Sensory remapping: a possible therapy option

Remapeamento sensorial: uma possível opção de terapia

Wanderson Silva Macedo de Sousa[1], Matheus Sam do Santos Lemos[1], Diego Agripino Chagas Silva[1], Therezza Inácia Martins Gomes Leite[1], Ana Cláudia de Miranda Adad[1], Ana Flávia Ferreira Sousa[3], Gabriela Veiga Macedo e Araújo[1], Jonatas Paulino da Cunha Monteiro Ribeiro[2]

ABSTRACT

The human sensory receptors are morphologically specialized to transduce specific stimuli into the brain. However, when an injury occurs, mainly in the spinal cord, which can be of traumatic or non-traumatic origin, it provokes various degrees of sensory deficits, autonomic, motor and sphincter dysfunction below the level of the injury. Based on this, a new therapeutic modality is being proposed by neuroscientist Miguel Nicolelis, which is based on the brain-machine interface, that is, using other pathways so that the information can reach the cerebral cortex and thus be consciously processed.
Keywords: Brain-computer interfaces, Neurosciences, Sense organs.

RESUMO

Os receptores sensoriais humanos são morfologicamente especializados para realizar a transdução de estímulos específicos para o encéfalo. Entretanto, quando ocorre uma lesão, principalmente, na medula espinal, que pode ser de origem traumática e não traumática, provocam diversos graus de déficits sensoriais, disfunção autônoma, motora e esfincteriana, abaixo do nível da lesão. Com base nisso, uma nova modalidade terapêutica está sendo proposto pelo neurocientista Miguel Nicolelis, que tem como base a interface cérebro máquina, isto é, utilizar-se de outras vias para que as informações possam chegar no córtex cerebral e assim serem processadas conscientemente.
Palavras-chave: Interfaces cérebro-computador, Neurociências, Órgãos dos sentidos.

INTRODUCTION

In the story Alice in Wonderland, when she meets the talking cat, the latter asks her which way she wants to go, and Alice replies that anyway will be fine, at that point, the animal replies: "If you don't know where you want to go, then any path will fine"[1]. Analogously, in the nervous system, unlike Alice's indecision, the information in neuronal patterns, that is, information coming from receptors inside and outside the body, know perfectly well which path to take to reach their destination, the brain, and then return to their starting point, as a two-way street.

It is known that these streets and avenues of patterns constitute the somatosensory system. This data set in dispositional representational forms[2] carries important instructions and information to the central nervous system, both externally and internally. The somatosensory system allows humans to enjoy pleasant sensations, such as smelling great food, and unpleasant ones, such as pain. In addition, somatic sensation allows the individual to feel tactile perception, pain, cold, heat, pressure, and which parts are being stimulated and is of fundamental priority for the delicate balance of human life[3].

However, when some injury occurs in the main connection pathway, the spinal cord, this information cannot ascend to the brain, so it is difficult to know if the limbs are ready to send stimuli and plan adaptive movements. As it is in cases of paraplegia and tetraplegia.[4]

In this way, as the main organ of the nervous system is left without knowing what to do and how to do it, given that a part of the body has disappeared from the neuronal representations[2,3,], it becomes consciously neglected, which ends up hindering decision making, the beginning, planning, and execution of the movement.

Therefore**,** the goal of this essay is to propose a new therapy that allows wheelchair users to have increased sensitivity in the lower

[1] Centro Universitário Uninovafapi, (PI), Brazil
[2] Universidade Federal do Piauí, (PI), Brazil
[3] Centro Universitário Unifacid, (PI), Brazil

https://doi.org/10.11606/issn.2176-7262.rmrp.2023.201531

limbs and that, based on this, neuroplasticity can act concomitantly with therapy to offer a better quality of life.

Sensory Code

A neuronal code is a relationship between the activity of specific neurons and the functional consequences for planning that follow, according to neuroscientist Kandel. In view of this, he describes the synaptic activity, the neuronal code, as a stimulus applied to the neuron, which causes synaptic firing using the action potential. However, there is debate about the best way to decode the temporal firing in a series of neurons[5,6], which can be analyzed by the electroencephalogram, a form of communication as if it were an image of the stimulus that is forwarded to the encephalon.

