MindPulse : A New Tool to Measure Decision-Making Abilities and Vigilance Level

Dr. S. Suarez (1), Dr. B. Eynard (2)

(1) PhD in Neuroscience and Neuropsychologist, Director of Research at It's Brain
(2) PhD in Mathematical Physics, Director of Research at CEA

1. Les Decision-Making Abilities: A Key Component of Executive Functions and a Major Operational Challenge!

Cognition encompasses a wide range of functions, playing a fundamental role in human behavior, social interactions, and the way individuals perceive and engage with their environment.

Within the realm of cognition, the ability to make informed decisions lies at the heart of the effectiveness of modern armed forces. In the face of increasingly complex environments and constantly evolving threats, the ability to make rapid and appropriate decisions is a crucial skill for soldiers. This ability, stemming from executive functions, is a key component of operational performance.

> **Cognition** refers to the set of mental processes related to the function of knowledge, involving essential elements such as memory, language, reasoning, learning, intelligence, problem-solving, decision-making, perception, and attention. Its definition has evolved to include emotional functions, which are an integral part of reasoning and decision-making.

However, decision-making abilities are sensitive and can be impaired by emotions such as stress, by lack of sleep, as well as by neurotoxic substances or environments (alcohol, drugs, etc.), and also by situations of cognitive overload—particularly those related to the use of increasingly numerous and complex equipment.

To anticipate and manage situations of cognitive overload, it is essential to be able to measure soldiers' baseline decision-making abilities. This makes it possible to identify potential cognitive weaknesses, support those most at risk, and tailor training programs to strengthen cognitive resilience under stress.

The challenge lies in being able to *objectively measure* whether decision-making capacity is affected or not, and to have an indicator that can support the development of methods to improve decision-making.

The MindPulse test is an innovative tool developed from recent models in neuroscience and advanced mathematics, specifically designed to measure these cognitive parameters (Suarez et al., 2021; Ansado et al., 2024). This technology is already being used in studies involving the navy, aerospace, firefighters, the army, and the gendarmerie.

Making the Right Decision: A Critical Challenge

Executive functions are a set of essential cognitive skills that play a central role in our ability to adapt to a changing environment, solve problems, and succeed in social and professional interactions. These functions enable us to plan, organize, manage our time and emotions, and make decisions. These abilities are crucial for success in many areas of life. Among these skills, decision-making holds a central place and serves as a window into how we use our executive functions to make informed and context-appropriate choices..

Making Decisions Under Pressure

In a military context, there is an increasing introduction of technologies and new equipment. These tools enable the processing of large amounts of data but also increase the cognitive load on soldiers.

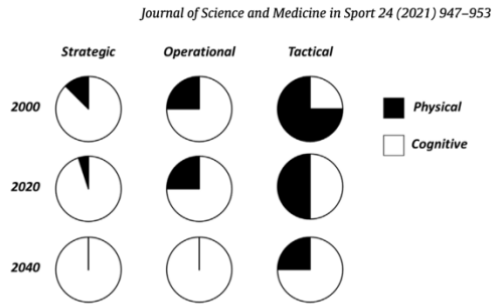


Fig. 1. Evolution of cognitive-physical balance of demands for the human combatant at the strategic, operation and tactical levels in 2000 and 2020 and projected through to 2040.

According to Billing et al. (2021), by 2040, "cognitive demand will fully dominate strategic and operational levels and will account for three-quarters of tactical requirements, profoundly transforming the soldier's role from a physically focused one to a role centered on advanced cognitive skills."

These innovations can thus increase the risks of cognitive overload, especially when soldiers must simultaneously interpret recommendations from these technologies and make informed decisions under time constraints. Inadequate management of this overload can lead to critical errors in high-risk tactical situations.

2. Measuring and Preventing Cognitive Overload

> Cognitive overload refers to a state in which an individual is confronted with an excess of information or mental demands that exceed their cognitive processing capacity. In a military context, cognitive overload can occur when soldiers must simultaneously manage numerous complex tasks, such as analyzing real-time information, making strategic decisions, communicating with other team members, and assessing threats. This overload can have serious consequences, including judgment errors, decreased performance, increased stress, and an inability to respond quickly and effectively to critical situations. Modern operational environments, with their advanced technologies and constantly increasing information flows, exacerbate this phenomenon.

