Wearable Augmented Cognition for Improving Medic Performance

An Adaptive Transcranial Cognitive Augmentation Device with Wearable Augmented Reality

Jayfus Tucker Doswell
Juxtopia® Advanced Mixed Reality (JAMR) Lab
The Juxtopia Group, Inc.
Baltimore, USA
e-mail: jayfus@juxtopia.com

Ken Wilson
Trauma and Acute Care Surgery
University of Chicago Medicine
Chicago, USA
e-mail: kwilson9@surgery.bsd.uchicago.edu

***Abstract*—Wearable Augmented Reality (AR) combines research in AR, mobile/ubiquitous computing, and artificial intelligence in which an optical see-through Head Mounted Display (HMD) facilitates multi-modal projection of, contextually relevant and computer generated visual and auditory data over physical real-world environments. Through advancements in Brain Computer Interfaces (BCI), wearable AR has capabilities to amplify human cognition by delivering on-demand assistance/training, especially in austere and extreme situations ranging from emergency medical first response and Tactical Combat Casualty Care (TCCC) to public health relief efforts in response to mass casualty events. This Intelligence Amplification (IA) intervention has potential to augment human cognition while wearers naturally interact with their environment. However, research gaps must be addressed to achieve an adaptive and wearable AR BCI that augments human cognition and consequently, improves human performance. This paper presents an innovative wearable AR HMD with an objective for improving human working/long term memory, reduce cognitive load; and contextually adapt to an individual's environment/cognitive/physiological state.**

Keywords-augmented cognition, augmented reality, BCI, context-awareness, cognitive display, intelligence amplification, wearable.

I. INTRODUCTION

A. BCI Enabled Wearable Augmented Reality

Wearable Augmented Reality (AR) combines research in AR technologies, mobile/ubiquitous computing, Artificial Intelligence (AI), and human ergonomics in which an optical see-through Head Mounted Display (HMD) facilitates multi-modal delivery of contextually relevant and computer generated visual, auditory, and transcranial data over a physical, real-world environment. Through decades of empirical research, wearable AR has demonstrated capabilities and promise of delivering on-demand assistance and training to humans who operate in austere and extreme environments ranging from emergency medical first response and surgery to Tactical Combat Casualty Care (TCCC) and public health relief efforts. This head worn Brain Computer Interface (BCI) has potential of providing a non-invasive method to augment human cognition and intellectual capabilities while wearers complete complex tasks. More specifically, wearable AR has capabilities to deliver, to humans, contextually aware assistance as multi-modal perceptual cues combining animation, graphics, text, video, and voice, as well as transcranial stimulation and tactile feedback. However, despite many advancements recently demonstrated by wearable AR systems, there are several research gaps that must be addressed in order for wearable AR to achieve an adaptive and wearable BCI that augments human cognition and consequently, improves human performance.

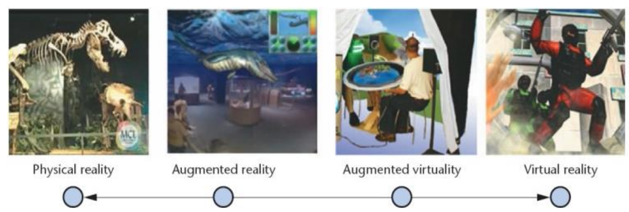

Figure 1. Milgram's Mixed Reality Continuum.

AR falls within Milgram's mixed reality continuum as illustrated in *Figure 1*. In AR, digital objects are added to the real environment. In augmented virtuality, real objects are added to virtual ones. In virtual environments (or virtual reality), the surrounding environment is completely digital [25]. Wearable AR combines research in AR and mobile computing in which a wearable see-through head mounted display (HMD) and increasingly smaller computer subsystem facilitate wireless communications and context-aware digital display [1][10][11]. A Wearable AR-BCI comprises non-invasive sensors with capabilities to digitally collect and interpret neuronal activity to facilitate activities ranging from non-verbal AR interface navigation to brain region assessment of human attention and learning.

B. Cognitive Overload

A primary challenge presented by such advanced BCI-HCI technologies is the development of scientifically-grounded methods for identifying appropriate BCI-HCI presentation, brain input, and multi-modal feedback in order to optimize performance and mitigate cognitive overload. Such multi-modalities must be dynamic, providing the human capabilities to adapt interaction configurations to accommodate various operational and environmental

 ISBN: 978-1-61208-705-4

conditions, as well as user cognitive states, which change over time in response to task demands and factors, such as sleep, nutrition, stress, and even time of day. Ideally, interactive technologies should be capable of adapting modalities, in real-time, and in response to task, environmental, and user psychophysiological states.

