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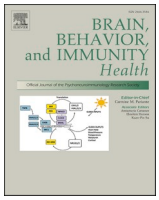

Decision-making under stress: A psychological and neurobiological integrative model

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ABSTRACT

Understanding the impact of stress on cognitive processes, particularly decision-making, is crucial as it underpins behaviors essential for survival. However, research in this domain has yielded disparate results, with inconsistencies evident across stress-induction paradigms and drug administration protocols designed to investigate specific stress pathways or neuromodulators. Building upon empirical studies, this research identifies a multifaceted matrix of variables contributing to the divergent findings. This matrix encompasses factors such as the temporal proximity between stressors and decision tasks, the nature of stressors and decision contexts, individual characteristics including psychobiological profiles and affective states at the time of decision-making and even cultural influences. In response to these complexities, we propose a comprehensive model that integrates these relevant factors and their intricate interplay to elucidate the mechanisms governing decision-making during stressful events. By synthesizing these insights, our model not only refines existing paradigms but also provides a framework for future study designs, offering avenues for theoretical advancements and translational developments in the field of stress's impact on cognitive functions. This research contributes to a deeper understanding of the nuanced relationship between stress and decision-making, ultimately advancing our knowledge of cognitive processes under challenging conditions.

1. Introduction

The stress response is commonly defined as an array of physiological and psychological changes that take place when we encounter external or internal stimuli capable of disrupt homeostasis (Ness and Calabrese, 2016). In response to various challenges, such as threats, physical demands, or cognitive stressors, the organism undergoes a series of changes, leading to the adoption of adaptive behaviors (De Kloet et al., 1999; Ness and Calabrese, 2016).

As well as individuals may perceive events differently, the stress response is influenced by a multitude of contextual and individual factors, challenging the notion of a universally consistent pattern. These factors encompass the type and duration of the stressor, cognitive appraisals, personality traits, sex hormones, age, body mass index, genetic background, among others (Allen et al., 2014). Consequently, the stress response involves a complex interplay of variables that may significantly modulate its course and outcomes.

Nonetheless, this complex constellation of interactions unfolds through two primary pathways: the hypothalamic-pituitary-adrenal (HPA) axis and the sympatho-adreno-medullary response (SAM) (Daviu et al., 2019). In the HPA axis, the paraventricular nucleus (PVN) of the hypothalamus synthesizes corticotropin-releasing hormone (CRH), leading to the release of adrenocorticotropin (ACTH) from the pituitary gland into the bloodstream. ACTH, in turn, stimulates the

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adrenal glands to release glucocorticoids (GCs) from the adrenal cortex (Russell and Lightman, 2019). Simultaneously, the activation of the autonomic nervous system plays a crucial role, initiating a rapid response characterized by the release of adrenaline and noradrenaline (NA) from the adrenal medulla, and the production of these catecholamines in the central nervous system (Ness and Calabrese, 2016; Rodrigues et al., 2009). GCs and catecholamines impact various tissues, mobilizing resources to meet the energy demands generated by stressful events. This includes an increase in cardiac and respiratory rates, a redirection of stored energy primarily toward the extremities and the brain, and the inhibition of costly processes, such as digestion and reproduction. Importantly, the stress response involves a complex interplay of neurotransmitters and hormones (Von Dawans et al., 2021).

The GCs bind to mineralocorticoid receptors (MRs) or, with lower affinity, to glucocorticoid receptors (GRs) (de Kloet et al., 2005). These receptors coexist in the hypothalamic PVN and various limbic areas, but GRs are predominant in nearly all brain regions (de Kloet et al., 2005). MRs are thought to be substantially occupied already at rest, whereas GRs occupancy largely depends on the increase in GCs levels during and following the stress response (Finsterwald and Alberini, 2014). These intracellular receptors are homologous in their structural domains and possess a DNA-binding site. Upon ligand binding, they undergo conformational changes, enabling them to translocate into the nucleus. There, they bind to specific DNA sequences or interact with transcription factors, ultimately controlling gene expression (Beato and Sánchez-Pacheco, 1996; Datson et al., 2008; Sandi, 2004; Zalachoras et al., 2013). Several genes associated with different signal transduction pathways, synaptic receptors, and proteins related to neuron morphology are influenced by these receptors (Groc et al., 2008; Harrell et al., 2004). Additionally, through genome-independent mechanisms, membrane-localized MRs and GRs (mMRs and mGRs) can rapidly modulate other processes, such as presynaptic glutamate release, neuronal excitability, or receptor trafficking, (Finsterwald and Alberini, 2014; Groeneweg et al., 2011).

In the realm of adrenergic pathway, the adrenal medulla release mainly adrenaline and a minor proportion of NA (van Stegeren, 2008). Several findings suggest that adrenaline activates vagal afferents terminating on noradrenergic cells in the nucleus of the solitary tract (NTS). There, noradrenergic projections influence NA release via direct or indirect projections to the locus coeruleus (LC), a primary source for an extensive NA network that includes hippocampus, amygdala and neocortex (McGaugh and Roozendaal, 2002; Ness and Calabrese, 2016; van Stegeren, 2008). This network provides basal neural activity for sensory alertness and modulates the gathering and processing of emotional relevant information (van Stegeren, 2008). There exists a total of three adrenergic receptors (AR) families (α1, α2, β) and nine subtypes, that displaying similar binding affinities evoke different physiological effects for the same catecholamines; signaling selectivity is achieved through the coupling to different G-proteins and effectors' systems in both temporal and spatial settings (Perez, 2020). All nine AR are expressed in the brain and this result in discrete expression patterns, signal transduction pathways, and physiological regulations as neuronal firing and excitability. LC regulates neuronal function via α and β -adrenergic receptors, which interact in the central nervous system (Timmermans et al., 2013). Additionally, the ARs are distinctly concentrated across the tissues, and throughout specific modulations it allows the sympathetic nervous system to fine tune the organism for the adaptive response.

As a result, exposure to a stressor leads to a prompt increase in central catecholamine levels, while corticosteroid levels in the brain rise more gradually and remain elevated for an extended duration. Catecholamines exert immediate effects; corticosteroids exhibit both rapid non-genomic and slower genomic effects, with the former potentially overlapping and interacting with the influence of catecholamines during an early time window (see Fig. 1). Subsequently, different waves of stress-related neurotransmitters and hormones exert varying impacts on widely distributed brain regions.

The aim of this review is to provide a comprehensive and integrated understanding of the interplay between stress and decision-making processes. By synthesizing existing knowledge on the physiological and psychological changes induced by stress response, we introduce a novel framework that integrates several variables contributing to the stress-decision-making relationship. We also hope to provide valuable insights for practical applications in fields such as psychology,

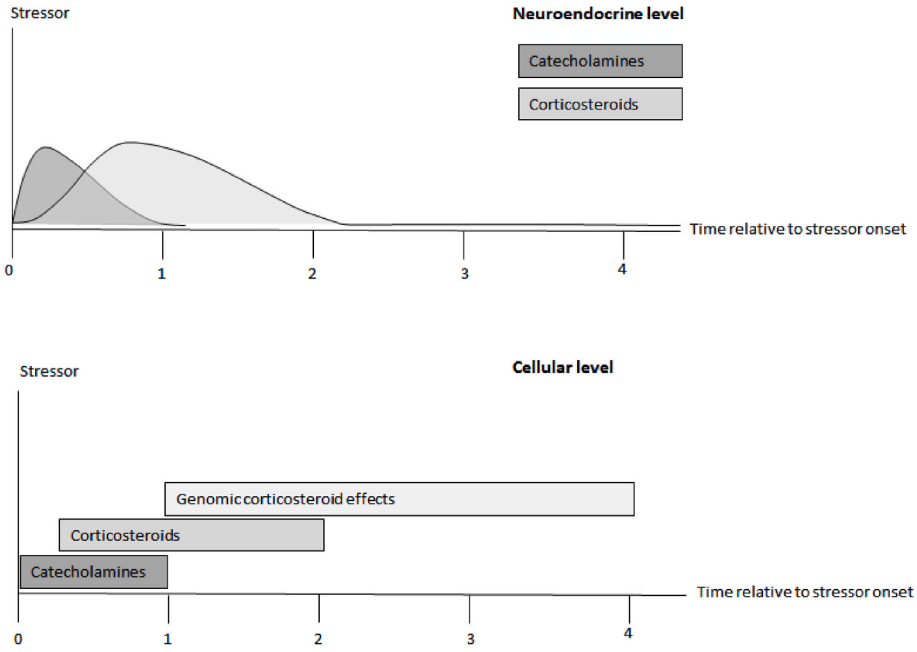

Fig. 1. Neuroendocrinology of the stress response after the stressor onset. First, an immediate response of the SAM system triggers catecholamines increase, which back to normal not long after stressor offset. On the other hand, the HPA axis response appears slowly and remains longer (top panel). At the cellular level, catecholamines may interact with the early non-genomic effects of corticosteroids, while genomic effects of cortisol appear approximately after 60 min of the stress onset (bottom panel). Time relative to stressor onset is expressed in hours. Adapted from Hermans et al., 2014).

neuroscience, and public health.

2. Cognitive processes under stress

Stress has a significant impact on various cognitive processes, with memory being a extensively studied domain. This interaction results in a diverse range of effects, contingent upon several explanatory factors. For instance, research has demonstrated a dose-dependent inverted-U effect of stress levels (or hormones released) on learning, memory, and plasticity (Finsterwald and Alberini, 2014; de Kloet et al., 1999; Joëls 2006). A second crucial factor is the duration of the stressful event, with different effects observed between short episodes (acute stress) or repetitive ones (chronic stress), the latter often contributing to the development of pathological conditions. Additionally, the phase of memory to which the stressful event is related plays a pivotal role; while stress tends to impair working memory, generally leads to consolidation benefits and memory recall damage (Abercrombie et al., 2003; Bahari et al., 2018; De Quervain et al., 2000; Joëls et al., 2011; Kuhlmann et al., 2005; Roozendaal, 2002; Shields et al., 2016a). According to the meta-analysis of Shields et al. (2017) when stress occurred prior to or during encoding it impaired memory, unless both the delay between the stressor and encoding was very short and the study materials were directly related to the stressor. A noteworthy observation in the literature is the potential positive impact of acute stress on the long storage of memories, since stress can safeguard recently acquired information in relevant contexts from being forgotten (Dunsmoor et al., 2015; Joëls et al., 2006; Lalumiere et al., 2017; McGaugh, 2013). Supporting this view, it has been shown that a learning inducing only short-term memory may establish a long-lasting memory if a stressful situation occurs within a critical window close to the learning. This was observed in rodents, for both spatial and aversive memories (Lopes da Cunha et al., 2018a; Lopes da Cunha et al., 2021), and in humans, with a stressor positively impacting on a graphical long-term memory (Lopes da Cunha et al., 2018b). Additionally, stress generally facilitates memory for emotional salient material versus neutral or unrelated contents (de Kloet et al., 1999; Dunsmoor et al., 2015; Joëls et al., 2006; Payne et al., 2006; Sandi, 1998). However, stress could impair lasting memory formation when the learning task itself triggers consolidation processes. In this way, it is proposed that the stress impact will depend on the state of the neural networks in the structures of its processing.

