Mental State Adaptive Interfaces as a Remedy to the Issue of Long-term, Continuous Human Machine Interaction

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Abstract – In order to promote safer and more efficient human-machine interaction, this article advocates for the employment of adaptive systems that account for the user's mental state throughout the duration of lengthy, continuous usage. Perhaps what is needed are adaptive systems that can adjust to the user's mood. The operator's state of mind may be inferred using a combination of operator-independent metrics (for instance, time of day and weather) and behavior (for instance, lane deviation and response time) and physiological (for instance, heart activity and electroencephalography) indicators. Several changes may be made to the dynamic between the operator and the system to mitigate the impacts of the operator's diminished cognitive capacity and preserve the reliability and efficacy of operations. Depending on the specifics of the job at hand and the difficulties that must be overcome, adjustments may be made to factors such as the type of the information presented, the structure of the presentation, the prominence of the stimuli, and the order in which the tasks are performed, frequently using the predictions produced by machine learning.

Keywords – Human-Machine Interaction, Mental State Adaptive Interfaces, Mental Fatigue, Cognitive Flexibility, Brain-Computer Interfaces, Situational Awareness.

I. INTRODUCTION

Over the last century, there has been a tremendous rise in efficiency in many fields of research with a transition to increasingly more complex systems. Today's operators must deal with increasingly intricate systems that have more potential for damage if anything goes wrong. For example, commercial aircraft typically transported much less than 50 people between the two world wars less than a century ago, but the deadliest aviation catastrophe claimed more than ten times that number in 1977. Human and machine interaction is shown in **Fig 1** as a simplified flowchart. Numerous situations show why it's vital to investigate the interface between humans and machines to prevent disaster. Even if human error did not directly cause the Three Mile Island disaster, poor HMI undoubtedly contributed to its severity.

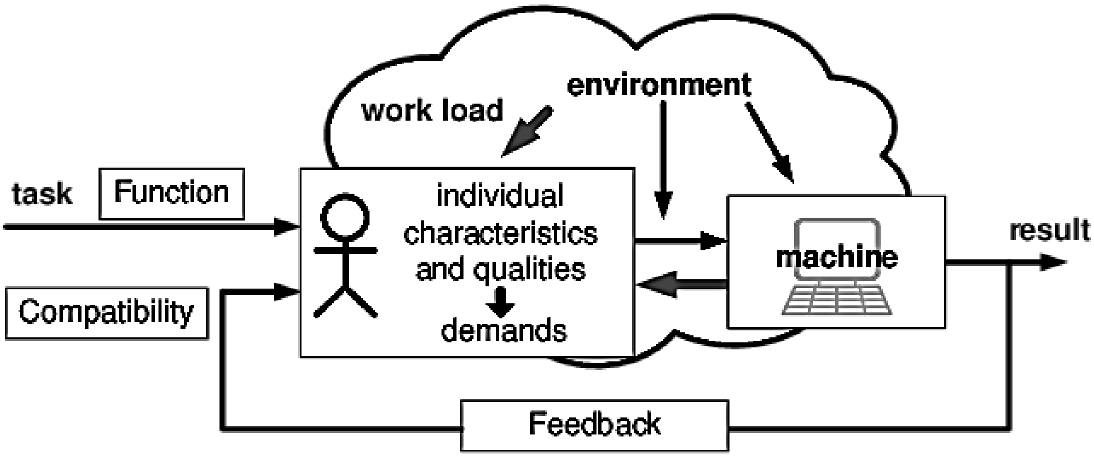

Fig 1. Schematic Illustration of the Human-Machine-System

The containment of the detrimental effects resulting from the release of radioactive hydrogen into the environment was impeded for nuclear plant operators due to an excessive number of alerts and an inadequately designed user interface. Due to the operators' failure to promptly regain control, the leakage persisted. A subsequent collision occurred as a result of the aircraft's crew being excessively engrossed in the task of replacing a malfunctioning light bulb, ultimately leading to the aircraft's impact with the ground. The aforementioned scenarios serve to underscore the inherent interdependence between the machine and the operator, emphasizing that the assurance of safety can only be achieved through the collaborative endeavors of both entities. According to Csathó, van der Linden, Hernádi, Buzás, and Kalmár [1], humans possess the capacity for mental fatigue, unlike robots. This phenomenon can result in heightened vulnerability and a greater likelihood of errors.

In the event that complete removal of the operator is unattainable through automation or human substitution, what other options are available? The concept of Time on Task (TOT) pertains to the duration that has elapsed since the initiation of a task, and the utilization of adaptive systems has the potential to mitigate its influence. The objective of these systems is to adapt to the cognitive aspect of operators, taking into account the particularities of the current task. Various methods can be employed by systems to accomplish this task. Adaptive automation has the capability to fully or partially automate a process, such as the autopilot system in an aircraft, depending on the prevailing conditions. Nevertheless, adaptive interfaces modify the manner in which individuals interact, as opposed to simply automating mundane tasks. Adaptive driving modes and automatic day/night smartphone settings serve as illustrative instances within the broader context of this discussion.

Remarkably, there has been a dearth of research examining the potential of adaptable interfaces grounded in mental state to assist the operator during prolonged and uninterrupted utilization. This article aims to explore the current state of research in the subject matter and endeavors to address the following inquiries: (i) What is the impact of consistent usage on mental faculties and actions? (ii) What data should an adaptable interface utilize in order to deduce the user's intention at any given moment? (iii) In what ways can adaptive interfaces alter the dynamics of human-computer interaction to mitigate these negative outcomes?

This article is aimed at addressing the aforementioned concerns in a manner that does not necessitate the utilization of a formal systematic review. This article critically examines the existing research pertaining to a cognitive state that is influenced by adaptable interfaces. It also explores various categories of metrics that can be utilized to identify mental fatigue, and investigates the potential impact of prolonged usage on cognitive abilities. The subsequent sections of the article maintain the following organizational framework: Section II reflects on prolonged continuous usage, effective links to mental fatigue. Section III discusses the aspect of adaptability and adaptive interfaces. In Section IV, the triggers, and markers for adaptation are discussed. Section V provides a general discussion to the themes in the article. Lastly Section VI concludes the article.

