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Bioelectricity and biomagnetism as keys to realization of neurotechnology

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ABSTRACT

The importance of bioelectricity and biomagnetism in neurotechnology has been outlined in this study. There are three main processes in neurotechnology, namely: signal delivery, data storage and data processing. These neurotechnological processes require three essential things, namely measurements, tools and materials. This scientific study describes the form of signal delivery in neurotechnology, the form of data storage and the form of data processing. The measurement methods that can be applied have also been described along with the tools and materials. Bioelectricity plays a very important role in building neurotechnology. Meanwhile, biomagnetism is an important aspect that cannot be separated from the phenomenon of bioelectricity which also supports systems in neurotechnology. The phenomena of bioelectricity and biomagnetism in neurotechnology are described in this study along with measurement devices and materials. Measuring devices and materials must be modified as conditions permit in their working conditions. It has also been studied that natural neurotechnological data storage in living creatures is through muscle memory, signal delivery occurs in the form of bioelectricity and data processing is a combination of data delivery and storage. This study also examines the future prospects of neurotechnology along with its moral aspects.

Keywords: Bioelectricity; biomagnetism; muscle memory; neurotechnology

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INTRODUCTION

Neurotechnology is a research area that is currently and actively being developed. This is considering the possible benefits that can be exploited from this research field; starting from the fields of medicine, health, defense and security, agriculture, communications and information, to the development of science and technology. In the medical field, brain and nervous disease and disorders can be reduced by the use of this technology; This also includes the treatment of Parkinson's disease, epilepsy, depression, obsessive compulsive disorder (OCD), acute headaches, chronic pain, high blood pressure, diabetes, rheumatoid arthritis and chronic colitis [1]. It is impossible to analyze all the potential benefits of this technology in detail, but it is worth noting that neurotechnology provides opportunities for the treatment of previously incurable diseases with new and better methods, and also increases human capacity; and through integration with artificial intelligence (AI), machines will be able to combine large amounts of information and make decisions very quickly and can improve the quality of resulting decisions [2].

The first documented event of bioelectricity was recorded in an Ancient Egyptian hieroglyph around 4000 BC which tells about the electrical properties of the scabbard fish; to Ragnar Granit who was a pioneer of bioelectromagnetism who received the Nobel Prize in 1967 [3]. Luigi Galvani in 1794 (De Viribus Electricitatis in Motu Musculari) demonstrated electrical phenomenon in animals by conducting electrical experiments on dead frog legs and finding the frog's legs twitching; bioelectricity research continues to be developed by scientists including Emil du Bois-Reymund [4], EJ Lund [5], HS Burr [6] to Lionel Jaffe and Richard Nuccittelli [7-9]. Luigi Galvani (1791) was the first physicist to observe electrical signals in animal tissue; Hodgkin and Huxley (1952) succeeded in measuring the membrane potential of squid axons; Neher and Sakmann laid the foundation for the study of ion channels in cell membranes [10]. Bioelectricity has experienced a very long and continuous period of development until now. Its application in the health and medical fields continues to be explored for use for the benefit of society.

The early period of biomagnetism began with the work of Baule and McFee (1963) in measuring magnetic fields in the human heart; then continued with the use of SQUID (Superconducting Quantum Interference Device) by Ed Edelsall, David Cohen and Jim Zimmerman [11]. SQUID is an ideal way of biological research, for example investigating neural activity in the brain [12]. Biomagnetism is an interdisciplinary research field that aims to understand the modulation, image, repair of human organs with internal and external magnetic fields; in the past few decades, biomagnetism has grown rapidly and its applications have expanded from the diagnosis of neural or heart disease to efforts to understand the basic mechanisms of the human brain and heart [13]. This scientific discipline provides prospects for researchers to profile and investigate the working properties of the human brain and nervous system with the aim of developing neuroscientific understanding. Very complex investigations are involved in this line of research. Detailed understanding and adequate measurement are absolute conditions necessary to ground neuroscience in neurotechnological applications.

