Chapter 1

Progress and Direction in Neuroergonomics

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INTRODUCTION

Recent advances in cognitive neuroscience and progress in neuroimaging have radically changed our understanding of the neural mechanisms underlying human perceptual, cognitive, and motor functioning. These findings are of great importance for applied scientific disciplines concerned with the evaluation of human performance. Since the early 2000s, Neuroergonomics, the intersection of Neuroscience, Cognitive Engineering, and Human Factors, proposes to examine the brain mechanisms and underlying human–technology interaction in increasingly naturalistic settings representative of work and everyday-life situations. The objective of merging these disciplines into a single field of research is to encourage cross-fertilization and provide new tools at the epistemological, methodological, and technical levels (see Fig. 1.1)[1a]. This approach, known as Neuroergonomics, was initially proposed by Prof. R. Parasuraman (1998), progressively conceptualized[1–3] and then formalized by Profs. Parasuraman and Rizzo in their book "Neuroergonomics: The Brain at Work."[4] This discipline is defined by its founder, Prof. Parasuraman, as the "scientific study of the brain mechanisms and psychological and physical functions of humans in relation to technology, work and environments." The postulate is that the understanding of the underlying neurocognitive processes that occur during complex real-life activities such as human–technology interaction could be used to improve safety and efficiency of the overall human–machine teaming. Thus, the objective of Neuroergonomics, consistently with Human Factors and Ergonomics, is to enhance the integration of the human by fitting machine with human and fitting the human to machine. This innovative approach has found several applications ranging from the operation of complex systems (e.g., flying aircraft, supervising nuclear power plants, driving autonomous vehicles, surgeons in the operating room) to the improvement of the performance of disabled patients or elderly people in their daily interaction with their environment.[5]

These goals are achieved by improving the design of the complex system to human cognition, adapting the interface dynamically during use for augmentation of human performance and its transfer to improved functioning at work or in everyday-life situations.

UNDERSTANDING THE BRAIN IN EVERYDAY ACTIVITIES

Neuroergonomics promotes the use of various brain-imaging techniques and psychophysiological techniques. A challenge of great importance for Neuroergonomics is to succeed in reproducing ecological conditions in a well-controlled laboratory. Thus, Neuroergonomics proposes to conduct a "gradient" of experiments starting with well-controlled protocols with high spatial resolution devices that are constrained by the use of low-fidelity simulators, progressing to more ecological experiments in dynamic microworlds using devices that are portable but with lower accuracy, to eventually conducting less-controlled experiments in simulators and real ecological conditions (see Fig. 1.2).

Indeed, functional Magnetic Resonance Imaging (fMRI) or Magnetoencephalography (MEG) provides precious insight into the neural mechanisms underpinning cognitive processes. However, these techniques have several drawbacks that prevent from designing ecological experiments to examine the brain "at work." Despite these apparent limitations, the use of such techniques with advanced signal processing allowed investigation of drivers'[6] or pilots' neural activation[7]; Durantin et al. (2017)[7a], while performing simulated tasks. An alternative approach to overcome the aforementioned limitations is to consider the use of field-deployable portable modalities such as Electroencephalography (EEG) or functional Near Infra-Red Spectroscopy (fNIRS), which allows the noninvasive examination of brain function under realistic settings. Although EEG allows assessment of the electrical activity of the neurons, fNIRS is a noninvasive optical brain-monitoring technology

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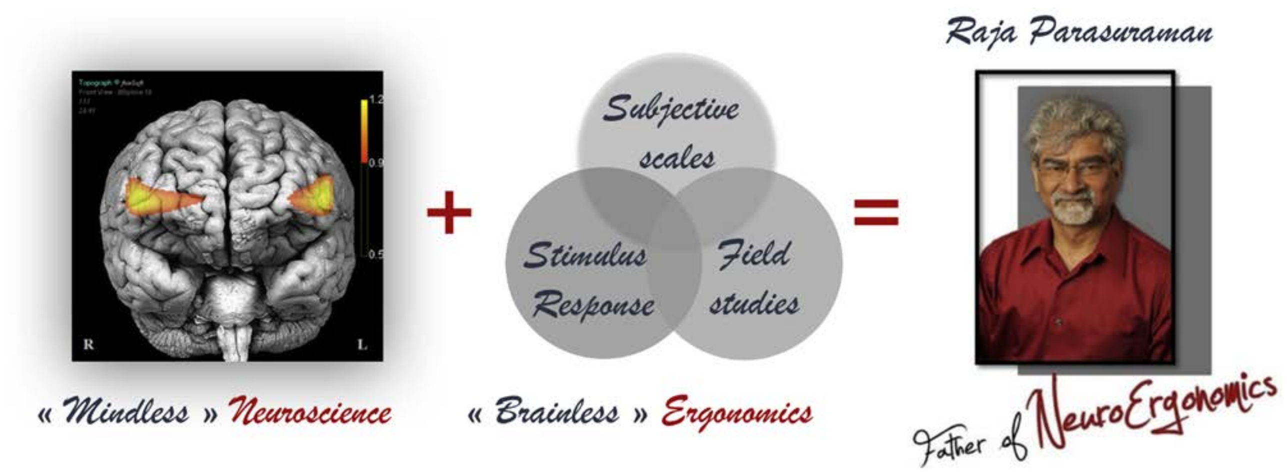

