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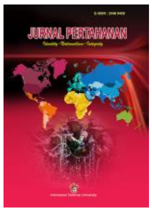

APPLICATION OF NEUROIMAGING TECHNOLOGY IN MILITARY

Rizki Edmi Edison
Neuroscience Center, University of Muhammadiyah Prof Dr HAMKA
Gandaria IV Street No 24, Kramat Pela, Kebayoran Baru, South Jakarta, Indonesia 12130
rizkiedmiedison@uhamka.ac.id

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Abstract

Understanding the function of the human brain at the level of cognition is a common goal of neuroscience. Neuroscience as one of the fastest-growing areas of multidiscipline that understand the biological basis for behavior through scientific research could be used in many areas, such as management, marketing, leadership, education, and military. For revealing the human mind especially soldiers as the most important part of the military, the implementation of technology to measure the brain of humans must be considered. Through this manuscript, potential uses of neuroimaging technology in the military were analyzed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendation was conducted to provide a comprehensive review of the application of neuroimaging technologies. For practical purposes, technology with advantages such as non-invasive, real-time, and mobile should be chosen. Through this study, electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and brain ECVT (Electrical Capacitance Volume Tomography) have potential use to measure the cognitive functions of soldiers in the military. Neuroimaging technologies have potential use in the military field, especially in the level of behavioral neuroscience. By understanding how a soldier's brain reacts to any circumstances especially those that mimic the combat situation, it has a beneficial effect on military strategy.

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INTRODUCTION

Neuroscience is known as a multidiscipline that reveals the biological basis of human behavior through scientific methods (Sandi, 2008). On other hand, cognitive sciences refer to an interdisciplinary study of the human mind that examines the structure and processes of the function itself (Trigg &

Kalish, 2011). Since the introduction of neuroscience for the first time, it has been signaling the start of an era when many disciplines may work cooperatively together like neuroscience and cognitive science that share a common goal: to understand the function of the human brain (Bassett & Gazzaniga, 2015).

Up to now, the understanding of the human brain in many circumstances especially in the level of cognition like decision making make neuroscience could be implemented in many fields such as marketing (neuro-marketing) (Fisher, Chin, Lisa, & Klitzman, 2010), leadership (neuro-leadership) (Edison, Juhro, Aulia, & Widiasih, 2019), education (neuro-education) (Gabrieli, 2016), and others. Since the fundamental unit of the military is the soldier as human (Tracey & Flower, 2014), it is not an unacceptable fact that gaining advances from knowledge and technique is expected from neuroscience. To enhance the effectiveness of combat by soldiers, cognitive neuroscience plays a crucial role in the development of the military through revealing human behaviors (Malish, 2017).

Two methods could be used for measuring brain functions, invasive and non-invasive methods (Raboel, Bartek, Andresen, Bellander, & Romner, 2012). Although the outer and inner layer of the human brain may be seen directly by invasive methods, it has high risks such as bleeding and infection (Tavakoli, Peitz, Ares, Hafeez, & Grandhi, 2017). We also cannot use an invasive approach with no clinical indication. Therefore, the only way we could use to record the activities of the human brain is by using a non-invasive approach. Unfortunately, not all technology of neuroimaging could be used for military purposes, especially in Indonesia.

Through this review, we would like to analyze the potential neuroimaging technology to be chosen to reveal a cognitive aspect of humans, especially soldiers to enhance our understanding of the mind for military strategy.

METHODS

To provide a systematic review of the application of neuroimaging technology in the military, from the history of the development of neuroimaging, the basic concept of theory and function of neuroimaging, and some examples of the use of technology to reveal the cognitive function, the investigation was conducted based on PRISMA recommendations (Liberati et al., 2009).

Eligibility Criteria

Since this study is focused on the application of electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and brain electrical capacitance volume tomography (Brain ECVT) with the possible implementation of neuroscience in the applied field, articles which reported the information were included that available both in English and Indonesian. The publication date of the article was not restricted. The article was excluded if it did not explain any neuroscience and neuroimaging-related field. Unscientific sources such as blogs or mass media are also non included in the investigation.

Information Source

Scientific and research-based articles were screened using Pubmed, Web of Science, and Google Scholar.

RESULTS AND DISCUSSION

Definition and Scope of Neuroscience

Although it is impossible to know the exact story of how the originator of medical disciplines started them, it is possible to recognize the current notions in empirical structure by retrospectively tracing thousand years of historical civilizations (Gjerstad, Gilhus, & Storstein, 2008).