The subsequent section will delve into the implications of Human-Machine Interface (HMI) utilization on cognitive processes and behavioral patterns.

II. PROLONGED CONTINUOS USAGE, EFFECTIVE LINKS TO MENTAL FATIGUE

The term "prolonged continuous use" or "prolonged operation," as employed in this context, refers to the engagement in an activity for a duration that exceeds the initial expectations. The acronym TOT is frequently employed within the realm of experimental sciences for descriptive purposes. The concept of mental fatigue is intricately linked to the aforementioned idea and is frequently examined in conjunction with it. In contrast to physical fatigue, which can be attributed to insufficient rest, mental fatigue arises gradually as a consequence of sustained cognitive exertion. This essay exclusively focuses on the cognitive impact of mental fatigue. The consistent utilization of a particular activity results in more than mere mental fatigue. However, the two concepts are interconnected. Numerous investigations on cognitive fatigue involve the inclusion of participants who are instructed to engage in a task for an extended duration. Therefore, the examination of TOT is essential in the investigation of mental fatigue using this particular research approach. The comprehensive analysis of the various effects of mental fatigue and tip-of-the-tongue phenomenon exceeds the limitations of this research article. This study aims to demonstrate that prolonged and continuous usage, as well as mental fatigue, have a significant impact on the essential components of Human-Machine Interaction (HMI).

Attention and Mental Fatigue

The capacity to consciously direct and filter attention towards specific stimuli, while disregarding others, is a fundamental component of human behavior. This cognitive ability serves two important functions: firstly, it enables individuals to allocate cognitive resources effectively, prioritizing the processing of incoming data in a way that enhances the achievement of immediate objectives; secondly, it aids in the avoidance of potential distractions that may impede progress towards these objectives. Maintaining a high level of attentiveness is a crucial aspect of engaging with automated systems. There exist multiple manifestations of attention, owing to its broad conceptualization. The classification of a process as exogenous (or "Top-Down") or endogenous (or "Bottom-Up") can be easily determined through identification. The cognitive process of directing one's attention in a hierarchical manner, starting from higher-level cognitive processes and moving towards lower-level sensory processes, is commonly referred to as "top-down attention."

Govaerts et al. [2] assert that there is a consensus among researchers regarding the substantial impact of mental fatigue on top-down attentional mechanisms. The individuals involved in this study successfully undertook an ANT (Attention

Networks Test). The disentanglement of top-down and bottom-up attention effects can be achieved through meticulous behavioral analysis due to the foundation of the ANT on a flanker task. There was no observed alteration in bottom-up attention as a result of tip-of-the-tongue (TOT) phenomenon following an extended period of performance. However, the performance of top-down attention experienced a significant decline. In a similar vein, Russell, Halson, Jenkins, Rynne, Roelands, and Kelly [3] discovered a negative correlation between heightened mental fatigue and performance on a visual attention assessment, as evidenced by longer response times (RT) and reduced accuracy (ACC). Remarkably, the performance of the participants exhibited an initial improvement as a result of the learning effects, followed by a subsequent decline attributed to exhaustion. According to the findings of Steele, Pinto, Nosaka, and Nuzzo [4], there is additional evidence supporting the notion that fatigue can have a detrimental impact on an individual's capacity to concentrate. The decrease in focus led to a subsequent increase in response times over a period of time.

The phenomenon known as "mental fatigue" refers to the subjective experiences that individuals may encounter following prolonged periods of mental exertion. This phenomenon is a common incidence in contemporary society. The current understanding of the psychophysiological foundations of mental exhaustion remains limited.

Cognitive Flexibility, Multitasking and Task-Switching

The engagement in multitasking is a prevalent phenomenon observed among individuals, notwithstanding the potential detrimental impact it may exert on one's work performance. The comprehension of the cognitive framework of the brain and the underlying mechanisms involved in information processing can be enhanced through the examination of the constraints associated with multitasking. The aforementioned theoretical concern has been extensively investigated through various experimental paradigms that manipulate the temporal and cognitive overlap in the processing of multiple activities. The definition of "multitasking" poses challenges due to the divergent paradigms that adopt distinct strategies for integrating multiple activities. The conceptualization of a "task" lacks a universally agreed-upon definition. A "task" refers to a cognitive or behavioral objective that is either given as instructions or self-imposed. The resulting representation of the cognitive and motor demands linked to this objective is termed a "task set."

For further insights into the concept of a task set, one can refer to scholarly discussions by Sakai [4]. A task encompasses a wide range of activities, ranging from basic stimulus-response translations to more intricate mental operations or physical movements. These activities can include simple tasks like pressing a response key upon seeing a specific letter, as well as more involved tasks like visuo-motor tracking or performing complex mental operations such as multiplication. Additionally, tasks may also involve complex physical movements, such as throwing a ball. Inevitably, variations may emerge given the expansive nature of this definition, particularly in the context of hierarchical occupations or those involving numerous sequential tasks.

The term "task" can have different meanings depending on the level of detail in the description. It can refer to a single step in a process or to a broader objective. Despite potential challenges in defining the concept of a task, the term "multitasking" is commonly employed to denote the scenario wherein cognitive processes required for the execution of multiple tasks occur concurrently, resulting in the simultaneous maintenance of two task sets. Time constraints are a defining characteristic of multitasking as they hinder the ability to complete any individual activity in isolation. Furthermore, it is imperative that cognitive processes, such as the updating of task rules in working memory, the retention of the current task state, and the evaluation of task outcomes, occur concurrently across multiple tasks and are thus concurrently represented within the cognitive framework. Hence, our conceptualization of multitasking encompasses not only the engagement in two activities that necessitate ongoing, simultaneous motor responses, but also the act of sequentially switching between tasks, temporarily suspending tasks, and subsequently resuming them.

Cognitive flexibility can be defined as the capacity to quickly change between different tasks. Quick task switching has been found to potentially impede individuals' performance, leading to decreased efficiency and reduced accuracy. According to Hund, Bove, and Van Beuning [6], cognitive flexibility plays a vital role in the effective functioning and sustained usage of intricate systems, as these systems typically consist of multiple sub-systems that operators need to transition between. Certain studies create a significant difference between cognitive flexibility that alludes to the capacity to change between different tasks, and task-switching, which specifically refers to the act of switching between tasks. Despite their frequent interchangeable usage, these terms are not synonymous. The subsequent perspective will be employed for the remainder of this article.

