



Neuroadaptive User Experience Framework for Human-AI Teaming in Defense Industry

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ABSTRACT

Modern defense operations require resilient human-AI teaming under cognitive stress, yet static systems often fail to adapt, reducing trust and mission effectiveness. A Systematic Literature Review (2016–2025) across human factors, neuroergonomics, and defense HCI was conducted to conceptualize a Neuroadaptive User Experience (NUX) framework. Findings show that multimodal neurophysiological sensing (EEG, heart rate variability, eye tracking) can detect workload fluctuations, while adaptive interventions—task redistribution, interface simplification, and timing adjustments—sustain performance and accelerate recovery. The NUX framework integrates state sensing, interpretation, adaptive automation, and transparent feedback. Despite challenges in sensor reliability, calibration, and ethical governance, NUX represents a paradigm shift toward human-centered defense systems that enhance resilience, trust, and mission outcomes.

INTRODUCTION

Defense missions increasingly rely on AI- Modern military operations demand that personnel make complex decisions under extreme stress, high cognitive load, and time pressure (Flood & Keegan, 2022). In such conditions, maintaining cognitive resilience, the capacity to sustain and recover cognitive performance under stress, is critical (Kakkos et al., 2025). Cognitive resilience has been defined as the ability to overcome the negative effects of setbacks and associated stress on cognitive function or performance. In military contexts, where most of personnel report significant work-related stress, deficits in cognitive resilience can lead to impaired situational awareness and decision-making with serious mission consequences. At the same time, military operations are increasingly carried out by human-AI teams, where artificial intelligence (AI) and autonomous systems support human operators in tasks like surveillance, targeting, and command-and-control. These Human-AI systems hold great promise for enhanced capabilities, but also introduce new challenges: information overload, automation complexity, and potential mismatches between machine speed and human cognitive bandwidth. In effect, the operational landscape has become a cognitive frontier, where human operators must collaborate with intelligent systems at machine pace while under volatile conditions (Picchi, 2025).

A critical issue in such settings is how to preserve user trust and effective cooperation between humans and AI. Trust in AI systems determines whether operators will appropriately rely on or ignore automated assistance. Under stress, humans may oscillate between over-reliance on AI and under-reliance if the system's behavior is not well aligned with the user's expectations. For example, an operator under high workload might uncritically defer to an AI recommendation (even if flawed), or conversely, after one perceived AI mistake, they might lose trust entirely and disregard useful alerts. Such trust miscalibrations can be catastrophic in military scenarios, leading to either disuse or misuse of automation (Picchi, 2025). Therefore, building trustworthy and resilient user experiences (UX) in military AI systems is as important as raw system accuracy or performance.

Recent advances in neurotechnology and human-computer interaction suggest an approach to these challenges: neuroadaptive UX. Neuroadaptive technology (NAT) is an emergent paradigm where implicit signals from the user's brain are fed back into the interface logic to adapt the system in real-time (Faiclough, 2023). In other words, the system monitors the user's neurophysiological state (e.g. brain activity, heart rate, eye gaze) and dynamically adjusts interface elements or automation support to help manage cognitive load and stress. This approach builds on the concepts of passive brain-computer interfaces and physiological computing, creating a closed-loop "biocybernetic loop" wherein real-time data from the operator inform continuous UI adaptations (Ewing et al., 2016). For instance, if a pilot's EEG and heart rate indicate extreme mental workload, a neuroadaptive cockpit might declutter the HUD (Heads-Up Display) and engage an autopilot assist to prevent information overload. Once the pilot's physiological markers return to

normal, control can be smoothly returned or information flow restored, thereby maintaining performance under pressure. This real-time pairing of sensing and interface adaptation is at the core of the Neuroadaptive UX framework.

