthcare, law enforcement, academia).

Crucially, the studies highlight that regulatory profiles are not merely dependent on task difficulty or emotional intensity, but are also shaped by how information is conveyed, how much sensorimotor resonance it induces, and how evaluative meaning is constructed and interpreted. This opens the door for cross-domain benchmarking, in which cognitive-affective engagement can be measured and compared across domains with different stakes and social affordances (e.g., high-consequence clinical triage vs. low-stakes educational assessment), provided that feedback structure and ecological framing are preserved.

The ecological coherence of the current paradigm also suggest its suitability for integration with mobile neurotechnologies such as wearable EEG, portable fNIRS, or biometric

wristbands, enabling deployment in naturalistic or semi-structured field settings. By maintaining core stimulus properties (gradual feedback valence, performance anticipation, socially relevant themes) while adapting the sensory and contextual envelope, future implementations may further test the robustness of stress-regulatory patterns observed here in in situ, high-fidelity environments.

Furthermore, this methodology provides a foundation for longitudinal tracking of regulatory strategies over time – particularly relevant for intervention research or training contexts aimed at enhancing stress resilience, executive functioning, or interpersonal adaptability. The capacity to extract time-resolved physiological markers under controlled yet lifelike conditions positions the paradigm as a powerful tool for evaluating the efficacy of targeted cognitive, behavioural, or neurofeedback interventions in shaping regulatory plasticity.

Lastly, the comparative structure and ecological embeddedness of the proposed framework resonate with a growing movement toward a neuroecological approach to human adaptability. This approach emphasizes the study of cognition and emotion not as isolated functions but as embedded, situated, and enacted processes, shaped by real-time interaction with a complex social world. In this sense, the methodological contributions of the present research are not merely instrumental, but also epistemologically generative, encouraging a shift from static, decontextualized views of stress to dynamic, embodied, and context-aware models of human functioning.

This convergence of methodological innovation and theoretical applicability sets the stage for future directions in both basic neuroscience and applied translational contexts, as explored in the following sections on theoretical contributions (5.2.2) and implications for digital human resource assessment and inclusive design (5.2.3).

5.2.2. Contributions to the neuroscience of social and organizational adaptability

5.2.2.1. Neurocognitive foundations of social evaluation and stress regulation

The findings reported across the three experimental studies contribute substantively to the emerging field of Organisational Neuroscience, offering a multilayered account of how individuals process, anticipate, and adapt to social evaluation in contexts that simulate the psychological demands of real-world performance and assessment. By integrating affective neuroscience, cognitive control theory, and embodied cognition within ecologically valid social stress paradigms, the present work advances both the theoretical granularity and functional relevance of neurocognitive models applied to organisational settings.

At the core of this contribution lies the empirical demonstration that social feedback, even when brief, symbolic, or simulated, elicits differential engagement of neurofunctional and autonomic systems, contingent upon its emotional valence, ambiguity, and expressive format. These findings underscore the validity of interpreting evaluative interactions – such as interviews, performance reviews, or public presentations – not simply as cognitive tasks, but as affective-informational exchanges that engage neural circuits related to self-regulation, social cognition, and goal-directed adaptation.

This reconceptualization has important implications for the theoretical architecture of organisational behaviour models. Traditionally, such models have focused on motivational, behavioural, or psychometric indicators of performance under stress, often overlooking the neurobiological mechanisms that underpin real-time adaptation to socially mediated pressure. The results from the present studies challenge this view, showing that anticipatory neural activity, autonomic reactivity, and behavioural adjustment are not peripheral reactions to stress – they are constitutive components of how individuals navigate social evaluation, interpret feedback, and optimise performance.

Importantly, the data offer empirical grounding for theories that treat organisations as predictive social environments, wherein individuals must continuously update internal models of status, expectation, and reward contingencies. The anticipatory EEG dynamics observed

across feedback conditions (e.g., the increase in gamma and beta activity prior to speech preparation) support the view that organisational settings engage hierarchical prediction systems, akin to those described in predictive coding theory (Clark, 2013; Friston, 2009). Within this framework, job interviews, meetings, and feedback sessions can be understood as epistemically volatile environments, where ambiguity and uncertainty regarding evaluation drive the mobilisation of attentional, memory, and affective resources.