According to a recent study conducted by Nijhof, Nijhof, van de Putte, Houtveen, van Montfrans, and Knoop [7], emerging evidence indicates that cognitive fatigue plays a significant role in the deterioration of task-switching performance. A total of thirty-three individuals were exposed to a controlled experiment in which they engaged in a timed task-switching paradigm. The study included a series of trials in which participants were required to either adhere to pre-established guidelines or develop new guidelines. The behavioral data exhibited indications of fatigue and task-switching. The performance, as measured by response time (RT) and accuracy (ACC), exhibited a decline over time. Surprisingly, the discrepancy between the experimental group, which underwent switching trials, and the control group, which underwent control trials, increased over time. This implies that cognitive flexibility is significantly more affected by mental fatigue compared to overall performance. The act of transitioning between tasks necessitated the utilization of working memory or the presence of an explicit signal. Additionally, it has been demonstrated that working memory has a certainly negative effective on a person’s capacity to transition between task when experiencing fatigue.

The practice of true multitasking is often deemed essential in complex systems, despite the fact that task switching occurs sequentially. Typically, investigations pertaining to task-switching and multitasking are carried out in isolation from one another. Multitasking, also known as dual-tasking, involves engaging in multiple activities simultaneously, while task-switching tasks are consistently evaluated in a sequential manner. In contrast, Sherbino and Norman [8] provide a comprehensive account of the various common attributes exhibited by task switching and multitasking. Multitasking exhibits several common characteristics, including the presence of switch-costs. In view of this, there has been a proposition that task-switching and multitasking are essentially identical processes, differing only in the degree to which a task is completed sequentially. To the extent of our current understanding, the correlation between multitasking and cognitive fatigue has not been thoroughly investigated. Researchers frequently examine the influence of multitasking on mental fatigue instead of focusing on the impact of mental exhaustion on the performance of multitasking. The impact of fatigue on multitasking performance is comparable to its effect on task-switching performance, as previous research has proposed a connection between the two.

Other Impacts of Situational Awareness and Mental Fatigue

According to Abd-Elfattah, Abdelazeim, and Elshennawy [9], individuals experiencing significant fatigue may exhibit a range of adverse effects on their cognitive functioning and performance, including diminished reaction time, decreased vigilance, impaired decision-making capabilities, compromised judgment, increased distraction during complex tasks, and diminished situational awareness in critical scenarios. Individuals employed in traditional day jobs are equally susceptible to developing chronic fatigue, which can have detrimental effects on their overall well-being, impair their job performance, and elevate the occurrence of errors and safety incidents, similar to those observed in 24/7 enterprises reliant on shift work. In order to mitigate the annual occurrence of accidents and fatalities, it is imperative to reassess our comprehension of weariness.

The decline in employee productivity can be attributed to fatigue, which manifests in challenges related to sustained attention, memory recall, rapid response, and information retention. In addition to its physical manifestations, fatigue can also exert psychological and behavioral repercussions. The impulsive behavior exhibited by workers has the potential to result in misunderstandings and conflicts within the workplace. Employees who are burdened with excessive workloads are more prone to a decrease in their ability to display empathy, maintain vigilance, and uphold ethical standards. These factors collectively contribute to a negative impact on both productivity and security within the workplace. Employees who lack concern for their colleagues are more inclined to refrain from actively reporting safety issues they observe. Fatigue, along with its associated physical problems and disorders, can lead to absenteeism among workers and contribute to increased healthcare costs. Exhaustion is a significant contributor to the squandering of time and energy. Various factors such as distractions, errors, difficulty in maintaining focus, and lack of motivation can exert a detrimental impact on employee morale, ultimately influencing the overall performance outcomes.

Another study that employed a methodology with greater ecological validity examined the prolonged and uninterrupted usage patterns among train drivers [10]. Two separate days were dedicated to simulating two 8-hour "shifts" of railway driving for professional conductors in order to assess their professional performance. As the operators' levels of weariness increased, their proficiency in avoiding errors declined from near perfection to a noticeable frequency of mistakes. The braking system was excessively utilized, exemplified by its frequent and prolonged usage. The cessation of errors was attributed to the individuals' state of fatigue, while the subsequent increase in errors was primarily a result of their failure to undertake necessary actions. The slip-ups can likely be attributed to a decrease in attention. Omission errors can be interpreted as a failure to thoroughly examine a particular situation. The study conducted by Staiano, Bonet, Romagnoli, and Ring [11] examined the influence of mental fatigue on methodical exploratory performance. The results of their investigation indicated a potential relationship between the two variables. Prior to engaging in an experimental computer task, participants were instructed to engage in cognitively demanding activities or to wait. The extent to which participants engaged in systematic exploration of the intricate interface was quantified. Our study revealed that individuals experiencing mental fatigue exhibited a significant decrease in the duration of time dedicated to systematic inquiry.

Extended procedures can potentially lead to alert fatigue. According to Marasco, Boner, Heidinger, Griffiths, and Monaghan [12], individuals may develop a form of immunity towards the effects of warnings due to prolonged and consistent exposure. This matter has been repeatedly substantiated, not only within the medical domain but also in the realms of mining and construction. The phenomena of limited adaptability to change, planning challenges, limited exploration, omission mistakes, and alert tiredness may be viewed as distinct versions, but they may also be considered as constituent elements of the broader concept of situational awareness. When engaging with intricate systems, it is imperative to bear in mind the perspective of situational awareness (SA). According to Tam and Jones [13], the perspective of SA alludes to the cognitive process of perceiving the various elements present in a given environment over a specific period of time and space, comprehending their significance, and predicting their future status. The concept of situational awareness (SA) encompasses more than just an individual's understanding of their objectives and purposeful actions. It also involves a comprehensive understanding of one's historical and current surroundings, along with considerations of potential future events and their significance or applicability.