Furthermore, the ability to reorient attention to potential threats is critical for immediate survival. Acute stress activates the LC, with the consequent release of NA, facilitating scanning of the environment, heightened vigilance and enhancing the detection of unexpected and potentially threatening stimuli (Hermans et al., 2014). A time-specific corticosteroid modulation is suggested: elevated corticosteroid levels are associated with emotional interference (selective attention to goals is hindered by emotionally salient information), temporarily promoting the detection of threats, before transitioning to more normalized attentional processing (Henckens et al., 2012). Neuroimaging studies in humans indicate increased amygdala activity immediately after stress induction (Hermans et al., 2014) as well as enhanced functional connectivity with other salience network regions (Van Marle et al., 2010). This network's role in autonomic-neuroendocrine control, visceral perception, attention, and vigilance supports the hypothesis that stress drives individuals toward well-learned habits and routines, optimizing rapid responses while conserving cognitive resources when faced with high demands (Hermans et al., 2014; Soares et al., 2012; Vogel et al., 2016). High levels of NA and dopamine observed under stress would disrupt prefrontal cortex (PFC) functioning and enhance amygdala processing, leading to a shift from thoughtful toward rapid and reflexive control of cognition and behavior (Arnsten, 2009). Executive control network would be suppressed when catecholaminergic effects dominate or coincide with corticosteroid elevation (Hermans et al., 2014).

Consequently, during the initial stress response, flexible and goal-directed behavior change to more rigid stimulus-response conducts, which favors more simplistic but effective systems (Plessow et al., 2012; Schwabe, 2017). However, once the stressful situation subsides, executive functioning is actively reversed, probably through corticosteroid genomic actions. Emotional reactivity is normalized, high-order cognitive processes enhanced, and a new allocation of resources supports cognitive flexibility and the adjustment of long-term goals and survival (Arnsten 2009; Hermans et al., 2014). It is important to note that maladaptation can arise when sympathetic activation cannot be adequately regulated by subsequently released corticosteroids, potentially compromising an individual's ability to exert cognitive control over the emotional aspects of a stressful event.

In this way, the stress response not only influences how much we learn or remember but also could change the nature of those memories and our experiences by adopting different behavioral or cognitive strategies (Schwabe et al., 2007; Seehagen et al., 2015).

3. Decisions under stress

Decision making (DM) constitutes the process of selecting specific options among a range of available alternatives, considering that each option may lead to diverse outcomes, which in turn may be translated into different consequences. Hence, DM requires an efficient information processing, integrating past experiences, stored as long-term memories, present goals and purposes, which may be influenced by perceived environmental information, and the anticipation of future outcomes, finally leading to specific behavioral responses (Lee, 2013; Rosenbloom et al., 2012).

DM represents a complex function, which involves cognitive and emotional processes, necessary for the implementation of adaptive behavioral responses. This is pertinent for simple and everyday decisions made easily, as well as to more complex decisions demanding intensive appraisal processes and more effective coping strategies, such as the experienced in response to different life stressors. This process may essentially aimed to achieve positive outcomes, like rewarding objectives, desirable goals, or avoiding negative stimuli linked to undesirable outcomes or punishment. Hence, the neurobiological processes involved in DM, and the neural structures underlying these processes, are closely associated with the neurobiological bases of other cognitive and emotional functions. In this regard, DM requires the concerted activation of specific areas of the prefrontal cortex (PFC), such as the dorso-lateral PFC (DL-PFC) and the ventro-medial PFC (VM-PFC), as well as subcortical structures, such as the thalamus, the amygdala, and the striatum. The VM-PFC overlaps with areas of the orbito-frontal cortex (OFC) and the anterior cingulate cortex (ACC). The OFC shares reciprocal connections with limbic structures and participates in reward-based and affective-based decisions. Connections between the OFC and the amygdala include projections to intercalated cells of the amygdala, whit a role in disinhibition of autonomic structures in the hypothalamus, and then, a possible increased autonomic arousal; and projections to the central nucleus of the amygdala, involved in autonomic homeostasis. The ACC shares reciprocal connections with other cortical structures, such as the OFC and the DL-PFC, contributing in assessing conflicting options, detecting processing errors and processing outcomes. The DL-PFC receives and integrates multiple sources of information, including perceived information from the present context and those related to past experiences, stored in long-term memories. Hence, the DL-PFC plays a critical role in working memory processes, and therefore, in the development of coping strategies and planning adaptive behavioral responses.

A neurobiological model has been proposed, where DM depends on the interaction between the OFC, the ACC, the DL-PFC, the amygdala and other subcortical neural structures (Wallis, 2007). According to it, the OFC, through reciprocal projections with the amygdala, encodes the value of potentially rewarding outcomes associated with particular decisions. Then, the DLPFC processes incoming information to develop specific strategies aimed at attaining rewarding outcomes, while the

ACC contributes to evaluate the succes probabilities of these strategies before the implementation of behavioral responses (Rosenbloom et al., 2012). In addition, different aminergic systems are involved in this process, such as the dopaminergic system, whit a critical role in effort-based DM. In this regard, a circuit has been described from the basolateral nucleus of the amygdala to the PFC, which then projects to specific striatum structures as the nucleus accumbens core and the ventral pallidum (Salamone and Correa, 2024). This highlights the value of the dopaminergic reward system in identifiyng and selecting among available choices and every effort-based decision making.

Both stress response and the DM process are important for survival. ¿What happens when these two processes take place together? A systematic review by Duque et al. (2022) reveals that chronic stress, with the consequent increase in cortisol levels, are associated with high immediate gains over larger future losses, heightened risk-taking, and reduced risk perception. Moreover, as Mather and Lighthall (2012) suggested, it is possible that acute stress enhances learning of positive outcomes and worsens learning of negative outcomes. Activation of the reward system may increase the salience of reward-associated behaviors, and an immediate gain may lead to neglect better options. Stress may interfere with the assessment of costs and benefits during DM, leading to more impulsive choices and greater reliance on habitual responding (Arnsten et al., 2017). Notably, stress improves "decision--making competence," which includes real-world decision-making abilities and ecological situations with an objectively correct choice (Shields et al., 2016b).

In the domain of pro-social DM, exposure to acute stressors has been linked to more altruistic or cooperative choices, a behavior positively correlated with cortisol levels (Duque et al., 2022). This increased pro-social behavior during stress would ensure support from others in challenging circumstances (Taylor et al., 2000). But it appears to be contingent on factors such as time and social distance. After stress exposure, generosity tends to increase toward socially close individuals but not distant ones, compared to non-stressed subjects or those tested after a delay following stressor onset (Margittai et al., 2015). Furthermore, biological sex and age serve as additional modulating factors (as will be detailed in later sections). Some studies reported that acutely stressed women exhibit greater risk-taking in financial decisions and are less prone to reject economic offers (Nowacki et al., 2019; Youssef et al., 2018). On the other hand, stress has been associated with increased risk-taking among adolescents, which has been attributed to an early stage of prefrontal areas development and higher reliance on subcortical systems (Duque et al., 2022).

Taken together, to comprehensively understand how stress impacts DM and other cognitive processes, numerous variables come into play. The diversity of stressors, their contexts, the time between stress exposure and cognitive tasks, the specific task type, and the individual differences in genetic background, life history, age, and biological sex of the stressed individuals all contribute to a complex matrix of stress effects (Duque et al., 2022; Joëls, 2018; Joëls and Baram, 2009). Factors such as the controllability and predictability of stressors can further modulate the impact of stress' (Maier and Watkins, 2005; Mineka and Hendersen, 1985). At the cellular level, the type of stressor influences the neural populations and mediators involved in adaptive responses. Each stress mediator operates within its preferred spatial and temporal domains. This enables the brain to cope with the wide range of stress-induced challenges; from immediate attention and strategic decisions important for short-term survival, to the storage of information about the stressful event for future reference. In essence, each unique stress situation requires an efficient and coordinated response from several neuronal ensembles throughout the central nervous system.

4. Stress and decision-making in the laboratory

4.1. Decision-making tasks

Classifying various types of choices provides insights into the nature of DM processes across diverse scenarios. This categorization includes distinctions as "Decisions under ambiguity/uncertainty", "Decisions under risk", "Loss aversion," "Intertemporal decisions," "Social decisions" and "Moral decisions". Those explore DM within contexts of uncertain outcome probabilities, known risk likelihood, sensitivity to losses, temporal decision preferences, social interactions or personal moral considerations, respectively. Researchers use model tasks to simulate these specific circumstances, offering valuable knowledge into human-behavior patterns. In Table 1 we provide a concise summary of these DM categories and their corresponding model task, with a brief description.

4.2. Stress protocols

The aim of stress protocols commonly used in experimental conditions is to emulate and study how natural episodes of stress could influence human behavior. In the field of DM, the gold standard protocol is the Trier Social Stress Test, which produces a robust response both of the HPA axis and the SAM system, registered by biological markers and subjective evaluations (Kirschbaum et al., 1993). Other frequent stress protocols, which include psychological and/or physical stressors, are also the Cold Pressor Task (with its variants), the Maastricht acute stress test, and the Matt Stress Reactivity Protocol.

4.2.1. Trier Social Stress Test (TSST)

The TSST covers a combination of tasks to induce stress in humans. Beyond different validated versions, the principal feature of this test lies in the participant's presentation of a short talk, usually framed as a job interview, with the accompaniment of juries, while the participant is video-recorded. After the presentation, the subject has to perform an arithmetic task, e.g: count backward from a large number and subtract another one.

This test has shown increase levels of cortisol, prolactin, hGH, and ACTH, as biomarkers of the HPA-axis (Kirschbaum et al., 1993) and salivary alpha-amylase, as an indirect marker of SAM activation (Petrakova et al., 2015). Furthermore, it has been shown changes in stress indicators such as heart rate and blood pressure (Sequeira et al., 2021).

4.2.2. Cold Pressor Task (CPT)

This is a well-established physical stressor where the participant places the hand or arm in cold water. The water temperature is around 0 °C for approximately 3 min. The cold water stimulus produces mild to moderate pain (Von Baeyer et al., 2005), becoming this test an important instrument in the study of pain, autonomic reactivity, or stress. It increases cortisol levels, heart rate, and skin conductance response (Deuter et al., 2012).

4.2.3. Socially evaluated cold pressor test (SECPT)

This protocol combines the traditional CPT with a social evaluation component. Participants are instructed to immerse a hand or foot in ice-cold water while being observed and socially evaluated by others. This added social dimension increases the stress experienced by the participant. The SECPT is a valuable tool for studying how social factors, such as judgment and observation, impact stress responses, particularly in the context of social anxiety and performance challenges (Kirschbaum et al., 1993).

4.2.4. Maastricht acute stress test (MAST)

The MAST is a protocol that elicits a strong stress response. It combines the TSST and the CPT, triggering the autonomic activation and GC pathways. It starts with a phase of preparation to read task instructions,

Table 1
Types of decisions and models to measured decision-making behavior.