Furthermore, the empirical evidence from Sections 3 and 4 extends the reach of organisational neuroscience beyond individual traits or outcomes, toward the interactional and situated properties of work environments. In particular, the comparison between static and dynamic feedback modalities demonstrates that not only the content of evaluation (i.e., what is said) but also its sensorimotor form (i.e., how it is conveyed) significantly shapes neurocognitive responses. This supports an embodied view of organisational interaction, in which social signals are processed through both linguistic and perceptual channels, and where simulation-based engagement plays a central role in guiding regulatory effort and affective investment.

In sum, the theoretical contribution of this work lies in bridging the domains of neurocognitive stress research and organisational psychology, offering a biologically grounded framework for understanding how evaluation, feedback, and task anticipation are processed by the brain and body in dynamic, socially situated contexts. The next section will develop these insights further by linking them to key constructs in organisational functioning, such as emotional labour, resilience, and the neural correlates of professional adaptability.

5.2.2.2. Cognitive Flexibility, Emotional Labour, and Adaptive Expertise

Building upon this foundation, the findings of this dissertation also intersect meaningfully with constructs central to the psychology of work and organizations, particularly in relation to emotional labour, adaptive expertise, and decision-making under uncertainty. These constructs, while traditionally explored through self-report, behavioural observation, or

performance metrics, gain new theoretical depth when examined through the lens of neurophysiological responsivity to social stress and feedback.

First, the data directly address the neurocognitive mechanisms underlying emotional labour, conceptualized as the internal effort required to regulate affective states and outward expressions in accordance with organizational expectations (Glomb & Tews, 2004; Jeung et al., 2018). In this framework, regulating one's emotional tone in evaluative situations – such as remaining composed in the face of critical feedback or generating enthusiasm after receiving neutral signals – requires both prefrontal executive engagement and «viscero-sensory» modulation. The EEG patterns observed in the current studies, particularly in the beta and gamma frequency bands, reflect this internal cost, with higher oscillatory activity corresponding to greater self-regulatory effort in managing ambiguity, disapproval, or disengaged evaluators. Likewise, alpha desynchronization and increased SCR in the dynamic interview condition suggest that emotionally rich environments heighten the physiological demand of emotional self-regulation, even when no explicit behavioural display is required.

Second, the anticipatory neurophysiological modulations documented across Sections 3 and 4 align with contemporary definitions of adaptive expertise, which emphasize the ability to flexibly respond to shifting task parameters and feedback in novel or complex environments (Arment et al., 2013; Jayawardena et al., 2024). Adaptive expertise is not simply a matter of knowledge breadth but depends on the real-time deployment of attentional, emotional, and strategic resources under pressure. The findings suggest that such flexibility is not a static capacity but a moment-to-moment negotiation between anticipatory models, environmental affordances, and neurocognitive resources. Individuals who sustained high gamma activity during demanding phases, or who showed context-sensitive shifts in autonomic activation, may exemplify this functional adaptability, even in the absence of explicit performance differences.

Third, the stress-inducing social feedback scenarios used in these experiments mirror real-world decision-making under evaluative pressure, a condition ubiquitous in modern organizational life. The ability to integrate emotionally salient input, maintain goal focus, and adjust communicative strategies in response to critical or ambiguous social feedback reflects core capacities involved in leadership, negotiation, crisis response, and conflict resolution.

Neurocognitive markers such as posterior beta activity, frontal theta suppression, or reduced HRV may therefore serve as physiological correlates of real-time decision quality, opening new theoretical space for operationalizing executive functioning in naturalistic settings.