Cognitive overload may be best described by the *Cognitive Load Theory (CLT)*, which is an information processing theory used to explain the human limits of working memory based on current knowledge of human cognitive architecture [20]. Cognitive architecture refers to the concept that human minds have structures, such as working memory, long term memory, and schemas [24]. In summary, CLT may be described as follows:

1) Working Memory can only handle seven (7) disconnected items at once [24].
2) Overload occurs when Working Memory is forced to process a significant amount of information too rapidly.
3) Long Term Memory is virtually unlimited and assists Working Memory.
4) Schemas are memory templates coded into Long Term Memory by Working Memory.
5) Working Memory is overloaded when its ability to build a schema is compromised.
6) If Working Memory has capacity left over, it can access information from long term memory in powerful ways.
7) Automation (i.e., doing something without conscious thought) results from well-developed schemas due to Working Memory's interaction with Long Term Memory. Well developed schemas come with repeated effort and effective practice. [20]

Furthermore, information that is retrieval from long term memory can be impacted based on external (fast moving or disruptive objects) or internal (physiological) stimuli, which may significantly impact human performance on tasks.

To augment human performance and apply empirically researched understanding of CLT constraints of information storage and retrieval to/from long term memory, an effective contextually intelligent information display is a potentially useful intervention; with the use of AI enabled pictorial mnemonic systems and non-invasive BCI.

Previous research demonstrates that memorization techniques (i.e., mnemonic strategies) has resulted in improvements in humans' ability to recall learned information [7][9][18] from long term memory. Mnemonic strategies are proven systematic procedures for enhancing memory recall [22] and facilitate the acquisition of factual information because they assist in the memory encoding process; either by providing familiar connections or by creating new connections between to-be-remembered information and the learner's information acquisition [21].

According to Bellezza [3], memory experts learn to create mental pictures that endure in the mental space. A medical pictorial mnemonic system has the capability to assist the recall of procedural steps in a single pictorial form, especially if depicted as intuitively formed symbols that are easily and immediately recognizable to the individual user.

A study by Estrada et al. [12], using a pictorial mnemonic system for recalling aviation emergency procedures, discovered that this system facilitated the recall of uncommon, unfamiliar terms and phrases in a population to a level comparable to that of highly-experienced pilots in just one week. The findings highlighted the potential for such a mnemonic strategy to aid in the encoding of information into long-term memory. This encoding and catalytic recall method "chunking" seven (7) pieces of information into a picture format results in decreased human cognitive overload, accelerates human decision making, and measurably augments human task completion performance.

C. *Amplifying Cognition*

The Defense Advanced Research Projects Agency (DARPA) Augmented Cognition (AugCog) and Random Access Memory (RAM) Replay programs were design to extend information processing and management capacity of human-computer symbiotic team by an order-of-magnitude more by developing and demonstrating enhancements to human cognitive ability and memory retrieval in diverse and stressful operational environments. Specifically, these programs sought to develop BCI required to measure and track a user's cognitive state and replay memories, in real-time, utilizing these measurements to augment the user's environment, and then tailor that environment to a particular user's state. The ultimate is to enhance a soldier's operational capability, support reduction in the numbers of soldier's required to perform current functions, and improve soldier performance in cognitively challenging environments. The resulting augmented technology (AR) systems include non-invasive sensors to assess human operators' neurophysiological responses to ongoing events. These measures were then combined with cognitive and contextual models of user intention and task objectives to invoke validated mitigation strategies to enable optimal performance from users, returning users to optimally functional states as needed.

The field of Augmented Cognition (AugCog) has demonstrated the technical feasibility of utilizing psychophysiological measures to support real-time cognitive state assessment and BCI reconfiguration to mitigate cognitive bottlenecks within a wide variety of operational environments. Therefore, Research and Development (R&D) in this domain has spanned a wide range of human-technology platforms and use case paradigms. However, little research has been dedicated to AugCog-based assessments of BCI within the context of AR. Furthermore, Intelligence Amplification (IA) is an AugCog that builds on human intelligence (i.e., that has evolved over millions of years) to adapt neuro-technology to the individual's neuronal state with a programmed goal to measurably amplify the individual's intellectual/cognitive capabilities to perform better than human expected optimal intelligence.

