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DIGITALIZATION AS A NEW ENVIRONMENTAL EXPOSURE FACTOR: THE IMPACT OF INFORMATION OVERLOAD ON HUMAN NERVOUS AND IMMUNE SYSTEM FUNCTIONS

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ABSTRACT

The increasing digitization of everyday life is associated with the increasing exposure of the population to informational, sensory, and social stimuli originating from screen devices and digital media. The digital environment is not a classically understood environmental factor; its impact on the body exhibits characteristics of a chronic stressor, affecting the functions of the neuroimmunoendocrine axis, neuroplasticity processes, and the regulation of the immune response. The aim of this study was to review current data on the impact of information overload and digital overstimulation on the human nervous and immune systems, as well as to assess the validity of considering the digital environment as a new form of environmental exposure in the context of public health. Research published between 2018 and 2025 in the PubMed, Scopus, and Web of Science databases was analyzed. This included: population based correlation studies between screen time and markers of stress and inflammation, fMRI studies illustrating changes in brain structure and function during digital overload, animal models examining the effects of sensory overstimulation on the HPA axis and immunity, and randomized intervention trials on reducing screen time. The review found consistent evidence of chronic activation of the HPA axis under digital stress, leading to elevated cortisol levels, impaired neurogenesis, and decreased parasympathetic activity. Brain changes are also observed that correlate with symptoms of depression, insomnia, and attention deficits. Reduced immunity and increased inflammatory markers were demonstrated. Interventions limiting digital exposure resulted in significant reductions in cortisol and CRP levels. The digital environment meets the criteria for an environmental stressor with a real impact on the nervous and immune systems. Digital hygiene should become an integral component of public health strategies, prevention, and the design of work and learning environments.

KEYWORDS

Infodemic, Mental Health, Doomscrolling, Cortisol, Digitalization Healthcare, Technostress

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1. Introduction

The contemporary human environment is undergoing drastic changes, not only physically but also in terms of information. The increasing digitization of everyday life has made exposure to both relevant and incidental information ubiquitous and difficult to control. This phenomenon has led to the emergence of a new type of environmental stressor: digital information overload, encompassing, among other things, an excess of sensory stimuli, so called technostress, doomscrolling, and constant attention fragmentation. (Kaltenegger et al., 2024; Bhattacharya et al., 2025)

Excessive exposure to digital content is increasingly associated with chronic psychophysiological stress, which affects the human nervous and immune systems. Chronic stimulation of the hypothalamic pituitary adrenal (HPA) axis caused by digital overstimulation is associated with elevated cortisol levels, and subsequently with weakened cellular immunity, increased inflammatory markers, and neurocognitive disorders (Kaltenegger et al., 2023; Kaltenegger et al., 2024).

In response to the growing threat of disinformation, false information, and cognitive overload, the World Health Organization (WHO) introduced the concept of "infodemic" information overload (both true and false) that complicates rational health decision making. This infodemic has been recognized as one of the major public health challenges of the 21st century.

There are also attempts to develop the concept of "information health" as a new component of environmental health. The authors propose treating information space similarly to physical space, taking into account the quality, quantity, and toxicity of incoming stimuli and their long term impact on individual and societal health (Shushkevich et al., 2024).

While the literature documents the growing importance of information stress for mental health, a systematic review of its impact on the immune system and inflammatory biomarkers is still lacking. The aim of this paper is to present the current state of knowledge in this area and to identify the biological mechanisms by which the digital environment may act as a new form of environmental exposure.

2. The digital environment as a stress factor

The contemporary digital environment, characterized by a constant supply of new stimuli and information, can be considered a new form of environmental stressor. Traditionally, stressors have been divided into physical (e.g., noise, temperature), psychological (anxiety, social pressure), and chemical (e.g., toxic substances). However, the increasing digitization of everyday life has led to the development of a category of digital stress, which encompasses, among other things, information overload, sensory overstimulation, and the social pressure associated with digital media (Kaltenegger et al., 2023).

Digital information stress results primarily from exposure to an excess of data in a short period of time, without the ability to process it deeply. This phenomenon is sometimes referred to as an infodemic, particularly in the context of the COVID 19 pandemic, when users were exposed to vast amounts of often contradictory information, increasing levels of uncertainty and emotional tension (Bhattacharya et al., 2025). Additionally, digital stress can be sensory in nature, for example, due to constant audio and visual notifications or the blue light emitted by screens, which disrupt circadian rhythms. Equally important is social stress, generated by social comparison mechanisms and the pressure to react in real time (e.g., FOMO, fear of missing out) (Shushkevich et al., 2024).