The early era of neurological concepts was not fully scientific until it became a science at some intervening stage. The utilized definition of science is preferred to a circumscribed body of knowledge that proved with reproducible test (Casadevall

& Fang, 2020) while explicit methods are contained in predictive theory (Keatley, Clarke, & Hagger, 2013). This definition of science could be the demarcation between pre-scientific in the ancient era and scientific disciplines in the modern era.

Neuroscience refers to disciplines that understand human behavior with a biological basis through scientific research (Falk et al., 2013). The overarching goal of neuroscience is to reveal the brain as the most complex biological entity in the known universe. In a wide range of research endeavors to cognitive bases of mental properties of individuals as they interact with environments and each other, from molecular bases of nerve cell, modern neuroscience today is spanned. The structure of cellular and circuitry of the brain is studied by neuroanatomists (Shoja & Tubbs, 20007) while chemical compositions of the brain are researched by neurochemists (Endres et al., 2015). If the properties of the brain bioelectric are revealed by neurophysiologists (Rothwell, 2009), the organization of neural basis of cognition and behavior is investigated by a neuropsychologist (Sturm, 2007).

Cellular and molecular neuroscience, cognitive neuroscience, and computational neuroscience are an example of interacting areas that are incorporated in neuroscience. The disease of the brain is concerned directly in many fields of clinical medicine, which the most closely associated in this branch are psychiatry, neurosurgery, and neurology. Important contributions to neuroscience are also made by other fields of medicine is neuroradiology (Rodesch et al., 2013). It is a branch of medicine that uses imaging of the brain for clinical studies, that also has potential technology to be used for the military.

The fundamental level of hierarchy from molecular, cellular, systems, and behavioral form the basis of operations involving neurons. At the level of molecular neuroscience (Südhof, 2017), molecules interactions that influence the expression of gene regulation and translation into proteins are examined. The synthesis of neurotransmitters is mediated by these proteins. On the cellular level (Simons & Winckler, 2016), the interaction of neurons through synaptic and glia as supporting cells is investigated. Investigation at the cellular level reveals the pathways of specific neurons that mediate the behavioral effect on the experimental condition. For the level of systems (Grillner, Kozlov, & Kotaleski, 2005), the pathway of interconnected neural to challenged environmental is examined. Sense of seeing, feeling, balancing, tasting, and hearing are specialized sensors that are included in system sensory. The controlling of limb, trunk, finger motions are examples of the motoric system. While examples of the system of internal regulation is body temperature controlling, functions of cardiovascular, and balance of salt and water. At the level of neuroscience in behavioral (Dutcher & Creswell, 2018), interactions between human and challenged environmental are revealed. Research on behavior also investigated the higher mental activity of cognition, such as reasoning, consciousness, learning, and memory. It is also known that the brain is an organ that has the capability of adaptation, named neuroplasticity. Hypothesize on experimental findings at four-level hierarchical of neuroscience is one of the significant consequences in neuroscience research.

To perform multiple functions of the brain, it relies on the compromised integrated autonomous system in the brain. The autonomous peripheral systems have essential control for subconscious interaction between the physical body with emotional and cognitive to the efficient and effective performance of humans under many conditions (Furness, 2006). Such kinds of systems are also controlled by the brain and be one of the functions of neuroscience. For example, understanding the relationship between fatigue and willpower may reveal by using neuroimaging technology that has benefits for the military as well.

Neuroimaging Technologies

To understand the activity of the human brain at the behavioral level, there are two kinds of aspects of the brain and two kinds of methods that must be considered. In the field of the aspect or origin, we must determine first, whether the anatomical aspect or physiological aspect would be analyzed. Although the abnormality of anatomical aspect may involve the physiological aspect than behavioral, investigation of functions should be chosen in the first place. Since the neuroimaging technology could be used as a limitation that not all aspects of the brain may be recorded at the same time, determining the goal of measurement is important.

In the field of the military where the central aspect is a soldier as a human individual, the activity of the brain at the behavioral level must be understood. It means, the aspect of the physiology of the brain should be revealed. To record the activities of the human brain, the invasive method could be used on a suspected clinical situation like epilepsy, Parkinson's disease, brain tumor, and many others. Unfortunately, since this approach has risks such as infection and bleeding (Reif, Strzelczyk, & Rosenow, 2016), it should not be used to measure the brain’s activity of a healthy individual. Therefore, the non-invasive method is the only approach that we can use to analyze the functions of the brain of soldiers for getting beneficial effects on military purposes.