The occurrence of a devastating accident involving an Eastern Air Lines L1011 Lockheed Tristar aircraft in Florida serves as a poignant illustration of the gravity associated with the loss of situational awareness. According to O'Brien and

Bull Schaefer [14], the captain, first officer, and flight engineer of Flight 401 became excessively focused on the task of replacing a burnt-out light bulb, resulting in their failure to perceive the decreasing altitude of the aircraft. Due to its significance in complex tasks and vulnerability to cognitive exhaustion, situational awareness (SA) emerges as a viable contender for enhancement via adaptive interfaces, as elaborated in the subsequent section.

III. ADAPTIVE INTERFACES AND ADAPTABILITY

General Concerns for Adaptive Interfaces

The concept of a "adaptive user interface" (AUI) pertains to a user interface (UI) that possesses the capability to be personalized by individual users according to their distinct needs and the particularities of their usage scenario. In an authentic Adaptive User Interface (AUI), the constituent elements comprising the interface possess the characteristics of adaptability and being adaptable. Consequently, various components of the interface have the capacity to adapt to one another and exert mutual influence. The aforementioned methodology is frequently employed to amalgamate two ostensibly disparate components, namely an interactive webpage and an application, such as a web browser. The adaptive user interface designers incorporate a mechanism that facilitates the negotiation between the designers and the user regarding the placement of user interface components. This negotiation process typically involves an automated approach, although exceptions may exist.

In order to enhance the exchange of information between humans and machines, researchers are currently working on the development of adaptive interfaces. Prior to delving into the intricacies of prolonged and uninterrupted utilization, it is crucial to analyze certain fundamental factors that are identified to affect the effectiveness of adaptive interfaces. The calibration of multiple variables is imperative in order to optimize operator performance, as adaptations do not occur in a binary manner.

Trust

Trust plays a pivotal role in facilitating effective communication between individuals and robotic entities. Despite lacking confidence in a given system, a user has the option to refrain from utilizing it, despite its potential utility. However, an alternative issue may arise when an excessive amount of trust is placed in a particular system. The crew of the Royal Majestic, a passenger liner registered in Panama, seemingly exhibited excessive reliance on the automated navigation systems installed on their vessel. The occurrence of negligence over a duration of 24 hours resulted in the ship engaging in a continuous circular trajectory along the coastline, resulting in the accumulation of damages amounting to nearly $7 million.

In their seminal work, Wischnewski and Krämer [15] propose the concept of calibrated trust in the context of automated systems, aiming to mitigate the risks associated with both excessive trust and distrust. When an operator's level of confidence in a system is directly proportional to the system's demonstrated reliability, it can be stated that the system has been calibrated to establish trust. Three key factors have been identified as crucial in achieving this objective: (i) the term "performance" is employed to denote the degree of achievement attained by the automated system, (ii) the term "process" pertains to the degree of familiarity that the operator possesses regarding the internal mechanisms of the automation, and (iii) the function serves to elucidate the efficacy of the automated system in executing its designated task.

Insufficient attention to these factors during the design phase of an adaptive system can result in a lack of trust or an excessive amount of trust. The likelihood of the operator rejecting task automation is higher when the system exhibits poor performance, a scenario that is easily foreseeable in adaptations reliant on automation. While ongoing research in [16] continues to explore the significance of trust in automation, several unresolved concerns persist regarding the dependability of adaptive user interfaces.

The mental state of operators can be deduced using adaptive interfaces that rely on mental state inference. The metrics, which are extensively examined in Section IV, play a decisive role in determining the timing and manner of system change. The user is required to possess confidence in the system's ability to accurately predict their individual cognitive state. When a system makes the decision to initiate an adaptation, the complexity of the situation increases significantly. The causal agent will certainly alert an operator regarding the system's assessment of the current interaction. The reliability of both parties will be tested if there is any inconsistency between the operators' and the interface's comprehension of the interaction. Users may opt to withdraw from using the interface if they harbor any reservations regarding its reliability. The aforementioned statement also applies to adaptive robotic systems. As such, this field remains relatively unexplored, yet its significance is heightened by the increasing prevalence of adaptive systems. Consequently, there is a pressing need to conduct further research in this area.

Design Concerns for Operative Adaptive Interfaces

According to Arcaini, Riccobene, and Scandurra [17], the consideration of trust is essential in the design of adaptive systems that aim to achieve high usability. The achievement of successful adaptations has been associated with a cognizance of the process, specifically the internal mechanisms involved in adaptations. The findings of the authors demonstrate a significant enhancement in participants' performance following their comprehension of the modification. It is imperative for the operator to have constant awareness of the adaptation's status, regardless of whether it is activated or not. Moreover, it is imperative for the operator to consistently possess the choice to assume control, which can be achieved by deactivating the adaptation mechanism.

There are two potential scenarios in which an operator may be "out of the loop": either the operator's involvement in an adaptation is terminated, thus removing them from the loop, or the adaptation itself introduces an interruption to the operator's ongoing activities. Morgeson, Reider, and Campion [18] emphasize the importance of accommodating individuals' distinct personalities, interests, and skill sets to a greater extent. It is imperative to take into account the potential collateral effects of any proposed modifications. While the process of adaptation has the potential to enhance performance in relation to a specific metric, it also has the capacity to diminish performance in relation to another metric.

Agrawal and Peeta [19] demonstrated a consistent trend of enhanced behavioral performance accompanied by diminished Situational Awareness. The matter concerning unintended consequences gives rise to a more extensive investigation into the criteria for evaluating the efficacy of an adaptation. While it may be relatively uncomplicated to handle simple activities, the difficulty level significantly increases when the tasks start to resemble simulations of intricate real-world scenarios. In the process of developing and testing an adaptive system, it is imperative to incorporate assessment as a crucial component. Furthermore, it is imperative to establish a system that possesses the capability to function autonomously in the event that an individual fail to execute tasks according to predetermined expectations.

Adaptive Interfaces in the Prolonged Use Context

Balachandran [20] propose an interim taxonomy of adaptations. The current classification system lacks the ability to distinguish between adaptive interfaces and adaptive automation. Due to this differentiation, the sustained and uninterrupted utilization necessitates additional caution. According to the authors, when employing an adaptive interface, substantial alterations in the level of automation can occur. In such cases, the modifications to the nature of the task may be so significant that it becomes inappropriate to consider it as the same activity. Consequently, it is advisable to refrain from utilizing the adaptive interface continuously over an extended duration. Hence, we propose a modified taxonomy in **Fig 2**.