The central biological mechanism responsible for the body's response to digital stress is the hypothalamic pituitary adrenal (HPA) axis. Working in a multi screen environment, multitasking, and constant exposure to micro interruptions in the form of notifications lead to chronic activation of this axis, and consequently, persistently elevated cortisol levels (Kaltenegger et al., 2024). Studies have shown that people exposed to high levels of so called Techno stressed individuals exhibit not only higher hair cortisol levels (an indicator of chronic stress) but also elevated levels of C reactive protein (CRP), a marker of low grade inflammation (Kaltenegger et al., 2023)

A specific aspect of the digital environment is its impact on sleep. Digital sleep deprivation, or the reduction of sleep time in favor of digital content consumption, is associated with both poorer quality of rest and additional neuroimmunological consequences. Exposure to blue light in the evening delays melatonin secretion, disrupting the circadian rhythm and making it difficult to fall asleep (Bhattacharya et al., 2025). Intervention studies suggest that reducing screen time can improve mood and subjective well being, but often without significant impact on stress biomarkers in the short term (Andersson et al., 2023).

Both the sensory and informational components of the digital environment therefore lead to chronic strain on the body's regulatory systems, making digital stress a significant and growing environmental health problem.

3. The impact of the digital environment on the nervous system

Chronic exposure to digital stressors leads to adaptive, and in the long term, dysfunctional, changes in the nervous system. The central mechanism responsible for stress processing is the hypothalamic pituitary adrenal (HPA) axis, whose chronic activation results in excessive secretion of cortisol, the primary stress hormone. Elevated cortisol levels, observed in individuals experiencing chronic information stress or digital deprivation, lead to, among other things, inhibition of neurogenesis in the hippocampus, an area responsible for memory consolidation and emotion regulation (Kaltenegger et al., 2023; Sousa et al., 2024).

Animal experiments and clinical studies suggest that excessive activation of the HPA axis is associated with a reduction in hippocampal volume and altered functioning of the prefrontal cortex and amygdala. Neuroimaging studies (fMRI) indicate that individuals exposed to information overload exhibit increased activity in the amygdala, involved in processing threats and emotional stimuli, and decreased activity in the anterior cingulate cortex and prefrontal cortex, which are responsible for cognitive control and emotion regulation (Bhattacharya et al., 2025; Loughan et al., 2023).

Concurrently, decreased activity in the parasympathetic nervous system, responsible for recovery and body homeostasis, is observed. Reduced heart rate variability (HRV), considered a biomarker of reduced vagal activity and depletion of adaptive resources, has been observed in individuals experiencing digital stress, measured by factors such as screen time, multitasking, or the number of notifications (Kaltenegger et al., 2024).

The clinical consequences of these phenomena encompass a wide spectrum of psychoneurological symptoms. The most frequently reported symptoms include sleep disturbances, chronic feelings of tension, reduced ability to concentrate, anhedonia, irritability, and, in more advanced cases, symptoms characteristic of affective disorders, including anxiety depressive disorder (Loughan et al., 2023; Andersson et al., 2023). It is worth emphasizing that these disorders often develop subliminally without a clear critical moment, which means they may be underestimated by both patients and the medical community. Meanwhile, a growing body of research suggests the existence of a neurobiological phenotype of information stress, which, although difficult to define at the individual level, may pose a serious health threat at the population level. The digitalization of everyday life has led to an unprecedented increase in human interaction with artificial information environments. Digital platforms are designed to maximize engagement, often through rapid content delivery, personalized algorithms, and continuous notifications. This persistent sensory stimulation induces a state of sustained cognitive vigilance and impairs the brain's ability to disengage from stimuli, leading to overstimulation of the central nervous system (CNS) [Canogulları, 2025]. Neurologically, this may be understood as a maladaptive form of allostatic load, wherein repeated exposure to informational stressors exceeds the brain's adaptive capacity, increasing the risk of emotional exhaustion and executive dysfunction [Akat & Ekinci, 2025].

One of the most concerning aspects of this phenomenon is doomscrolling, which has been found to directly mediate psychological distress and perpetuate a state of chronic hyperarousal. Doomscrolling behaviors activate the limbic system particularly the amygdala and anterior cingulate cortex which are central to fear and threat processing [Anand et al., 2022]. With repeated exposure to emotionally negative digital content, these regions become hypersensitized, reinforcing maladaptive feedback loops between perceived danger and compulsive digital engagement. This creates a neurobiological scenario analogous to trauma exposure, even in the absence of real world danger [Samuel & Selvam, 2025].

Furthermore, chronic digital overexposure affects neuroendocrine regulation via the hypothalamic pituitary adrenal (HPA) axis. Prolonged engagement with negative digital content is associated with elevated cortisol levels, particularly in individuals with high levels of digital dependency [James et al., 2023]. Excess cortisol impairs hippocampal function, which is critical for memory consolidation and learning, and disrupts prefrontal cortex activity involved in attention, impulse control, and emotional regulation [Delgado et al., 2021]. Cortisol dysregulation also contributes to sleep impairments and increases vulnerability to neurodegenerative changes [De Nys et al., 2022].

Disruption of circadian rhythms due to excessive screen time further exacerbates neurological stress. Blue light emitted by screens suppresses melatonin production, delays sleep onset, and leads to poor quality sleep architecture, including decreased rapid eye movement (REM) sleep and fragmented deep sleep cycles [Goyal, 2022]. Poor sleep, in turn, diminishes cognitive flexibility and emotional stability, impairing decision making and increasing sensitivity to stress [Yang et al., 2024]. This sleep cognition emotion triad is now recognized as a key component of the digital environment's neurological toll [Pedersen et al., 2022].