The two foundations of Indonesia's development progress are schools and hospitals [14]. These two foundations can be considered as the basis for the progress of a nation in general. School can be interpreted as the development of science and technology. Hospitals can be interpreted as efforts to improve the quality of public health. These two basics of progress have one main goal, namely realizing social welfare. Neurotechnology is one aspect that can be empowered to make this happen.

The rate of environmental degradation is increasing across the globe; Environmental change occurs at a faster pace than previously thought [15]. This bad condition will be followed by a series of other unexpected problems. Scarcity of natural resources and socio-economic problems are real consequences that can occur if the situation gets worse. The population growth rate shows significant figures from year to year [16]. After a period of rapid population growth, demographers predict that world population will peak by the end of the century [17]. An increase in number of people means an increase in the need for food, water, housing, energy, health services, transportation and many others; also, all consumption contributes to ecological destruction, increased conflict, and carries a greater risk of being impacted by wide-scale disasters such as pandemics [18]. If this condition is not immediately addressed, the situation the world will get worse and reach a condition where the damage cannot be minimized or even repaired.

An estimated 16% of the world's population experiences significant disability; people with disabilities are at risk of depression, asthma, stroke, obesity or poor oral health ; people with disabilities experience many injustices in the health sector [19]. Various methods have been used to overcome this problem, but often the improvements have not been significantly positive. More effective alternatives are needed to overcome this unpredictable and very undesirable problem.

An important point that must be stated is the enriching capabilities of neurotechnology that can transform the contents of the mind into material form which then provides the ability to cross the divide between “things that are possible and things that are actually” [20]. This implies the infinity of neurotechnological possibilities because human thought is limitless. With this infinite potential, it becomes energy to not only create new innovations in society, but also provide new discoveries that are very useful for life. So that the realization of the two basic principles of Indonesia's progress, overcoming environmental damage, anticipating population problems and solutions to human disability problems, is not impossible.

This study aims to provide ideas, motivation and directions for efforts towards neurotechnology applications. The realization and rationalization of the objectives of this study lie in the process of measuring and analyzing two main aspects, namely bioelectricity and biomagnetism.

RESEARCH METHODS

The following research uses analysis and literature review methods, both digital, manual and audio-visual; and supported by Wolfram Mathematica® 9 software on the Microsoft Windows® platform (64-bit).

The postulation of a neuroscientific memory function formula was carried out by reviewing several available literature and data and referring to the general characteristics of human memory.

Simple analogies such as computer systems, games of throwing and catching a ball and reflex movements are also used to provide visualization of neurotechnological processes.

The measurement devices, tools and materials used in neurotechnology studies are described with reference to the latest research results.

RESULTS AND DISCUSSION

Key Processes of Neurotechnology

Digital computers built from mechanical elements or electrical binary elements (for example, switches) not only perform computational functions, but also provide a prototype or model for the study of neural transmission and neural switching [21]. By using a computer mechanism as a prototype, it can be seen that there are three main processes involved, three main processes which are also the main processes in neurotechnology, namely: signal delivery, data storage and data processing. If we refer back to the computer mechanism model, when the computer is turned on and word processing software is run, a user can type "A" on the keyboard and almost immediately the monitor displays "A". The stroke or signal "valued" with the letter A is sent from the keyboard into the computer's "brain" system. Then the computer's "brain" system will process ("think") the data, and transmit its decision to the monitor with display "A". Next, the data containing the letter "A" will be stored in the computer's memory system, the user can give a save command input signal to the computer using the keyboard and mouse and the computer's brain will decide to save the data in its memory so that the data can be remembered (opened) again later.

When two people play catch and throw a ball or someone accidentally steps on a thumbtack in the street, all of this involves three main neurotechnological processes [22]. In the game of throwing and catching the ball, when the ball is headed towards player 1, his eyes will receive a signal of the ball's arrival, this signal is transmitted by the eye's nervous system to the brain, then the brain will process (think about) this data or signal, the decision signal will be sent to the entire movement system player 1 (hands, feet, body position, back muscle position, etc.) to catch the ball that is heading towards him. When someone accidentally steps on a thumbtack on the road, a signal of injury to the foot will be sent to the reflex system to immediately lift the foot, and also sent to the brain; the brain then gives the command to the mouth to shout “Ouch!” and eyes to see objects that signal injury to the foot. These two models are highly simplified cases of very complex real events, but provide sufficient visualization of the three main neurotechnological processes.