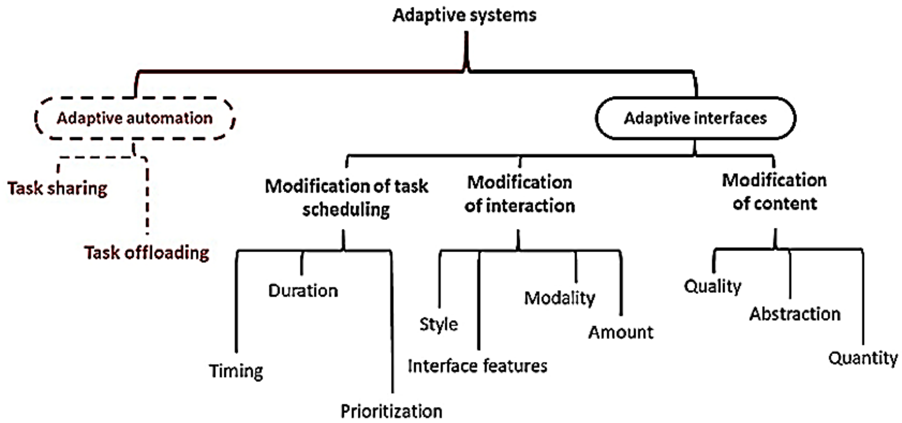

Fig 2. Provisional Classification of Various Types of Adaptations

The examination of the reasons behind the adaptation of an interface is pivotal in determining the appropriate approach for its adaptation. In order to mitigate the potential onset of adverse effects stemming from prolonged usage and cognitive fatigue, it may be imperative to implement preventive measures. Conversely, adaptive systems can be engineered to mitigate the effects of degradation and adapt to the operator's changing cognitive condition. Caffeine, hydrotherapy, chicken essence, and physical exercise have demonstrated potential as strategies to alleviate mental fatigue; however, their practical efficacy remains constrained. Nevertheless, previous studies have provided evidence indicating that the introduction of external motivation, specifically in the shape of a reward, can have a notable impact on reducing cognitive fatigue.

Nevertheless, there exist two factors that may impede the possibility of motivation being a viable choice: Piechowski et al. [21] suggest that the performance of an operator could potentially be enhanced through the provision of external incentives. However, the duration of this effect remains uncertain. Furthermore, it is prevalent for operators to engage in exploitative behavior within reward-based systems. The sole objective of direct reward maximization, also known as the external motive, takes precedence over all other considerations, leading to the neglect of other factors. Given the apparent unlikelihood of completely preventing weariness, it is more rational to direct attention towards mitigating mental exhaustion. In the following discourse, we explore the subject matter of flexible interfaces and the theoretical frameworks pertaining to interfaces that possess the ability to adapt. Specifically, we delve into the operators' attentional allocation, cognitive flexibility, and situational awareness.

Attention

There exist two primary perspectives within the field of adaptive interfaces that aim to address attentional challenges. Numerous advancements in autonomous vehicles and robotics have been implemented to automate specific tasks, thereby enabling operators to allocate their time and attention to more critical activities. The study conducted by Zak, Parmet, and Oron-Gilad [22] aimed to examine the potential advantages that unmanned vehicle operators could derive from the implementation of partial automation in their roles. Both an Unmanned Ground Vehicle (UGV) and Unmanned Aerial System (UAS) require active piloting by the operators. The process was automated in an adaptive manner based on performance metrics. In instances where operator performance experienced a decline in the context of a change detection task, the responsibility for routine tasks was assumed by automated machines. When operators were assisted by adaptive automation, their level of focus was significantly greater compared to the control condition.

Several studies have examined strategies for minimizing the occurrence of errors by optimizing the advantages of the bottom-up attention through the manipulation of alert prominence and data salience. Wee, Lye, and Pinheiro [23] proposed four modifications, with two focusing on concentration, as suggested measures for air traffic controllers to effectively manage the escalating cognitive load. The system identified and emphasized aircraft that were engaged in active communication with the controller. Moreover, the interface would incorporate an animated alert system to notify users in the event of a potential midair collision. The findings of this research showed that the activation of adaptations during periods of intense cognitive stress can effectively improve performance and aid in the recuperation process from such circumstances. The enhancement of UAS pilots' focus was achieved through the implementation of a user interface that possesses comparable adaptability. During the initial phase of the study, participants engaged in a simulated Unmanned Aerial System (UAS) flight task, while their attentional state was monitored using a portable Electroencephalography (EEG) device.

According to Coll-Martín, Carretero-Dios, and Lupiáñez [24], participants were notified through an alarm whenever their attention deviated. The size of the sample (N = 4) was insufficient to derive any significant inferences regarding the outcomes. The efficacy of the "Red Alert" technique employed in air traffic control was also notable. In the event of a possible midair collision, the entire display would undergo a color change to red. According to the authors, the process of salience enhancement resulted in improved performance on the air traffic control (ATC) task.

Cognitive Flexibility

There has been a limited amount of research done on cognitive flexibility and adaptive systems, despite the extensive investigation into the impacts of task-switching on intricate tasks. Multiple studies propose various strategies for reducing the cost associated with task switching. The study conducted by Mittelstädt, Miller, and Kiesel [25] investigated the potential reduction of task-switching costs through the utilization of voluntary switches in contrast to planned switches. Interestingly, it has been discovered that even when task-switching is done willingly, it still leads to decreased response times. Additional research has substantiated the effects on accuracy, as supported by Soares 3rd, Price, Prast, Tarbox, Mader, and Blanchard [26]. The optional inclusion of switches appears to alleviate the cognitive flexibility demands, yet the question of whether switches can be discretionary or necessitate predetermined timing or response to significant circumstances within intricate processes is a matter of debate. The concept of providing operators with advance notice or alternative indicators prior to a switch holds a certain degree of appeal.