In occupational settings, the burden of technostress has also gained scientific attention. Healthcare professionals and knowledge workers exposed to high digital workloads report increased symptoms of burnout, cognitive fatigue, and mental disengagement, often accompanied by subclinical neuroinflammatory markers [Kaltenegger et al., 2023]. The mechanistic link may involve low grade systemic inflammation, driven by chronic stress exposure, which in turn disrupts blood brain barrier integrity and alters glial activity key components of neuroimmune interactions [Kaltenegger et al., 2024].

Additionally, the persuasive architecture of digital platforms amplifies attentional capture and cognitive overload. Algorithms designed to prioritize emotionally charged, high salience content especially during infodemics can hijack attentional resources, fragment working memory, and impair deep cognitive processing [Borges do Nascimento et al., 2022]. This "attention economy" undermines sustained focus and metacognitive awareness, essential for regulating emotional responses and inhibiting impulsive behavior [Dominguez Rodriguez et al., 2025].

Even structural changes in neural connectivity may be implicated. Emerging neuroimaging evidence suggests that individuals with high digital dependency exhibit altered white matter integrity in the prefrontal limbic circuitry, associated with difficulties in emotion regulation, attention switching, and stress modulation [Yang et al., 2024]. While causal relationships require further longitudinal data, the convergence of neuroendocrinological, psychological, and behavioral data strongly supports the notion that excessive digital exposure can lead to functional and potentially structural changes in the CNS [Salisbury, 2023].

Finally, it is critical to consider developmental neuroplasticity. Adolescents and children, whose brains are still undergoing myelination and synaptic pruning, may be particularly vulnerable to the neurological effects of digital overstimulation. Overexposure during critical periods of cognitive and emotional development may disrupt normative trajectories, with long term consequences for executive functioning, emotional resilience, and stress reactivity [Goyal, 2022].

4. The Impact of Digital Exposure on the Immune System

In response to chronic exposure to digital stressors (e.g., information overload, constant notifications, multitasking), a complex regulatory system, the so called neuroimmunoendocrine axis, is activated, linking the functions of the nervous, endocrine, and immune systems. The primary mediator of stress is activation of the hypothalamic pituitary adrenal (HPA) axis, leading to cortisol secretion, which plays a significant role in short term adaptation, but under chronic stimulation can lead to immune dysregulation (Segerstrom & Miller, 2023).

Cortisol acts as an immunosuppressant by inhibiting the activation of antigen presenting cells (APCs), inhibiting T cell proliferation, and reducing the activity of natural killer (NK) cells. This also shifts the immune response from Th1 to Th2, resulting in greater susceptibility to viral infections and reduced antitumor surveillance (Zhou et al., 2023). Numerous clinical studies have shown that long term stress, including digital stress, leads to decreased lymphocyte counts (both CD4+ and CD8+), reduced natural killer (NK) cell activity, and increased neutrophil counts, which are classic markers of immunosuppression and a shift toward low grade inflammation (Padalkar et al., 2025). Reduced expression of receptors on immune cells is also observed, indicating the development of so called glucocorticoid resistance, a phenomenon that weakens the inhibitory effect of cortisol and allows chronic inflammation to persist despite high levels of stress hormones (Cohen et al., 2023).

Chronic digital stress leads to sustained activation of the HPA axis and the sympathetic nervous system, resulting in elevated levels of inflammatory cytokines: interleukin 6 (IL 6), tumor necrosis factor alpha (TNF α), and C reactive protein (CRP). Inflammatory markers are strongly associated with the risk of lifestyle diseases such as type 2 diabetes, atherosclerosis, and depression (Furman et al., 2019; Black & Slavich, 2022).

This phenomenon is called chronic low grade inflammation (LGI) and is one of the key biomarkers of contemporary environmental exposures, including those related to digital technology. Studies have shown that people with high levels of technostress had significantly higher levels of IL 6 and CRP than people with limited exposure to digital media (Kaltenegger et al., 2024).

All the changes described above lead to weakening of antiviral and anticancer immunity, increased risk of infections (especially respiratory infections), recurrence of autoimmune diseases and exacerbation of depressive symptoms and adjustment disorders. Long term effects of chronic LGI are also associated with accelerated immune aging processes and increased overall mortality (Franceschi et al., 2018).

Although much of the current literature on digitalization has concentrated on its psychological and neurological outcomes, an increasing body of evidence suggests that the immune system is also susceptible to the downstream effects of chronic digital engagement. The concept of the "digital environment" as a novel environmental exposure encompasses not only the sheer volume of information consumed but also its emotional valence, delivery mechanisms, and the behavioral responses it elicits, such as compulsive checking, doomscrolling, and prolonged screen time. These patterns of use can trigger a cascade of neuroendocrine changes that ultimately impair immune homeostasis, potentially increasing vulnerability to infections, chronic inflammation, and autoimmune dysregulation [James et al., 2023].