In this sense, according to neuroscientists, the strategy is based on following the flow of sensory information from the receptors to the cognitive centers and thus trying to understand the processing mechanisms that occur in each neuron. [6]

Somatosensory System

Human sensory receptors are morphologically specialized to transduce specific stimuli to the brain. Because of this, most receptors are selective, responding to only one type of energy, i.e., the stimulus.[6,7]

Furthermore, the receivers are classified into: [2,6]

- Mechanoreceptors;
- Photoreceptors;
- Chemoreceptors;
- Thermoreceptors.

However, chemoreceptors and thermoreceptors have the greatest distribution and variability in form and function[6].

Furthermore, the somesthetic system is divided into three subsystems: an exteroceptive system, which includes the tactile sensitivity coming from the skin; the proprioceptive system, which brings information about the sensitivity of muscles and joints, which serves mainly for motor coordination; and finally the interoceptive system, which gathers a large number of distinct receptors, that indicate subjective sensations, emotions, and a global state of knowledge of the human body.[7]

Sensations from the external world can be assigned into two main parts[3]: tactile and pain. Tactile sensation is defined as direct contact with some surface, either actively or passively. In the active form, it refers to when a conscious movement is made to contact a material outside the body. In the passive form, the object touches the epithelial surface of the body.[6]

Tactile receptors are spread all over the surface of the skin, so there are at least six different types of receptors, which are:[8]

1. Free nerve endings: They trigger sensations of touch and pressure;
2. Meissner's corpuscle: They have great sensitivity, with thick myelinated sensory nerve endings of the AP type, elongated and encapsulated;
3. Merkel discs: They are often clustered in a receptor organ called Iggo's dome receptor; they transmit an initially strong signal but adapt partially, followed by a weaker, continuous signal that adapts slowly. They are receptors involving epithelial cells with expanded endings;
4. Terminal hair organs: These are connected to the base of the hair. They detect the slight movement of any body hair;
5. Ruffini endings: These are deeper in the skin and are also located in internal tissues. They have endings that adapt slowly and, therefore, transmit information from continuous states of tissue deformation, such as signals from intense and prolonged touch and pressure;
6. Pacinian corpuscles: Located below the skin, they are deep in the fascia tissues. Stimulated by rapid local compression of the tissues, they have rapid adaptation.

In this context, most tactile receptors detect vibrations; however, some differ in the vibration frequency. Pacinian corpuscles detect vibration signals at 30 to 800 cycles per second, and respond quickly to minimal and rapid deformations, while Meissner's corpuscles adapt slowly and are stimulated by low-frequency vibrations of two to 80 cycles. [8]

Next, a type of sensory information that is important for the survival of the complex organism is pain. Pain is a subjective perception that can be distinguished into two types: slow pain and rapid pain.[9]

Rapid pain can be characterized as acute and localized. Through myelinated fibers, the message is transmitted to the central nervous system. In light of this, slow pain is more diffuse and originates far from the central nervous system. For this system, the receptors are called nociceptive. These types of receptors function using chemical, mechanical, and thermal stimulation.[8,9]

The pain mechanism is of utmost priority, for it is through this physiological mechanism that several clinical symptoms can be presented[10], and when the loss of this mechanism occurs, the individual becomes vulnerable to different insidious external factors that put lives at risk, especially in people with paraplegia or who have suffered a stroke in the region of the postcentral gyrus, known as the primary somesthetic region. [11]

Sensory Remapping

In recent decades neuroscience has made significant advances in gaining knowledge about information traffic in the central and peripheral nervous system.