AR provides a complement to human cognitive processes via integrated information access, error potential reduction, enhanced motivation, and the provision of concurrent training and performance. Likewise, Nagao [26] proposed that psychophysiological signals, such as Electroencephalogram (EEG), Electrocardiogram (ECG), and Galvanic Skin Response (GSR) could be used to support personalization of AR interaction. However, subsequent R&D has not fully explored this approach. Other researchers [27] outlined a framework in which physiological measures, such as EEG, heart rate, and body temperature could be used to add intelligence to a wearable BCI, predicting individualized, programmable user behaviors, both offline and online. This functionality was predicted to support faster user response rates, and to support increased freedom and flexibility. This framework also included the option to selectively vary the weights from the various physiological inputs according to contextual factors. Finally, Navarro proposed that the incorporation of technologies, such as AR and multimodal personalized BCI techniques could be used to increase accuracy in dynamic environments, and that this functionality, combined with the adoption of wireless technologies, would support instantiation of this paradigm within increasingly mobile and dynamic contexts. Bonanni, Lee, and Selker [6] provided evidence that multimodal AR based interactions can enhance procedural task performance; and suggested that providing visual cues decreases cognitive load because memory is a more complex process than visual search based on cueing and search principles from attention theory. However, metrics of cognitive load were not directly assessed. Likewise, Kim and Dey [19] demonstrated the effective use of context-sensitive information and a simulated AR representation, combined to minimize the cognitive load in translating between virtual information spaces and the real world. Other researchers proposed the use of VR and AR in combination with hierarchical BCIs and learning models in order to increase BCI usability and interaction with physical and virtual worlds. Specifically, the proposed approach leverages the benefits of two paradigms of Event Related Potential (ERP) stimuli: environmental stimuli and stimuli generated by mental imagery. The goal of this approach was to combine environmental and user-generated inputs within a hierarchical BCI system capable of adapting to individual users.

This paper will discuss cognition BCI gaps (i.e., in Section II); augmenting medical personnel with IA (i.e., in Section III); and researchers conclusion and next steps (i.e, in Section IV).

II. AUGMENTED COGNITION BCI GAPS

A primary BCI gap that must be addressed in order for wearable AR to improve human working/long term memory involves real-time assessment of cognitive workload, real-time adaptive information presentation to mitigate cognitive overload, and non-invasive neuronal interpretation to ascertain attention and learning to activating neurons in the pre-frontal cortex and hippocampus regions. IA and AugCog R&D is grounded in a multi-disciplinary scientific approach to address issues of human-technology interaction through a blending of cognitive science, human factors, and operational neuroscience, and artificial intelligence. While much of the research in this field has focused on the use of physiological assessment metrics to drive real-time adaptive HCI, Tang, Owen, and Biocca [4][5] demonstrated improved task performance using AR and suggested that AR systems can reduce mental workload on assembly tasks. This study also addressed the issue of attention tunneling, indicating that AR cueing has the potential to overwhelm the user's attention, reducing performance by causing distraction from important relevant cues of the physical environment. This phenomenon has yet to be explored using objective measures of user attention and associated cognitive workload. Multiple AR studies have employed the National Aeronautics and Space Administration (NASA) Task Load Index (NASA-TLX) to assess mental workload [4][5][23]. However, the TLX provides only subjective ratings of mental workload and is not assessing in real time during task performance, relying on the user's memory of perceived task demands. Authors proposed a framework and research methodology to support instantiation of an adaptive AR to reduce cognitive load, as well as contextually adapt to an individual's environment or cognitive/physiological state (e.g., stress) using AugCog principles. Specifically, authors propose real-time monitoring and assessment of neurophysiological measures capable of indicating user cognitive workload, and specifically differentiating between verbal working memory and spatial working memory. Within this framework, indices of cognitive workload would drive a closed-loop HCI adaptive AR interface, reducing information presentation to the user during periods of high workload and increasing information as appropriate during periods of low workload. The proposed system would further differentiate between verbal working memory overload and spatial working memory overload, adapting information presentation as necessary to avoid overtaxing one working memory system. The goal of such a methodology is to extend human cognitive capabilities while remotely interoperating with a network of federated computing services.

III. AUGMNENTING MEDICAL PERSONNEL WITH IA

This section provides a use case scenario, selected from the medical domain involving cognitive, psychomotor, and perceptual skills within a dynamic operational environment. Recent wearable AR medical research from Azimi, Doswell, Kazanzides J., [2], demonstrated the use of context-aware wearable AR for use in surgical and trauma medical assistance with future implications of augmenting human perceptual cues with multi-modal cognitive cues.