One of the central mechanisms linking digital exposure to immune function involves the chronic activation of the hypothalamic pituitary adrenal (HPA) axis in response to psychological stressors present in the online information landscape. Repeated exposure to threatening, contradictory, or fear inducing digital content such as during a health crisis or natural disaster triggers a state of heightened arousal and cognitive vigilance. This stress response leads to sustained release of cortisol, a glucocorticoid hormone that exerts profound immunosuppressive effects when maintained at elevated levels over time. High cortisol disrupts the proliferation and activity of T lymphocytes, diminishes natural killer (NK) cell cytotoxicity, and interferes with cytokine signaling required for coordinated immune responses [Kaltenegger et al., 2024; De Nys et al., 2022].

Beyond hormonal modulation, digital overstimulation has been associated with systemic, low grade inflammation a condition characterized by elevated levels of inflammatory biomarkers in the absence of acute infection. Individuals who engage excessively with distressing or emotionally charged content online have shown increased expression of cytokines such as interleukin 6 (IL 6) and tumor necrosis factor alpha (TNF α), which are implicated in both somatic illness and mood disorders. This inflammatory phenotype has been particularly well documented in occupational contexts, such as among healthcare workers exposed to high technostress levels and digital burden in clinical environments [Kaltenegger et al., 2023]. The physiological toll of persistent digital stress resembles that of other chronic stressors, with the key distinction being its invisible, cognitive nature and rapid, repetitive exposure cycles.

Importantly, the relationship between digital behavior and immunity is not merely mediated by stress hormones. Behavioral correlates of digital dependency such as sedentarism, disordered sleep, irregular eating, and reduced outdoor activity serve as independent and compounding risk factors for immune suppression. For instance, prolonged screen time is frequently associated with a sedentary lifestyle, which impairs metabolic regulation and reduces the production of anti inflammatory myokines derived from muscle activity. This contributes to chronic, systemic immune dysregulation and heightens the risk of metabolic and inflammatory diseases [Pedersen et al., 2022]. Similarly, digital exposure at night disrupts circadian rhythm and melatonin secretion, both of which are essential for proper immune cell trafficking and function during sleep cycles [Goyal, 2022].

These effects were especially pronounced during the COVID 19 pandemic, when the phenomenon of the "infodemic" a parallel epidemic of misinformation and excessive digital information resulted in widespread emotional dysregulation and anxiety, particularly among vulnerable populations such as older adults. Several studies reported increased mental health burden and physiological distress linked to overexposure to alarming or contradictory online health information. This psychophysiological response was accompanied by indicators of immune system disruption, such as increased inflammation and heightened allostatic load [Braz et al., 2023; Delgado et al., 2021; Han et al., 2024]. In such cases, the immune consequences were not only a product of stress induced physiological changes but also of behavioral adaptations such as social withdrawal, healthcare avoidance, or self medication arising from exposure to unreliable or fear inducing information.

Furthermore, digital misinformation and algorithm driven content engagement can influence public health behaviors that have direct immunological consequences. Exposure to antivaccine rhetoric, denialist narratives, or unverified health advice often reduces adherence to medical recommendations and decreases vaccine uptake, indirectly weakening population level immunity and exacerbating vulnerability to infectious outbreaks [Borges do Nascimento et al., 2022]. These digital behaviors are not merely cognitive in nature; they result in tangible, measurable changes in immune protection both at the individual and community levels.

Another emerging area of concern is the role of neuroimmune interactions, particularly microglial activation in response to sustained psychological stress. Chronic exposure to emotionally intense or negative digital content may activate central nervous system immune cells, such as microglia, promoting a neuroinflammatory environment that can further suppress adaptive immunity. Neuroinflammation not only impacts mood and cognitive function but also interferes with central immune regulatory mechanisms, thus creating a feedback loop in which emotional distress and immune dysfunction mutually reinforce each other [Ball & Darby, 2022; James et al., 2023].

In conclusion, the immune system traditionally understood in the context of pathogens and physical stressors must now be considered within the broader framework of digital exposure. The cumulative effects of information overload, technostress, digital behavioral patterns, and misinformation constitute a novel form of environmental exposure that acts through psychoneuroimmunological mechanisms. Recognizing digitalization as an immunologically relevant stressor is critical for developing holistic preventive health strategies, especially in the context of future public health crises where digital media will play a central role in information dissemination and behavioral influence.

5. Doomscrolling and Cognitive Overload as Mediators of Psychoneuroimmunological Disruption

The digital environment's influence on human health cannot be adequately understood without recognizing the behavioral and cognitive mechanisms through which its effects are transmitted. Among these, doomscrolling defined as the compulsive consumption of negative or alarming online content and cognitive overload, the saturation of mental processing capacity due to excessive information intake, have emerged as key mediators of psychoneuroimmunological disruption in the digital age [Samuel & Selvam, 2025; Satici et al., 2023].

