Conceptual and Neurocognitive Foundations of Cognitive Stamina

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Abstract: Objectives: This paper aims to conceptually define cognitive stamina, delimit it from related constructs (cognitive reserve, mental fatigue, psychological resilience), identify its neurobiological and molecular substrates, and outline the theoretical models that explain its dynamics. **Prior Work:** The study builds on integrative literature (2018–2026) covering executive function, prefrontal cortex physiology, adenosine accumulation, Default Mode Network dynamics, and neural oscillation research. **Approach:** A systematic bibliographic synthesis was conducted across peer-reviewed journals (Frontiers in Physiology, Brain Sciences, Cognitive Science, Behavioural Brain Research), structured around conceptual delimitation and neurobiological evidence. **Results:** Cognitive stamina is a dynamic neurofunctional property governed by prefrontal adenosine accumulation and frontoparietal network balance, not a fixed genetic trait. Sustained linear attention is biologically impossible due to theta oscillations. **Implications:** Findings have direct relevance for academic performance design, professional training, and workplace ergonomics, offering evidence-based frameworks for educators, organizational psychologists, and cognitive neuroscientists. **Value:** The paper provides a rigorous conceptual taxonomy and integrated neurobiological model of cognitive stamina, bridging psychology, neuroscience, and applied performance science within a coherent theoretical framework.

Keywords: cognitive stamina; mental fatigue; prefrontal cortex; adenosine; neural networks

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1. Introduction and Conceptual Delimitations of Cognitive Stamina

In contemporary society—characterized by massive digitalization, information oversaturation, and the transition toward a knowledge-based economy—the demand placed on higher cognitive functions has reached unprecedented levels. Unlike earlier eras, in which productivity was measured primarily through physical effort, present-day performance depends directly on the individual's capacity to process, analyze, and synthesize complex streams of data over extended periods. In this landscape, cognitive stamina (cognitive endurance) emerges not merely as a desirable psychological trait but as a critical variable for professional success, academic adaptation, and the maintenance of mental health (Gupta, 2021).

In the specialized literature, cognitive stamina is defined as the capacity of the central nervous system to maintain an optimal level of executive performance and sustained attention during intense and prolonged mental activity, resisting the onset of mental fatigue. From a psychometric perspective, it cannot be reduced to the simple intelligence quotient (IQ) or to information-processing speed; rather, it represents a dynamic component of executive control (Chapman, 2013; Frontiers in Physiology, 2026).

1.1. Cognitive Stamina vs. Cognitive Reserve

Although apparently similar, the two concepts operate on entirely different dimensions of the cognitive resource. Whereas stamina is a predominantly functional and short-term property, cognitive reserve is a structural and long-term plasticity property (Small & Vorgan, 2015). Cognitive reserve refers to the brain's ability to find alternative neural pathways to compensate for cellular damage caused by aging or neurodegenerative pathologies. Figure 1 illustrates this fundamental dichotomy:

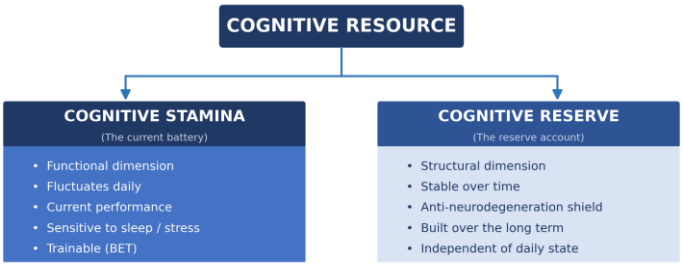


Figure 1. The Cognitive-Resource Dichotomy: Cognitive Stamina vs. Cognitive Reserve

A person may possess a vast cognitive reserve (a brain that is structurally protected over the long term) yet exhibit low cognitive stamina on a given day due to acute sleep deprivation—the two dimensions are independent and complementary.

1.2. Cognitive Stamina vs. Mental Fatigue

Mental fatigue is the psychophysiological state manifested through declining performance, lethargy, and an increased error rate, triggered by prolonged cognitive effort (Holgado et al., 2026). In this equation, cognitive stamina is the buffer property: the greater an individual's stamina, the further in time the threshold for mental fatigue onset is pushed—a process controlled directly by the dynamics of theta-rhythm oscillations in the frontoparietal network (Brain Sciences, 2025; Cognitive Science, 2025).