Decision-making (DM) categories	Description	Model task to simulate category-specific decision
Decision under ambiguity/ uncertainty	Involves decisions where the probabilities of outcomes are unknown (Starcke and Brand, 2016)	- Iowa Gambling Task (IGT): detects the ability to alter card choice in response to fluctuating reward contingencies (Bechara et al., 1994) - Ballon Analogue Risk Task (BART): assess risk-taking with uncertain outcomes, through virtual balloon inflation decisions (Lejuez et al., 2002)
Decision under risk	DM with known probabilities of outcomes, assessing and managing risks (Donati et al., 2019)	- Cambridge Gambling Task (CGT): Decisions are taken in a gambling like-scenario and participants generally see the probabilities of gains/losses (Woodrow et al., 2019). -Game of Dice Task (GDT): measures DM under objective risk conditions; participants bet on the results of a dice roll (Donati et al., 2019).
Loss aversion	Choices in context of greater sensitivity to losses than to equivalent gains, that people show when making decisions (Kahneman and Tversky, 1979)	- Lottery task: Decisions are made between lotteries with varying chances of winning/ losing (Margittai et al., 2018).
Intertemporal decisions	Choice preference analysis that is carried out concerning rewards available at different moments in time.	- The Kirby Delay-Discounting Task (DDT): Assess preference for immediate vs. delayed rewards (Kirby et al., 1999) -A 5-trial adjusting delay discounting task: Measure discounting of future rewards over time (Koffarnus and Bickel, 2014)
Social decisions	Choices affecting self and others, often involving psychological conflicts between self-interest and other's he interests (Sanfey, 2007)	-Trust Game: Entrust money to others, hoping for returns (Von Dawans et al., 2012). -Ultimatum Game (UG): Explore fairness and cooperation in money-sharing One player (dictator) propose a split of a sum, and the other accept or reject the offer. (Youssef et al., 2018). - Dictator Game: similar to UG by one the responder could only accept the proposer's offers (Engel, 2011) -Prisoner dilemma: Study of cooperation or selfishness between subjects that not know the other's choice (Heuer and Orland, 2019).
Moral decisions	Subjects are exposed to moral conflict scenarios, challenging altruistic or selfish responses	- Moral Dilemma: participants must decide between options with moral, emotional and personal implications (Greene et al., 2004).

followed by physical stress (CPT) plus a socially evaluated arithmetic task. The procedure incorporates participant's lack of control by its uncertainty about hand immersion duration, and it considers variations in autonomic responses due to anticipatory fear effects. The use of this protocol increases salivary cortisol and alpha-amylase levels in the same way as other usual stressors (Shilton et al., 2017) and shows an increment in blood pressure and heart rate (Smeets et al., 2012).

4.2.5. *Matt Stress Reactivity Protocol (MSRP)*

The MSRP consists of a series of physical and mental stressors. The subjects sat in front of a computer and underwent the stressors in a set order: a Stroop color-word task, mental arithmetic test, anagram task, the CPT, and an interpersonal interview about an own stressful event. It was shown that increases the heart rate response as well as the ACTH and cortisol levels (Traustadottir et al., 2003).

4.2.6. *Overview of stress protocols*

Stress protocols serve as invaluable tools for investigating stress responses in controlled settings, offering researchers reliable means to induce and measure stress reactions. Their relatively low cost and technical simplicity enhance accessibility and reproducibility across different research settings. However, each protocol presents its own set of limitations. The TSST provides a realistic simulation of social stressors, enabling examination of stress responses in interpersonal contexts, while the CPT excels at inducing physical discomfort, useful for studying pain perception and autonomic reactivity. The CPT lacks the social context of real-life stressors, potentially limiting its ecological validity; then the SECPT addresses this limitation by integrating social evaluation into the stress induction process, enabling to explore the interplay between social factors and stress responses. The MAST offers versatility by combining elements of the TSST and CPT, eliciting both social and physical stress responses, while the MSRP incorporates a variety of stressors, providing a comprehensive assessment of stress responses. In conclusion, these protocols offer valuable means to explore stress responses, each with unique advantages and limitations, allowing researchers to optimize the validity and utility of their findings. Researchers should select these protocols judiciously, considering their specific objectives and resource constraints.

4.3. *Drug administration of stress neuromodulators*

Drawing upon established principles of stress neurophysiology, the utilization of pharmaceutical agents with stress neuromodulatory properties offers a valuable avenue for investigating specific physiological aspects of the stress response. This approach makes it possible the emulation of stress-inducing scenarios or the targeted manipulation of specific stress response pathways, facilitating the assessment of their impact on DM. We emphasize however, that these pharmacological agents often replicate certain stress response features, and they do not fully mirror the complexity of the natural stress response. For instance, hydrocortisone is commonly employed to simulate the activation of the HPA axis, a pivotal component of the stress response (Metz et al., 2020; Riis-Vestergaard et al., 2018). Likewise, yohimbine and propranolol find frequent application in modulating the SAM system, respectively augmenting or inhibiting its activity. Notably, hydrocortisone and fludrocortisone both replicate the actions of cortisol, but the second one selectively binds to MRs, enabling a focused examination of this specific receptor's role (Deuter et al., 2017). In the SAM system research, yohimbine and reboxetine are employed to heighten autonomic nervous system responses, effectively emulating the adrenergic pathway during stress (Metz et al., 2020). Conversely, propranolol acts as an inhibitor, attenuating autonomic responses and diminishing markers of arousal (Rogers et al., 2004). In Table 2 we present an overview of frequent pharmacological agents used and its mechanism of action, according if they modulate/emulate HPA axis or SAM pathway.

This broad pharmacological toolkit equips researchers to dissect the intricate interplay between stress response pathways and associated DM processes, while recognizing that pharmacological agents do not fully replicate the natural stress response.

Table 2
Pharmacological agents acting as neuromodulator of the stress response.

Pathway modulated	Drug	Action
HPA, Axis	Hydrocortisone	It is a synthetic analog of natural cortisol, which binds to GRs and MRs cytoplasmic receptors. **Mimic effects induced by stress episode**.
	Fludrocortisone	It exerts major mineralocorticoid action and minor glucocorticoids activity, **binding especially to MRs.**
	Spironolactone	This drug blocks the MRs. This blockade increases available cortisol in basal conditions, which implies greater binding to the GRs. The combination of MR blockade and the release of additional cortisol during stress can lead to a substantial **reduction in the MR/GR activation ratio.**
SAM response	Yohimbine	It is an α2-adrenergic receptor antagonist and increases the Locus Coeruleus firing rate, with a resultant increase in sympathetic outflow. Its application has shown increases in blood pressure, confirming **SAM response activation**. It emulate the catecholaminergic effect triggers during stress.
	Reboxetine	It is a selective NA reuptake inhibitor. In the cerebral cortex, blockade of this process at noradrenergic synapses can lead to arousal. At peripheral synapses, blockade of NA uptake produces a **sympathomimetic effect.**
	Propranolol	Propranolol is a nonselective competitive antagonist of β adrenergic receptors. It exerts its effects primarily by blocking the action of the endogenous catecholamines (A and NA), producing **SAM response inhibition.**

HPA: Hypothalamic-Pituitary-Adrenal axis. SAM: Sympathetic-Adreno-Medullar response. GRs: glucocorticoid receptors. MRs: mineralocorticoid receptors. A: adrenaline. NA: Noradrenaline.

5. Discrepancies in literature

The existing body of literature that explores the interaction between DM and stress episodes reveals a multitude of inconsistencies in its findings. These disparities emerge not only when participants are subjected to well-established stress protocols but also when pharmacological methods are employed (Von Dawans et al., 2021).

For instance, studies employing hydrocortisone, a synthetic cortisol analog used to simulate HPA-axis activation and cortisol increase, have yielded diverse outcomes when assessing DM under risk. While Margittai et al. (2018) detected no discernible effect, Metz et al. (2020) observed a decline in risk-taking, and Kluen et al. (2017) noted an increase in risk-taking. Furthermore, when hydrocortisone was administered alongside yohimbine, thus activating the SAM system, disparate results emerged (Kluen et al., 2017; Metz et al., 2020). Additionally, in the administration of propranolol, a drug known to diminish SAM activity, some studies revealing heightened risk-taking behavior (Rogers et al., 2004) while others focus on loss aversion alteration (Sokol-Hessner et al., 2015). Additional investigations have suggested that individuals under stress protocols tend to modify the risk level of their decisions (towards higher risk) compared to non-stressed counterparts (Lighthall et al., 2009; Wise et al., 2015), although some exceptions, such as the study by Gathmann et al. (2014), challenge this trend. Sex differences have been observed, with men generally making riskier decisions than women do (Lighthall et al., 2009; Mather and Lighthall 2012; Nowacki et al., 2017). Regarding loss aversion, Metz et al. (2020) found no significant effects following the administration of hydrocortisone and yohimbine, while Margittai et al. (2018) reported a decrease in this behavior. These studies use similar but not identical stress or DM protocols and reveal that control of such variables, as well as biological sex of participants, could be an important key to compare results.

When examining intertemporal DM, a significantly effect was observed only when the task was presented 15 min after hydrocortisone administration, with no significant effects detected at later time points (Riis-Vestergaard et al., 2018). The decisions tended to favor sooner rewards in these instances. Neither yohimbine (Herman et al., 2019) nor propranolol administration (Lempert et al., 2012) demonstrated any substantial impact on intertemporal decisions. Studies conducted within laboratory-induced stress settings have indicated that stressed participants exhibit a preference for immediate rewards (Lempert et al., 2012), but an investigation have reported no such effect (Haushofer et al., 2013). Interestingly, the authors recognized that unmeasured variables such perceived stress, reward responsiveness, as well as differences in stress task, may explain the lack of effects or fluctuations in stress' impact on delay discounting.

Furthermore, research on social decisions has produced discrepancies. One study observed an increase in pro-social decisions among stressed women following lab-induced stress episodes (Von Dawans et al., 2019), while a study using the same DM protocols with male participants did not replicate this effect (Von Dawans et al., 2018). But different stressors are combined in these works. When trust-related decisions were studied, as component of social behavior, male individuals under stress displayed greater trust (Von Dawans et al., 2012). However, opposite findings have emerged in works of Salam et al. (2017) and Steinbeis et al. (2015), where stress significantly reduced trust, but towards outgroup people.

Turning to moral DM, stressed participants have often exhibited more altruistic choices than controls (Singer et al., 2017). Interestingly, one study found that stressed women particularly, made more pro-social decisions (Singer et al., 2021). Conversely, other investigations reported that stress had no substantial influence on moral decisions (Starcke et al., 2011) or that stressed participants leaned toward less utilitarian choices (those that maximizes benefits for all individuals involved) (Starcke et al., 2012). Altogether, methodological differences should be considered, regarding the sex of the samples, personality traits, and chosen set of everyday moral dilemmas (with high-emotional content in Starcke studies).

Given the inconsistencies in this field (resumed in Table 3), we have identified key variables in a model to guide future research in the domain of stress and DM. In the next section we offered a detailed explain of this model. As we navigate the intricate web of stress's impact on our choices, it is evident that our understanding remains a work in progress. The divergent findings emphasize the urgency of further investigations looking at the several factors that shape our responses under real-world stress, with a particular focus on underlying and interacting mechanisms.

6. Influence of variables on decision-making under stress: the model

Based on extensive research and the findings presented, we analyze below pivotal variables that modulate DM processes under stress, and summarize them in Fig. 2.

6.1. Decision-making tasks

The selection of DM tasks is a critical component in experiment design, with far-reaching implications for the resulting conclusions. To ensure meaningful comparisons, the decision domain studied must be consistent across studies. Moreover, similar tasks could focus in different facets of the DM process.

For instance, when examining under-risk decisions, some experiments employ a lottery task that explicitly outlines the probabilities of winning or losing. In contrast, the Balloon Analogue Risk Task or the Iowa Gambling Task, introduces an implicit probability risk, where participants are unaware of the exact chances of winning or losing. It is essential to recognize that certain decision types encompass a wide array

Table 3
Divergent results in decision-making under stress.