Basically, there are three types of pathways that carry information to the brain:[12]

1. Divergent routes;
2. Non-aware relay paths;
3. Conscious relay routes.

The conscious relay pathways refer to information regarding the location and type of stimulation to the cerebral cortex. They have high fidelity, which provides precise details regarding the stimulus and its location. In addition, they make it possible to make final distinctions between stimuli. Tactile and proprioceptive discriminative information occurs ipsilaterally through the posterior spinal cord.[12]

Furthermore, the divergent pathways transmit information from various locations in the brainstem and brain. In this regard, inaccurate pain is a form of information that is transmitted by divergent pathways.[12]

Then there is the third pathway, the non-conscious relay pathway, which carries information to the cerebellum about proprioception and other information related to movements performed in a non-conscious way. Based on this, this pathway plays an essential role in the automatic modulation of movements and posture.[12]

However, neurophysiological structures that are also intrinsically related, such as the thalamus, the spinal cord, the spinal lemniscus, the trigeminothalamic tract, the anterior and lateral spinothalamic tract, the gracilis nucleus, the cuneiform nucleus, and other structures located in the central nervous system[3,8] work in harmony so that all the data can be decoded for decision making.

However, when an injury occurs, mainly in the spinal cord, which can be of traumatic or non-traumatic origin, it causes various degrees of sensory deficits, and autonomic, motor, and sphincter dysfunction below the level of the injury. Paraplegia is characterized by thoracic, lumbar, or sacral injuries, while quadriplegia is characterized by injuries in the cervical region.[13]

Thus, the lesion impedes the transmission of information from receptors scattered throughout the body, and as a result, the person stops feeling sensations and no longer has the ability to perform movements.

However, a new therapeutic modality is being proposed by neuroscientist Miguel Nicolelis, which is based on the brain-machine interface, that is, using other pathways so that the information can reach the cerebral cortex and thus be consciously processed.

Moreover, with the advance of technology, in his study, Miguel Nicolelis, "Assimilation of virtual legs and perception of floor texture by complete paraplegic patients receiving artificial tactile feedback"[14] performed a perception training with augmented virtual reality, where terrains with different textures were simulated. In addition, tactile vibrators connected to the computer were placed on the forearm region of the patient, after which several simulations with different gait speeds were performed.

During therapy, the information about the foot touch sensation, which occurred in the virtual world, was transmitted to the region of the forearm; therefore, the brain resembled this information as coming from the lower limb, which in this case was disconnected because of the spinal cord lesion, i.e., the neuronal pattern could travel another path, deviating from the lesion to reach the cerebral cortex.

Another important finding is that the brain began to incorporate the virtual lower limb as being part of the physical body, causing new synapses, that is, the neuroplasticity[6] to occur more intensely, and the paraplegic patients submitted to this technique reported feeling the sensation of touch, partially discriminating the texture in which the virtual limb touched.

Such a discovery resembles technologies from fictional series, such as Star Wars and Star Trek, where robotic limbs embedded in the body aided in locomotion and sensation.

Not only was this possible, but another study "Non-invasive, Brain-controlled Functional Electrical Stimulation for Locomotion Rehabilitation in Individuals with Paraplegia"[15], through the brain-machine interface, with functional electrical stimulation, promoted the partial recovery of paraplegic patients. The patients were able to walk safely with 65 to 70% body weight support, with cardiovascular improvement and less dependence on ambulation. Such findings in the studies show that, possibly, patients with spinal cord injuries can recover part of their mobility, receptor sensation, and sphincter control.

Certainly, the brain-machine interface can be used as a means to remap sensory sensations, but the use of the gait protocol allied to this method can induce the partial recovery, again, of paraplegic patients[16] with the use of visual tactile feedback and exoskeleton, as a way to reorganize the synapses and promote a rearrangement in the path of information to the brain, thus, amplifying the nervous system, putting it outside the confines of the body, for the first time.

At this juncture, we are closer to Star Trek fiction than we imagined, the possible applications of this technology, not only in the rehabilitation of people with spinal cord injury but can contribute to the advancement of humanity in this sector, for example, controlling a machine only with the commands of the mind, through a wireless connection.

Sensory remapping shows itself as a potentiality beyond comprehension, such that new philosophical questions can be formulated, such as: what is the human being in the face of this innovation? Can the consciousness of an individual be transferred to a machine? Can a machine obtain a consciousness similar to a human being? A priori, we are still far from being able to answer these questions and future questions that will arise; however, a posteriori, as a therapy option for recovery from several neurological injuries, is promising.

Concluding Remarks

Little is known about what it is to be a human now that we are learning the physiological processes concerning such a peculiar being that shows an immense capacity to evolve over time, especially in neurosciences.