To prevent the effects of cognitive overload, it is crucial to regularly measure and assess the decision-making abilities of soldiers in order to identify individuals most likely to experience the detrimental effects of cognitive overload. This assessment would help detect potential vulnerabilities and could offer a personalized response, either by reducing cognitive load or by enhancing specific skills and/or emotional regulation.

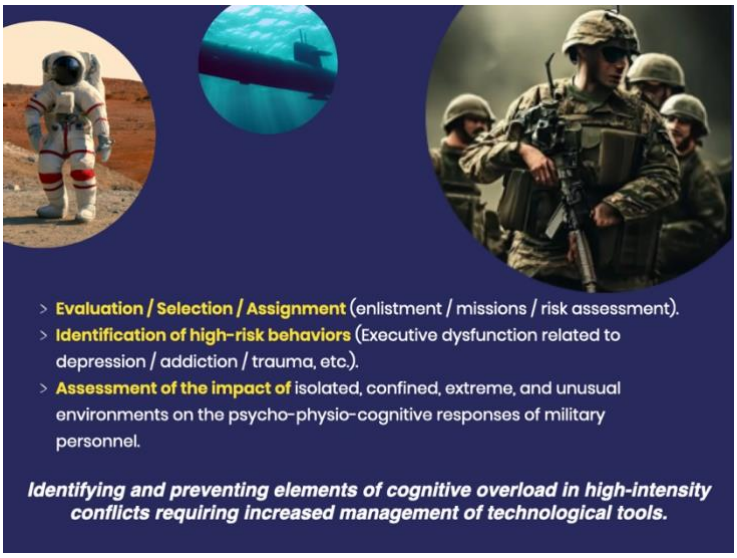
.

MindPulse: An Innovative Tool for Measuring Decision-Making

MindPulse is a digital neurocognitive test that evaluates and quantifies attentional and executive functions, including decision-making ability. It is a French innovation, patented, and a winner of the iLab scientific innovation competition. The test measures reaction times and response accuracy to characterize the cognitive state of the subject.

> Time scales show that our brain takes longer to think than to perceive and respond physically.

A simple reaction time, which includes the time for perception and visual analysis, a simple action decision, and muscle action, varies between 200-300 ms. However, if we ask the subject to perform an image categorization task, even a simple one, the average time is around 500 ms. For a task requiring double categorization and inhibition, the action time increases to around 800 ms..



The device measures, to the hundredth of a second, the subject's reaction to images under increasingly complex categorization conditions. An algorithm then analyzes the subject's performance to derive a

measure of decision-making abilities, encompassing their psychomotor speed related to their alertness state, executive functions (in a speed-accuracy balance), shared attention, and a new indicator called "Reaction to Difficulty," which provides insight into how the subject adapts to perceived difficulty (linked to their emotional state in relation to the situation) with a quantified measure of the impact of this adaptation/maladaptation on their executive cognitive speed. In just 15 minutes, this tool provides a detailed report with 16 indicators, which helps identify an individual's cognitive strengths and weaknesses.
This test is particularly relevant for the armed forces, as it allows for the tracking of soldiers' cognitive skills over time, both in person and remotely, and distinguishes the effect of physical fatigue from a deeper executive impairment on decision-making abilities.

The Key Role of Vigilance

Vigilance (or alertness) is the first level of attention. It is our ability to suddenly increase our state of awareness in response to an event in our environment, which allows us to react quickly and appropriately to environmental stimuli. It is influenced by the interaction between the individual and their environment, making its replication in the laboratory challenging. Although many assessment methods exist, such as psychometric tests and physiological measures, it is often difficult to reconcile objective results with subjective feelings of fatigue, giving rise to recent models that view vigilance as a dynamic process affecting the interactions between the brain, behavior, and the environment (Klösch et al., 2022).

This issue is so important that it led to the creation of a research unit within the French Armed Forces Biomedical Research Institute (IRBA), the "Fatigue and Vigilance" unit, whose area of interest is: "fatigue and degradation of vigilance induced by military operational situations and the management of recovery." Its work aims to "understand the physiological consequences of disruptions in the wake/sleep cycle and the time spent on tasks."

The development of tools like MindPulse opens new perspectives for assessing vigilance in controlled contexts where distractions are eliminated, thus providing a precise benchmark measure of a soldier's maximum cognitive abilities in interaction with their executive functioning.

3. The Notion of Task Complexity and Cognitive Overload

Task complexity is a determining factor that directly influences the cognitive performance of soldiers in operational situations. As task complexity increases, the cognitive demands on soldiers intensify, which can lead to cognitive overload and, in particular, executive difficulties, resulting in problematic decision-making.