The processes responsible for transmitting signals are action potentials, synaptic transmission and neurotransmitters [23]. Action potentials are sometimes also called spikes, nerve impulses or discharges.

Data storage occurs in a mechanism called muscle memory. Muscle memory is a form of procedural memory that involves the consolidation (use of several) specific motor tasks into memory through repetition, which has also been used as a synonym for the term motor learning [24, 25]. When you hear the term muscle memory, the image that comes to mind is the condition of muscles that are able to remember certain movements, such as dribbling the ball in soccer or playing the song Happy Birthday on the piano [26]. Neuroscientifically, the entire process of storing data (or storing memories) in humans and vertebrates occurs through the muscle memory process.

In general, the storage memory of a data storage device, such as a flash disk, is directly proportional and is a linear function of the memory/storage capability of the material [27-29]. Brain storage memory for each individual depends on each individual's memory abilities [30]. Exceptional memory depends on genetics, brain development and experience [31, 32]. The recall curve throughout life varies in the form of a normal curve/normal curve deformed over time [33, 34]. Normal and pathological aging affects neural data at different levels and profoundly affects the mind and brain [35]. Episodic memory and working memory decline with age [36]. The frequency of repetition (attempts to repeat) is very important in reproducing a content (memory) [37]. The exponential learning (remembering effort) equation indicates a slowly decreasing increase, is one of the equations that describes the learning (or remembering) process [38]. The learning curve shows that the performance percentage is a deformed exponential function of the amount of effort exerted in the learning process [39]. A family of curves can be expressed in terms of differential equations [40]. Meanwhile, differential equations can be solved using the variable separation method [41].

The function of neuroscientific memory can be postulated [42] as follows:

$$M_e(\beta, W, t) = \mu(\beta).m(W).T(t) \quad (1)$$

$$A\,\beta\,\mu'(\beta) + \mu(\beta) = 0 \quad (2)$$

$$B\,m'(W) + m(W) = 0 \quad (3)$$

$$T''(t) + C.(t-D)\,T'(t) + E.T(t) = 0 \quad (4)$$

$Me(\beta, W, t)$ is a function of neuroscientific memory. $Me \geq 0$, $Me \in$ R. β s the ability to remember of the subject/object/material. W represents all effort, energy and ways to “learn” or store data. t is time. β, W, $t \geq 0$; β, W, $t \in$ R. And also μ, m, $T \geq 0$; μ, m, $T \in$ R. A, B, C, D and E are corresponding constants. The accent marks in Equations (2) to (4) indicate the first and second derivatives of the function, respectively.

Data storage in neuroscience is very different from computer systems. In computer systems, data is stored on the hard disk in the form of magnetic domains, whereas in neuroscience or neurotechnology, data is stored through a process called muscle memory. In the brain, when forming memories, neurons make new proteins and expand the network of neurons and synapses that make neurotransmitters work efficiently; and there is no single location where all memories are stored, different parts of the brain store different memories, when a memory is recalled this part of the memory works together with other parts to produce a consolidated memory [43]. The network of connections (like cables) in the brain is always changing, when new memories are formed, the number of synapses increases thereby increasing the number of connections in the brain [44].

The computer system "thinks" (processes data) with a central processing unit (CPU) which contains a microprocessor. Humans think (process data) with their brains, which are composed of neurons. This data processing occurs when there is activity of neurons in the brain which is indicated by phenomenon of fire up/light up/ignition in parts of the brain [45]. Data processing in neuroscience and neurotechnology is not as simple as that in computer systems. Neuroscience cannot answer questions such as contemplation, affection, innovation, desires, morality, preferences and so on, all of which are examples of states when the brain processes data. In other words, neuroscience is unable to explain why neurons activate in the way they do when the subject experiences these things; and what causes the human brain to be capable of contemplation, compassion, innovation, desire, morality, preferences and so on? This question cannot be answered by science but can be answered by philosophy; After all, science begins with philosophy, so the use of philosophy in analyzing this problem is a justifiable and valid scientific process.