The hypothesis driving NUX is that by integrating neurophysiological sensing with adaptive interface logic, we can enhance cognitive resilience and user trust in high-risk, high-load contexts. By sensing when an operator is overwhelmed or under-engaged and adapting accordingly, the system can help the human maintain effective cognition. At the same time, making these adaptations transparent and in tune with the operator's expectations can engender trust, as the user sees that the system "understands" their state and acts as a supportive teammate. Early evidence for this approach comes from both research prototypes and defense industry developments. For example, Fairclough (2023) demonstrate that detecting excessive mental workload via EEG can trigger *intelligent aiding* or adaptive automation to assist an overloaded operator. In a military context, the U.S. Army's Augmented Cognition experiments showed that monitoring soldiers' EEG and heart-rate could allow information delivery to be postponed when a leader was overloaded, preventing cognitive breakdown in the field. More recently, a defense technology platform introduced a "*neuroadaptive interface*" module that actively modulates the UI based on operator stress and workload, claiming to reduce cognitive load through real-time filtering and prioritization of information. These developments suggest that neuroadaptive UX design could be a game-changer in creating military systems that are not only smart, but also responsive to the human's cognitive needs and limitations.

This paper presents a literature-based conceptual framework for Neuroadaptive UX (NUX) to enhance cognitive resilience and trust in military Human-AI systems. We adopt a formal systematic literature review method to synthesize findings from 2016–2025 in human factors, neuroergonomics, and defense HCI. Our goals are to (1) consolidate current knowledge on neurophysiological sensing (EEG, heart-rate variability, eye tracking, etc.) for user state detection in high-stakes environments; (2) review adaptive interface techniques that support users under stress; and (3) propose an integrated NUX framework that leverages these insights to improve warfighter performance, resilience, and trust in human-AI teaming. Through this literature, we aim to demonstrate that a NUX framework can serve as a theoretical foundation for next-generation military systems that actively bolster the human operator's cognitive resilience and foster a safer, more trustworthy human-AI collaboration in the most demanding situations.

LITERATURE REVIEW

Cognitive Resilience in High-Stakes Military Operations

Cognitive resilience refers to an individual's ability to maintain or quickly regain cognitive effectiveness under stress and adversity (Kakkos et al., 2025). It is a specialized facet of psychological resilience focused on cognitive functions such as attention, working memory, decision-making, and executive control. In military contexts, cognitive resilience is essential for mission success and soldier

survival, as warfighters must perform complex mental tasks amid intense stressors like time pressure, fatigue, extreme environments, and life-threatening danger (Flood & Keegan, 2022). Cognitive resilience defined as the capacity to overcome the negative effects of setbacks and associated stress on cognitive function or performance, highlighting that resilience involves both experiencing adversity (stress) and achieving positive adaptation. In other words, a cognitively resilient operator can withstand high stress without significant performance degradation, or recover quickly from cognitive perturbations.

Research shows that stress can severely impair various cognitive processes, from narrowing attention to degrading working memory and decision quality (Picchi, 2025). For military personnel, failure to stay cognitively resilient under fire can lead to critical mistakes. For example, under acute stress an operator may fixate on a single alert and neglect other vital cues. Over time, cumulative stress and fatigue further erode decision-making and situational awareness. Thus, enhancing cognitive resilience is a high priority in defense human factors research (Flood & Keegan, 2022).

Traditionally, building cognitive resilience in soldiers has been approached via selection, training, and mental skills development. Techniques such as mindfulness training, stress inoculation, and cognitive-behavioral strategies have shown some success in improving soldiers' stress tolerance and recovery. For instance, mindfulness practice has been found to promote cognitive resilience in high-stress cohorts by enhancing attentional control and emotional regulation under pressure (Lee et al., 2025). A recent study by Tran et al. (2024) argues that the chaotic, high-stakes military environment can inspire new "Operator 5.0" solutions that bolster the operator's own resilience by technological means. In essence, rather than expecting warfighters to shoulder the entire burden of resilience, advanced systems should share the load by mitigating stress effects on the fly.

Neuroadaptive Systems and Physiological Computing

The concept of neuroadaptive systems has its roots in the fields of neuroergonomics, brain-computer interfaces (BCI), and physiological computing. Neuroergonomics is the study of the brain at work, examining how neural measures can inform the design of equipment and tasks to improve human performance and safety. One of the paradigms emerging from neuroergonomics is to use real-time neurophysiological data to adapt computer systems. This approach is encapsulated in the term Neuroadaptive Technology (NAT), defined as "a closed-loop neurotechnology designed to enhance human-computer interaction" (Fairclough, 2023). In NAT, implicit signals from the user's brain and body (such as EEG, cardiac rhythms, eye movements) are continuously collected and analyzed by the system to infer the user's cognitive state. These inferences (e.g., high mental workload, confusion, drowsiness, etc.) are then used to trigger adaptations in the interface in real-time, without the user needing to explicitly intervene.