Brenner et al. [27] have indicated that both preparation time and cuing have demonstrated the ability to reduce response time in experimental trials. However, it should be noted that the total reaction time did not exhibit a decrease when the additional preparation time was considered. The articles do not provide sufficient evidence to determine whether preparation has an impact on accuracy, due to the low occurrence of errors in all settings (potentially indicating a ceiling effect) and a dearth of recorded data. Umemoto and Holroyd [28] report error rates in their research done on prompted task switching. A reduction of approximately 30% in errors was observed when trials were prompted, although no statistical analysis of the findings was provided. According to the results obtained, the utilization of cuing task-switches emerges as a favorable choice for adaptive interfaces, especially when there is limited tolerance for waiting time in return for enhanced precision. Based on the findings in [29], the impact of extended usage on cognitive flexibility may be intensified by the requirement to utilize working memory. The potential efficacy of adaptive systems for outsourcing working memory could be considered. It is noteworthy that the process of automation itself may entail the imposition of switching costs on the individual, potentially leading to adverse effects on cognitive flexibility.

Situational Awareness

The fundamental essence of situation awareness (SA) lies in comprehending the environment, its constituents, and their temporal transformations as well as their responses to external stimuli. In various contexts, the absence of situational awareness can impede decision-making. The technical definition of environmentalism can be described as the cognitive process of perceiving and understanding the various elements present in a given environment, considering both the spatial and temporal dimensions. Furthermore, it involves the interpretation of the significance of these elements and the anticipation of their future conditions within a proximate timeframe. Alternatively, situation awareness can be conceptualized as a cognitive state characterized by an external orientation and adaptability, leading to the acquisition of information about one's environment and the ability to appropriately respond to it.

The significance of situation awareness has been acknowledged by decision-makers in various industries, such as aviation, law enforcement, air traffic control, healthcare, ship navigation, emergency response, control operations and military command, transmission system operators, offshore oil, self-defense and nuclear power plant control. Accidents are frequently attributable to human error, with a common contributing factor being a deficiency in situational awareness. When confronted with a potentially hazardous circumstance, it is imperative to employ an appropriate and precise decision-making methodology. This methodology encompasses the identification and correlation of patterns, the construction of intricate mental frameworks, and the assimilation of archetypal knowledge that enhances the ability to make sound judgments. These principles are put forth in Endsley's theory of situation awareness.

The efficacy of various adaptive systems in enhancing operators' situational awareness has been evaluated through multiple tests. The subject of automation has received significantly more scholarly attention compared to other forms of flexibility, such as attention and cognitive agility. According to previous research conducted by Cayeux, Macpherson, Laing, Pirovolou, and Florence [30], it has been demonstrated that automation has a detrimental effect on situational awareness (SA). The study conducted by the authors found that while automation improved performance on objective task measures, it had a notable negative impact on situation awareness (SA). This was observed in the context of participants being presented with a choice between a route specified by the operator and one automatically advised by the system. The analogy employed by lumberjacks, which states that "the higher they are, the further they fall," has been effectively utilized in a meta-analysis conducted by Fasth, Stahre, and Dencker [31] to examine the impact of "Level of Automation" (LOA) on worker productivity.

IV. TRIGGERS/MARKERS FOR ADAPTATION

According to Junaid [32], the effectiveness of adaptive interfaces is contingent upon both the type of adaptation employed and the criteria used to determine when to activate or deactivate an adaptation.

In this proposal, we propose a categorization of the metrics utilized for assessing an operator's cognitive state into three distinct classifications: covariate, behavioral, and physiological. The covariate metrics (1) do not rely on the operator. Factors such as the time of day, type of mission, weather conditions, and system health are all considered in the determination of TOT. A covariate-based adaptive system would exhibit consistent responses in identical circumstances, irrespective of the operator involved. (2) Metrics that rely on the conventional input devices of a system, such as the keyboard, mouse, and joystick, are classified as behavioral metrics. The spectrum of cognitive engagement can vary, encompassing both deliberate user input, such as activating an autopilot through adaptive interfaces, as well as quantifiable behavioral outcomes, such as response times and accuracy. In addition, the acquisition of physiological measurements necessitates the utilization of either a novel system input device or an alternative sensor distinct from those employed for the recording of behavioral data.

Electrocardiography, electroencephalography, and eye-tracking are widely utilized modalities for electrophysiological monitoring. The signals obtained from these sensors can be used to derive metrics in both the spectral and temporal domains. Subsequently, a decision must be rendered according to the selected metrics. When considering automated decision-making, individuals have the option to adopt a heuristic/rule-based strategy, a machine learning approach and a reinforcement learning approach. The selection of machine learning techniques is contingent upon the specific circumstances, encompassing prevalent approaches like support vector machines and linear discriminant analysis.

Operator and Covariate Independent Metrics

Covariate measurements are frequently employed in the context of adaptive user interfaces. The time-of-day sensor integrated within a smartphone can prompt the device to transition into night mode. In a similar vein, the driving characteristics of a vehicle can vary according to the road type it traverses. Consequently, it is unsurprising that covariate measures are rarely employed in isolation within adaptive automation and adaptive interfaces systems designed for prolonged, and continuous utilization. Nevertheless, the utilization of covariate measurements has been observed in integration with other types of metrics in specific research studies. Herrington, Zahed, and Fields [33] utilized a time series clustering model to analyze the participants' actions in a simulated Unmanned Aerial System (UAS) task.

The findings of the study highlighted the significant role of TOT (Tip-of-the-Tongue) phenomenon in the task performance. Moreover, the utilization of time of day has been incorporated in mathematical models within the automobile industry to simulate driver fatigue. One could posit that the lack of operator dependence in covariate measurements can be considered as a disadvantage. Nonetheless, it is our argument that the operator-agnostic frameworks also have a particular disadvantage. The necessity to rely on these systems is reduced due to their lack of dependence on operator calibration and their tendency to make fewer assumptions regarding the operator's mental state. Lastly, these tools may prove advantageous due to their user-friendly nature and inconspicuousness.