Doomscrolling represents a maladaptive coping behavior, particularly prevalent during periods of uncertainty and perceived threat, such as pandemics or natural disasters. It is characterized by prolonged, often involuntary, engagement with pessimistic news cycles, typically through social media platforms. This behavior has been shown to intensify psychological distress, including anxiety, depressive symptoms, and sleep disturbances, and is closely associated with heightened emotional reactivity and reduced executive function [Price et al., 2022; Salisbury, 2023]. The compulsive nature of doomscrolling sustains a chronic stress response, thereby maintaining activation of the hypothalamic pituitary adrenal (HPA) axis and sympathetic nervous system, both of which exert regulatory control over immune functioning [Anand et al., 2022].

The psychological toll of doomscrolling is not merely ephemeral but has biological consequences. Repeated exposure to threatening digital stimuli elicits a sustained vigilance state, which is energetically costly for the central nervous system and disrupts sleep, appetite regulation, and social interaction all critical modulators of immune resilience. Cortisol dysregulation associated with chronic doomscrolling has been shown to reduce lymphocyte proliferation and impair natural killer (NK) cell activity, leading to increased susceptibility to infections and a slower recovery from illness [James et al., 2023; Kaltenegger et al., 2024]. Furthermore, doomscrolling often occurs late in the evening or at night, interfering with melatonin release and circadian rhythm entrainment, which are essential for the coordination of immunological processes such as leukocyte trafficking and cytokine signaling [Yang et al., 2024; Goyal, 2022].

Parallel to this behavioral component is the phenomenon of cognitive overload, which occurs when the quantity, complexity, or ambiguity of information surpasses an individual's cognitive processing threshold. In the digital context, this often stems from simultaneous exposure to multiple news sources, conflicting messages, algorithmic content, and fragmented attention due to constant notifications. Cognitive overload reduces the efficiency of working memory, impairs decision making, and weakens emotional regulation, fostering a state of chronic mental fatigue [Loru et al., 2025]. Psychologically, this has been linked with an increased risk of maladaptive responses such as emotional numbing, irritability, and withdrawal [Dominguez Rodriguez et al., 2025].

Biologically, cognitive overload contributes to a state of chronic low grade neuroinflammation. Sustained mental exertion and the inability to filter or prioritize information activate microglial cells in the brain, which release proinflammatory cytokines such as IL 1β and TNF α. These molecules not only interfere with neuroplasticity and memory but also disrupt the delicate neuroimmune crosstalk necessary for immune surveillance and tissue repair [Ball & Darby, 2022]. The feedback loop created between mental stress and inflammatory signaling underpins many stress related diseases, including cardiovascular, metabolic, and autoimmune disorders [Kaltenegger et al., 2023].

Recent studies have begun to map the interface between doomscrolling, cognitive overload, and biomarkers of immune dysfunction. For example, individuals who report higher levels of doomscrolling behavior also show elevated hair cortisol concentrations and C reactive protein (CRP) levels both markers of systemic stress and inflammation [Kaltenegger et al., 2024; Pedersen et al., 2022]. Similarly, exposure to digital misinformation has been shown to increase negative affect and maladaptive cognitive appraisals, which are significant predictors of immune downregulation and behavioral disengagement from protective health behaviors [Han et al., 2024; Borges do Nascimento et al., 2022].

Moreover, cognitive overload may undermine immune regulation indirectly by reducing health literacy and increasing susceptibility to misinformation. In digital ecosystems saturated with conflicting messages, individuals with lower cognitive reserves may find it difficult to assess the credibility of information, which can lead to heightened anxiety, poor health choices, and reduced adherence to public health measures such as vaccination or physical activity all of which further weaken immune competence [Cascini et al., 2022].

Crucially, the co occurrence of doomscrolling and cognitive overload may have synergistic effects. While doomscrolling triggers emotional arousal and sustained threat appraisal, cognitive overload compromises the capacity to disengage, reframe, or critically evaluate the stimuli. This combination traps individuals in a state of allostatic load, where the body’s adaptive systems neurological, endocrine, and immune are persistently activated beyond their optimal thresholds [Satici et al., 2023; Canoğulları, 2025]. Over time, this erodes physiological resilience, increases oxidative stress, and promotes the emergence of chronic inflammatory states that have systemic consequences.

In sum, doomscrolling and cognitive overload function not merely as symptoms of digital overuse but as central behavioral and cognitive mechanisms through which digital exposure exerts harmful effects on the nervous and immune systems. Their mediating role in psychoneuroimmunological disruption highlights the need for interdisciplinary strategies that integrate digital hygiene, cognitive resilience training, and public health communication. Understanding and targeting these mediators may offer a novel route for mitigating the health consequences of life in an increasingly digital world.

6. Groups particularly sensitive to digital stress and its neuroimmunological consequences.

The maturing brain exhibits high neuroplasticity but is also exceptionally vulnerable to environmental factors, including digital stress. Research shows that information overload, exposure to social media, and sleep disruption in children and adolescents lead to prolonged activation of the HPA axis, resulting in elevated cortisol levels and impaired limbic system development, particularly in the amygdala and prefrontal cortex (McLaughlin et al., 2020). In the long term, this increases the risk of anxiety and depressive disorders, as well as immune dysregulation, including reduced T cell counts and elevated IL6 levels (Keles et al., 2024).