Altogether, the theoretical contribution of this work lies in offering a multidimensional neurocognitive account of organisational adaptability: one that is sensitive to the affective, sensorimotor, and contextual characteristics of the workplace, and capable of describing how individuals navigate social complexity, interpersonal evaluation, and performance pressure not just through traits or attitudes, but through temporally unfolding, system-level coordination.

This perspective is consistent with a broader shift in organisational neuroscience toward models of cognition that are situated, embodied, and dynamic. By anchoring theoretical constructs such as emotional labour, adaptability, and professional resilience to measurable neurophysiological processes, the present findings contribute to a more refined understanding of human functioning within contemporary organisational systems – particularly those mediated by digital technologies, remote communication, and real-time feedback.

The following section (5.2.3) examines how these findings can inform the development of digital tools for human resource assessment, the implementation of neuro-inclusive organisational practices, and the design of adaptive work environments that foster both performance and well-being.

5.2.3. From neuroethics to neuro-inclusive design: rethinking digital assessment

As digital technologies increasingly permeate talent assessment and professional evaluation, the need for empirically informed, cognitively sustainable, and ethically grounded design principles becomes urgent. The findings of this dissertation contribute to this agenda by offering a neurocognitive framework for understanding how digital feedback environments interact with attentional resources, emotional engagement, and regulatory effort – insights that are directly relevant to the development of adaptive and inclusive digital HR systems.

One of the most actionable implications lies in the design of evaluative feedback interfaces, which emerged as a key modulator of stress response across the three studies. The contrast between static and dynamic conditions in Section 4 demonstrates that not all digital feedback is cognitively equivalent: dynamic video-based stimuli, while more ecologically valid and interpersonally resonant, induce higher physiological arousal, greater cognitive load, and more sustained cortical activation than static, image-based alternatives. These differences suggest that the emotional and sensorimotor structure of digital feedback – its pacing, expressivity, and timing – can be engineered to calibrate the challenge level, attentional demand, and affective resonance of the evaluative experience.

This insight is particularly relevant considering current trends in remote assessment, asynchronous interviews, and AI-mediated performance review systems. Many of these systems favour standardization and automation, sometimes at the expense of affective nuance or social authenticity. Yet, as the data here suggest, even neutral or ambiguous feedback delivered through dehumanised or minimally expressive interfaces can generate heightened attentional effort and ambiguity-related stress, particularly in high-stakes settings. This effect, indexed by the increase in beta-band activity and SCR under neutral or non-affirmative feedback (Sections 2 and 3), highlights the risk of affective under-specification in digital environments. Paradoxically, low-expressivity systems may impose higher regulatory burdens than more overtly expressive or emotionally rich ones.

From a design perspective, these findings support the development of affect-sensitive feedback systems that dynamically modulate valence, expressivity, and timing based on user state, task phase, and performance trajectory. For instance, following a particularly ambiguous or demanding task segment, a brief, warm-toned positive reinforcement – whether textual, visual, or vocal – could help reduce anticipatory strain and restore cognitive equilibrium. Conversely, systems that repeatedly deliver flat or delayed feedback may inadvertently amplify uncertainty, leading to maladaptive oscillations in attention and affect regulation.

Additionally, the temporal structure of digital assessments – in terms of preparation time, response latency, and pacing of evaluative inputs – should be carefully aligned with known cognitive chronometry and the oscillatory dynamics of attentional readiness. As shown in

Section 3, feedback received during prior tasks continues to influence neural activation and autonomic state during the preparation phase of subsequent tasks, suggesting that digital HR systems should account for inter-phase emotional carryover. This could involve the inclusion of buffer segments, recovery intervals, or adaptive pacing algorithms to minimize cumulative load and support real-time resource regulation.

