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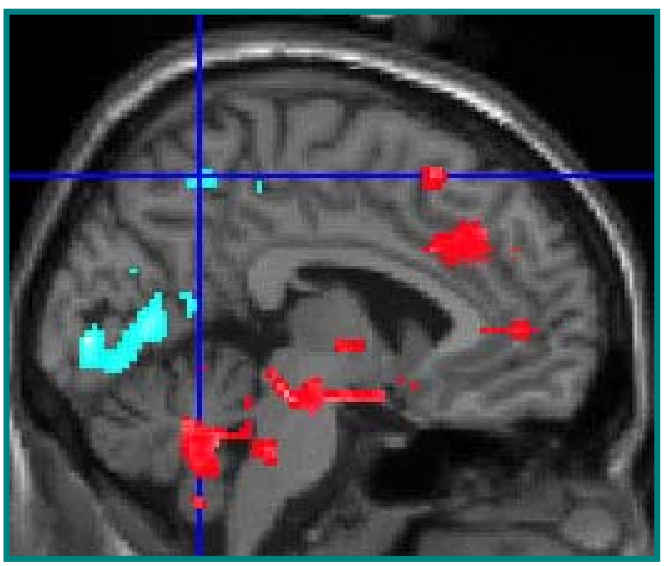
Defense and Biology: Fundamentals for the Future

As a biologist and neuroscientist, my view is that DARPA is really about **The Brain**.

The operational environment will continue to become more crowded with information, so it is clear that our warfighters must be able to manage complex situations with faster, more accurate, and more concentrated cognitive capabilities. This means that issues such as cognitive overload, fatigue, and decision-making under stress are fast becoming crucial factors in performance.

DARPA's Defense Sciences Office is focused not just on point solutions for the problems of the moment. We are obsessed with understanding the underlying biology, physiology, and neuroscience of big problems. Thus, when we attempt to decode the biological fundamentals of questions—about sleep, learning, and decision-making—we are actually developing the potential to improve the warfighter's experience in ways that we can't even predict yet. Armed with this new, fundamental knowledge, we can develop elegant and specific solutions to problems, both current and future.



Sleep Different, DARPA-funded research of sleep deprivation has shown that people who function well when sleep-deprived have different patterns of brain activation (blue) than those whose performance is substantially diminished when tired (red).

Let us consider some of the biggest issues facing our warfighters and how we are approaching them as biologists.

Sleep is a critical issue in military operations, but quality sleep is a luxury few warfighters enjoy during high optempo, and is almost unheard of for particular populations such as submarine operators. Sleep is also one of those great mysteries in biology: we still do not know all the biological events that occur during sleep, or even, fundamentally, we need sleep, though its importance is indisputable.

In an ongoing DSO program, we are investigating both near-term and far-term ways to mitigate the effects of sleep deprivation. In the near-term, molecules called ampakines, which control how neurons transmit information, have shown the ability to reverse sleep-induced changes in bran activity and cognitive performance decreases in humans.

For the far-term, we are studying the mechanisms of sleep—in creatures from flies to humans—in an effort to uncover the critical components, neural substrates, and modulators of sleep. For example, we are beginning to understand the brain networks utilized in sleep-deprived and non-sleep-deprived individuals using functional magnetic resonance imaging. On a microlevel, we now know that specific genes can regulate sleep and wakefulness needs, and these genetic sequences will be used to identify candidate biomolecules that might eliminate the deleterious effects of extended sleep loss.

Stress

A battlefield reality that almost always compounds sleep deprivation is stress. Straddling the fine line between adaptive stress, which keeps warfighters engaged, and pathological stress, which comes home from the battlefield, is certainly a “DARPA-hard” task, but one that may be tractable if we understand and take advantage of the biological fundamentals.