 ISBN: 978-1-61208-705-4

For example, surgical resection is one of the most common treatments for brain tumors. The treatment goal is to remove as much of the tumor as possible, while sparing the healthy tissue. Image guidance (e.g., with preoperative Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) is frequently used because it can more clearly differentiate diseased tissue from healthy tissue. Most image guidance devices contain special markers that can be easily detected by a computer tracking system. Registering the tracker coordinate system to the preoperative image coordinate system gives the surgeon "x-ray vision." However, this modality can be challenging for the surgeon to effectively use a navigation system because the presented information is not physically co-located with the operative visual display field, requiring the surgeon to look at a computer monitor rather than at the patient. This is especially awkward when the surgeon wishes to move an instrument within the patient while observing the display. Such ergonomic issues may increase operating times, fatigue, and the risk of errors. Furthermore, most navigation systems employ optical tracking, due to its high accuracy, but this requires line-of-sight between the cameras and the markers in the operative field, which can be difficult to maintain during the surgery.

After researchers observed several neurosurgeries, and spoke with neurosurgeons and neurosurgical residents, they identified a need to overlay a tumor margin (boundary) on the neurosurgeon's view of patient's anatomy, which served as a pictorial mnemonic triggering memory recall and visual landmark to cognitively assist surgeons accurately complete a psychomotor procedure. It was also desired to correctly track and align the distal end of the surgical instruments with the preoperative medical images. The aim of the research was to investigate the feasibility of implementing a head-mounted tracking system with an AR environment to provide the surgeon with visualization of both the tumor margin and the surgical instrument in order to create a more accurate and natural overlay of the affected tissue versus healthy tissue and, hence, provide a more intuitive HCI [2].

The resulting wearable AR allows the surgeon to see the precise boundaries of the tumor for neurosurgical procedures, while simultaneously, providing contextual overlay of the surgical tools intraoperatively which are displayed on Juxtopia® optical see-through goggles worn by the surgeon. This AR overlay capability provides the most pertinent information without unduly cluttering the visual field. It provides the benefits of navigation and visualization while being ergonomically more comfortable and intuitive for the surgeon.

The majority of related research has focused on AR visualization with HMDs, usually adopting video see-through designs. Many of these systems have integrated one or more on-board camera subsystems to help determine head pose [13][16][31] and some have added inertial sensing to improve this estimate via sensor fusion [8]. None of these systems, however, attempt to provide a complete tracking system and continue to rely on external trackers.

Combining the aforementioned wearable AR intervention with multi-modal sensors and BCI that track both dynamically changing internal and external stimuli, surgeons may visually monitor the AR display feedback based on their cognitive fatigue and stress level, as well as performance based multi-model cues including, but not limited to, multimedia mnemonics that augment's the surgeon capability to better perform the surgery.

IV. CONCLUSION AND FUTURE WORK

Figure 2. U.S. Army Combat Medic Wearing HoloLens AR Performing Cricothyrotomy.

To prepare young 18-20 year old brains for accelerated learning of combat medic skills (as illustrated in Figure 2) in preparation for delivering accurate clinical proficiency in austere battlefield environments, Dr. Jayfus Tucker Doswell and his research team are applying their preliminary AugCog and IA research to investigate non-invasive BCIs sensors (e.g., EEG, fMRI, etc.) integrated into wearable AR HMDs, and with capabilities to contextually and autonomously extract neuronal data from target brain regions ranging from pre-frontal cortex (attention), inferior frontal junction (visual processing), and hippocampus (memory) to substantia nigra (eye movement and motor planning), and cerebellum (fine motor movement). A primary opportunity presented by such advanced BCI technologies is the development of methods to quantifiably improve human's intellectual/cognitive state to optimally perform better than historically trained persons. Such modality selection methodologies must be dynamic, providing the capability to adapt interaction configurations to accommodate various operational and environmental conditions, as well as user cognitive states, which change over time in response to task demands and factors, such as sleep, nutrition, stress, and even time of day. Ideally, interactive technologies must be capable of adapting interaction modalities, in real-time, in response to task, environmental, and user psychophysiological states. The fields of Intelligence Amplification (IA) and Augmented

 ISBN: 978-1-61208-705-4

Cognition (AugCog) have demonstrated technical feasibility of utilizing psychophysiological measures to support real-time cognitive state assessment and BCI reconfiguration to mitigate cognitive bottlenecks within a wide variety of operational environments.

Researchers will continue to explore how to integrate a dynamically changing BCI sensor device/software framework into a context-aware AR platform [1][2][10][11] to augment human perceptual capabilities and for improving human performance®.

ACKNOWLEDGMENT

This research was supported by the Juxtopia® Advanced Mixed Reality (JAMR) program of The Juxtopia Group, Inc.

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