Taken together, these insights offer a principled basis for advancing from functionalist and transactional models of assessment toward an architecture of neuroergonomic HR design – one that is attuned to the cognitive architecture, emotional vulnerability, and attentional ecology of human candidates. In the next paragraph, these implications are extended to address the broader challenge of neuro-inclusivity, with a focus on how assessment and training environments can be designed to accommodate interindividual variability in neurocognitive functioning. Moreover, the increasing demand for fairness, transparency, and accessibility in organisational assessment practices intersects with a parallel movement within neuroscience and psychology: the recognition of neurodiversity as an inherent dimension of human cognitive functioning. The findings presented in this dissertation offer not only general principles for the design of digital human resource systems but also specific insights into how neurocognitive variability – in domains such as attention, affective regulation, sensorimotor processing, and anticipatory control – can and should inform inclusive evaluation frameworks.

Specifically, neurodivergent individuals, such as those with ADHD, autism spectrum profiles, or high trait anxiety, may process social feedback, ambiguity, or multi-sensory input differently than neurotypical individuals (Pellicano & Burr, 2012; Mottron et al., 2021). The evidence presented here – particularly the differential EEG and autonomic profiles elicited by dynamic versus static feedback, or by emotionally ambiguous conditions – demonstrates that identical evaluative tasks can generate distinct physiological burdens depending on how the environment is structured. These findings reinforce the importance of designing flexible assessment interfaces that allow for individualized calibration of sensory richness, response pacing, and emotional feedback properties.

A neuro-inclusive system, informed by these principles, would not assume a uniform trajectory of engagement or stress reactivity, but would instead monitor and adapt to the user's

real-time state. For example, physiological markers such as increased SCR, prolonged RTs, or elevated frontal beta activity could be interpreted by the system not as performance deficits, but as indicators of elevated regulatory load, prompting a contextual adjustment in task difficulty, stimulus presentation speed, or feedback style. This adaptive responsiveness could enhance performance validity while simultaneously reducing unnecessary stress, frustration, or disengagement – outcomes particularly relevant in selection settings where underperformance due to misaligned task demands may obscure true capability.

Moreover, the incorporation of bio-informed user profiling – based on normative and within-person baselines of autonomic and EEG reactivity – could support dynamic equivalence in assessment. Rather than aiming for uniform difficulty levels across all users, the goal would shift toward equivalent regulatory demand, wherein each candidate engages with the task at a level that challenges, but does not overwhelm, their attentional and affective capacities.

Such principles are already being explored in affective computing and adaptive learning technologies but have yet to be robustly translated into human resource assessment or professional training environments. The present findings provide a neurocognitively anchored rationale for this translation, and suggest that future systems should be designed not only for precision and efficiency, but also for cognitive accessibility, emotional safety, and regulatory fairness.

Beyond individual assessments, these implications extend to the design of team-based platforms, virtual collaboration tools, and remote communication systems in the workplace. Interfaces that incorporate sensorimotor realism (e.g., video presence, expressive avatars) should be deployable in customizable formats, giving users the ability to adjust the degree of emotional immediacy and multisensory load according to their preferences or needs. This flexibility aligns with the broader vision of inclusive digital infrastructures that respect not only diversity in identity and ability, but also in neurocognitive style.

In conclusion, the theoretical and empirical contributions of this work provide a robust foundation for the development of adaptive, ecologically sensitive, and neuro-inclusive assessment environments. These environments would serve not only to enhance the validity of

information and the accuracy of performance prediction but also to promote well-being, equity, and dignity within evaluative contexts. The final section (5.2.4) offers a broader reflection on the notion of human adaptability in the era of digital evaluation, integrating the implications of the present research for the future development of systems, organisational policies, and ethical frameworks.

5.2.4. Final remarks: human adaptability and neurocognitive plasticity in evaluation contexts

The trajectory traced throughout this dissertation – moving from the microdynamics of social feedback to the system-level regulation of stress and performance – has consistently pointed toward a central construct: human adaptability. In the age of algorithmic evaluation, remote interaction, and high-frequency feedback loops, the ability to flexibly regulate one's cognitive, emotional, and physiological resources in response to socially mediated demands has become a cornerstone of professional functioning.