If we use non-invasive neuroimaging technology, we must know the two kinds of resolution (He & Lian, 2002) while recording the human brain. First, the temporal resolution. Second, the spatial resolution. The definition of temporal resolution refers to how fast capability of the instrument to record the activities of the human brain. Since our brain has speed in the order of milliseconds, faster technology is better. The definition of spatial resolution is referred to the minimum large surface of the outer layer of the brain that is needed for recording or how deep the instrument could record. The smaller needed surface of the outer layer and deeper is better.

There are many kinds of neuroimaging technologies that have the non-invasive capability for measuring physiological aspects. Those are functional Magnetic Resonance Imaging (fMRI) (Glover, 2011), Magnetoencephalography (MEG) (Ioannides, 2009), EEG (Biasiucci, Franceschiello, & Murray, 2019), Positron Emission Tomography (PET) (Kapoor, McCook, & Torok, 2004), Single-Photon Emission Computerized Tomography (SPECT) (Buck et al., 2008), and fNIRS (Pinti et al., 2018). Based on temporal resolution and spatial resolution, it is clear that MEG is the best choice.

But we must consider another thing. It is not just the non-invasiveness, real-time measurement (temporal resolution), a spatial resolution that involves the recording process of activities of the brain of a human. We also must consider the mobility of the instrument and participant and the practicality of the use. To get beneficial in military purpose by neuroscience, the level that could be used easily is behavioral level in which individuals are facing challenging circumstances. The participants should have the advantages of mobility while the brain is recorded. Therefore, EEG and fNIRS are the most potential technologies that could be used for military purposes in Indonesia.

Electroencephalography (*EEG)*

The primary non-invasive neuroimaging technology used to record the working of the central nervous system was the measurement of a signal of electrical from the scalp up to now, although the advent of modern computer-based approach has appeared.

The term electroencephalography or EEG was first adopted from reports of human cerebral electrical activity from the scalp in the 1920s (Sklerov, Dayan, &

Browner, 2019). Although the first attempt in that era was not successfully great, the idea was then developed by clinicians with a deep understanding of electronics. By the end of the 1930s, three-channel EEG recording devices were applied to neurological disease patients and gave first descriptions of EEG changes during the epileptic seizure (Reif et al., 2016).

Years after the second world war, EEG found major progress in the clinical field. The ability of EEG to record the brain's activities through the scalp was continued to be made using amplifiers and written onto paper. From three channels, the number of electrodes was increased which may record to 16 channels. The knowledge of EEG was slowly but sure increased.

The first major change in the technology of EEG since the 1990s was computerization where the electrical signals recorded from the scalp could be digitized. It may allow signals to be analyzed with many types of montages, following to more objective localization of abnormalities in the brain and avoiding artifacts in identification. The next advantage of digitalization is much longer recording becomes possible to understand the human brain. Incorporation with simultaneous video recording at the same time of EEG leads to better identification of artifacts (Lee Morris III, Galezowska, Leroya, & North, 1994).

The developments of EEG have refined how in the modern era, EEG could be used in many other fields, like the military. There are many examples of the application of EEG in the military. In the 2020s, the activities of soldiers' brains were explored during the simulation of handling combat vehicles (Diaz-Piedra, Sebastián, & Stasi, 2020). The quantitative EEG (QEEG) supported by high advanced computers may show a good indicator of brain function that varies area involved during simulation (Idiazabal-Alecha et al., 2018). The attention of soldiers in combat was also revealed by using EEG. The level of task execution and information processability are known dependent on the state of the cerebral activation. Moreover, in the field of the military where trauma or injury during combat that affects the brain could happen anytime, the evaluation of the human brain by using EEG could be used as additional data by the clinician.

Functional Near-Infrared Spectroscopy (fNIRS)

fNIRS is an optical and non-invasive technology of neuroimaging that by neural activation followed with changes of oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (HbR) concentration, the brain's activities measurement, allowed (Ferrari & Quaresima, 2012). With relative transparency of the biological tissue of the head, the light will reach the brain tissue by shining near-infrared (NIR) light into the head. NIRS light travels to the brain tissue through many layers like skin, skull, and cerebrospinal fluid with different optical properties. Interaction of NIR light with human tissue can be simplified considering the absorption and scattering for light attenuation (Young, Germon, Barnett, Manara, & Nelson, 2000).