Behavioral Metrics

Behavioral metrics have some advantages in research and analysis due to their non-intrusive nature, lack of additional equipment requirements, and potential to enhance accuracy by taking into account an individual's behavior. However, in contrast to variables, classifiers typically require a calibration phase, commonly referred to as training a classification algorithm. The utilization of steering and the integration of multiple measurements have demonstrated their efficacy in the surveillance of mental fatigue among drivers, rendering these behavioral metrics appealing for prolonged application. Gavelin, Neely, Dunås, Eskilsson, Järvholm, and Boraxbekk [34] conducted a study in which they employed various measures to assess mental exhaustion by observing mouse and keyboard activity during a task. Fatigue can be categorized according to six out of the fifteen metrics. Metrics were established to quantify variables such as error frequency during typing and typing speed. Similar to the covariate metrics and the research encompassing multiple driving measures, the autors illustrated the superiority of employing a diverse range of measurements as opposed to relying on a singular metric.

Physiological Metrics

This research focuses on the examination of passive brain-computer interfaces and physiological computing, specifically when utilizing only a single measure of brain activity for estimation purposes. Sandberg, Bibby, Timmermans, Cleeremans, and Overgaard [35] have discovered a number of task-independent measures that exhibit a high level of accuracy. The acquisition of training data and the intrusive characteristics of numerous technologies diminish their practicality. With the increasing prevalence of robots, it is inevitable that they will be increasingly utilized as social and supportive companions in various settings such as classrooms and hospitals. In order to effectively engage in social interactions, establish prolonged connections with the user, and enhance natural human-robot interaction (HRI), it is imperative for robots to possess the capability to evaluate the emotional condition of human counterparts, in addition to comprehending human intentions and directives. Furthermore, in order to ensure ergonomic and safe collaboration between humans and robots in domestic and industrial environments, it is imperative to accurately assess factors such as effort, anxiety, and errors. In this study, the primary emphasis is on the utilization of brain-computer interfaces (BCIs) to passively identify the cognitive and emotional states of human users. The objective is to effectively modify a robot's behavior in a closed-loop engagement with human partners, as illustrated in **Fig 3**.

Hence, Angrisani et al. [36] excluded articles, which utilized active brain-computer interfaces (BCIs) for controlling motion, such as operating robots through motor imagery, or reactive BCIs for deliberately choosing actions within the robotic interface, such as triggering robot manipulations via event-based P300 or SSVEP (Steady State Visually Evoked Potential). In order to be considered for inclusion in the study, it was necessary for the research to incorporate EEG signals and AI-driven prediction models. The main purpose of the research was to establish a passive BCI classifier that could be utilized in real-time interactions with robots. The omission or prior inclusion of studies focusing solely on brain oscillation patterns in the setting of robot interactions within the section dedicated to Affective/Cognitive State Estimation and Brain-Computer Interfaces (BCIs) has been observed in neuroscience literature. Ultimately, it was necessary for the study to document a passive brain-computer interface (BCI) interaction with an actual physical robot. This decision was made in order to exclude engagements with simulated or virtual agents, as the meaning of a simulated agent encompasses a wide range of applications, such as gaming implementations of passive BCIs and the human-computer interaction.

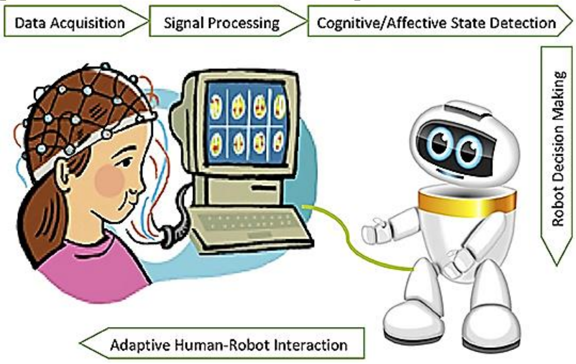

Fig 3. Closed-loop Human-Machine Interaction Based Passive BCIs

V. DISCUSSION

The objective of this research was to review the effectiveness of adaptive systems, particularly adaptive interfaces that consider users' mental states, for application in extended, uninterrupted operations. Based on the findings of the study, it has been observed that there is an elevated likelihood of errors and unsuccessful outcomes in complex tasks as the TOT (Task Overload Tendency) escalates. This can be attributed to a decline in cognitive flexibility, attentional capacity, and situational awareness. There are several factors that contribute to the effectiveness of adaptive interfaces in mitigating the aforementioned consequences. The significance of operators possessing trust and proficiency in the system they are utilizing has been emphasized in previous studies.

Furthermore, the consideration of ecological validity can help mitigate secondary effects, establish boundary conditions, ensure scalability, facilitate calibration, and address the complexities associated with the phenomenon. Target highlighting, attentional warnings, and data suppression represent a subset of the various potential modifications that can be implemented. Gupta and Kaplan [37] have indicated that utilizing a collection of measures, alongside dependable estimation approach, surpasses individual measures in the identification of a declining mental condition resulting from prolonged usage. To enhance the robustness of their findings, researchers can address the constraints associated with relying on a solitary metric by incorporating data from alternative sources, such as behavioral and physiological measurements

The literature review conducted by Stuerzlinger, Chapuis, Phillips, and Roussel [38] reveals a limited number of instances where fully adaptable interfaces, which are contingent upon a user's mental state, have been effectively implemented. In order to effectively assess qualities such as trust, it is imperative that future endeavors focus on the development and evaluation of more comprehensive systems. The authors involved in the development of these interfaces should consistently question the potential deployment of the system in an actual operational setting, if that is indeed the ultimate objective. However, it is important to consider the practical limitations in this context. The calibration stages required for machine learning algorithms may vary depending on the specific measure being employed. Furthermore, the process of certifying these algorithms for practical application may involve a considerable amount of time. Based on current understanding, the examination of trust within adaptive interfaces remains unexplored. However, this represents a promising avenue for future research [39].

Based on the content presented in this article, it is possible to initiate the initial phase of addressing the existing gaps in our comprehension of the complexities associated with prolonged human-machine interaction. Additionally, potential remedies such as adaptive user interfaces [40] can be explored as potential solutions. However, there remain unresolved inquiries regarding specific aspects that were deliberately concealed [41]. Prolonged utilization can potentially impact various aspects such as sleep patterns, circadian rhythms, and performance in shift work, among other factors [42]. The variability in the conceptualization of sleep and the diverse methodologies employed to assess it across different studies precludes the establishment of definitive conclusions regarding the association between sleep and mental fatigue. It is imperative to analyze the interplay between operator competence and preference, as well as the impact of prolonged usage, in relation to the specific sensory modality being engaged [43].