The studies presented in this dissertation offer a nuanced understanding of adaptability in socially evaluative contexts. Rather than conceptualising it as a fixed trait or a unidimensional skill, the empirical evidence indicates that adaptability is distributed across multiple modalities, shaped by contextual factors, and modulated by the properties of social feedback. The neurocognitive markers identified – oscillatory variations in beta and gamma frequency bands, anticipatory suppression of alpha activity, and phasic fluctuations in skin conductance responses – do not merely represent secondary correlates of stress, but constitute indicators of continuous, recursive regulatory processes grounded in predictive models of social relevance, evaluative threat, and environmental affordances.

These adaptive processes increasingly unfold within environments that are digital, technologically mediated, and often asymmetrical. The shift from face-to-face interaction to virtual modalities, the diffusion of automated assessment systems, and the growing prevalence of real-time performance feedback have transformed the structure of evaluation, introducing novel forms of ambiguity, temporal compression, and sensorimotor abstraction. Such changes

present both challenges and opportunities: they can intensify the regulatory burden by amplifying informational and perceptual demands, or, when designed effectively, can facilitate new forms of individualisation, accessibility, and adaptive support.

The findings of this research suggest that for adaptability to be sustained, digital evaluation systems must themselves incorporate adaptive principles. This entails moving beyond uniform standards of timing, content, and stimulus presentation, toward interfaces that are responsive to the regulatory dynamics of everyone, capable of detecting and adjusting to fluctuations in arousal, attentional focus, and engagement. It also requires recognizing that feedback is not merely informational but constitutes a neurocognitive event – a signal capable of recalibrating internal models, redirecting attentional allocation, and activating resource-conservation mechanisms.

More broadly, the present work contributes to a redefinition of how performance under pressure is conceptualised. Success in evaluative contexts is not determined solely by knowledge or technical competence, but by the capacity to sustain attentional alignment, emotional stability, and sensorimotor coherence in the presence of complex and often implicit social demands. Within this framework, the study of stress is reframed not as the study of dysfunction, but as the investigation of adaptation, resilience, and strategic regulatory modulation.

As digital systems continue to permeate the architectures of education, work, and assessment, a neuroscientifically informed, ethically grounded, and ecologically sensitive approach to design becomes essential. The model of stress adaptation developed here – rooted in multilevel physiology, contextual embedding, and neurocognitive realism – may serve as a foundational step toward this vision. A vision in which evaluation becomes not a site of depletion or exclusion, but a space for attuned interaction, cognitive equity, and the cultivation of adaptive intelligence in a connected and unpredictable world.

Concluding, this dissertation set out to investigate how individuals adapt, at multiple levels of functioning, to the demands of social evaluation under conditions of cognitive load, emotional salience, and sensorimotor variability. By integrating evidence from neurophysiological, autonomic, and behavioural measures across three ecologically valid

experimental studies, the work has offered a comprehensive, biologically grounded account of anticipatory stress regulation and performance readiness in socially challenging environments.

A key contribution of this research lies in demonstrating that stress is not inherently maladaptive: under controlled, contextually meaningful conditions, it can facilitate attentional sharpening, cognitive restructuring, and behavioural optimisation. Yet this adaptability comes at a neurocognitive cost, which varies not only across individuals, but also as a function of how feedback is delivered, how uncertainty is structured, and how the social environment is embodied – or disembodied – within digital contexts.

The proposed integrative model underscores that stress adaptation is not a unitary process, but the product of dynamic interactions among central executive control, emotional regulation systems, sensorimotor integration, and peripheral physiological coordination. It situates these mechanisms within a framework that is both theoretically rigorous and «applicationally» relevant, particularly in the face of accelerating digitisation of evaluative practices.

In practical terms, the findings support a rethinking of how we design, implement, and interpret performance assessments, particularly in professional, educational, and organisational settings. Rather than seeking to eliminate stress or standardise evaluation experiences, future systems should aim to recognise and accommodate neurocognitive variability, support regulatory balance, and foster environments where adaptive functioning – not just correctness or speed – is the principal indicator of competence.