Stress inducement	Decisions under risk	Loss aversion	Intertemporal decisions	Social decisions	Moral decisions
Stress protocols in laboratory	Leder et al.(2013) Lighthall et al. (2009) Bendahan et al.(2017) Wise et al. (2014) Gathaman et al.(2014) Canale et al. (2017) Cingl et al. (2018) Lighthall et al. (2012)		Lempert et al. (2016) Haushofer et al.(2013)	FeldmanHall et al. (2015) Margittai et al. (2015) Potts et al. (2019) Steinbeis et al. (2015) Vinkers et al. (2013) Youssef et al. (2018) Schweda et al. (2019) Von Dawans et al. (2012) Von Dawans et al. (2019) Zhang et al.(2019) Von Dawans et al.(2019) Salam et al. (2017) Nickels et al. (2017) Sollberger et al. (2016)	Singer et al.(2017) Singer et al.(2021) Starcke et al.(2012) Starcke et al.(2011) Youssef et al. (2012)
Pharmacological stress	Kluen et al. (2017) [H] Putman et al. (2010) [H] Cueva et al. (2015) [H] Metz et al. (2020) [H] Margittai et al. (2018) [H] Robertson et al., (2016) [H] Metz et al. (2020) [H+Y] Kluen et al. (2017) [H+Y] Rogers et al. (2004) [P] Sokol-Hessner et al. (2015) [P]	Margittai et al., (2018) [H] Metz et al., (2020) [H] Margittai et al., (2018) [H+Y] Metz et al., (2020) [H+Y] Rogers et al. (2004) [P] Sokol-Hessner et al. (2015) [P]	Cornelisse et al.(2013) [H] Riis-Vestergaard et al.(2018) [H] Herman et al, (2019) [Y] Lempert et al. (2017) [P]		

Upper half: results from laboratory-induced stress protocols, examining specific DM tasks post-stress
Lower half: pharmacological administration of stress neuromodulators in DM tasks.
Dark gray shading: increase in the measured decisions among stressed participants compared to control group,
Light gray shading: decrease in the measured decisions among stress participants vs control group
Unshaded: no significant effect between stressed and control groups
H: Hydrocortisone; Y:Yohimbine; P: Propanolol

of subdomains. Consider the social-decisions domain, particularly in the context of trust. Here, measurement tasks range from the Game Theory (situations in which decision-makers must interact with one another) to the economic field. The approach known as the "trust game" is used to measure DM in social interactions with financial outcomes (Tzieropoulos, 2013). But alternative quantifications of trust exist, for example, presenting a facial image and prompting the participant to determine whether the depicted face appears trustworthy or not (Salam et al., 2017).

6.2. Habitual versus novel decisions

Habits represent automatic or reflex responses initiated by environmental cues (Robbins and Costa, 2017). Before the development of a habit, an action is a goal-directed response. However, through repetition and training, the response gradually becomes automatic (Carden and Wood, 2018). These two systems exhibit distinct energy requirements, with goal-directed actions consuming more energy compared to habitual responses. Certain decisions can readily evolve into habits (e.g., opting for fast food, tuning in to the news on television, or taking a bus) and remain susceptible to alterations or deactivation in response to changes in the context (Ji and Wood, 2007; Wood et al., 2005).

As we posited earlier, stress may trigger a shift in these responses, from goal-directed actions to more rigid stimulus-response behaviors. This has been observed in both humans and rodents (Dolan and Dayan, 2013; Plessow et al., 2012; Schwabe, 2017; for a comprehensive review).

6.3. Timing effects

A critical time frame exists between the onset of a stressor and the responses of both the HPA-axis and the SAM system. In the case of the HPA-axis, the release of GC from the adrenal cortex peaks at around 20 min after stress initiates and GC remain increased for a longer period. Regarding the SAM system, catecholamines are released almost immediately upon the stressor's onset, returning to normal levels within 30–60 min (Hermans et al., 2014). It's important to remember that GC exerts both fast non-genomic and slower genomic effects (Von Dawans et al., 2021). The genomic changes become evident approximately 1 h after the onset of stress and persist for several hours. On the other hand, non-genomic effects of GC may be coupled to earlier catecholaminergic activation. Importantly, genomic and non-genomic effects can support distinct actions and even describe opposite changes over time. In summary, when designing a stress study to assess its impact on cognitive tasks, the timing of task presentation should be carefully considered, irrespective of stress-inducing protocol (behavioral or pharmacological).

In the context of DM, studies have shown intriguing outcomes following the hydrocortisone administration. People receiving hydrocortisone doses tend to exhibit a preference for smaller, more immediate rewards when decisions are made around 15 min (Riis Vestergaard et al., 2018). But no effects are observable at other time points. The earlier influence of hydrocortisone seems to involve the non-genomic aspect of GC effects. In contrast, the effects of hydrocortisone on risk-taking behaviors seem to involve genomic-GC influences, since they are observed when drugs are administered around 60 min (or more) before DM task. Several studies have reported increased risk-taking in this timeframe (Cueva et al., 2015; Kluen et al., 2017; Putman et al., 2010). Nevertheless, other studies have shown a decrease in risk-taking (Metz et al., 2020), or even inconclusive results, when the decision task is conducted 45 min after drug administration (Margittai et al., 2018). In the Game of Dice task different results were found among participants in accordance with the time between the onset of psychosocial stress and the execution of DM task, with even a few minutes making a difference (Pabst et al., 2013). It is essential to highlight the significance of considering the precise timing of events in stress related DM studies.

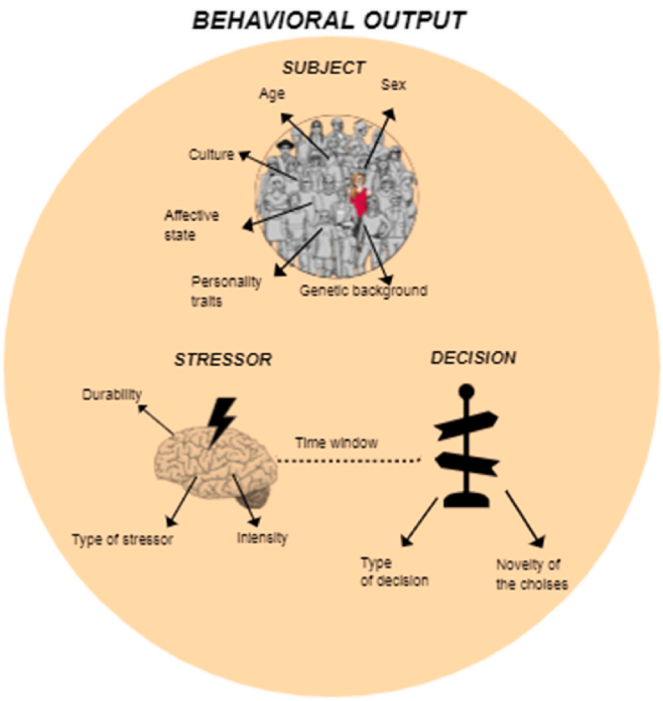

Fig. 2. A proposed model of decision-making under stress. The inconsistencies observed in experimental results of several scientific research could be explained by the interplay of numerous variables. They encompass the nature of stress event, type of decision to be made and the particular individualities of person involved. After the appearance of the stressor, the timing between its onset and the decision is crucial; as well as whether the DM process involves habitual or novel choices. Furthermore, each individual is under the pervasive influence of multiple factors, as their genetic background, predisposition to stress, personality traits, age, sex, and cultural context. This model posit that all of the detailed variables detail interact with each other and converge to generate a specific decision output.

6.4. Dose-dependency and receptor stimulation in pharmacological studies

The administered doses of stress neuromodulators are a critical factor, potentially reflecting different activation of the stress circuits. For instance, it has been reported that the administration of a high dose (20 mg) of a drug or combinations of drugs (e.g., hydrocortisone and yohimbine) led to a reduction in loss aversion (Margittai et al., 2018). However, when a lower dose (10 mg of both drugs) was administered, no significant effects were observed (Metz et al., 2020).

It should be considered that drug studies aim to emulate specific mechanisms of the stress response but cannot entirely replicate all the changes induced by stressor stimuli in a natural context. Furthermore, the drugs used may act on specific receptors of neural populations. For instance, hydrocortisone and fludrocortisone both stimulate the HPA axis, but hydrocortisone attaches to GR and MR and fludrocortisone specifically binds to MR. Additionally, the type of stress event will influence the specific population of neurons and mediators involved. To illustrate, physical stressors such as blood loss rapidly recruit hypothalamic and brainstem regions, whereas psychological stressors like exams primarily involve brain regions associated with emotions (amygdala), learning and memory (hippocampus), and DM (prefrontal cortex) (Joëls and Baram, 2009).

6.5. Differences according to sex and age

The influence of sex on interaction between DM and stress processes has become a topic of increasing interest in recent research. Several studies assessing different types of decision have showed a predominance of male participants (Margittai et al., 2018; Metz et al., 2020; Montoya et al., 2014; Putman et al., 2010; Riis-Vestergaard et al., 2018; Robertson et al., 2016). This sex imbalance prompts consideration of its relevance in explaining the observed differences in DM under stressful conditions.

Therefore, while certain studies leave a gap for the examination of biological sex disparities, others have provided valuable insights. Mather and Lighthall (2012) reported significant e findings, suggesting that male participants tend to make riskier decisions compared to their female counterparts. On the other hand, similar results between male and female samples were obtained for Von Dawans and coworkers in the context of social decisions, with alternative stressor (Von Dawans et al., 2012, 2019),. Additional studies have shown that, under acute stress, women exhibit greater risk-taking behavior in financial decisions than men, and display lower rates of rejection in response to economic offers (Nowacki et al., 2019; Youssef et al., 2018). Overall, it is crucial to emphasize the interplay among task types, decision processes involved, sexual hormones and stress-specific factors, which can yield diverse outcomes rather than a singular trend.

In the review conducted by Oyola and Handa (2017), it is explained that from early stages, gonadal steroids can influence the HPA axis, thereby modifying the responsiveness of this axis and modulating the levels of corticosterone. Circulating estradiol in women influence stress hormones, stress response and could mediate adaptive DM, as it is most effective for organisms to exhibit behaviors that are appropriate to their reproductive states (Orsini and Setlow 2016; Oyola and Handa 2017). Also, elevated stress hormones can negatively regulate the reproductive axis and consequently the circulating gonadal hormones. The presence of sex hormones during gestation and development organize whether and how acute stress will affect the acquisition of new information in adulthood (Shors and Miesegaes, 2002). On the other hand, DM is sensitive to the dopaminergic pathway, and interactions between gonadal hormones (such as estradiol) and dopamine signaling are documented (Orsini and Setlow, 2016). How decisional making processing centers, like the prefrontal cortex, interact with other targets to regulate the activation of the HPA and hypothalamus-gonadal axis still needs revision.

The age of individuals exerts its own influences in stress-decision matrix. Joëls and Baram (2009) remark that signal perceived as a stressor change with aging, as well as do the molecular cascades activated by stress in specific cerebral regions: mediators in infant stage could differ from those in adulthood. Furthermore, glucocorticoids are important for normal brain maturation. Vast literature documents that exposure to stress and/or sex hormones early in the development could significantly modify behaviors expressed in adulthood (Lupien et al., 2009; Shors, 2004).