> Identifying and preventing elements of cognitive overload in high-intensity conflicts that require increased management of technological tools has become a major operational challenge.

The difficulty in understanding the impact of cognitive overload lies in measuring the degree of difficulty of a task. One of the technical achievements of the MindPulse test is precisely its ability to deduce a scale from the brain's processing of task difficulty. That is, to measure "how much" one task is "more difficult" than another! This allows for comparing responses and, most importantly, the speed and accuracy of responses during tasks of varying difficulty. This very important objectification point is what then allows for the potential extension of measurements to real-time and real-world environments with Artificial Intelligence (see below).

The development of new tools based on the latest advances in neuroscience, capable of finely detecting cognitive functioning and anticipating the risks of cognitive overload, is fundamental for having scientific tools. MindPulse is currently used in a dozen military studies to assess the impact of stressful or extreme environments; isolation; lack of sleep; gravity; and survival conditions on the psycho-cognitive response of soldiers (e.g., Le Roy et al., 2023; 2024).

> "Human cognition in high-risk situations is a major security issue in an extremely dynamic technological and operational environment. The complexity of weapon systems requires them to be subordinated to the capabilities of the operator for reasons of performance and safety. It is necessary to have biomarkers and associated profiles that allow for the identification and prevention of cognitive and emotional dysfunctions."

4. The Role of Emotions in Decision-Making

> "For better or for worse, emotions are an integral part of reasoning and decision-making. Without emotions, our reasoning is flawed."

For a long time, it was believed that emotions and rational decisions were independent, or even opposite, but this dogma was shattered, notably thanks to the research of Prof. A. Damasio, who published a groundbreaking essay in 1995 titled *Descartes' Error*. In this work, Damasio demonstrates that emotions and feelings play a fundamental role in rationality, the development of logical thinking, and human decision-making. He presents the theory of "somatic markers," which shows the mechanism through which emotions are indispensable to adjusted behavior and decision-making.

MindPulse provides insight into the interaction of emotions on decision-making abilities. The new "Reaction to Difficulty" index, which is the subject of a joint patent with CNRS and the University of Paris-Saclay, is a measure correlated to the emotional state of the subject (Suarez et al., 2021).

5. A New Model for Understanding Brain Function: the DDM

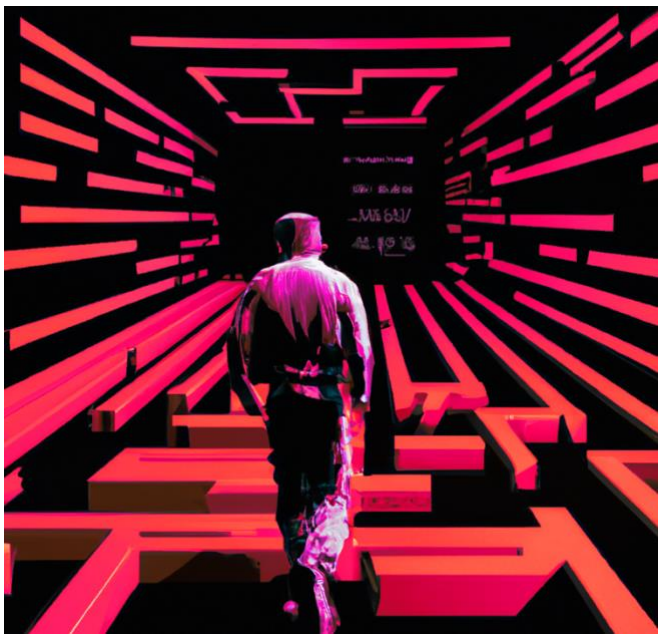
Thanks to the collaboration with high-level mathematicians and physicists, the MindPulse test uses the Decision Diffusion Model (DDM) in an experimental version to analyze how an individual makes decisions.

The DDM constitutes a paradigm closest to neurobiological functioning, allowing the modeling and analysis of decision-making based on a Go-NoGo task. Diffusion is a physical principle, describing, for example, how electrons diffuse by interacting with each other, randomly bouncing in a material to ultimately produce an electric current. It was the physicist and neuroscientist Roger Ratcliff (Ratcliff, 1978) who first proposed using the stochastic diffusion model to understand the functioning of neurons in decision-making abilities. This model has been validated in numerous experimental studies, both in humans and animals, and is considered the most reliable model of decision-making, particularly in identifying indices that reflect both the attention level and a more "emotional" component.