Neuroadaptive technology builds upon earlier concepts of passive BCI and physiological computing (Fairclough, 2023). In passive BCI, brain

signals are not used for explicit command, but rather to implicitly modulate the system's behavior in the background (e.g., the system "notices" the user is stressed and adjusts itself). Physiological computing similarly encompasses using any bodily signals (heart rate, respiration, EEG, eye blink rate, etc.) as inputs to a computing system for adaptation purposes. A seminal example is the biocybernetic loop, where an operator's EEG was used to infer engagement level and automatically adjust task difficulty to prevent lapses in attention. In a biocybernetic loop system, the real-time data stream from brain and body is continuously monitored and compared to desired states; if the user's state deviates from optimal, the system introduces an adaptive intervention to modulate the user's state (Ewing et al., 2016)

In recent years, several studies have proven the feasibility of real-time cognitive state detection via neurophysiological measures in realistic settings. Gateau et al. (2018) demonstrated accurate detection of excessive workload from EEG in pilots, triggering automation assistance when needed. Eye-tracking can reveal where attention is directed and for how long, indicating potential cognitive tunnelling or loss of situational awareness. Importantly, these sensors have become increasingly portable and rugged. *Mobile EEG* systems and wearables allow deploying neuroadaptive loops outside the lab, even in field exercises (Wascher et al., 2021). Kakkos et al. (2025) used EEG headsets on elite military personnel during sustained stress tasks and, via interpretable machine learning, could distinguish periods of acute stress vs. recovery with 95% accuracy. They identified neural markers that correlated with better adaptation to stress, illustrating the potential to assess an individual's cognitive resilience through brain data. Such findings underscore that neurophysiological signals provide a direct window into the operator's cognitive state and resilience, which a system can leverage for adaptive support.

Adaptive Interfaces and Cognitive Workload Management

Adaptive interfaces play a crucial role in ensuring that defense operators maintain performance in high-stakes and cognitively demanding environments. Unlike static systems, adaptive designs continuously adjust to the operator's mental workload, stress, and situational context. These adjustments rely on real-time neurophysiological monitoring, including signals such as EEG, heart rate variability (HRV), and eye-tracking, which serve as reliable indicators of overload or fatigue (Arico et al., 2016).

Studies in neuroergonomics confirm that adaptive automation reduces mental strain and enhances operational effectiveness by triggering interface simplifications, filtering irrelevant data, or reallocating tasks when operators approach critical workload thresholds. For example, experiments in air traffic control demonstrated that EEG-based adaptive automation maintained operator performance under pressure better than static interfaces (Hinss et al., 2022).

In defense applications such as UAV control, combat information centers, and cyber defense, adaptive systems also help mitigate alert overload

and decision fatigue. Strategies include multimodal cueing, workload-driven task redistribution between humans and AI, and cognitive state-based automation, all of which support decision accuracy under stress

Ultimately, these mechanisms enhance cognitive resilience, enabling defense personnel to sustain performance during prolonged operations. By showing responsiveness to user needs, adaptive systems also reinforce trust in human-AI teaming, since operators perceive the interface as supportive and context-aware. This synergy forms the backbone of the proposed Neuroadaptive UX (NUX) framework, linking workload detection with adaptive response to strengthen mission readiness.

Furthermore, the integration of adaptive UX with AI-driven decision-support systems suggests a paradigm shift in defense technology design. Instead of relying solely on human capacity or fully automated functions, adaptive interfaces create a middle ground where the system continuously negotiates workload distribution with the human operator. This not only enhances mission success rates but also reduces the risks associated with human error and automation bias, thereby establishing adaptive UX as a cornerstone of resilient, human-centered defense systems.