The functional immaturity of the immune system and underdeveloped self regulatory strategies lead young individuals to react more strongly both physiologically and behaviorally, as documented in longitudinal studies using inflammatory biomarkers and neuroimaging (Mills et al., 2023). Older adults are at increased risk of experiencing the negative effects of digital stress due to physiological immunosuppression and age related weakening of cellular and humoral immunity. This group is also more susceptible to chronic low grade inflammation (LGI) and increased levels of inflammatory cytokines (IL 6, TNF α), which are further exacerbated by digital overload and technology induced sleep deprivation (Franceschi et al., 2018; Black et al., 2022).

Another risk factor is a lower level of digital literacy, which can lead to frustration, digital alienation, and difficulty using new technologies. This stress enhances HPA axis responses and increases heart rate variability, as confirmed in population studies (Riedl et al., 2021). A stronger impact of digital stress on sleep disorders is also observed in older adults, significantly impacting immune regeneration and the proper functioning of the nervous system (Potvin et al., 2023). Individuals with HPA axis disorders (e.g., in the course of PTSD, depression, or ADHD) and those with autoimmune diseases are also particularly vulnerable, as excessive digital stress can exacerbate existing immune dysregulation. This group exhibits a faster progression of chronic inflammation and more frequent exacerbations of psychosomatic symptoms (Dhabhar et al., 2014).

Social factors also play a significant role: low socioeconomic status, digital loneliness, lack of control over technology use, and lack of emotional support amplify the impact of technological stressors and intensify inflammatory responses. Multifactorial models indicate that individuals with a low sense of coherence (SOC) and high "FOMO" (fear of missing out) exhibit elevated cortisol and CRP levels (Huang et al., 2024; Slavich & Irwin, 2019).

Identifying these at risk populations is crucial for implementing preventative environmental and behavioral interventions. High neuroplasticity in children, deteriorating immunity in seniors, and psychosomatic and social predispositions in adults should be the starting point for designing health policy in the context of the impact of the digital environment on public health.

7. Epidemiological and experimental evidence

In recent years, a growing number of population based studies have demonstrated a strong association between heavy digital device use and biological markers of stress and inflammation. A cross sectional analysis of over 13,000 participants from Europe showed that individuals spending more than 6 hours per day online had significantly higher salivary cortisol levels, serum CRP, and a higher neutrophil to lymphocyte ratio (NLR), considered a nonspecific marker of inflammatory burden (Kaltenegger et al., 2024). Furthermore, research conducted in the United States showed that among young adults, excessive social media use (>3 h/day) correlated with higher levels of IL 6 and TNF α, even after controlling for factors such as BMI, physical activity, and sleep quality (Creswell et al., 2023). At the same time, significant subclinical symptoms were noted, including: Increased fatigue, insomnia, and difficulty concentrating indicate an overload of the nervous and immune systems.

Animal models (primarily mice and rats) simulating conditions of digital sensory overload have shown that chronic exposure to blue light, variable noise intensity, and an interrupted sleep wake cycle lead to impaired HPA axis function and a decrease in T and B lymphocytes, as well as increased levels of proinflammatory cytokines (IL1β, IL 6, TNF α) in brain and peripheral tissues (Giménez et al., 2022).

Rodents subjected to chronic digital stress also exhibited decreased hippocampal volume, increased expression of glucocorticoid receptors in the amygdala, and decreased neurogenesis mechanisms analogous to those identified in humans suffering from digital overload (Kim et al., 2023). Studies using immunohistochemical techniques have also confirmed an increase in the penetration of microglia and astrocytes in areas responsible for memory and emotion, which may explain inflammatory mechanisms within the nervous system and the associated behavioral symptoms.

Results from interventional studies indicate that limiting screen time can provide measurable health benefits in regulating stress and inflammation. In a randomized clinical trial conducted among a group of students (n=210), individuals who limited their use of digital devices to a maximum of one hour per day for two weeks demonstrated an average decrease in cortisol levels of 18% and a significant reduction in serum CRP and IL 6 levels compared to the control group (Allen et al., 2024). Similar effects were observed in an intervention study involving adult corporate employees, where a 10 day digital detox (disabling notifications, eliminating multitasking, and limiting screen intensive work) resulted in increased heart rate variability and improved sleep quality and mental well being (Trentini et al., 2023). Importantly, inflammatory biomarkers remained lower for a week after the intervention ended.

Both population based and experimental studies clearly indicate a causal relationship between intensive digital technology use and neuroimmune dysregulation. Even short term exposure reduction can effectively reduce stress levels, inflammatory cytokines, and restore homeostasis in regulatory systems. These data support the need to implement digital hygiene programs as a preventative public health measure.

8. Public health implications

Accumulated experimental and epidemiological evidence confirms that the digital environment, defined as the constant presence of screen technologies, information overload, sensory overstimulation, and digital sleep deprivation, exhibits characteristics similar to classic environmental stressors such as noise, air pollution, and nighttime light. It demonstrates the ability to sustain long term activation of the neuroimmunoendocrine axis, triggering chronic physiological changes with documented health consequences (Slavich & Irwin, 2019; Kaltenegger et al., 2024).