1.3. Cognitive Stamina vs. Psychological Resilience

Although the terms sound similar, resilience refers to the emotional and behavioral capacity to recover after a trauma, failure, or major psychological stressor (Holdevici, 2011). Cognitive stamina is strictly limited to the performance of the critical apparatus (attention, working memory, flexibility) under continuous effort.

2. Fundamental Theoretical Models of Cognitive Stamina

The analysis of cognitive stamina rests on three major theoretical pillars that attempt to explain the degradation or maintenance of mental energy:

2.1. The Limited-Capacity Model (Kahneman, 1973): It posits that the individual has a finite reservoir of attentional resources. Simultaneously engaging several processes rapidly depletes this reservoir, causing stamina to decline.

2.2. The Ego Depletion Model (Baumeister et al., 1998): It holds that acts of willpower, self-control, and intense concentration draw on a shared energy resource. When this resource is exhausted, cognitive stamina collapses.

2.3. The Cost–Benefit Model of Motivation (Hockey, 2013): A modern approach arguing that the decline in stamina is not caused by a physical lack of "fuel" in the brain but is an alarm mechanism. The brain weighs the metabolic cost of the current effort against the perceived reward; when the cost exceeds the benefit, it induces a state of fatigue to force a change of activity. This interaction indirectly blocks dopamine release owing to the local accumulation of adenosine in the prefrontal cortex (Pageaux et al., 2018/2024).

3. Neurobiological Foundations of Prolonged Mental Effort

3.1. The Prefrontal Cortex — The Central Dispatcher

Cognitive stamina is not an isolated property of a single brain region but the result of a dynamic interaction among complex neural networks. The central pillar of this system is the prefrontal cortex (PFC), particularly its dorsolateral region (dlPFC). This area acts as a "central dispatcher", being responsible for executive control, keeping goals in working memory, and inhibiting distracting stimuli (Chapman, 2013; Brain Sciences, 2025).

During a task requiring sustained attention, the dlPFC works closely with the anterior cingulate cortex (ACC), the region responsible for error monitoring and for evaluating the effort needed to correct them. When cognitive stamina begins to decline, the efficiency of signal transmission between the dlPFC and the ACC diminishes, leading to an exponential increase in reaction time and error rate (Cognitive Science, 2025).

3.2. FPN–DMN Dynamics: The Core of Cognitive Stamina

The sustainability of mental effort over long periods is closely tied to the alternation and balance between two large brain networks, illustrated in Figure 2:

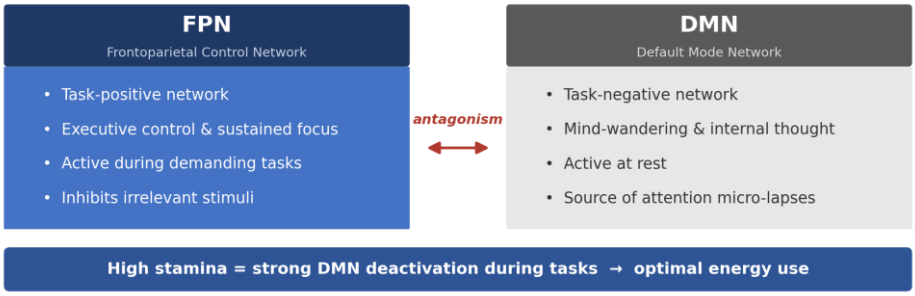


Figure 2. Dynamics of the FPN and DMN Neural Networks in Cognitive Stamina

Recent functional magnetic resonance imaging (fMRI) research shows that individuals with high cognitive stamina display a superior ability to deactivate the DMN while performing difficult tasks (Brain Sciences, 2025). In fatigued individuals or those with low stamina, the DMN "antagonizes" FPN activity, generating attention micro-lapses. Consequently, cognitive stamina does not mean merely strong brain activation but the optimization of energy use through the perfect isolation of the networks responsible for execution (Cognitive Science, 2025).