User Trust, Transparency, and Human-AI Teaming

Trust is a critical determinant of how effectively humans and AI systems can collaborate in defense operations. Without sufficient trust, operators may reject or underutilize automated support; conversely, excessive reliance can lead to overtrust and automation bias. Research in neuroergonomics and adaptive automation emphasizes that trust must be calibrated through transparency, explainability, and reliability of the system's actions.

Transparency mechanisms, such as explainable AI interfaces, allow operators to understand why a system provides certain recommendations or automates specific tasks. This understanding reduces uncertainty and strengthens confidence, especially in high-risk defense environments where decision accountability is crucial (Arico et al., 2016). Furthermore, adaptive UX designs that incorporate workload monitoring can directly influence trust dynamics: when the system visibly adjusts to an operator's cognitive state, users perceive it as responsive and supportive (Hinss et al., 2022).

In human-AI teaming, the balance between autonomy and human control is essential. Studies show that successful teams are characterized by shared situational awareness, where both human and AI agents operate with a mutual understanding of the mission context and goals. This requires interfaces that foster communication, adaptive task allocation, and continuous feedback loops. By aligning system behavior with operator expectations and mental models, trust becomes sustainable rather than fragile.

Ultimately, trust, transparency, and effective teaming form an interdependent triad: transparency enhances trust, trust fosters acceptance of adaptive features, and human-AI teaming ensures resilience in mission-critical defense scenarios. This triad is a foundational element of the Neuroadaptive UX

(NUX) framework, bridging cognitive workload management with relational dynamics between humans and intelligent systems.

Synthesis: Toward Neuroadaptive UX for Defense

From the above literature, a few key threads emerge. First, real-time neurophysiological monitoring of operators is becoming practical and has been shown to reflect meaningful aspects of cognitive state and resilience (Kakkos et al., 2025). Second, adaptive interfaces and automation triggered by these signals can help manage cognitive load and prevent performance decrements. scenarios (Arico et al., 2016). Third, user trust and transparency need to be built into the loop; the human must remain informed and comfortable with the system's supportive actions to fully benefit from them (Fairclough, 2023). Prior studies highlight that when adaptation aligns with the user's own experience, users come to view the system as an extension of their own capabilities. This can yield a highly effective partnership. However, misalignment (system thinks user is fine when they feel overwhelmed, or vice versa) can erode trust and even cause the user to question their own self-assessment. Thus, careful calibration and feedback mechanisms are necessary

Finally, it is apparent that implementing neuroadaptive UX in a military environment represents a paradigm shift in design philosophy, from treating the human as a component that must accommodate to technology, to designing technology that adapts to the human. The literature increasingly calls for a human-centric, cognitive ergonomics approach in military systems (Tran et al., 2024). This involves cognitive interoperability, where human mental models and machine processes are aligned and mutually adaptive (Picchi, 2025).

METHODOLOGY

This research adopts a Systematic Literature Review (SLR) to ensure a rigorous and replicable approach in synthesizing knowledge on User Experience (UX), Human-Computer Interaction (HCI), and neuroadaptive systems within defense contexts. The methodology followed four main phases: planning, conducting, screening & extraction, and synthesis & reporting. In the planning stage, the primary research objective was defined: to conceptualize a Neuroadaptive User Experience (NUX) framework capable of enhancing cognitive resilience in human-AI defense operations. Research questions were formulated to explore (a) how neurophysiological sensing (EEG, HRV, eye-tracking) is currently applied in adaptive defense systems, and (b) what design gaps exist in UX frameworks that limit their resilience under high-stress operational environments. The scope was restricted to works published between 2016 and 2025, to capture recent advances in neuro-ergonomics and defense-related HCI.

The conducting stage involved systematic searches across IEEE Xplore, SpringerLink, Scopus, and ScienceDirect. Search strings were constructed using keywords and combinations such as "neuroadaptive systems," "defense UX," "neuro-ergonomics," "adaptive human-AI teaming," and "cognitive resilience". The inclusion criteria admitted peer-reviewed journal articles,

conference proceedings, and authoritative reports focusing on military or high-stakes UX/HCI research. Non-peer-reviewed, non-technical, or outdated sources were excluded.