Humans can live because they are given a spirit or life by God [46]. God gave reason to man, it is reason that is his guardian and that controls him [47, 48]. Humans are moved by a force called will [49]. So that what causes man to reflect, innovate and do contemplation on himself is his spirit (life), will and reason. This is also one of the proofs of God's existence.

To analyze and study the main processes in neurotechnology three very important things are needed, namely: measurements, equipment or instruments, and materials/objects/subjects of measurement. Measurements, equipment /instruments, and materials/objects/subjects must be properly modified and conditioned according to the working conditions.

The application of a technology can be realized if each element that makes up the technology has been measured sufficiently and the performance of the technology has also been measured sufficiently. The same applies to neurotechnology.

Bioelectricity for Neurotechnology

One of the main processes of neurotechnology is signal transmission. Neurons communicate with each other through electrochemical processes [44]. As a result, bioelectricity has become an integral part of neurotechnology.

In electricity there are quantities such as electric current, electric potential, energy, resistance, inductance and capacitance [50]. The semiconductivity character of a material must also be a concern, because integrated circuits can be made into electronic neuron models [3]. The electronic quantities of action potentials, synaptic transmission and neurotransmitters must also be measured. Neurons and neurotransmitters must be characterized. Characterization methods that can be used include: optical microscope, Ultraviolet-Visible (UV-Vis), Fourier-Transform Infrared Spectroscopy (FTIR), Photoluminescence (PL), Wavelength-dispersive X-ray Spectroscopy (WDXS), Dynamic Light Scattering (DLS).), Dielectric Thermal Analysis (DETA) [51], Electrochemical Impedance Spectroscopy (EIS) [52], and analytical chemistry [53].

Organic material as measurement material can be giant squid nerves [54]. Animals such as cockroaches and frogs can also be used as measurement material [55]. Places that can be sources of measurement material: slaughterhouses, fish markets and places selling fishermen's catches, people's markets, agricultural land, houses, livestock and others. For squid nerve material, the voltage clamp method can be used [56]. For noninvasive measurements , human subjects can be used using a bioelectrical signal recording device (electromyography) with modeling represented in the Hodgkin-Huxley equation, which is an approximation of electrical activity in neurons [57]. To extract the electrical dimensions of the specimen quantitatively, glass microelectrode techniques (invasive), the vibrating voltage probe (noninvasive), the vibrating ion-selective microelectrode (noninvasive), and studies using fluorescence (somewhat invasive) are used. Electroencephalogram (EEG) is a testing technique that measures electrical activity in the brain, this equipment can be used to study the brain electrically [58].

Biomagnetism for Neurotechnology

One of Maxwell's equations [59] is stated as:

$$\nabla \times \mathbf{B} = \mu_0 \boldsymbol{J} + \mu_0 \epsilon_0 \frac{\partial \boldsymbol{E}}{\partial t} \tag{5}$$

Descriptively, this equation states that changes or spatial variations in a magnetic field will produce a current density along with an electric field that changes from time to time. This principle can be used as a method for imaging brain biomagnetism (brain imaging). Hippocampal theta oscillations are one important aspect of brain imaging that utilizes biomagnetism. Hippocampal theta oscillations are a key brain signal that indicates various aspects of cognition and behavior including memory and spatial navigation [60]. Despite this, human hippocampal recordings still show divergent theta correlations to memory formation [61].

There are several brain imaging techniques including Computed Axial Tomography (CAT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Single-photon Emission Computed Tomography (SPECT), Cranial Ultrasound, Functional Magnetic Resonance Imaging (fMRI), Diffuse Optical Imaging (DOI), Event-related Optical Signal (EROS), Magnetoencephalography (MEG), Functional Ultrasound Imaging (fUS) and Quantum optically-pumped magnetometer [62]. One popular technique is MEG which utilizes a detector called SQUID (Superconducting Quantum Interference Device) [63].