FIGURE 1.1 Professor R. Parasuraman, father of Neuroergonomics, decided to combine the objective mindless cognitive neuroscience approach and the subjective brainless Ergonomics approach.

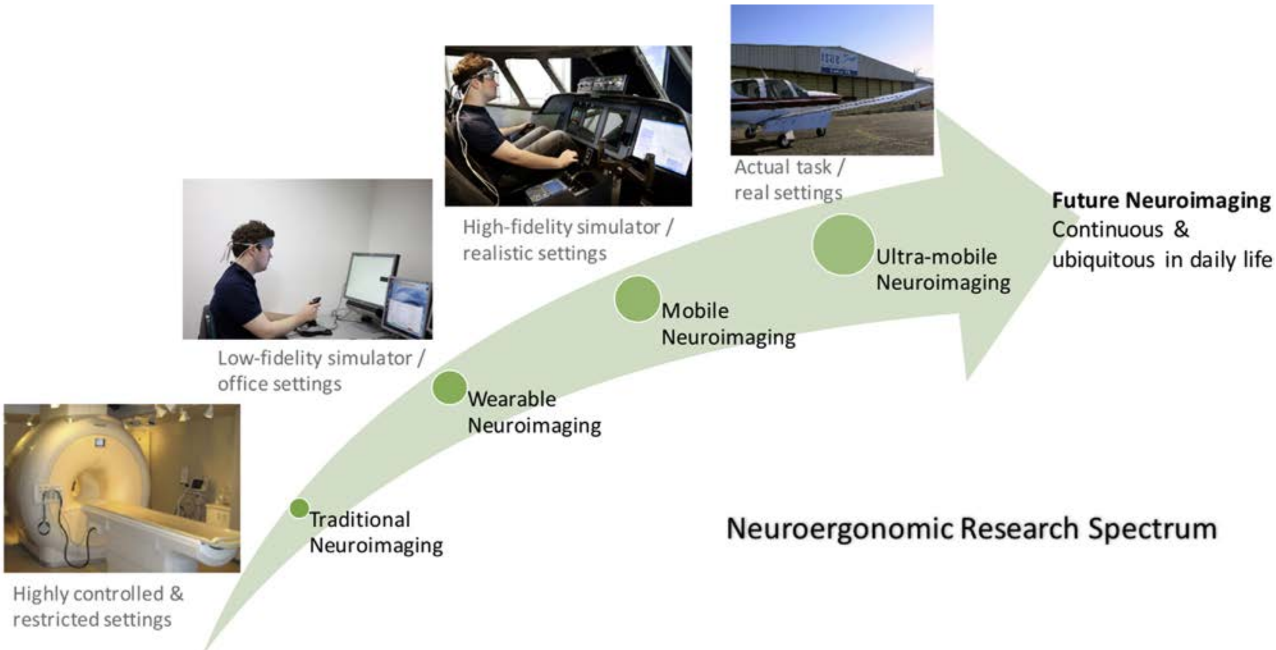

FIGURE 1.2 Illustration of the Neuroergonomics methodology defined by Parasuraman and Rizzo[4]: from highly controlled but less ecological situations to highly ecological but less-controlled situations. Cerebral and autonomous nervous system activations are compared across different situations to ensure the validity of the measurements. This methodology allows to tackle human cognition through an experimental continuum.

that measures the cerebral hemodynamics associated with neural activity.[8] fNIRS and EEG are complementary as they overcome each other's measurement weaknesses in terms of spatial and temporal information (Liu, Ayaz and Shewokis 2017)[8a]. Moreover, correlational and causal analyses between the two signals can provide a deep understanding of the neurovascular coupling and brain dynamics offering interesting prospects for Neuroergonomics.[9]