3.3. The Adenosine–Dopamine Balance: The Molecular Mechanism

At the molecular level, cognitive stamina is limited by the balance between two essential neurotransmitters: adenosine and dopamine. Prolonged mental effort accelerates cellular metabolism in the prefrontal cortex, leading to the rapid burning of ATP molecules. The by-product of this burning is adenosine, a neuromodulator with an inhibitory effect. As the working hours pass, adenosine accumulates in the dlPFC synapses, binding to the A1 and A2A receptors (Pageaux et al., 2018/2024). Adenosine accumulation has two major neurobiological consequences:

- **Blocking dopamine:** Adenosine directly inhibits the release of dopamine, the neurotransmitter responsible for motivation, reward anticipation, and the maintenance of vigilance.
- **Altering effort perception:** Although the muscles or organs are not physically affected, the accumulation of adenosine in the brain drastically increases the subjective rating of perceived effort (RPE). The subject feels

enormous psychological resistance to continuing the task, with the brain interpreting the additional effort as metabolically inefficient (Pageaux et al., 2018/2024).

3.4. Neural Oscillations and the Impossibility of Perfect Attention

For a long time, the dominant theory was the metabolic one (associated with the Ego Depletion model), suggesting that cognitive stamina declines because of the depletion of local glucose stores in the brain (Baumeister et al., 1998). Recent studies have nuanced this perspective, proposing the neural-oscillation hypothesis. According to it, the brain does not run out of physical fuel but loses its capacity for electrophysiological synchronization. Prolonged effort provokes an abnormal increase in the power of low-frequency oscillations (the theta rhythm) in the frontal regions (Cognitive Science, 2025; Holgado et al., 2026). These theta waves act as "forced micro-pauses" that the brain autonomously introduces to protect itself from overload, explaining why perfectly linear attention is a biological impossibility.

4. Modulating Factors of Cognitive Stamina

4.1. Biological and Physiological Factors: Sleep and Cellular Homeostasis

The fundamental pillar of daily cognitive stamina is sleep–wake homeostasis. Acute or chronic sleep deprivation severely degrades the functional connectivity between the dorsolateral prefrontal cortex (dlPFC) and the rest of the executive networks (Small & Vorgan, 2015). Biochemically, deep NREM sleep activates the brain's glymphatic system, responsible for clearing metabolic waste accumulated during wakefulness, especially adenosine (Pageaux et al., 2018/2024). In the absence of quality sleep (a minimum of 7–8 hours), the baseline level of synaptic adenosine remains elevated from the very start of the day, drastically lowering the tolerance threshold for mental effort and accelerating the onset of cognitive fatigue (Gupta, 2021).

4.2. Psychological Factors and the Motivational Equation

Beyond biological constraints, cognitive stamina is massively modulated by the subject's psychological state. Figure 3 illustrates the mechanism through which motivation modulates the adenosine–dopamine balance:

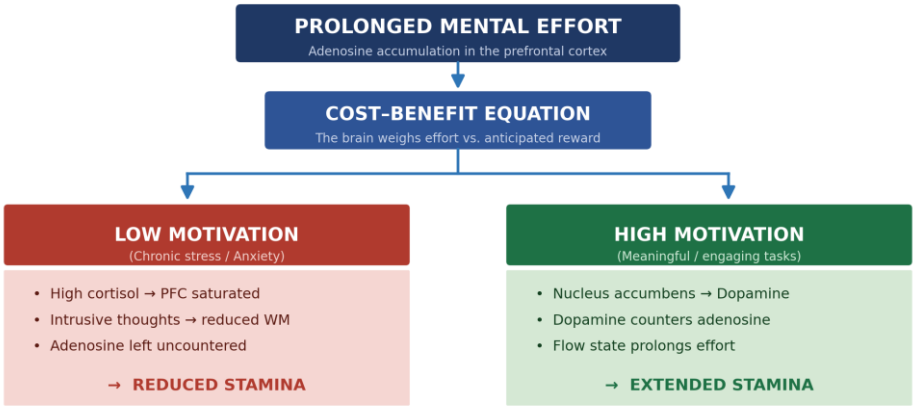


Figure 3. The Motivational Equation: Motivation as a Modulator of Cognitive Stamina

According to the modern cost–benefit model, the brain constantly reassesses the effort expended relative to the value of the anticipated reward (Hockey, 2013). When a task is perceived as highly motivating or personally meaningful, the nucleus accumbens releases pulses of dopamine needed to counteract the inhibitory effect of adenosine—a phenomenon that explains why an individual can exhibit remarkable cognitive stamina in activities they are passionate about (Holgado et al., 2026). At the opposite pole, the elevated levels of cortisol and adrenaline characteristic of chronic stress saturate the receptors in the prefrontal cortex, while anxiety parasitically consumes working memory through intrusive thoughts (Holdevici, 2011).