Additionally, it is imperative to acknowledge that the impact of mental fatigue on cognitive processes extends beyond the scope of the issues discussed in this article [44]. Ultimately, the acquisition of knowledge and skills plays a pivotal role in facilitating sustained and effective utilization over an extended period of time. Undoubtedly, the pursuit of education, particularly within the potentially virtual confines of a classroom, requires a substantial commitment of time to engage in rigorous exercises and challenging tasks, which may necessitate repetition. The investigation of adaptive strategies for e-learning and digital reading has been initiated by various authors, who have utilized users' self-reported estimations of their mental states as a basis for their research. To the best of our understanding, the potential impact of adaptable interfaces on the interactions between training and extended application of sophisticated interfaces remains unexplored in the literature.

Another limitation of this study is the inconsistency in the total effort (TOT) used to induce mental fatigue across different research studies. When conducting comparative analyses of research findings, it is crucial to consider the substantial variation in the duration of these studies, which ranges from 35 to 180 minutes. There is a lack of consensus regarding the precise definition of mental fatigue, as it appears to differ across activities, tasks, and individuals. Plebankiewicz, Juszczyk, and Malara [39] propose a captivating approach to ascertain the optimal duration for task completion. The authors conducted an empirical investigation wherein they examined the effects of different intervals of rest periods between consecutive blocks of demanding activities. One additional limitation of this research is its failure to encompass machine learning and its associated subjects, including transfer learning and the utilization of brain-computer interface. For example, previous studies have demonstrated that the Technique of Operations Review (TOT) had a significant impact on the allocation of traditional indicators used to assess mental workload and the accuracy of the processes that relied on these indicators.

The perception of human mental workload is a fundamental principle in the field of research aimed at understanding human interaction with technology. The main objective of a mental workload assessment is to quantify the cognitive effort necessary to accomplish a task, thereby enabling the prediction of operator or system performance. Nevertheless, it has been demonstrated that both insufficient mental stimulation and excessive mental demands can have adverse impacts on performance. On one hand, individuals may frequently experience feelings of dissatisfaction or agitation while engaging in information processing, particularly when the mental workload is low. Nevertheless, there is a correlation between a heightened mental workload and impaired cognitive abilities, decreased speed of information processing, and an increased likelihood of committing errors.

There are several methods available for quantifying mental workload, including primary-task measurement, secondary-task measurement, and subjective assessment. Furthermore, there have been recent findings regarding physiological indicators of mental workload. The measurement of primary task is a performance-based approach used to assess the cognitive demands associated with a particular job. The resultant outcome is contingent upon the specific task at hand, thereby rendering the comparison of results across different activities challenging. Furthermore, the metrics employed for assessing performance lack adequacy in estimating mental workload.

The assessment of operators' mental workload through the execution of secondary tasks is a widely employed methodology. To effectively carry out supplementary tasks, the operator is required to perform the primary task within predetermined conditions, utilizing the resources and capabilities at hand. The level of multitasking proficiency exhibited by the operator serves as an indicator of the operator's cognitive workload. There exist several advantages associated with the utilization of secondary tasks as a measure. Initially, it is a discerning metric of operator proficiency and possesses the ability to distinguish between various configurations of machinery that would otherwise pose challenges in differentiation. One additional advantage is that it provides a nuanced evaluation of task impairment resulting from stress. Furthermore, it provides a standardized metric for comparing different activities. Nevertheless, this particular approach possesses a significant limitation as it diverts attention away from the primary task at hand. Moreover, operators possess a degree of flexibility in the approaches they employ to fulfill their tertiary obligations.

Self-evaluation is widely recognized as the predominant and uncomplicated method for assessing mental workload. Operators have a responsibility to evaluate the cognitive demands associated with carrying out additional tasks and communicate their observations. The enhanced sensitivity and streamlined nature of this approach render it a more feasible alternative in practical contexts. Objective rating schemes such as the Subjective Workload Assessment Technique (SWAT) and NASA Task Load Index (NASA-TLX) are extensively employed in various domains. Another potential issue is the presence of cognitive weaknesses. The utilization of subjective assessment offers numerous advantages, including cost-effectiveness, non-invasiveness, ease of administration, and suitability for implementation on a wide scale encompassing various vehicles and activities. Nevertheless, there are certain limitations that should be acknowledge, and these include the possibility of mental and physical workload being intertwined, the challenge of differentiating between external demand or task difficulty and actual workload, the presence of unconscious information processing that cannot be subjectively assessed by the operator, the potential disconnect between subjective ratings and task performance, the necessity for well-defined questions, and the reliance on short-term memory.

According to Singh, Chanel, and Roy [40], there is a belief that physiological indicators can be utilized as a means of quantifying mental workload. The relationship between heart rate and the P300 wave, an event-related potential (ERP) element stimulated during the decision-making cognitive process, has been demonstrated to align with the degree of novelty associated with the presented information. Physiological indicators possess the advantage of maintaining consistency throughout the duration of an experiment, while also refraining from impeding participants' capacity to perform their primary tasks. However, it should be noted that these physiological indicators can be influenced by extraneous factors, and their measurement necessitates the use of specialized equipment.

VI. CONCLUSION

The demand for adaptive interfaces, which can potentially alleviate the adverse effects of prolonged and uninterrupted usage, is expected to rise in tandem with technological advancements and the ongoing trend towards increasingly complex systems. The integration of operator and user mental state approximation may play a significant role in determining their ultimate achievement. The design of mental state-oriented adaptive interfaces integrates studies from various fields, including neuroergonomics, cognitive science, human-machine interaction, and human factors. Additionally, the design takes into account the specific research findings and distinctive characteristics of each application area, such as aircraft and automotive industries. The impetus for this study stemmed from the acknowledgment that scholars within a particular discipline are compelled to develop proficiency in interconnected fields due to the increasing prevalence of interdisciplinary approaches. The questions posed in the article are formulated in a manner that, if addressed prior to the development of a flexible interface that takes into account the user's cognitive state, could enhance the design methodology and yield superior outcomes. There is an expectation that the technologies that have been discussed and presented in this context will become more prevalent in the future, thereby augmenting worker safety during complex tasks.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate

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Competing Interests

There are no competing interests.

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