Adapting Interaction

The aforementioned neurophysiological measures can be collected and computed in an off-line manner to assess the user's experience and evaluate system design. Recent progress in signal-processing and machine-learning techniques has also opened promising solutions for human–machine interaction. Indeed, another facet of Neuroergonomics is the design of an "active" or a "passive" Brain–Computer Interface (BCI) based on the online processing of the neurophysiological signals.[10] "Active" BCI allows a user to control artifacts with his brain wave without requiring any physical actions on the user interface. Different paradigms have been implemented so far, such as P300 spellers,[11] and Steady State Visually Evoked Potential (SSVEP).[12] and allow the user to drive a car,[13] operate robots,[14] fly a helicopter[15] or use a wheelchair.[16] However, such BCIs need to be improved as they require extensive training and lead the users to focus on controlling their own brain waves, leaving few cognitive resources to monitor or interact with their systems. Alternatively, "Passive" BCIs are not meant to directly control a device (e.g., a mouse) via brain activity but to support "implicit interaction."[17,18] Research on "passive" BCIs provides interesting insight as they aim to infer the human operator's mental state (Gateau, Ayaz, and Dehais, 2018[18a]; Gateau, Durantin, Lancelot, Scannella, and Dehais, 2015)[18b] and may either provide "neurofeedback" to user (Grozea, Voinescu, and Fazli, 2011)[18c] or adapt the nature of the interactions to overcome cognitive bottlenecks. For instance, adaptive automation, task reallocation, or the triggering of cognitive countermeasures are potential solutions to assist humans and optimize human-system performance (Dehais, Causse, and Tremblay, 2011[18d]; Szalma and Hancock, 2008)[18e]. Thus, the design of the neuroadaptive user interface represents a growing field full of promise for Neuroergonomics.

Augmenting Cognition

The rediscovery, over two decades ago,[19] of transcranial brain stimulation has led to a proliferation of research on brain and cognitive augmentation, in both healthy adults and patients with neurological or psychiatric disease.[20,21] Noninvasive brain stimulation techniques, such as transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), and transcranial magnetic stimulation (TMS) provide researchers with unique opportunities to alter brain activity in both clinical and healthy groups and study causal mechanism of brain activity and behavior as well as clinical outcome measures. Moreover, utilizing simultaneous neuroimaging together with such neurostimulation has shown to be possible, for example fNIRS and tDCS,[22] EEG and tDCS,[23] fNIRS and TMS,[24] and fMRI and tDCS[25] are some examples of multimodal studies.

Noninvasive brain stimulation has also been shown to accelerate learning and enhance human performance in healthy individuals with complex natural tasks.[26,27] Such approaches present unique opportunities for research as well as field deployment, because most of the hardware is portable and miniaturized. Further research is needed to understand optimized stimulation parameters and operational needs; hence, simultaneous neuroimaging could provide new insights, uncover the effects of neurostimulation in the brain, and provide opportunity to adapt stimulation per participant and in real time.

CONCLUSION AND FUTURE CHALLENGES

Taken together, Neuroergonomics offers conceptual, theoretical, and technical prospects for human factors, neuroscience, and neuroengineering among other disciplines. The neuroergonomic approach has been considerably facilitated by the recent rise of development of portable and wearable neuroimaging devices, including EEG and fNIRS. As use of mobile neuroimaging becomes more practical and widespread, neuroergonomic research is expected to reach its full potential. And the emerging wearable neurostimulation techniques such as tDCS and tACS seem to fuel the growth further. As the Neuroergonomic field grows and moves from lab to routine practice, neuroethics should take a more central role in the design and execution of studies.

Recent trends in Neuroergonomics have established it as a tool to inform design, development, and use of complex interfaces, as well as operational procedures and anywhere human-to-machine and human-to-human interaction is required. In its full capacity, Neuroergonomic approaches are expected to contribute to a diverse array of domains from single participant, product development, and daily procedure design, and hence benefit society.

BOOK ORGANIZATION

This book aims to provide a comprehensive description of state-of–the-art Neuroergonomics research. Following an introduction, the next segment is devoted to methodology, and each subsequent chapter is a tutorial for popular and emerging techniques of interest to Neuroergonomics practitioners. The following three chapters are application areas. Segment three is a collection of the latest neuroadaptive interfaces and operator assessment studies. Segment four is neurostimulation applications. Segment five presents emerging applications in decision-making, usability, trust, and emotions. The last segment contains entries from the Inaugural International Neuroergonomics Conference that took place on October 6 and 7, 2017, in Paris, France.

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