4.3. Contextual and Environmental Factors: Sensory Load

The architecture of the environment in which mental activity takes place dictates the rate at which executive energy is consumed. Auditory and visual distractions (phone notifications, background conversations in open-office spaces) force the frontoparietal control network (FPN) to perform constant processes of inhibiting irrelevant stimuli (Brain Sciences, 2025). Each act of filtering out a distraction represents a hidden metabolic cost. According to Attention Restoration Theory, prolonged exposure to artificial and chaotic stimuli exhausts top-down attention mechanisms, whereas brief visual pauses oriented toward natural settings allow the

FPN to enter a state of functional rest, partially restoring cognitive stamina (Cognitive Science, 2025).

5. Synthesis of Recent Research (2018–2026)

Table 1. Synthesis of Recent Research on Cognitive Stamina (2018–2026)

Author / Year	Study objective	Methodology	Key results
Brain Sciences (Gkintoni et al., 2025)	Identifying the neural mechanisms underpinning prolonged cognitive effort	fMRI and connectivity studies during executive tasks	High cognitive stamina is associated with reduced DMN activity and optimized frontoparietal interactions
Cognitive Science (Sharpe & Tyndall, 2025)	Analyzing the biological limits of perfect vigilance	Interdisciplinary analysis: aviation, medicine, elite military settings	Perfect continuous attention is biologically impossible due to theta oscillations; optimal stamina involves rapid recovery after micro-lapses
Behavioural Brain Research (Holgado et al., 2026)	Monitoring the dynamics of cognitive-stamina degradation	Temporal Experience Tracing (TET) during sustained cognitive effort	Stamina is non-linear; cognitive fatigue interacts dynamically with subjective micro-pauses
Frontiers in Physiology (Zhang et al., 2026)	Assessing the impact of Brain Endurance Training on mental fatigue	Meta-analysis of 9 peer-reviewed articles (11 clinical studies)	BET significantly increases mental stamina; better reaction times on Stroop and PVT tests under acute fatigue
Journal of Sports Sciences (Pageaux et al., 2018/2024)	Investigating the correlation between cognitive fatigue and physical endurance	Laboratory experiment: 30–90 min of highly demanding cognitive tasks (AX-CPT)	Prolonged cognitive demand → adenosine accumulation in the PFC → drastic rise in RPE, with no physical muscle weakening

6. Conclusions

The integrative analysis of the specialized literature from 2018–2026 reveals that cognitive stamina represents a neurofunctional variable of critical importance in a modern, information-oversaturated society (Gupta, 2021). From the cumulative processing of the data, the following fundamental conclusions emerge:

Cognitive stamina is not a static, purely genetically determined trait but a dynamic property of executive control (managed predominantly by the dlPFC and ACC), situated at the intersection of biological homeostasis, metabolic load, and motivational factors (Chapman, 2013; Hockey, 2013).

Mental fatigue is not defined by a simple depletion of glucose but is governed by the accumulation of adenosine in the synapses of the prefrontal cortex, a process that alters the subjective rating of perceived effort (RPE) and blocks the dopaminergic circuits of motivation (Baumeister et al., 1998; Pageaux et al., 2018/2024).

From an electrophysiological standpoint, continuous linear attention is biologically limited by the emergence of low-frequency theta waves, which act as automatic micro-pauses of cortical protection introduced by the brain during prolonged tasks (Cognitive Science, 2025; Holgado et al., 2026).

Future research directions point to the need to develop real-time monitoring systems (wearables) based on artificial intelligence, capable of detecting DMN intrusions and personalizing work–rest cycles in professional settings (Brain Sciences, 2025; Frontiers in Physiology, 2026).

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