6.6. Influence of affective state

The affective state of an individual could influence their cognitive control processes, and. It significantly impact how an individual evaluates and engages in specific actions. As highlighted by Culot and Gevers (2021), emotions can modulate the subjectively perceived cost-benefit of numerous actions, ultimately influencing the choices individuals make. For instance, positive emotions have been associated with a reduced perception of effort required to complete tasks, making complex activities appear more manageable and even no stressful (Askim and Knardahl, 2021). The interplay between affective states and DM is an intriguing area of study, shedding light on how our emotional experiences shape our cognitive responses and behavioral choices. In this sense, seems pertinent to note that individuals with mental disorders may display alternative behaviors. Those exhibiting addictive behaviors (Amlung et al., 2017; Kirby et al., 1999), depressive disorders (Pulcu et al., 2014), and schizophrenia (Brown et al., 2018), for example, have demonstrated a pronounced preference for smaller yet more immediate rewards over larger but delayed ones.

6.7. Genetic background, experience, and cultural influences

In the intricate tapestry of human behavior, genetic factors, individual experiences, and cultural influences converge to mold several cognitive functions, and DM is not an exception. It is essential to recognize that our genetic pool, including the genes we inherit and how they are expressed, has been influenced by the experiences of our ancestors. Moreover, our present experiences continue to shape the expression of these genes, as can be seen with the environmental enrichment or isolation, which also influence the range of stressors and their impact on an individual's brain (Joëls and Baram, 2009).

Therefore, our genetic predispositions, along with our present state of being, determine how we interact with the world around us, perceive our environment, and make decisions, in a dynamic that can evolve over time (Pinel and Barnes, 2017). As it is proposed by these authors the confluence of our genetic heritage and our lived experiences underpins the mechanisms of choice.

Furthermore, the influence of culture adds another layer of complexity to DM under stress. While there is limited research on this topic (Chen et al., 2020; Sachdeva et al., 2011; Salam et al., 2017), cultural differences could be a crucial factor. For instance, the response to stimuli like pedestrian traffic lights varies between cultures; while in a European country, the reaction is often to stop, in a Latin-American city, individuals may rely on environmental cues, such as looking both ways for oncoming cars, rather than the traffic lights. The shared beliefs, values, behaviors, and traditions that make up an individual's culture affect the way of subjects communicates and receives information and impacts complex DM. People go through a process of negotiation between their individuality and their cultural, political, and social situatedness. Therefore, given that each individual's cultural background and learning experiences could significantly shape perception and DM, especially in response to stressors, this variable could contribute to determining the ultimate behavioral outcome.

To comprehend how individuals make decisions and navigate the complexities of their environment, it is imperative to explore the interplay between nature and nurture, genes and experiences, and cultural factors, as they collectively contribute to the mosaic of human behavior.

6.8. Model highlights and future directions

By presenting a unified model with the different variables mentioned, we aim to offer a holistic perspective on DM under stress. It serves as a valuable framework for comprehending the complex interplay of factors that influence DM and stress response, shedding light on the inconsistencies often observed in scientific research. The model, encapsulated in Fig. 2, points to the integration of key factors that modulate the DM process.

First and foremost, the nature of the DM (in natural environments or ecological laboratory settings) stands as a critical determinant. The specific task employed in research studies, whether involving risk assessments, social decisions, or intertemporal choices, to illustrate, is a remarkable point. The distinction between tasks that may appear similar but focus on different aspects of the decision process underscores the need for careful consideration when designing experiments. It is imperative to account for the diverse subdomains within decision types and acknowledge that a variety of quantification approaches exist. We recommend employing specific-subdomain, consistent, standardized, and scalable tests, that enable comparability of results, facilitating the derivation of reliable conclusions.

Another crucial dimension in monitoring is whether decisions that subjects confront are habitual responses or involve novel experiences and choices, and how those might interact with the elicited level of stress. The stress situations can shift goal-directed responses to more rigid stimulus-response conduct, and it is determinant in behavior elicited.

The model also proposes the key role of timing between the stressor and the DM process. The temporal alignment between the stressor's appearance and the ensuing responses of the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic-adrenal-medullary (SAM) system must be meticulously considered. The genomic and non-genomic effects of stress hormones, along with the changes prompt by the catecholamine cascade, unfold over different temporal phases. Therefore, each pathway not only will trigger effects at different times, but could interact distinctively with the stages of DM processing. Moreover, the method chosen to induce stress (e.g.: drug-injection or natural stressful tasks), may engage different circuits with specific temporal dynamics. Future studies ought to take note of these factors, managing the required temporal windows between procedures and considering all interacting underlying mechanisms.

The model also emphasizes the relevance of paying attention when pharmacological studies are conducted. The selection of pharmacological agents and its dosage can yield profound consequences, given that: (i) each drug emulate specific mechanisms of stress response rather than encompassing the entire complex array elicited by natural stressors, (ii) neuromodulation is contingent upon specific cellular population affected as well as the affinity and occupancy of its receptors (iii) the emergence of negative or positive feedbacks associated with drug accumulation (iv) potential interactions may arise with the simultaneous administration of multiple drugs. Therefore, in the formulation of pharmacological studies (or their comparison with others) a delineation of these parameters becomes imperative.

Biological sex is an additional factor influencing behavioral differences. The impact of stress on DM can vary significantly between women and men, with specific directions depending on decision type and context. As we expose before, age also contributes to differences in stress response and decisions made across the life-span, according to the development of key brain regions and changes in mediators or circuits involved. By examining the influence of sex hormones, age range of population, or even cultural sex biases on stress response and DM, a comprehensive insight into their interactions may be elucidated. If the data includes different values for these variables, it is imperative to utilize them as covariates in the respective analyses.

An additional proposition posited by the model entails considering the affective state of individuals. This recognizes the influence of positive emotions, negative feelings and even mental disorders on altering preferences and the perception of stressful situations. Specific conditions within the affective state can be assessed through suitable tests, typically integrated into the experimental protocol.

The model also highlights the dynamic relationship between an individual's genetic configuration and predispositions, and the experiences that shape their behavior. This interplay influences an individual's response to events, their perception of the environment, and how these dynamics evolve over time.

Finally, we also introduce the significance of cultural factors, albeit an area with limited current research. The norms, practices, and interpretations within a culture can profoundly influence how individuals respond to stressors and make decisions. Future studies should approach this factor with caution, opting to stratify populations based on diverse origins and/or cultural backgrounds, or alternatively, incorporate this element as an additional covariate. By acknowledging this dimension, the model adds an extra layer of complexity to the understanding of DM under stress.

7. Concluding remarks

Our model is built upon an extensive review of the existing literature regarding the influence of stress on cognition, focusing particularly on various facets of DM in humans. It is essential to note that this model primarily pertains to individuals without pre-existing medical conditions, as the presence of diseases certainly introduce new variables that should be discussed.

Additionally, the variables proposed in our model affecting DM have yielded disparities in other studies examining cognition under stress conditions. For instance, the effects of acute stress on working memory appears to vary between men and women (Schoofs et al., 2013), as well as occurs with scores in spatial attention tasks (Richardson and VanderKaay Tomasulo, 2022).

Furthermore, our model introduces the novel concept of assessing cultural factors, an aspect that has remained largely unexplored in empirical research to date. In summary, the multiple factors described here, encompassing the timing between the stressor onset and the decision-making task, the specific decision type (e.g., moral or social/novel or habitual), the nature and intensity of stressor, the individual's affective state, as well as their personality traits, genetic background, age, and sex, built a complex interplay culminating in multiple DM outcomes.

8. Limitations

Our work is not without limitations. First, while the comprehensive model of DM under stress presented provides an integrative framework for understanding variables interaction, details of mechanisms underlying its interactions are desirable. The specific neural pathways as well as biochemical processes warrant more in-depth knowledge in this field. Second, the model encapsulates a wide array of variables, making it challenging to tease apart the relative contributions of each one in decision outcomes. Additionally, the model does not account for complex interactions or feedback loops between variables, which could yield nonlinear or unexpected effects. Third, the cultural dimension remains a largely uncharted territory in existing research. Finally, the model is a theoretical integrative framework and does not provide experimental results. The complex interaction between DM process, stress response and multiple covariates, make it challenging to build a testable model in the traditional way. We aim to illustrate the significance of particular features, the potential influences they exert (in order or directions), the inherent challenge of understanding their impact when uncontrolled, and the imperative need to examine them closely in DM tasks. As such, it is essential to conduct further research to test and refine the model's propositions.

Criteria for studies selection

We conducted an extensive literature search of peer-reviewed journal articles focusing on the effects of stress induction, either through laboratory procedures or pharmacological administration of stress neuromodulators, on decision-making in healthy individuals, as compared to a control group. We excluded review articles, case studies, book chapters, pilot studies, and non-human animal research. Our search spanned across APA PsycNet, Cochrane, PubMed, ScienceDirect, Scopus, and Web of Science databases. Additionally we conducted manual searches, including Google Scholar and cross-referencing relevant publications. Please, see supplementary material for additional details.

CRediT authorship contribution statement

Luis Felipe Sarmiento: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Pamela Lopes da Cunha:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Data curation, Supervision. **Sonia Tabares:** Resources. **Gustavo Tafet:** Supervision, Writing – review & editing. **Amauri Gouveia Jr:** Supervision.

Declaration of competing interest

I am writing to confirm that as the corresponding author of the manuscript. I, Dr. Luis Felipe Sarmiento, hereby certify that all authors involved in the publication of the aforementioned paper declare no conflicts of interest pertaining to the research conducted and its outcomes.

Data availability

No data was used for the research described in the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bbih.2024.100766.

References

Abercrombie, H.C., Kalin, N.H., Thurow, M.E., Rosenkranz, M.A., Davidson, R.J., 2003. Cortisol variation in humans affects memory for emotionally laden and neutral information. Behav. Neurosci. 117 (3), 505. https://doi.org/10.1037/0735-7044.117.3.505.

Allen, A.P., Kennedy, P.J., Cryan, J.F., Dinan, T.G., Clarke, G., 2014. Biological and psychological markers of stress in humans: focus on the trier social stress test. Neurosci. Biobehav. Rev. 38, 94–124. https://doi.org/10.1016/j.neubiorev.2013.11.005.

Amlung, M., Vedelago, L., Acker, J., Balodis, I., MacKillop, J., 2017. Steep delay discounting and addictive behavior: a meta-analysis of continuous associations. Addiction 112 (1), 51–62. https://doi.org/10.1111/add.13535.

Arnsten, A.F., 2009. Stress signalling pathways that impair prefrontal cortex structure and function. Nat. Rev. Neurosci. 10 (6), 410–422. https://doi.org/10.1038/nrn2648.

Arnsten, A.F., Lee, D., Pittenger, C., 2017. Risky business: the circuits that impact stress-induced decision-making. Cell 171 (5), 992–993. https://doi.org/10.1016/j.cell.2017.11.004.

Askim, K., Knardahl, S., 2021. The influence of affective state on subjective-report measurements: evidence from experimental manipulations of mood. Front. Psychol. 12, 601083 https://doi.org/10.3389/fpsyg.2021.601083.

Bahari, Z., Meftahi, G.H., Meftahi, M.A., 2018. Dopamine effects on stress-induced working memory deficits. Behav. Pharmacol. 29 (7), 584–591. https://doi.org/10.1097/FBP.0000000000000429.

Beato, M., Sánchez-Pacheco, A., 1996. Interaction of steroid hormone receptors with the transcription initiation complex. Endocr. Rev. 17 (6), 587–609. https://doi.org/10.1210/edrv-17-6-587.

Bechara, A., Damasio, A.R., Damasio, H., Anderson, S.W., 1994. Insensitivity to future consequences following damage to human prefrontal cortex. Cognition 50 (1–3), 7–15. https://doi.org/10.1016/0010-0277(94)90018-3.