Therefore, the digital environment should be considered an environmental exposure, which, like other environmental factors, can accumulate over time, causing oxidative stress, neurotransmission disruption, decreased immunity, and low grade inflammation. Lack of awareness of this risk may lead to underestimating the impact of new technologies on population health.

Similarly to sleep hygiene, work hygiene, and diet, digital hygiene should be considered an integral component of preventive health care. It encompasses a set of habits and practices that help reduce the negative impact of digital exposure, including reducing multi screen work, eliminating unnecessary notifications, periodic "digital detoxes," and appropriately planning offline time (Allen et al., 2024; Reinecke et al., 2023).

Particular attention should be paid to the digital hygiene of children and adolescents, whose nervous and immune systems are particularly susceptible to deregulation. Education in this area should be introduced as early as primary school, as part of health and mental health education. Simultaneously, it is essential to incorporate digital hygiene strategies into therapeutic interventions, including those for depression, anxiety disorders, insomnia, and chronic fatigue syndrome, as a component supporting neurological regeneration and immune rebuilding (Slavich, 2020).

From a public health perspective, it is necessary to reformulate the current legal and educational framework in a way that recognizes the impact of the digital environment on health as a real and measurable risk factor. Key areas of intervention include:

- In education: introducing digital resilience education programs, information management, and technological stress prevention in schools and universities;
- In work environments: implementing digital ergonomics principles, digital fatigue standards, and designing spaces that support deep work and recovery periods;
- In healthcare: incorporating digital exposure into a patient's environmental history and developing tools for assessing digital stress levels in clinical practice (Keles et al., 2024; OECD Health Working Papers, 2022).

Furthermore, cross sectoral collaboration is necessary: a combination of environmental, legislative, and educational initiatives, while engaging the technology industry in designing solutions that are less invasive for users' neurobiological functioning (e.g., reducing the intensity of notifications, supporting night modes, limiting content that generates excessive arousal).

The digital environment, although not intuitively perceived as a threat, plays an increasingly important role as a factor disrupting neuro immune homeostasis. Given the scope of exposure and the lack of physical barriers, its significance for public health is comparable to that of classic environmental stressors. Integrating digital hygiene into education, work, and healthcare systems could become one of the most important prevention challenges of the 21st century.

The psychoneuroimmunological disruptions induced by chronic digital exposure especially through mechanisms such as doomscrolling and cognitive overload present an emerging challenge for public health systems globally. As digital environments become increasingly integrated into everyday life, the boundary between digital behavior and biomedical health risk continues to blur. Therefore, public health frameworks must urgently evolve to recognize digital exposure as a legitimate environmental risk factor, warranting intervention at multiple levels of prevention [Brönneke & Debatin, 2022; Majcherek et al., 2024].

One of the most pressing implications lies in the burden of mental and inflammatory disorders linked to excessive digital engagement. Public health surveillance data now indicate a rise in mood disturbances, sleep dysfunction, and stress related immunological changes, which correlate strongly with digital behavior metrics such as screen time, doomscrolling frequency, and content sentiment exposure [Pedersen et al., 2022; Samuel & Selvam, 2025]. These psychosomatic effects contribute to increased healthcare utilization, reduced productivity, and a heightened burden on mental health services especially among adolescents, older adults, and healthcare workers, who are particularly vulnerable to technostress and infodemic exposure [Delgado et al., 2021; Kaltenegger et al., 2023].

The infodemic phenomenon, defined by the World Health Organization as an overabundance of information some accurate, some not has highlighted the critical intersection between digital content ecosystems and behavioral immune health. Misinformation not only undermines individual decision making but also promotes fear based behaviors, vaccine hesitancy, and chronic vigilance states that impair immune modulation [Borges do Nascimento et al., 2022; Han et al., 2024]. Public health institutions must therefore address not only the content of health communication but also the cognitive bandwidth and emotional state of the information consumer.

In this context, digital hygiene emerges as a vital public health strategy. Analogous to hand hygiene in infection control, digital hygiene refers to intentional practices aimed at reducing cognitive, emotional, and behavioral exposure to harmful digital stimuli. This includes actions such as limiting screen time, curating information sources, scheduling "digital detox" periods, using content moderation tools, and implementing mindfulness based technology use [Canoğulları, 2025; Goyal, 2022]. Evidence from randomized controlled trials indicates that restricting digital screen exposure significantly improves mood, stress biomarkers, and parent child behavioral synchrony, reinforcing the efficacy of structured digital hygiene protocols [Grøntved et al., 2024; Pedersen et al., 2022].

Public health policies must also integrate educational interventions that promote digital literacy and emotional regulation. Teaching individuals to recognize cognitive biases such as negativity bias and confirmation bias that fuel doomscrolling is a foundational step toward behavioral change [Anand et al., 2022; Dominguez Rodriguez et al., 2025]. Schools, workplaces, and health systems should incorporate curricula or training that enhance critical thinking, foster psychological flexibility, and encourage self monitoring of digital habits [Stoumpos et al., 2023].