In the screening and extraction stage, titles, abstracts, and keywords were reviewed to identify relevant studies. Duplicates were removed, and a standardized coding sheet was used to extract information such as objectives, methods, theoretical contributions, and empirical findings. Particular attention was given to studies addressing adaptive interface design, real-time physiological monitoring, and trust-building in defense UX.

Finally, the synthesis and reporting stage organized findings into thematic clusters: (1) neurophysiological sensing for workload detection, (2) adaptive interfaces in high-risk environments, (3) UX frameworks in defense HCI, and (4) cognitive resilience and trust in human-AI interaction. These clusters were integrated into the conceptualization of the NUX framework, which is presented as a novel contribution. The reporting emphasizes transparency, replicability, and academic rigor, aligning with IEEE publication standards.

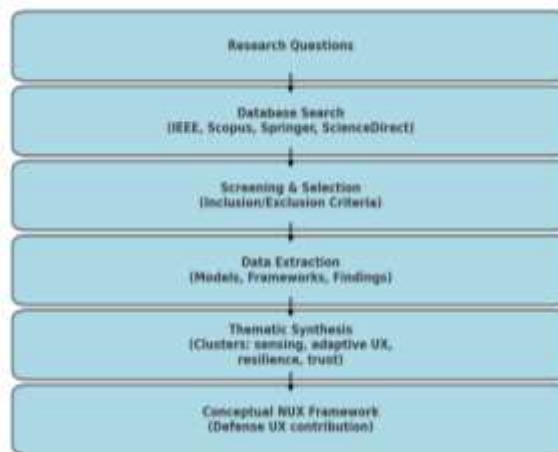


Figure. 1 Conceptual Framework Diagram for Systematic Literature Review

RESEARCH RESULT

Real-Time Cognitive State Sensing is Feasible and Informative

Multiple studies confirm that real-time monitoring of neurophysiological signals can reliably monitoring an operator's cognitive state in an operational environment. EEG shows a high correlation between mental workload levels and specific brainwave bands (theta, alpha) (Kakkos et al., 2025). Ewing et al. (2016) demonstrated that frontal theta EEG power increases with higher task demand and can serve as a trigger for adaptive difficulty in a closed-loop system. Heart rate and HRV measures provide complementary insight, as high stress typically reduces HRV. Eye-tracking metrics, such as pupil dilation and blink rate, were also correlate with mental workload and fatigue in vehicle drivers and soldiers in the field. Importantly, combining EEG, HRV, and eye gaze can improve robustness of state detection (Arico et al., 2016). This review found that wearable sensors (like around-ear EEG, chest-strap ECG, eye trackers in smart glasses) have been successfully used in field simulations, suggesting the practicality of instrumenting warfighters without

undue burden. In summary, the technology to continuously sense cognitive workload, stress, and related states exists and has been validated in contexts relevant to military operations.

Adaptive Interventions Mitigate Overload and Stabilize Performance

There is strong evidence that systems which adapt interface elements or task allocation in response to user state can help maintain performance under high load. Numerous simulation studies reported improved outcomes with adaptive aid versus static systems. In air traffic control scenarios, adaptive automation triggered by EEG-based workload indices led to 20% faster conflict resolution and higher operator accuracy compared to non-adaptive conditions (Borghini et al., 2020). In vehicular operation, an experiment with Army drivers showed that when an interface dynamically filtered out non-critical map symbols during periods of high mental workload, drivers navigated more effectively and reported lower perceived workload (Gorji et al., 2023)

Notably, interventions must occur early enough to prevent performance breakdown but not so early or frequent as to be intrusive (Fairclough, 2023). The reviewed studies underscore several effective adaptive strategies: (a) Information Prioritization (e.g., highlighting the most relevant data); (b) Dynamic Task Sharing (e.g., engaging autopilot); (c) Adaptive Level of Detail (e.g., simplifying graphics); and (d) Adaptive Timing (e.g., delaying non-urgent decisions). Collectively, these adaptations serve to maintain the user's cognitive state in an optimal range, thereby preserving functional performance.