Brown, H.E., Hart, K.L., Snapper, L.A., Roffman, J.L., Perlis, R.H., 2018. Impairment in delay discounting in schizophrenia and schizoaffective disorder but not primary mood disorders. NPJ schizophrenia 4 (1), 1–7. https://doi.org/10.1038/s41537-018-0050-z.

Carden, L., Wood, W., 2018. Habit formation and change. Current opinion in behavioral sciences 20, 117–122. https://doi.org/10.1016/j.cobeha.2017.12.009.

Chen, X.J., Ba, L., Kwak, Y., 2020. Neurocognitive underpinnings of cross-cultural differences in risky decision making. Soc. Cognit. Affect Neurosci. 15 (6), 671–680. https://doi.org/10.1093/scan/nsaa078.

Cueva, C., Roberts, R.E., Spencer, T., Rani, N., Tempest, M., et al., 2015. Cortisol and testosterone increase financial risk taking and may destabilize markets. Sci. Rep. 5 (1), 1–16. https://doi.org/10.1038/srep11206.

Culot, C., Gevers, W., 2021. Happy is easy: the influence of affective states on cognitive control and metacognitive reports. Cognit. Emot. 35 (6), 1195–1202. https://doi.org/10.1080/02699931.2021.1932427.

Datson, N.A., Morsink, M.C., Meijer, O.C., de Kloet, E.R., 2008. Central corticosteroid actions: search for gene targets. Eur. J. Pharmacol. 583 (2–3), 272–289. https://doi.org/10.1016/j.ejphar.2007.11.070.

Daviu, N., Bruchas, M.R., Moghaddam, B., Sandi, C., Beyeler, A., 2019. Neurobiological links between stress and anxiety. Neurobiology of stress 11, 100191. https://doi.org/10.1016/j.ynstr.2019.100191.

de Kloet, ER, Joëls, M, Holsboer, F, 2005. Stress and the brain: from adaptation to disease. Nat Rev Neurosci 6, 463–475.

De Kloet, E.R., Oitzl, M.S., Joëls, M., 1999. ¿Stress and cognition: are corticosteroids good or bad guys? Trends Neurosci. 22 (10), 422–426. https://doi.org/10.1016/S0166-2236(99)01438-1.

De Quervain, D.J., Roozendaal, B., Nitsch, R.M., McGaugh, J.L., Hock, C., 2000. Acute cortisone administration impairs retrieval of long-term declarative memory in humans. Nat. Neurosci. 3 (4), 313–314. https://doi.org/10.1038/73873.

Deuter, C.E., Kuehl, L.K., Blumenthal, T.D., Schulz, A., Oitzl, M.S., et al., 2012. Effects of cold pressor stress on the human startle response. PLoS One 7 (11), e49866. https://doi.org/10.1371/journal.pone.0049866.

Deuter, C.E., Wingenfeld, K., Schultebraucks, K., Hellmann-Regen, J., Piber, D., et al., 2017. Effects of mineralocorticoid-receptor stimulation on risk taking behavior in young healthy men and women. Psychoneuroendocrinology 75, 132–140. https://doi.org/10.1016/j.psyneuen.2016.10.018.

Dolan, R.J., Dayan, P., 2013. Goals and habits in the brain. Neuron 80 (2), 312–325. https://doi.org/10.1016/j.neuron.2013.09.007.
Donati, M.A., Frosini, A., Izzo, V.A., Primi, C., 2019. The effectiveness of the *Game of Dice Task* in predicting at-risk and problem gambling among adolescents: the contribution of the neural networks. J. Gambl. Stud. 35 (1), 14. https://doi.org/10.1007/s10899-018-9796-5.
Dunsmoor, J.E., Murty, V.P., Davachi, L., Phelps, E.A., 2015. Emotional learning selectively and retroactively strengthens memories for related events. Nature 520 (7547), 345–348. https://doi.org/10.1038/nature14106.
Duque, A., Cano-López, I., Puig- Pérez, S., 2022. Effects of psychological stress and cortisol on decision making and modulating factors: a systematic review. Eur. J. Neurosci. 56 (2), 3889–3920. https://doi.org/10.1111/ejn.15721.
Engel, C., 2011. Dictator games: A meta study. Experimental economics 14, 583–610. https://doi.org/10.2139/ssrn.1568732.
Finsterwald, C., Alberini, C.M., 2014. Stress and glucocorticoid receptor-dependent mechanisms in long-term memory: from adaptive responses to psychopathologies. Neurobiol. Learn. Mem. 112, 17–29. https://doi.org/10.1016/j.nlm.2013.09.017.
Gathmann, B., Schulte, F.P., Maderwald, S., Pawlikowski, M., Starcke, K., et al., 2014. Stress and decision making: neural correlates of the interaction between stress, executive functions, and decision making under risk. Exp. Brain Res. 232 (3), 957–973. https://doi.org/10.1007/s00221-013-3808-6.
Greene, J.D., Nystrom, L.E., Engell, A.D., Darley, J.M., Cohen, J.D., 2004. The neural bases of cognitive conflict and control in moral judgment. Neuron 44 (2), 389–400. https://doi.org/10.1016/j.neuron.2004.09.027.
Groc, L., Choquet, D., Chaouloff, F., 2008. The stress hormone corticosterone conditions AMPAR surface trafficking and synaptic potentiation. Nat. Neurosci. 11 (8), 868–870. https://doi.org/10.1038/nn.2150.
Groeneweg, F.L., Karst, H., de Kloet, E.R., Joëls, M., 2011. Rapid non-genomic effects of corticosteroids and their role in the central stress response. J. Endocrinol. 209, 153–167. https://doi.org/10.1530/JOE-10-0472.
Harrell, J.M., Murphy, P.J., Morishima, Y., Chen, H., Mansfield, J.F., et al., 2004. Evidence for glucocorticoid receptor transport on microtubules by dynein. J. Biol. Chem. 279 (52), 54647–54654. https://doi.org/10.1074/jbc.M406863200.
Haushofer, J., Cornelisse, S., Seinstra, M., Fehr, E., Joëls, M., et al., 2013. No effects of psychosocial stress on intertemporal choice. PLoS One 8 (11), e78597. https://doi.org/10.1371/journal.pone.0078597.
Henckens, M.J., Van Wingen, G.A., Joëls, M., Fernández, G., 2012. Time-dependent effects of cortisol on selective attention and emotional interference: a functional MRI study. Front. Integr. Neurosci. 6 (66) https://doi.org/10.3389/fnint.2012.00066.
Herman, A.M., Critchley, H.D., Duka, T., 2019. The impact of Yohimbine-induced arousal on facets of behavioural impulsivity. Psychopharmacology 236 (6), 1783–1795. https://doi.org/10.1007/s00213-018-5160-9.
Hermans, E.J., Henckens, M.J., Joëls, M., Fernández, G., 2014. Dynamic adaptation of large-scale brain networks in response to acute stressors. Trends Neurosci. 37 (6), 304–314. https://doi.org/10.1016/j.tins.2014.03.006.
Heuer, L., Orland, A., 2019. Cooperation in the Prisoner's Dilemma: an experimental comparison between pure and mixed strategies. R. Soc. Open Sci. 6 (7), 182142 https://doi.org/10.1098/rsos.182142.
Ji, M.F., Wood, W., 2007. Purchase and consumption habits: not necessarily what you intend. J. Consum. Psychol. 17 (4), 261–276. https://doi.org/10.1016/S1057-7408(07)70037-2.
Joëls, M., 2006. Corticosteroid effects in the brain: U-shape it. Trends Pharmacol. Sci. 27, 244–250. https://doi.org/10.1016/j.tips.2006.03.007.
Joëls, M., 2018. Corticosteroids and the brain. J. Endocrinol. 238 (3), R121–R130. https://doi.org/10.1530/JOE-18-0226.
Joëls, M., Baram, T.Z., 2009. The neuro-symphony of stress. Nat. Rev. Neurosci. 10 (6), 459–466. https://doi.org/10.1038/nrn2632.
Joëls, M., Fernandez, G., Roozendaal, B., 2011. Stress and emotional memory: a matter of timing. Trends Cognit. Sci. 15 (6), 280–288. https://doi.org/10.1016/j.tics.2011.04.004.
Joëls, M., Pu, Z., Wiegert, O., Oitzl, M.S., Krugers, H.J., 2006. Learning under stress: ¿How does it work? Trends Cognit. Sci. 10 (4), 152–158. https://doi.org/10.1016/j.tics.2006.02.002.
Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–292. https://doi.org/10.2307/1914185.
Kirby, K.N., Petry, N.M., Bickel, W.K., 1999. Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. J. Exp. Psychol. Gen. 128 (1), 78. https://doi.org/10.1037/0096-3445.128.1.78.
Kirschbaum, C., Pirke, K.M., Hellhammer, D.H., 1993. The 'Trier Social Stress Test' a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 28 (1–2), 76–81. https://doi.org/10.1159/000119004.
Kluen, L.M., Agorastos, A., Wiedemann, K., Schwabe, L., 2017. Cortisol boosts risky decision-making behavior in men but not in women. Psychoneuroendocrinology 84, 181–189. https://doi.org/10.1016/j.psyneuen.2017.07.240.
Koffarnus, M.N., Bickel, W.K., 2014. A 5-trial adjusting delay discounting task: accurate discount rates in less than one minute. Exp. Clin. Psychopharmacol 22 (3), 222–228. https://doi.org/10.1037/a0035973.
Kuhlmann, S., Piel, M., Wolf, O.T., 2005. Impaired memory retrieval after psychosocial stress in healthy young men. J. Neurosci. 25 (11), 2977–2982. https://doi.org/10.1523/JNEUROSCI.5139-04.2005.
Lalumiere, R.T., Mcgaugh, J.L., Mcintyre, C.K., 2017. Emotional modulation of learning and memory: pharmacological implications. Pharmacol. Rev. 69, 236–255. https://doi.org/10.1124/pr.116.013474.
Lee, D., 2013. Decision making: from neuroscience to psychiatry. Neuron 78 (2), 233–248. https://doi.org/10.1016/j.neuron.2013.04.008.
Lejuez, C.W., Read, J.P., Kahler, C.W., Richards, J.B., Ramsey, S.E., et al., 2002. Evaluation of a behavioral measure of risk taking: the balloon analogue risk task (BART). J. Exp. Psychol. Appl. 8 (2), 75–84. https://doi.org/10.1037/1076-898X.8.2.75.
Lempert, K.M., Porcelli, A.J., Delgado, M.R., Tricomi, E., 2012. Individual differences in delay discounting under acute stress: the role of trait perceived stress. Front. Psychol. 3, 251. https://doi.org/10.3389/fpsyg.2012.00251.
Lighthall, N.R., Mather, M., Gorlick, M.A., 2009. Acute stress increases sex differences in risk seeking in the balloon analogue risk task. PLoS One 4 (7), e6002. https://doi.org/10.1371/journal.pone.0006002.
Lopes da Cunha, P., Ramírez Butavand, D., Chisari, L.B., Ballarini, F., Viola, H., 2018a. Exams at classroom have bidirectional effects on the long-term memory of an unrelated graphical task. npj Science of Learning 3 (1), 1–5. https://doi.org/10.1038/s41539-018-0036-7.
Lopes da Cunha, P., Villar, M.E., Ballarini, F., Tintorelli, R., Viola, H., 2018b. Spatial object recognition memory formation under acute stress. Hippocampus 29 (6), 491–499. https://doi.org/10.1002/hipo.23037.
Lopes da Cunha, P., Tintorelli, R., Correa, J., Budriesi, P., Viola, H., 2021. Behavioral Tagging as a mechanism for aversive-memory formation under acute stress. Eur. J. Neurosci. https://doi.org/10.1111/ejn.15249.
Lupien, S.J., McEwen, B.S., Gunnar, M.R., Heim, C., 2009. Effects of stress throughout the lifespan on the brain, behaviour and cognition. Nat. Rev. Neurosci. 10 (6), 434–445. https://doi.org/10.1038/nrn2639.
Maier, S.F., Watkins, L.R., 2005. Stressor controllability and learned helplessness: the roles of the dorsal raphe nucleus, serotonin, and corticotropin-releasing factor. Neurosci. Biobehav. Rev. 29 (4–5), 829–841. https://doi.org/10.1016/j.neubiorev.2005.03.021.
Margittai, Z., Strombach, T., Van Wingerden, M., Joëls, M., Schwabe, L., et al., 2015. A friend in need: time-dependent effects of stress on social discounting in men. Horm. Behav. 73, 75–82. https://doi.org/10.1016/j.yhbeh.2015.05.019.
Margittai, Z., Nave, G., Van Wingerden, M., Schnitzler, A., Schwabe, L., et al., 2018. Combined effects of glucocorticoid and noradrenergic activity on loss aversion. Neuropsychopharmacology 43 (2), 334–341. https://doi.org/10.1038/npp.2017.75.
Mather, M., Lighthall, N.R., 2012. Both risk and reward are processed differently in decisions made under stress. Curr. Dir. Psychol. Sci. 21 (1), 36–41. https://doi.org/10.1177/0963721411429452.
McGaugh, J.L., 2013. Making lasting memories: remembering the significant. Proc. Natl. Acad. Sci. USA 110 (2), 10402–10407. https://doi.org/10.1073/pnas.1301209110.
McGaugh, J.L., Roozendaal, B., 2002. Role of adrenal stress hormones in forming lasting memories in the brain. Curr. Opin. Neurobiol. 12 (2), 205–210. https://doi.org/10.1016/s0959-4388(02)00306-9.
Metz, S., Waiblinger-Grigull, T., Schulreich, S., Chae, W.R., Otte, C., et al., 2020. Effects of hydrocortisone and yohimbine on decision-making under risk. Psychoneuroendocrinology 114, 104589. https://doi.org/10.1016/j.psyneuen.2020.104589.
Mineka, S., Hendersen, R.W., 1985. Controllability and predictability in acquired motivation. Annu. Rev. Psychol. 36 (1), 495–529. https://doi.org/10.1146/annurev.ps.36.020185.002431.
Montoya, E.R., Bos, P.A., Terburg, D., Rosenberger, L.A., van Honk, J., 2014. Cortisol administration induces global down-regulation of the brain's reward circuitry. Psychoneuroendocrinology 47, 31–42. https://doi.org/10.1016/j.psyneuen.2014.04.022.
Ness, D., Calabrese, P., 2016. Stress effects on multiple memory system interactions. Neural Plast. 2016 https://doi.org/10.1155/2016/4932128.
Nowacki, J., Heekeren, H.R., Deuter, C.E., Joerißen, J.D., Schröder, A., et al., 2019. Decision making in response to physiological and combined physiological and psychosocial stress. Behav. Neurosci. 133 (1), 59. https://doi.org/10.1037/bne0000288.
Nowacki, J., Heekeren, H., Wingenfeld, K., Otte, C., 2017. Decision making under risk in response to psychophysiological stress. Psychoneuroendocrinology 83, 15. https://doi.org/10.1016/j.psyneuen.2017.07.279.
Orsini, C.A., Setlow, B., 2016. Sex differences in animal models of decision making. J. Neurosci. Res. 95 (1–2), 260–269. https://doi.org/10.1002/jnr.23810, 2017 Jan 2.
Oyola, M.G., Handa, R.J., 2017. Hypothalamic-pituitary-adrenal and hypothalamic-pituitary-gonadal axes: sex differences in regulation of stress responsivity. Stress 20 (5), 476–494. https://doi.org/10.1080/10253890.2017.1369523.
Pabst, S., Brand, M., Wolf, O.T., 2013. Stress and decision making: a few minutes make all the difference. Behavioral Brain Research 250, 39–45. https://doi.org/10.1016/j.bbr.2013.04.046.
Payne, J., Jackson, E., Ryan, L., Hoscheidt, S., Jacobs, J., et al., 2006. The impact of stress on neutral and emotional aspects of episodic memory. Memory 14 (1), 1–16. https://doi.org/10.1080/09658210500139176.
Perez, D., 2020. Alfa1-adrenergic receptors in neurotransmission, synaptic plasticity, and cognition. Front. Pharmacol. 11, 581098 https://doi.org/10.3389/fphar.2020.581098.
Petrakova, L., Doering, B.K., Vits, S., Engler, H., Rief, W., et al., 2015. Psychosocial stress increases salivary alpha-amylase activity independently from plasma noradrenaline levels. PLoS One 10 (8), e0134561. https://doi.org/10.1371/journal.pone.0134561.
Pinel, J.P., Barnes, S., 2017. Biopsychology. Pearson Higher Ed. https://lib.hpu.edu.vn/handle/123456789/34497.
Plessow, F., Kiesel, A., Kirschbaum, C., 2012. The stressed prefrontal cortex and goal-directed behaviour: acute psychosocial stress impairs the flexible implementation of task goals. Exp. Brain Res. 216 (3), 397–408. https://doi.org/10.1007/s00221-011-2943-1.