Researchers who study the neurotransmitter systems in the brain have discovered that mutations in particular genes (particularly those for serotonin) can make people more susceptible to the negative impact of stress. This argues for a neural basis—and a modifiable one, at that—for the behavioral symptoms associated with stress. To help our warfighters on the battlefield, we need to measure stress levels, predict cognitive deficiencies, and provide tools to facilitate decision-making even under the most challenging scenarios. Moreover, stress effects can go beyond the immediate; we must prevent stress from having long-term consequences on overall physiology such as heart and immune function as well as cognitive and emotional health.

Environmental Extremes

In fact, fundamental physiology—especially the way in which warfighters’ bodies adapt to their environments—is another area desperately in need of this deep approach.

Military operations demand that we place our warfighters in extreme environments of heat, cold, altitude, pressure, and oxygen concentrations, with some destinations involving multiple factors. Right now, we can provide some protection, but we really need to come up with a better plan, solutions that address the root cause of the performance degradations in these settings.

The body can naturally adapt to environmental insult. Unfortunately, these adaptations take weeks to occur, certainly longer than we can afford at our current operational pace. However, understanding the genes, mechanisms, and regulation of these natural adaptive responses would be extremely useful in developing new techniques for situations where troops must deploy rapidly.

In addition to studying human physiology directly, we have the potential to unlock these mysteries by studying extreme environments themselves. Take for example extremeophiles, organisms that are able to live and adapt to exceptionally harsh habitats. These are the organisms that live in thermal vents, and saline environments and thrive in the ice-locked tundra. We suspect there are conserved genes and proteins (essential building blocks that are found in the cells of microorganisms and animals) that can give us insight into how adaptation can occur under such harsh conditions. How can we learn from these organisms in order to protect human biology?

Operational Neuroscience

As compelling as these issues are, they are not the most exciting questions at the intersection of defense and biology. Rather, we need information about high-level cognitive processes that can enable better training, protection, and design of systems for our warfighters.

My goal is to apply this fundamental approach to pure neuroscience for the benefit of the warfighter, what I call “operational neuroscience.” To do that, we have to investigate the higher-order, metacognitive concepts like learning, memory, perception, intelligence, decision-making, and situational awareness in the context of the warfighting experience.

One program beginning to approach this paradigm is Neurotechnology for Intelligence Analysts. This effort is investigating the brain signals triggered when an analyst sees something of interest in a satellite image. Preliminary research shows that an analyst’s brain registers the discovery long before the analyst becomes cognitively aware of it. Thus, the brain can signal the discovery three times faster than the analyst can respond. In this example of operational neuroscience, a neural signal (evoked brain responses) are used to approach a military problem: rapid identification of important images.

This is a promising beginning, yet a major effort is needed to measure, classify, and understand neural functioning in the battlefield environment. This is a significant challenge since nearly all data on human cognitive processing is collected in laboratory environments, under conditions that do not approach the realities faced by military operators in their task environments. The current neuroscience literature provides a baseline from which to begin a comprehensive investigation, but cannot replace measurements made specifically for the operational environment.

The fact is, we do not have all of the right tools or techniques to break the code, yet.

Much of what is unknown about brain function is not due to a lack of understanding, but due to inadequate measurements. Current recordings of brain activity often fall short in the appropriate setting, spatial, or temporal resolution.

This is where a multidisciplinary effort is critical: engineers, mathematicians, and signal processing experts are needed to contribute the solutions to overcome these limitations.

We need improvements in noninvasive neuroimaging to capture signals at high resolution, in real-time, with spatial, temporal, and neurochemical precision throughout the entire volume of the brain.

Operational Neuroscience, the synthesis of in-depth biology signal processing, and engineering promises to assist and protect warfighters.

We need new sensors to detect signals of interest including the signals we have not yet discovered or are just beginning to understand, such as the fluctuations in neurotransmitters at the synapse.

My goal is to use these technologies together with the most advanced signal processing we can harness to measure the speed of thought. This is no small feat, though I know it's possible, especially if we confront these challenges—not just as problems of biology and neuroscience—but problems of physics, math, materials science, and microtechnology. That is where DARPA comes in and, with your help, we can lead the way, unlocking the fundamentals and applying those discoveries.

Image: Wellcome Trust Medical Photographic Library