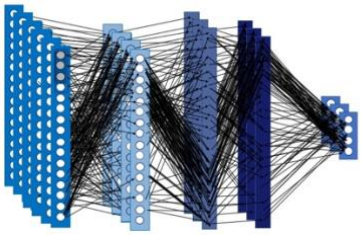
However, its high technical level from a mathematical point of view has been a barrier to its use, and MindPulse is one of the first to implement it—in the development phase today—in a short and usable test. It is currently being tested in some studies with commandos.

6. The use of artificial intelligence to understand each individual's decision-making adaptation style.

"The MindPulse technology evolves with the contribution of a classifier-based Artificial Intelligence, allowing the evaluation of Dynamic Decision-Making Adaptation Profiles (DDAP) for each subject. These profiles track how each individual adapts and evolves their decision throughout the test. Therefore, what the AI observes is not simply the average performance but the dynamic way in which each subject adapts as the task progresses, which helps identify difficulties related to the individual's adaptation style (unsupervised classifier AI)."



The profiles obtained by the AI take into account the subjects' speed, accuracy, variability, and their evolution throughout the test, including behavioral changes after an error. Cognitive measures become 'dynamic' rather than a static snapshot, making them much closer to real-world functioning.



These innovations provide unprecedented clinical insights, and they are currently used to study adaptation difficulties in patients with major unipolar depression. With these new developments, MindPulse is moving towards more dynamic models and aims to identify reliable cognitive and pathological biomarkers to better target treatments.

7. Monitoring Decision-Making Capacities Despite Cognitive Overload, in Real-Time and in Real Environments?"

Could we achieve real-time monitoring of decision-making capacities in real environments?

We can imagine that such devices will develop in the future. AI could first be used to calibrate a cognitive test, initially in a controlled environment, free from distractions and interferences, then in a simulator with calibrated distractions, and finally in real environments. Ultimately, AI could recognize optimal cognitive states in a simulator and track soldiers' performance in the field, monitoring attentional and executive drift.

The technical challenge would then be to compare tasks of different levels of difficulty, a goal that MindPulse has already begun to achieve.
The ultimate objective is to have personalized dynamic indicators of the subject's cognition in real situations, in order to propose dynamic regulation actions for cognition.

---

* All images were created by Artificial Intelligence (https://www.craiyon.com/) or DALL.E and edited (GIMP).

Bibliography :

- Ansado J, Eynard B, Mirofle N, Mennetrey C, Banchereau J, Sablon M, Lokietek E, Le Vourc'h F, Tissot J, Wrobel J, Martel C, Granon S, Suarez S. Adult norms for the decision-making MindPulse Digital Test. Appl Neuropsychol Adult. 2024 Feb 14:1-19.
- Billing DC, Fordy GR, Friedl KE, Hasselstrøm H. The implications of emerging technology on military human performance research priorities. J Sci Med Sport. 2021 Oct;24(10):947-953.
- Damasio AR *L'Erreur de Descartes : la raison des émotions*, Paris, Odile Jacob, 1995, 368 p.
- Klösch G, Zeitlhofer J, Ipsiroglu O. Revisiting the Concept of Vigilance. Front Psychiatry. 2022 Jun 14;13:874757.
- Ratcliff R. A theory of memory retrieval. *Psychological Review.* 1978;85:59–108.
- Le Roy B, Martin-Krumm C, Gille A, Jacob S, Vigier C, Laborde S, Claverie D, Besnard S, Trousselard M. Evaluation of taVNS for extreme environments: an exploration study of health benefits and stress operationality. Front Neurol. 2023 Nov 22;14:1286919.
- Le Roy B, Martin-Krumm C, Poupon C, Rouquet C, Trouve C, Jego C, Giaume L, Trousselard M. Lost at sea: Impact of an ocean survival experience on psychological, physiological and cognitive abilities (RAD'LÔ), European Journal of Trauma & Dissociation, Volume 8, Issue 4, 2024,100452, ISSN 2468-7499.
- Suarez S, Eynard B, Granon S. A Dissociation of Attention, Executive Function and Reaction to Difficulty: Development of the MindPulse Test, a Novel Digital Neuropsychological Test for Precise Quantification of Perceptual-Motor Decision-Making Processes. Front Neurosci. 2021 Jul 19;15:650219.