Pulcu, E., Trotter, P.D., Thomas, E.J., McFarquhar, M., Juhász, G., et al., 2014. Temporal discounting in major depressive disorder. Psychol. Med. 44 (9), 1825–1834. https://doi.org/10.1017/S0033291713002584.
Putman, P., Antypa, N., Crysovergi, P., van der Does, W.A., 2010. Exogenous cortisol acutely influences motivated decision making in healthy young men. Psychopharmacology 208 (2), 257–263. https://doi.org/10.1007/s00213-009-1725-y.
Richardson, A.E., VanderKaay Tomasulo, M.M., 2022. Stress-induced HPA activation in virtual navigation and spatial attention performance. BMC Neurosci. 23 (1), 1–13. https://doi.org/10.1186/s12868-022-00722-y.
Riis-Vestergaard, M.I., van Ast, V., Cornelisse, S., Joëls, M., Haushofer, J., 2018. The effect of hydrocortisone administration on intertemporal choice. Psychoneuroendocrinology 88, 173–182. https://doi.org/10.1016/j.psyneuen.2017.10.002.
Robbins, T.W., Costa, R.M., 2017. Habits, 20 Curr. Biol. 27 (22), R1200–R1206. https://doi.org/10.1016/j.cub.2017.09.060. PMID: 29161553.
Robertson, C.V., Immink, M.A., Marino, F.E., 2016. Exogenous cortisol administration; effects on risk taking behavior, exercise performance, and physiological and neurophysiological responses. Frontiers in physiology 7, 222123. https://doi.org/10.3389/fphys.2016.00640.
Rodrigues, S.M., LeDoux, J.E., Sapolsky, R.M., 2009. The influence of stress hormones on fear circuitry. Annu. Rev. Neurosci. 32, 289–313. https://doi.org/10.1146/annurev.neuro.051508.135620.
Rogers, R.D., Lancaster, M., Wakeley, J., Bhagwagar, Z., 2004. Effects of beta-adrenoceptor blockade on components of human decision-making. Psychopharmacology 172 (2), 157–164. https://doi.org/10.1007/s00213-003-1641-5.
Roozendaal, B., 2002. Stress and memory: opposing effects of glucocorticoids on memory consolidation and memory retrieval. Neurobiol. Learn. Mem. 78 (3), 578–595. https://doi.org/10.1006/nlme.2002.4080.
Rosenbloom, M.H., Schmahmann, J.D., Price, B.H., 2012. The functional neuroanatomy of decision-making. J. Neuropsychiatry Clin. Neurosci. 24 (3), 266–277. https://doi.org/10.1176/appi.neuropsych.11060139.
Russell, G., Lightman, S., 2019. The human stress response. Nat. Rev. Endocrinol. 15 (9), 525–534. https://doi.org/10.1038/s41574-019-0228-0.
Sachdeva, S., Singh, P., Medin, D., 2011. Culture and the quest for universal principles in moral reasoning. Int. J. Psychol. 46 (3), 161–176. https://doi.org/10.1080/00207594.2011.568486.
Sandi, C., 2004. Stress, cognitive impairment and cell adhesion molecules. Nat. Rev. Neurosci. 5 (12), 917–930. https://doi.org/10.1038/nrn1555.
Sandi, C., 1998. The role and mechanisms of action of glucocorticoid involvement in memory storage. Neural Plast. 6 (3), 41–52. https://doi.org/10.1155/NP.1998.41.
Sanfey, A.G., 2007. Social decision-making: insights from game theory and neuroscience. Science 318 (5850), 598–602. https://doi.org/10.1126/science.1142996.
Salam, A.P., Rainford, E., van Vugt, M., Ronay, R., 2017. Acute stress reduces perceived trustworthiness of male racial outgroup faces. Adaptive Human Behavior and Physiology 3 (4), 282–292. https://doi.org/10.1007/s40750-017-0065-0.
Salamone, J.D., Correa, M., 2024. The neurobiology of activational aspects of motivation: exertion of effort, effort-based decision making, and the role of dopamine. Annu. Rev. Psychol. 75, 1–32. https://doi.org/10.1146/annurev-psych-020223-012208.
Schoofs, D., Pabst, S., Brand, M., Wolf, O.T., 2013. Working memory is differentially affected by stress in men and women. Behavioral brain research 241, 144–153. https://doi.org/10.1016/j.bbr.2012.12.004.
Schwabe, L., 2017. Memory under stress: from single systems to network changes. Eur. J. Neurosci. 45 (4), 478–489. https://doi.org/10.1111/ejn.13478.
Schwabe, L., Oitzl, M.S., Philippsen, C., Richter, S., Bohringer, A., et al., 2007. Stress modulates the use of spatial versus stimulus-response learning strategies in humans. Learn. Mem. 14 (1–2), 109–116. https://doi.org/10.1101/lm.435807.
Seehagen, S., Schneider, S., Rudolph, J., Ernst, S., Zmyj, N., 2015. Stress impairs cognitive flexibility in infants. Proc. Natl. Acad. Sci. USA 112 (41), 12882–12886. https://doi.org/10.1073/pnas.1508345112.
Sequeira, I.K., Longmire, A.S., McKay, N.J., 2021. Trier Social Stress Test elevates blood pressure, heart rate, and anxiety, but a singing test or unsolvable anagrams only elevates heart rate, among healthy young adults. Psych 3 (2), 171–183. https://doi.org/10.3390/psych3020015.
Shields, G.S., Sazma, M.A., Yonelinas, A.P., 2016a. The effects of acute stress on core executive functions: a meta-analysis and comparison with cortisol. Neurosci. Biobehav. Rev. 68, 651–668. https://doi.org/10.1016/j.neubiorev.2016.06.038.
Shields, G.S., Lam, J.C., Trainor, B.C., Yonelinas, A.P., 2016b. Exposure to acute stress enhances decision-making competence: evidence for the role of DHEA. Psychoneuroendocrinology 67, 51–60. https://doi.org/10.1016/j.psyneuen.2016.01.031.
Shields, G.S., Sazma, M.A., McCullough, A.M., Yonelinas, A.P., 2017. The effects of acute stress on episodic memory: a meta-analysis and integrative review. Psychol. Bull. 143, 1–40.
Shilton, A.L., Laycock, R., Crewther, S.G., 2017. The Maastricht acute stress test (MAST): physiological and subjective responses in anticipation, and post-stress. Front. Psychol. 8 (567) https://doi.org/10.3389/fpsyg.2017.00567.
Shors, T.J., 2004. Learning during stressful times. Learn. Mem. 11 (2), 137–144. https://doi.org/10.1101/lm.66604.
Shors, T.J., Miesegaes, G., 2002. Testosterone in utero and at birth dictates how stressful experience will affect learning in adulthood. Proc. Natl. Acad. Sci. USA 99 (21), 13955–13960. https://doi.org/10.1073/pnas.202199999.
Singer, N., Sommer, M., Döhnel, K., Zänkert, S., Wüst, S., et al., 2017. Acute psychosocial stress and everyday moral decision-making in young healthy men: the impact of cortisol. Horm. Behav. 93, 72–81. https://doi.org/10.1016/j.yhbeh.2017.05.002.
Singer, N., Sommer, M., Wüst, S., Kudielka, B.M., 2021. Effects of gender and personality on everyday moral decision-making after acute stress exposure. Psychoneuroendocrinology 124 (105084). https://doi.org/10.1016/j.psyneuen.2020.105084.
Smeets, T., Cornelisse, S., Quaedflieg, C.W., Meyer, T., Jelicic, M., et al., 2012. Introducing the Maastricht Acute Stress Test (MAST): a quick and non-invasive approach to elicit robust autonomic and glucocorticoid stress responses. Psychoneuroendocrinology 37 (12), 1998–2008. https://doi.org/10.1016/j.psyneuen.2012.04.012.
Soares, J.M., Sampaio, A., Ferreira, L.M., Santos, N.C., Marques, F., et al., 2012. Stress-induced changes in human decision-making are reversible. Transl. Psychiatry 2 (7). https://doi.org/10.1038/tp.2012.59 e131–e131.
Sokol-Hessner, P., Lackovic, S.F., Tobe, R.H., Camerer, C.F., Leventhal, B.L., et al., 2015. Determinants of propranolol's selective effect on loss aversion. Psychol. Sci. 26 (7), 1123–1130. https://doi.org/10.1177/0956797615582026.
Starcke, K., Brand, M., 2016. Effects of stress on decisions under uncertainty: a meta-analysis. Psychol. Bull. 142 (9), 909. https://doi.org/10.1037/bul0000060.
Starcke, K., Ludwig, A.C., Brand, M., 2012. Anticipatory stress interferes with utilitarian moral judgment. Judgment and Decision making 7 (1), 61–68. https://doi.org/10.1017/S1930297500001832.
Starcke, K., Polzer, C., Wolf, O.T., Brand, M., 2011. Does stress alter everyday moral decision-making? Psychoneuroendocrinology 36 (2), 210–219. https://doi.org/10.1016/j.psyneuen.2010.07.010.
Steinbeis, N., Engert, V., Linz, R., Singer, T., 2015. The effects of stress and affiliation on social decision-making: investigating the tend-and-befriend pattern. Psychoneuroendocrinology 62, 138–148. https://doi.org/10.1016/j.psyneuen.2015.08.003.
Taylor, S.E., Klein, L.C., Lewis, B.P., Gruenewald, T.L., Gurung, R.A., et al., 2000. Biobehavioral responses to stress in females: tend-and-befriend, not fight-or-flight. Psychol. Rev. 107 (3), 411–429. https://doi.org/10.1037/0033-295X.107.3.411.
Timmermans, W., Xiong, H., Hoogenraad, C.C., Krugers, H.J., 2013. Stress and excitatory synapses: from health to disease. Neuroscience 248 (2013), 626–636. https://doi.org/10.1016/j.neuroscience.2013.05.043.
Traustadottir, T., Bosch, P.R., Matt, K.S., 2003. Gender differences in cardiovascular and hypothalamic-pituitary-adrenal axis responses to psychological stress in healthy older adult men and women. Stress 6 (2), 133–140. https://doi.org/10.1080/1025389031000111302.
Tzieropoulos, H., 2013. The trust game in neuroscience: a short review. Soc. Neurosci. 8 (5), 407–416. https://doi.org/10.1080/17470919.2013.832375.
Van Marle, H.J., Hermans, E.J., Qin, S., Fernández, G., 2010. Enhanced resting-state connectivity of amygdala in the immediate aftermath of acute psychological stress. Neuroimage 53 (1), 348–354. https://doi.org/10.1016/j.neuroimage.2010.05.070.
van Stegeren, A.H., 2008. The role of the noradrenergic system in emotional memory. Acta psychologica 127 (3), 532–541. https://doi.org/10.1016/j.actpsy.2007.10.004.
Vogel, S., Fernández, G., Joëls, M., Schwabe, L., 2016. Cognitive adaptation under stress: a case for the mineralocorticoid receptor. Trends Cognit. Sci. 20 (3), 192–203. https://doi.org/10.1016/j.tics.2015.12.003.
Von Baeyer, C.L., Piira, T., Chambers, C.T., Trapanotto, M., Zeltzer, L.K., 2005. Guidelines for the cold pressor task as an experimental pain stimulus for use with children. J. Pain 6 (4), 218–227. https://doi.org/10.1016/j.jpain.2005.01.349.
Von Dawans, B., Ditzen, B., Trueg, A., Fischbacher, U., Heinrichs, M., 2019. Effects of acute stress on social behavior in women. Psychoneuroendocrinology 99, 137–144. https://doi.org/10.1016/j.psyneuen.2018.08.031.
Von Dawans, B., Fischbacher, U., Kirschbaum, C., Fehr, E., Heinrichs, M., 2012. The social dimension of stress reactivity: acute stress increases prosocial behavior in humans. Psychol. Sci. 23 (6), 651–660. https://doi.org/10.1177/0956797611431576.
Von Dawans, B., Trueg, A., Kirschbaum, C., Fischbacher, U., Heinrichs, M., 2018. Acute social and physical stress interact to influence social behavior: the role of social anxiety. PLoS One 13 (10), e0204665. https://doi.org/10.1371/journal.pone.0204665.
Von Dawans, B., Strojny, J., Domes, G., 2021. The effects of acute stress and stress hormones on social cognition and behavior: current state of research and future directions. Neurosci. Biobehav. Rev. 121, 75–88. https://doi.org/10.1016/j.neubiorev.2020.11.026.
Wallis, J.D., 2007. Orbitofrontal cortex and its contribution to decision-making. Annu. Rev. Neurosci. 30, 31–56. https://doi.org/10.1146/annurev.neuro.30.051606.094334.
Wise, R.J., Phung, A.L., Labuschagne, I., Stout, J.C., 2015. Differential effects of social stress on laboratory-based decision-making are related to both impulsive personality traits and gender. Cognit. Emot. 29 (8), 1475–1485. https://doi.org/10.1080/02699931.2014.989815.
Wood, W., Tam, L., Witt, M., 2005. Changing circumstances, disrupting habits. J. Pers. Soc. Psychol. 88 (6), 918. https://10.1037/0022-3514.88.6.918.
Woodrow, A., Sparks, S., Bobrovskaia, V., Paterson, C., Murphy, P., et al., 2019. Decision-making ability in psychosis: a systematic review and meta-analysis of the magnitude,