In theoretical terms, this research invites a more ecologically grounded understanding of cognitive-affective processes, one that privileges complexity, context sensitivity, and the embodied nature of human reasoning under pressure. It also opens pathways for further inquiry into how feedback, prediction, and self-regulation co-evolve across time and communicative modalities.

Ultimately, the broader ambition of this work is to contribute to a science of human adaptability – one that embraces the layered, uncertain, and socially embedded character of

cognition, and one that seeks to build systems, practices, and institutions that amplify, rather than constrain, our capacity to engage, perform, and grow under conditions of evaluative stress.

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Papers under review

Ciminaghi, F.*, Rovelli, K., & Balconi, M. (under review). Neural dynamics during moral persuasion process: An EEG hyperscanning study. Group Processes & Intergroup Relations.

Rovelli, K.*, & Balconi, M. (under review). Moral belief updating (MBU) as a neurocognitive and communicative process: A multidimensional perspective. Social Neuroscience.

Balconi, M., Allegretta, R. A., Acconito, C., & Rovelli, K.* (under review). Single-subject and dyadic electroencephalography during persuasive communication: A hyperscanning paradigm applied to interpersonal synchronization. Language, Cognition and Neuroscience.

Balconi, M., Rovelli, K., & Allegretta, R. A.* (under review). Follow morality for what reason and for what "value"? Personal choices and people's brains tell us. Journal of Behavior Analysis.

Acconito, C.*, Rovelli, K., & Balconi, M. (under review). Working memory, awareness of choice (AoC) and awareness of action (AoA) in the decision-making process in a professional frame. International Studies of Management & Organization.

Rovelli, K.*, Angioletti, L., & Balconi, M. (under review). Who decides for me? EEG correlates of authorship between "me" and "you" in organizational decisions. Journal of Human Values.

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Conference contributions

Rovelli, K.*, & Balconi, M. (2025, October 15–17). Cognitive stress decoded through language: A multimodal AI-based neuroscientific study. In Proceedings of the NeuroMI 2025 – International Conference on Neuroscience and Neurotechnology (Milano, Italy). Accepted abstract.

Balconi, M.*, & Rovelli, K. (2025, October 16–19). From still faces to embodied evaluation: A multimodal study of behavioral, EEG, and autonomic stress markers in static vs. dynamic interview contexts. In Proceedings of the ICECCME 2025 – International Conference on Electrical, Computer, Communications and Mechatronics Engineering (Zanzibar, Tanzania). Accepted abstract.

Rovelli, K.*, & Balconi, M. (2025, September 23–26). Interpersonal morality and cognitive integration: A neurophysiological study of belief revision in dyadic moral exchange. In Proceedings of the S4SN 2025 – Society for Social Neuroscience Annual Meeting (Lisbon, Portugal). Accepted abstract.

Rovelli, K.*, Angioletti, L., Allegretta, R. A., Daffinà, A., & Balconi, M. (2025, September 11–13). Collective minds, individual brains: EEG evidence from organizational decision-making. In Proceedings of the AIP Sperimentale 2025 – 31° Congresso annuale (Torino, Italy). Accepted abstract.

Rovelli, K., Acconito, C., Angioletti, L., Allegretta, R. A., & Balconi, M. (2025, September 4–6). Persuasive communication during shared decision-making: Single-subject and dyadic EEG insights from a hyperscanning paradigm. In Proceedings of the 9th Scientific Meeting of the Federation of the European Societies of Neuropsychology (FESN) & 40th Annual Meeting of the German Neuropsychological Society (GNP) (Leipzig, Germany). Accepted abstract.

Balconi, M., Ciminaghi, F., Eugeni, R., Bionda, F., Acconito, C., & Rovelli, K. (2025, September 4–6). Decoding moral and emotional complexity in cinema: A multimodal approach integrating AI and neurophysiological analysis. In Proceedings of the 9th Scientific Meeting of the Federation of the European Societies of Neuropsychology (FESN) & 40th Annual Meeting of the German Neuropsychological Society (GNP) (Leipzig, Germany). Accepted abstract.