Moreover, technological platforms themselves bear a degree of ethical responsibility. Algorithmic design can either amplify or buffer harmful content exposure. Public health stakeholders must engage with tech companies to promote platform level changes, such as limiting engagement based content prioritization, implementing usage nudges, and increasing the visibility of credible sources during health crises [Loru et al., 2025; Cascini et al., 2022].

On the policy level, governments and international bodies should incorporate digital behavior surveillance and intervention into broader health equity initiatives. For example, socioeconomically disadvantaged populations may face greater barriers to implementing digital hygiene due to occupational demands or limited access to health education. These disparities must be accounted for in digital health policies to avoid amplifying existing inequities in mental and immune health outcomes [Majcherek et al., 2024; Carboni et al., 2022].

Finally, interdisciplinary collaboration is essential. Addressing digital exposure as an environmental determinant of health requires cooperation between neuroscientists, immunologists, psychologists, epidemiologists, and digital technologists. Together, these fields can develop and validate composite biomarkers of digital stress, inform clinical screening protocols, and create adaptive digital interventions tailored to individual cognitive and immune profiles [Ball & Darby, 2022; Kaltenegger et al., 2024].

In conclusion, the public health implications of digital overexposure extend far beyond traditional concerns about screen addiction or productivity loss. Emerging evidence links digital environments directly to neuroendocrine and immunological dysregulation, positioning digital hygiene as a critical pillar of preventive medicine in the 21st century. Timely action is essential to protect population health in a world increasingly shaped by algorithms, information saturation, and pervasive connectivity.

9. Conclusion and future research directions

With increasing exposure to digital stimuli, from intense social media use to chronic screen based work, it is becoming increasingly clear that the digital environment impacts the human body in a way comparable to classic environmental factors such as noise, pollution, and artificial light. The scientific evidence presented in this paper suggests that information, sensory, and social overload associated with modern technologies can lead to persistent activation of the neuroimmunoendocrine axis, decreased immunity, and the development of symptoms from the spectrum of psychoneuroautoimmune disorders.

Although epidemiological, imaging, and experimental data support this association, research remains limited, and many mechanisms remain poorly understood. A key challenge for the coming years will be conducting research using neurological and immunological biomarkers, such as levels of proinflammatory cytokines (IL 6, TNF α), expression of genes associated with stress response, neuroimaging changes (fMRI, PET), and markers of neurotoxicity and neurogenesis. Only such an approach will allow for the precise determination of the long term consequences of digital exposure and the development of effective intervention strategies.

Future long term studies, both experimental and cohort, encompassing various age, socio cultural, and occupational groups, will be necessary to understand individual susceptibility to digital overload and its relationship to other environmental and genetic factors. Translational research, combining molecular biological data with clinical and behavioral observations, may be particularly valuable.

One of the most promising directions for development in this field is the integration of the concept of the "digital exposome" (i.e., overall exposure to the digital environment throughout the lifespan) with classical environmental models used in environmental medicine. This approach considers both quantitative and qualitative aspects of digital exposure (time, type of content, interactivity, social context) and their interactions with other environmental and biological factors.

In summary, the digital environment is becoming one of the most important and fastest growing areas of environmental impact on human health in the 21st century. Only through an interdisciplinary, long term and systemic approach to research can we understand its full biological, psychological and social impact and, consequently, effectively protect the population from this new type of environmental stress.

The convergence of neuroscience, immunology, and behavioral science reveals an urgent and previously underestimated reality: chronic digital exposure can disrupt the psychoneuroimmunological balance essential for maintaining health and resilience. Through mechanisms such as doomscrolling, cognitive overload, and sustained exposure to emotionally charged or misleading content, digital environments activate prolonged stress responses, impair executive control, and weaken immunological integrity. These findings challenge the traditional compartmentalization of mental, neurological, and immune health and underscore the need to view digital behavior as a biologically consequential health determinant.

As the digital landscape continues to evolve with increasingly immersive technologies such as virtual reality, algorithmic personalization, and artificial intelligence the cognitive and emotional load on users is likely to intensify. Without structured interventions, both at the individual and systemic level, populations may face rising rates of anxiety disorders, chronic inflammation, and stress related somatic illnesses. This scenario highlights the need for anticipatory public health strategies that include digital hygiene education, content regulation, and resilience training.

Importantly, the burden of responsibility does not lie solely with the individual. Digital platforms, content curators, healthcare institutions, and policymakers must adopt a shared accountability model in shaping environments that promote neurological recovery, cognitive clarity, and immunological robustness. Future research should aim to develop standardized digital health metrics, identify psychoneuroimmunological biomarkers of digital stress, and evaluate the long term effects of content moderation strategies.

Ultimately, embracing a psychoneuroimmunological framework for digital health allows for a more integrative understanding of how modern lifestyles affect the human organism. It opens avenues for interdisciplinary collaboration and offers actionable insights that can inform preventive care, public health education, and policy development in the digital age. By acknowledging and mitigating the biological consequences of our online behaviors, we can begin to restore balance not just to the immune system, but to the entire psychophysiological ecology of the human being.

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