specificity, and correlates of impaired performance on the Iowa and Cambridge Gambling Tasks. Psychol. Med. 49 (1), 32–48.
Youssef, F.F., Bachew, R., Bissessar, S., Crockett, M.J., Faber, N.S., 2018. Sex differences in the effects of acute stress on behavior in the ultimatum game. Psychoneuroendocrinology 96, 126–131. https://doi.org/10.1016/j.psyneuen.2018.06.012.
Zalachoras, I., Houtman, R., Meijer, O.C., 2013. Understanding stress-effects in the brain via transcriptional signal transduction pathways. Neuroscience 242, 97–109. https://doi.org/10.1016/j.neuroscience.2013.03.038.

Further reading

Bendahan, S., Goette, L., Thoresen, J., Loued, L., Hollis, F., et al., 2017. Acute stress alters individual risk taking in a time-dependent manner and leads to anti social risk. Eur. J. Neurosci. 45 (7), 877–885. https://doi.org/10.1111/ejn.13395.
Canale, N., Rubaltelli, E., Vieno, A., Pittarello, A., Billieux, J., 2017. Impulsivity influences betting under stress in laboratory gambling. Sci. Rep. 7 (1), 1–12. https://doi.org/10.1038/s41598-017-10745-9.
Feldman Hall, O., Raio, C.M., Kubota, J.T., Seiler, M.G., Phelps, E.A., 2015. The effects of social context and acute stress on decision making under uncertainty. Psychol. Sci. 26 (12), 1918–1926. https://doi.org/10.1177/095679761560580.
Leder, J., Häusser, J.A., Mojzisch, A., 2013. Stress and strategic decision-making in the beauty contest game. Psychoneuroendocrinology 38 (9), 1503–1511. https://doi.org/10.1016/j.psyneuen.2012.12.016.
Lempert, K.M., Johnson, E., Phelps, E.A., 2016. Emotional arousal predicts intertemporal choice. Emotion 16 (5), 647. https://doi.org/10.1037/emo0000168.
Lempert, K.M., Lackovic, S.F., Tobe, R.H., Glimcher, P.W., Phelps, E.A., 2017. Propranolol reduces reference-dependence in intertemporal choice. Soc. Cognit. Affect Neurosci. 12 (9), 1394–1401. https://doi.org/10.1093/scan/nsx081.
Lighthall, N.R., Sakaki, M., Vasunilashorn, S., Nga, L., Somayajula, et al., 2012. Gender differences in reward-related decision processing under stress. Soc. Cognit. Affect Neurosci. 7 (4), 476–484. https://doi.org/10.1093/scan/nsr026.
Nickels, N., Kubicki, K., Maestripieri, D., 2017. Sex differences in the effects of psychosocial stress on cooperative and prosocial behavior: evidence for 'flight or fight' in males and 'tend and befriend' in females. Adaptive Human Behavior and Physiology 3 (2), 171–183. https://doi.org/10.1007/s40750-017-0062-3.
Potts, S.R., McCuddy, W.T., Jayan, D., Porcelli, A.J., 2019. To trust, or not to trust? Individual differences in physiological reactivity predict trust under acute stress. Psychoneuroendocrinology 100, 75–84. https://doi.org/10.1016/j.psyneuen.2018.09.019.
Schweda, A., Faber, N.S., Crockett, M.J., Kalenscher, T., 2019. The effects of psychosocial stress on intergroup resource allocation. Sci. Rep. 9 (1), 1–12. https://doi.org/10.1038/s41598-019-54954-w.
Vinkers, C.H., Zorn, J.V., Cornelisse, S., Koot, S., Houtepen, L.C., et al., 2013. Time-dependent changes in altruistic punishment following stress. Psychoneuroendocrinology 38 (9), 1467–1475. https://doi.org/10.1016/j.psyneuen.2012.12.012.
Youssef, F.F., Dookeeram, K., Basdeo, V., Francis, E., Doman, M., et al., 2012. Stress alters personal moral decision making. Psychoneuroendocrinology 37 (4), 491–498. https://doi.org/10.1016/j.psyneuen.2011.07.017.