If the bioelectricity and biomagnetism of the brain have been quantized, mapped and measured well and sufficiently; then the road to neurotechnology applications will be wide open.

Neurotechnology Prospects

Using two basic references to Indonesia's progress, the direction of development and prospects for neurotechnology are divided into two main paths, namely the science and technology path and the path to improving the quality of public health.

On the path of science and technology, neurotechnology can present the prospect of a Brain-Computer Interface (BCI) that enables Radical Closure, the "creation" of objects through thought, Id-Machines (a technology that gives substantial reality to humans' deepest hopes and fantasies), and communication technology between mind [20]. Radical Closure means disconnected from the environment, but open to diagrams, or to other realities, or to nothingness [64].

Neurotechnology uses the knowledge and tools of mathematics, physics, chemistry, biology and engineering to help reduce the burden of brain-related diseases [65]. Neuroscientists apply a wide range of scientific disciplines including anatomy, biochemistry, computer science, pharmacology, physiology, psychology and zoology [66]. However, neurotechnology will require other scientific disciplines in its development, such as philosophy, law, related social sciences, materials science, and brain surgery.

On the pathway to improving the quality of public health, neurotechnology can be used as a means of examination (e.g. neuroimaging and thermography) and also intervention (e.g. transcranial stimulation, implants, brain-machine interfacing); and its use to gain knowledge about the function of the human nervous system, especially to understand the processes involved in health and disease [67]. Neurotechnology includes a variety of devices, algorithms and methodologies that can monitor or modulate neural activity, including nerve stimulators, brain implants and bioprostheses ; This technological capability provides a capable device for carrying out targeted therapies for sufferers of neurological disorders [68].

Ian Burkhart has been a test subject for a BCI designed to control simulated muscles; a device was inserted into his brain through a surgical procedure, resulting in Ian being able to move his fingers just by thinking about it [69]. Neurotechnology has been proven to have enormous potential to improve the lives and well-being of people affected by paralysis, neurological disorders, mental illness and depression [70]. In recent years, developments in neurotechnology have opened up new opportunities for people with disabilities, promising to improve quality of life and promote inclusivity [71]. The prospect of neurotechnology in improving the quality of public health is very real.

Neurotechnological Morality

Neuroethics is a study of the implications of neuroscience on human self-understanding, ethics and policy [72]. In addition, neuroethics is also an interdisciplinary field that focuses on ethical issues caused by increasing understanding of the brain and the ability to monitor and influence it [73]. There are two big categories regarding neuroethics issues, namely something that comes from what can be done and something that comes from what is known [74, 75]. Something that comes from what can be done is all the efforts, techniques, methods and experiments that can be done; such as neuroimaging, psychopharmacology, brain implants, brain-machine interfaces and others. Meanwhile, something that comes from what is known includes behavior, personality, consciousness and a state of spiritual transcendance. Neuroethics then becomes the basis for dealing with the moral principles of neurotechnology.

Learning from the broad spectrum of problems that have emerged after the presence of smartphone technology, neurotechnology morality will be categorized into Artificial Intelligence (AI) morality, individual morality of technology users, social morality of technology users and a combination of the three. The moral field is the field of human life seen from the aspect of goodness as a human being, while the actual moral attitude is called morality [76]. AI morality, the individual morality of technology users and the social morality of technology users must be adjusted to the norms that apply in that society. There are five norms that apply in Indonesian society, namely religious norms, legal norms, customary norms, moral norms and civility norms. Neurotechnological morality must be able to include these five norms.

CONCLUSION

There are three main processes of neurotechnology, the three are signal delivery, data storage and data processing. Contemplation is one example of data processing that neuroscience cannot explain. It has been shown that philosophy is also involved in the analysis of Neuroscience and neurotechnology. Neurotechnological applications can be realized when the bioelectricity and biomagnetism of the brain have been properly quantized, mapped and measured. Neurotechnology has enormous prospects for Indonesia's progress. Neurotechnological morality must include the five norms that apply in Indonesian society.

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