Cognitive Resilience is Enhanced Through Continuous Support

The literature suggests that neuroadaptive systems can actively contribute to cognitive resilience by helping users *bounce back* from stress or errors more quickly. One mechanism is through cognitive buffering, by offloading some mental tasks during peak load, the system prevents the user from entering cognitive fatigue (Picchi, 2025). Several studies have found that operators who use adaptive scaffolding during high workloads not only perform better but also recover more quickly afterward (Flood & Keegan, 2022). By trimming the peaks of stress, the adaptive system preserves more of the operator's cognitive resources for later challenges, which is a hallmark of resilience. Additionally, neuroadaptive systems can facilitate acclimation. For example, in adaptive training simulators, when the system sensed a trainee becoming overwhelmed, it provided on-the-spot tutoring or reduced difficulty (Fairclough, 2023). Over time, this scaffolding was gradually removed as the trainee's capacity increased, resulting in a higher final performance than trainees who either never received support or always had full support. Another aspect is emotional resilience, the system can detect and reduce extreme stress in users by adjusting the pace of tasks or initiating calming protocols. Experimental evidence suggests that this system helps users maintain accuracy and reduce anxiety in stressful situations, allowing them to remain effective for longer.

Trust and User Acceptance Depend on Design Choices

Key design factors include transparency, user control, and perceived reliability. The AI studies described show that users are more likely to trust adaptive recommendations if the system's reasoning is observable (Fairclough, 2023). For example, an adaptive decision aid that highlights which sensor data triggered its alert (e.g., "Alert generated due to high infrared signature in Zone X") is more trusted by naval analysts than a contextless black box alert. In contrast, when adaptivity is hidden, some users become uncomfortable. Pilots in one study were more receptive to EEG-triggered autopilot interventions when they knew they could always immediately take control if desired. Conversely, completely mandatory adaptations sometimes cause frustration, especially if the system makes an incorrect decision. Perceived sensing reliability is another issue: if the system adapts inappropriately, trust can decline rapidly. Several papers emphasize the importance of using sensors to avoid false positives/negatives in detecting user state. In practice, a short calibration phase for each user has been shown to increase user trust, as the system better adapts to individual differences (e.g., some people naturally have higher heart rates). Finally, when users understand what the system is monitoring and how it adapts, they are more cooperative. In a study of fighter pilots, those who received a pre-flight briefing on the jet's neuroadaptive cockpit aids showed higher trust scores and more effective use of the aids than those who were not briefed (Picchi, 2025). In short, the research findings suggest that NUX should be user-centric not only in its effects but also in its transparency and control, ensuring that humans remain empowered agents in the adaptive loop.

DISCUSSION

Framework Overview and Components

The Neuroadaptive UX (NUX) framework is conceptualized as a closed-loop adaptive system that continuously aligns defense technology with human cognitive and emotional states. Its architecture consists of four components that work synergistically to enhance performance in high-risk environments. The first component, user state sensing, relies on multimodal physiological and behavioral measurements, including EEG for brain activity, HRV for stress, and eye tracking for attention monitoring (Arico et al., 2016). This continuous monitoring ensures that the system can detect subtle fluctuations in workload and fatigue before they manifest as performance degradation.

The second component, state interpretation, transforms raw signals into actionable insights. Using machine learning algorithms and individual calibration, the framework classifies operator states into categories such as overload, optimal workload, disengagement, or fatigue. This layer is crucial because it reduces false triggers and adapts the system's response to each operator's unique neurocognitive profile (Hinss et al., 2022).

The third component, adaptive interface and automation, responds dynamically to the interpreted states. When the workload is high, the interface can filter out low-priority information or temporarily delegate routine tasks to autonomous subsystems. Conversely, when the workload is low, the system can

increase task engagement by reducing automation to maintain situational awareness.

Finally, the user feedback and trust management component ensures that adaptations are easily understood by operators. This involves explainable adaptation cues, notifications indicating why the system has changed its behavior, and manual override options to maintain user agency. This step is crucial for preventing bias and mistrust and aligns with human-centered design principles in defense UX.