Balconi, M., & Rovelli, K.* (2025, July 26–30). Designing for the mind: The impact of university environments on well-being in students by using neurophysiological responses. In Proceedings of the 16th International Conference on Applied Human Factors and Ergonomics (AHFE 2025) (Orlando, FL, USA). https://doi.org/10.54941/ahfe1006618

Rovelli, K.*, Allegretta, R. A., & Balconi, M. (2025, May 30). Dinamiche decisionali gerarchiche: Il ruolo dell'esperienza professionale e dei fattori individuali nella valutazione delle scelte organizzative. In Atti del XVII Convegno Nazionale di Psicologia dell'Invecchiamento (SIPI 2025) (Padova, Italy).

Allegretta, R. A., Rovelli, K., Angioletti, L., & Balconi, M. (2024, December 13). Strategie di regolazione emotiva e feedback sociale: Un'analisi EEG delle performance cognitive sotto stress moderato. In Riunione Autunnale Società Italiana di Neuropsicologia (SINP) (Bologna, Italy).

Ciminaghi, F., Allegretta, R. A., Rovelli, K., & Balconi, M. (2024, December 13). Effetti del feedback positivo e negativo sulla memoria decisionale e sull'attivazione neurale: Un'analisi comportamentale ed elettroencefalografica tra decisori junior e senior. In Riunione Autunnale Società Italiana di Neuropsicologia (SINP) (Bologna, Italy).

Allegretta, R. A., Rovelli, K., Angioletti, L., & Balconi, M. (2024). The interplay of working memory and decisional complexity: Insights from behavioural and EEG measures. In Program of the INS Global Neuropsychology Congress 2024. International Neuropsychological Society.

Balconi, M., & Rovelli, K. (2024). Neurophysiological processes and well-being experience as response to space: Some evidence from a neuroarchitecture approach. In Abstract Book of the 18th European Workshop on Imagery and Cognition (EWIC 2024) (p. 41).

Rovelli, K., Angioletti, L., & Balconi, M. (2024). Navigating the ethical landscape: Unveiling the transformative impact of digital technologies on occupational stress assessment. In Programme of the 15th International Scientific Conference on Neuroethics and 10th Conference of the Italian Society for Neuroethics (SINe). Società Italiana di Neuroetica.

Angioletti, L.*, Rovelli, K., & Balconi, M. (2024). La gestione dello stress psicosociale negli studenti universitari atleti professionisti: Uno studio pilota. In Programma del XXIV Congresso Nazionale AIPS. Associazione Italiana di Psicologia dello Sport e dell'Esercizio.

Ciminaghi, F.*, Angioletti, L., Rovelli, K., & Balconi, M. (2024, September). Collaborative intelligence and hyperscanning: Exploring AI application to human-robot collaboration through a neuroscientific approach. In International Conference on Extended Reality (pp. 334–341). Springer Nature. https://doi.org/10.1007/978-3-031-71707-9_27

Rovelli, K., Angioletti, L., & Balconi, M. (2024, September 9–13). Neuroarchitecture study: Academic spaces' impact on neurophysiological processes. In 9th International Conference on Spatial Cognition (ICSC) (Rome, Italy).

Ciminaghi, F., Rovelli, K., Angioletti, L., & Balconi, M. (2024, September 23–25). Beyond the screen: A neuroscientific approach to remote vs. in-person job interviews. In XXX Congresso Associazione Italiana di Psicologia (AIP) – Sezione Sperimentale (Noto, Italy).

Rovelli, K., Angioletti, L., Ciminaghi, F., & Balconi, M. (2024, September 21–24). Exploring the effects of emotional salience on neurophysiology, decision-making and action execution. In 37th European College of Neuropsychopharmacology Congress (ECNP) (Milan, Italy).

Ciminaghi, F., Rovelli, K., & Balconi, M. (2024, September 21–24). Evaluating mental workload in human-robot collaboration in industrial context: A multidimensional research proposal. In 37th European College of Neuropsychopharmacology Congress (ECNP) (Milan, Italy).