When a brain area is activated while executing certain tasks, oxygen in the brain is increasing as the demand of metabolic of the brain. It will lead to an oversupply of regional cerebral blood flow (CBR) for metabolism purposes. The increase of CBR is called functional hyperemia mediated by changes in the diameter of capillary and vasoactive metabolites. This oversupply was followed by the increase of HbO2 and decrease of HBR that measured by fNIRS. So, we could measure the activities of the human brain indirectly (Pinti et al., 2020).

Since fNIRS may measure the function of the brain, this technology also may be applied in many fields. For example, the implementation of NIR light in the brain of monkeys to measure the working memory (Fuster et al., 2005). The study showed different amplitudes of HbO2 in different regions of the brain based on the task.

Interestingly, since fNIRS has advantages of mobility and practicality, it made the possibility of the study in freely-moving participants, a very important aspect to consider for research in the military field (Piper et al., 2014). Many showed the flexibility that may be applied in medicine like epilepsy (Rizki et al., 2015), practicing sports (Tempest & Reiss, 2019), playing musical instruments (Heinze, Vanzella, Morais, & Sato, 2019), and many others.

On the other hand, the flexibility of fNIRS leads to many other aspects of research like social sciences (Burns et al., 2019). Persuasive videos on safety topics were shown to participants while the function of the brain is recorded by fNIRS. It opened the possibility the research in the military by showing videos to soldiers and recording the reaction of the brain by using fNIRS.

Brain ECVT (Electrical Capacitance Volume Tomography)

Although both EEG and fNIRS have advantages in spatial and temporal resolution while recording the activities of the brain, they have a limitation where they cannot reach the deeper layer of the brain. It is possible to measure the deep side of the brain by using EEG, unfortunately, it involves the invasive technique by operation, that cannot be permitted to be implemented in healthy soldiers.

Since fMRI and MEG do not have advantages of mobility and freely-moving participants for research purposes, finding novel technology to resolve the problems faced by other neuroimaging technologies.

From years ago, a novel neuroimaging instrument is developed in Indonesia, named ECVT (Taruno et al., 2013). Based on the difference of capacitance in layers of the human head and brain, it could measure the activities of the brain indirectly by using an electrical field from Brain ECVT. ECVT is promising non-invasive neuroimaging that provides three-dimensional and real-time images of the sensing domain, which leads it to measure a deeper layer of the brain.

The capability of Brain ECVT to measure brain functions in a deeper layer is shown by the successful results in capturing brain tumors (Maharani, Edison, Ihsan, & Taruno, 2020). It has the same potential as fMRI or MEG with advantages of practicality and mobility. The difference of pattern of functions of human brain between stress and relaxed condition (Nirmala et al., 2015) also revealed by Brain ECVT, that make it possible to measure the mental state of a soldier in real-time.

As novel neuroimaging technology, comparison with gold-standard technology like EEG is a must. Fortunately, studies in the 2020s investigated the pattern of data by Brain ECVT at the same time with EEG in many conditions and situations, which revealed the validity (Ihsan, Edison, Pratama, Rohmadi, & Taruno, 2020). Brain ECVT also has potential applications in medicine like epilepsy (Edmi, Fathul, Rohmadi, Harke, & Purwo, 2021). With proven technology, this novel neuroimaging also has the potential to be used for military purposes.

CONCLUSIONS AND RECOMMENDATION

The main conclusion of this literature review is that neuroimaging technologies have potential use in the military field, especially in the level of behavioral neuroscience. By understanding how a soldier's brain reacts to any circumstances especially those that mimic the combat situation, it has a beneficial effect on military strategy.

Unfortunately, it is still hard to find the implementation of research of neuroscience in Indonesia, especially the military field although neuroimaging technologies are already applied in many other countries. The research of neuroscience in the military in Indonesia are highly recommended. Although the development of research of neuroscience could start from the molecular level, since the implementation of neuroimaging technologies is to reveal the mysteries of cognitive functions, we should focus on the response of soldiers in many circumstances. Respond speed of soldiers in shooting, attention visual while driving in war fields, or perception test in defense-related-problems are some examples of research that could be chosen.

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