Seamless Skin Integration of Brain/Body-Computer Interfaces for Cybernetic Human Advancement

Motivation. Integrating technology with the human body provides transformative opportunities to overcome our natural limitations, unlock new realms of cognitive and physical potential, and enhance wellness. For example, brain-computer interfaces enable severely motor-impaired patients to control prosthetics and other devices through real-time neurofeedback, improving communication and interaction with the environment. However, limitations on performance, safety, convenience, size/weight, and cost make these systems inaccessible and under-utilized for the general public. For techno-biological interfaces to reach full potential to enhance the human condition for all, major transdisciplinary advances are needed to make brain/body-computer interfaces seamless, comfortable, long-lasting, affordable, safe, and ethical.

Key Research Idea. As the body's most external organ, skin is privileged for human-computer interfaces because it can be accessed non-invasively. Despite much progress on thin flexible devices that conform to skin for physiological sensing, an insurmountable limitation is that these devices become uncomfortable and provide short service life because the epidermis needs to breathe and shed. Implanted devices, in contrast, provide long lasting service and comfort but require invasive surgery. Between the extremes of topicals and implants, tattoos are permanent body modifications that remain untapped for human-computer interfaces, despite being seamless, comfortable, inexpensive, and minimally invasive to implant without surgeons or hospitals. Our research will lay the groundwork to re-invent tattoos as a technology for safe, low-cost, semi-permanent or permanent electrophysiological sensing devices that integrate seamlessly *within* skin to provide 24/7-operational brain- and body-computer interfaces. With sufficient R&D, this research could unlock visionary future technologies such as in-scalp and in-ear brainwave sensors that enable instantaneous detection of neuropathology and even techno-telepathic communication.

New Strength for CU Boulder. While the promise of cybernetic human advancement is enormous, from restoring lost functions to augmenting human capabilities, this vision requires us to tackle complex technical, biological, and socio-ethical challenges by fusing innovations in materials, computing, bioengineering, and the social sciences. CU Boulder faculty from a vast array of departments, institutes, and programs have an opportunity to build a world-class innovation center in human augmentation to empower individuals to lead healthier, more fulfilling lives and drive societal progress toward a future where human capabilities are continually reimagined and expanded.

Team & Approach. We will weave two threads of research, each led by a Co-PI, to converge on a new paradigm for seamless electrophysiological body-computer and brain-body computer interfaces.

Thread 1: Conductive Nanobiomaterial Tattoos. **(Carson Bruns - ATLAS, Mechanical Engineering, Materials Science, Biomedical Engineering)**. With the goal of achieving bio-safe conductive materials capable of seamless and stable connections between skin tissue and electronic components, Dr. Bruns will bring his expertise inventing nanomaterials for intradermal smart tattoos to create the conductive bio-inks and methods to integrate them with skin models. We will use topical and synthetic models of the intradermal environment to avoid animal experiments for foundational proof-of-concept work. Bruns also brings entrepreneurial experience to commercialization efforts; an invention disclosure was filed with Venture Partners for a liquid-metal-based conductive tattoo ink for low-resistance skin-implantable circuits.

Thread 2: Seamless and Screenless Brain/Body-Computer Interfaces. **(Grace Leslie - ATLAS, College of Music, Institute for Cognitive Science).** Dr. Leslie will bring her expertise in designing brain-body computer interfaces, addressing associated signal-processing challenges, and validating real-world applications of screen-free biofeedback paradigms, to prototype and evaluate a novel electrophysiological sensing and feedback scenario utilizing the proposed on-skin circuit technology. Leslie will focus on the electromagnetic characterization of the conductive materials, design the necessary electronic circuitry, and engineer the software needed to monitor, process, and analyze electrophysiological data. Additionally, she will design a novel audio and haptic biofeedback paradigm to characterize the unique advantages offered by an on-skin and screen-less brain- and body- computer interface system: stable sensor placement, non-intrusive and less stigmatizing wear, constant monitoring, and screenless, minimally intrusive audio-haptic feedback.

Budget. We request $50k to support one graduate student each to spend one-half of their time planning experiments with the PIs and gathering preliminary data during the 12-month planning phase.