Balconi, M., Di Lernia, D., Cassioli, F., Angioletti, L., De Gaspari, S., Serino, S., Sajno, E., Sansoni, M., Mauri, M., Rovelli, K., Allegretta, R. A., Amadini Genovese, L., & Riva, G. (2023, September 27–29). Exploring the neurophysiological correlates of face-to-face vs. remote learning during lecture and group discussions: A hyperscanning paradigm. In 8th Scientific Meeting of the Federation of European Societies of Neuropsychology (FESN) & 2nd Hellenic Neuropsychological Society (HNPS) Conference (Thessaloniki, Greece).

Acconito, C., Rovelli, K., Angioletti, L., Amadini Genovese, L., & Balconi, M. (2023, September 27–29). Set your goals! Gender differences and decision-making process: A psychophysiological study in the managerial field. In 8th Scientific Meeting of the Federation of European Societies of Neuropsychology (FESN) & 2nd Hellenic Neuropsychological Society (HNPS) Conference (Thessaloniki, Greece).

Rovelli, K., Acconito, C., Allegretta, R. A., & Amadini Genovese, L. (2023, September 18–20). Neuroscience insights on adaptability and decision-making: Implications for effective management. In XXIX Congresso Associazione Italiana di Psicologia (AIP) – Sezione Sperimentale (Lucca, Italy).

Rovelli, K., & Crivelli, D. (2023, September 18–20). Age management e potenziamento neurocognitivo in contesti professionali: Un confronto tra junior e senior manager. In XXIX Congresso Associazione Italiana di Psicologia (AIP) – Sezione Sperimentale (Lucca, Italy).

Allegretta, R. A., Acconito, C., & Rovelli, K. (2023, September 18–20). Autonomic measure responses to risk-taking and risk management in decision-making. In XXIX Congresso Associazione Italiana di Psicologia (AIP) – Sezione Sperimentale (Lucca, Italy).

Rovelli, K., Angioletti, L., & Balconi, M. (2023, May 26–29). Creatività e problem-solving in un campione di giovani e di senior manager: Effetti del gruppo nel pensiero creativo. In XVI Convegno Nazionale di Psicologia dell'Invecchiamento (SIPI) (Pavia, Italy).

Balconi, M., Rovelli, K., Angioletti, L., & Acconito, C. (2023, May 26–29). Validazione di un digital tool per gli stili decisionali in una popolazione middle-age. In XVI Convegno Nazionale di Psicologia dell'Invecchiamento (SIPI) (Pavia, Italy).

Angioletti, L., Acconito, C., Rovelli, K., Crivelli, D., & Balconi, M. (2023, May 10–12). Neuroempowerment for age management in high-level professional contexts: A comparison of junior and senior managers. In 14th International Scientific Conference on Neuroethics (SINe) (Pisa–Lucca, Italy).

Balconi, M., Rovelli, K., & Angioletti, L. (2023, May 10–12). Investigating decision making in a sample of lawyers: Challenges and opportunities of a first neurolaw study with wearable EEG. In 14th International Scientific Conference on Neuroethics (SINe) (Pisa–Lucca, Italy).

Acconito, C., Rovelli, K., Angioletti, L., & Balconi, M. (2023, May 10–12). The use of Covid-19 themed advertising and their impact on autonomic, oculometric and self-report responses. In 14th International Scientific Conference on Neuroethics (SINe) (Pisa–Lucca, Italy).

La borsa di dottorato è stata cofinanziata con risorse del Piano Nazionale di Ripresa e Resilienza PNRR Componente 1 "Potenziamento dell'offerta dei servizi di istruzione: dagli asili nido all'Università" - Componente 2 "Dalla Ricerca all'Impresa", Investimento 3.3, Introduzione di dottorati innovativi che rispondono ai fabbisogni di innovazione delle imprese e promuovono l'assunzione dei ricercatori da parte delle imprese"