Although the brain-machine interface can be used as a therapeutic measure with efficient results, the question is, if this is applied to weapons, what catastrophe can be unleashed over time? In the 21st century, this technology would help millions of people around the globe in the area of health, but it could also be implemented in the consumer goods industry; as mentioned above, its applications are countless.

In summary, the brain-machine interface shows itself as a therapeutic modality that still needs to be further studied and improved, so that future patients can enjoy this therapy. Although, for this to happen, private and public sectors of several countries must invest so that research can take place. Therefore, politics and science must go hand in hand for the progress of society.

REFERENCES

1. Carroll L. Alice in Wonderland. 1ed. São Paulo: Darkside; 2016.
2. Damásio AR. O erro de Descartes: Emoção, razão e o cérebro humano. 3. ed. São Paulo: Companhia das letras; 2012.
3. Bear MF, Connors BW, Paradiso MA. Neurociência: desvendando o sistema nervoso. 4. ed. Porto Alegre: Artmed; 2017.
4. Gill ML, Grahn PJ, Calvert JS, Linde MB, Lavrov IA, Strommen JA, et al. Neuromodulation of lumbosacral spinal networks enables independent stepping after complete paraplegia. Nat Med. 2018 ;24(11):1677-1682. https://doi.org/10.1038/s41591-018-0175-7.
5. Cordeiro VL, Pena RFO, Ceballos CAC, Shimoura RO, Roque AC. Aplicações da teoria da informação à neurociência. Scielo, 2019; 41(2): e20180197.
6. Kandel ER, Schwartz JH, Jessell TH, Siegelbaum SA, Hudspeth AJ. Princípios de neurociências. 5. ed. Porto Alegre: Artmed; 2014.
7. Roberto L. Cem bilhões de neurônios?. 2. ed. Rio de Janeiro: Atheneu; 2010.
8. Hall JE, Guyton AC. Tratado de Fisiologia Médica. 12.ed. Rio de Janeiro: Elsevier; 2011.

9. Silvertrone DU. Fisiologia humana: Uma abordagem integrada. 7 ed. Porto Alegre: Artmed; 2017.

10. Gosling AP. Mecanismos de ação e efeitos da fisioterapia no tratamento da dor. Revista Dor . 2012; 13(1): 65-70.

11. Sá JFR, Mota-Rolim SA. Out-of-body experiences: historical and neuroscientific aspects. Cien. Cogn. [Internet]. April 30, 2015 [cited October 25, 2022];20(1). Available from: http://www.cienciasecognicao.org/revista/index.php/cec/article/view/985.

12. Lundy-Ekman L. Neurociências: Fundamentos para a reabilitação. 2 ed. Rio de Janeiro: Elsevier; 2004.

13. Rocha AS, Cavalcante LR, Alves SSF, Souza ALL. Perfil funcional das sequelas de lesão medular nas diferentes etiologias. Rev. CIF Brasil. 2021; 13(1): 38-51. doi: 10.4322/CIFBRASIL.2021.006.

14. Shokur S, Gallo S, Moioli R, Donati ARC, Morya E, Bleuler H, et al. Assimilation of virtual legs and perception of floor texture by complete paraplegic patients receiving artificial tactile feedback. Sci Rep.2016 ;6 (32293). https://doi.org/10.1038/srep32293.

15. Selfslagh A, Shokur S, Campos DSF, Donalt ARC, Almeida S, Yamauti SY, et al. Non-invasive, Brain-controlled Functional Electrical Stimulation for Locomotion Rehabilitation in Individuals with Paraplegia. Sci Rep .2019; 9 (6782). https://doi.org/10.1038/s41598-019-43041-9.

16. Donati AR, Shokur S, Morya E, Campos DS, Moioli RC, Gitti CM, et al.Long-Term Training with a Brain-Machine Interface-Based Gait Protocol Induces Partial Neurological Recovery in Paraplegic Patients. Sci Rep. 2016; 6 (30383).https://doi.org/10.1038/srep30383.

Corresponding Author:
Wanderson Silva Macedo de Sousa
wandersonsousa8@hotmail.com

Editor:
Prof. Dr. Felipe Villela Gomes

Received: aug 27, 2022
Approved: nov 22, 2022