Taken together, these four components form a symbiotic cycle: sensing informs status interpretation, interpretation drives adaptive responses, and transparency fosters trust. By collaborating these processes, the NUX framework not only optimizes real-time performance but also strengthens long-term cognitive resilience and human-AI collaboration in the defense context.

How NUX Enhances Cognitive Resilience

The Neuroadaptive UX (NUX) framework enhances cognitive resilience by ensuring human operators remain effective under sustained stress. NUX integrates real-time EEG, HRV, and eye tracking sensing to capture workload fluctuations, attention shifts, and fatigue indicators (Arico et al., 2016). These signals are continuously analyzed to classify operator states such as overload, underload, and engagement. With early identification, NUX enables the system to intervene before performance declines.

Adaptation is achieved through dynamic workload management strategies. For example, when EEG and HRV indicate overload, the interface can suppress non-critical data. Similarly, when eye tracking indicates decreased alertness, the system can adjust the tempo to re-engage the operator (Hinss, 2022). These interventions not only stabilize performance but also help operators recover quickly, thereby extending mission endurance.

NUX explicitly supports the core dimensions of cognitive resilience: focus, adaptation, and recovery. Focus is maintained through a simplified interface that minimizes distractions; adaptation is enabled by flexible task redistribution between human and AI agents. and recovery is facilitated by a pacing mechanism that reduces mental strain during sustained operations. By embedding this mechanism into the system, NUX ensures that operators maintain situational awareness and decision quality even under extreme pressure. Equally important, NUX incorporates trust calibration and transparency as resilience drivers. Adaptive actions are clearly communicated, maintaining clarity and enabling override options. This approach addresses the risk of bias and mistrust, ensuring that operators perceive adaptive support as reliable and cooperative.

In sum, the NUX framework enhances cognitive resilience by integrating physiological monitoring, adaptive workload management, and trust calibration into a symbiotic cycle. This enables defense technologies to not only optimize performance but also safeguard the cognitive well-being of operators.

How NUX Fosters User Trust and Partnership

Trust is a cornerstone of effective human-AI teaming, and the Neuroadaptive UX (NUX) framework addresses this by embedding transparency, and shared control into its design. In defense operations, where decisions have life-or-death consequences, operators must understand not only what the system is doing but also why it is making certain changes. NUX achieves this through explainable adaptive cues, providing timely feedback, modifying task allocations, or adjusting alert priorities. This clarity reduces uncertainty, thereby mitigating the risk of over- or under-trust (Arico et al., 2016).

Another crucial element is user agency. By integrating manual override functions and decision checkpoints, NUX maintains the operator's role as the ultimate authority. This ensures that automation is perceived not as a replacement for humans, but as a complement. Research in neuroergonomics shows that when operators have control over adaptive interventions, they are more willing to engage with the system and maintain long-term trust (Hinss et al., 2022). In practice, this means operators view NUX less as a tool than as a reliable partner.

NUX also strengthens partnerships by aligning adaptive responses with the operator's cognitive state. For example, when workload increases sharply, the system filters out non-critical data while signaling why this change occurred. This synchronization fosters shared situational awareness, where both humans and AI operate with an understanding of mission priorities.

Finally, by combining transparency and context-aligned interventions, NUX contributes to the ongoing calibration of trust. Operators do not blindly rely on automation but instead develop a dependency that adapts to the mission context. This quantified trust is crucial because it ensures adaptive support is received when needed. Thus, the NUX framework goes beyond technical adaptations to develop a partnership model for human-AI interaction, enabling defense personnel to maintain authority, confidence, and mission effectiveness.

Comparison to Traditional Systems and Potential Challenges

Traditional defense interfaces are typically static and inflexible, presenting uniform information. While this design ensures consistency, it also places the entire burden of filtering, prioritizing, and interpreting information on the human operator. In high-demand missions, such rigidity can lead to cognitive overload and decreased situational awareness, which reduces mission effectiveness. In contrast, the NUX framework introduces adaptability, continuously adjusting information density, warning times, and task allocation in response to real-time physiological and cognitive indicators. This responsiveness allows operators to remain focused on mission-critical cues while avoiding distractions, effectively creating a more resilient human-AI partnership (Hinss et al., 2022; Arico et al., 2016).

However, several challenges must be overcome for NUX to reach operational maturity. First, sensor reliability, as EEG monitors, HRV, and eye-tracking devices are susceptible to noise, environmental constraints, and user movement in military environments. Second, personalization and calibration are necessary, as neurophysiological responses vary across individuals and contexts.

Furthermore, data governance and ethics: Continuous monitoring of brain and physiological signals raises concerns about the privacy of sensitive data. Furthermore, adaptive automation can introduce new risks, such as operator confusion if system adjustments are not transparent.

Defense systems are often legacy-based and highly regulated, making it difficult to integrate adaptive interfaces without rigorous testing, certification, and operator training. The transition from static to adaptive systems requires a cultural shift. These challenges highlight that while NUX offers improvements in adaptability, resilience, and trust calibration, its success will depend on addressing technical resilience, human-centered design, and ethical safeguards.

CONCLUSIONS AND RECOMMENDATIONS

The Neuroadaptive UX (NUX) framework is an innovative approach to designing defense systems, shifting from rigid interfaces to dynamic, user-centric models. It works by leveraging multiple sensors (such as EEG to measure mental workload, HRV for stress, and eye tracking for attention) to understand the operator's cognitive state in real time. This enables the system to make intelligent adjustments, such as simplifying the interface, shifting tasks to AI, or managing alerts to prevent cognitive overload and maintain situational awareness during demanding operations. At the same time, NUX helps build trust by ensuring transparent actions. While it excels in robustness and responsiveness, its implementation faces challenges, including ensuring sensor reliability in harsh environments, achieving accurate personalization, and protecting the privacy of sensitive neurophysiological data.

Based on these insights, several recommendations can be made. First, future research should focus on developing prototypes and validating them in simulators to refine the technology. Second, field trials are crucial to test how well the system performs in realistic scenarios. Third, designers must incorporate transparent adaptation mechanisms to build and maintain user trust. Fourth, establishing a robust data governance framework is crucial to ensure the ethical use and security of sensitive physiological data. Finally, interdisciplinary collaboration between neuroscientists, AI specialists, engineers, and human factors experts is essential to creating systems that are both technically sound and ethically responsible.

In conclusion, the NUX framework offers defense UX innovation, combining cognitive resilience, adaptive automation, and trust-centered design into a unified model. NUX has the potential to transform defense systems from clunky devices into intelligent partners that protect operator well-being while enhancing mission success in demanding operational environments.

ADVANCED RESEARCH

Advancing the Neuroadaptive UX (NUX) framework requires a transition from conceptual modelling to prototyping and practical implementation. The first step is the creation of pilot systems such as adaptive cockpits, command interfaces, or UAV control stations that integrate EEG, HRV, and eye-tracking sensors to inform real-time adjustments in workload

management (Arico et al., 2016). These prototypes can be tested in simulators to evaluate usability, workload mitigation, and trust-building effects before moving to more challenging environments.

Future field studies should validate neuroadaptive systems in realistic defense operations, such as cyber defense center, by comparing operator resilience, situational awareness, and mission performance with traditional systems (Hinss et al., 2022). Beyond single-operator use, multi-operator neuroadaptive teamwork represents a key research frontier, where adaptive algorithms can balance cognitive demands across teams to optimize mission outcomes. Emerging technologies such as augmented reality (AR) interfaces, wearable haptics, and AI-based adaptive algorithms offer new opportunities to enhance NUX applications. Furthermore, longitudinal research is needed to assess whether continued NUX use strengthens or diminishes operator confidence and skills. Ethical and data security considerations are equally important, as continuous neurophysiological monitoring raises concerns about privacy, consent, and the responsible use of soldier cognitive data.

In conclusion, future NUX research should pursue an interdisciplinary agenda that combines neuroscience, AI, human factors, and defense UX design, systematically progressing from prototype to field validation while incorporating ethical safeguards. Such research will ensure that neuroadaptive systems evolve into mission-ready capabilities that enhance resilience, confidence, and operational effectiveness in defense context.

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