Chapter

EEG Measurement as a Tool for Rehabilitation Assessment and Treatment

Hideki Nakano

Abstract

In recent years, neuroscience-based rehabilitation, also known as neurorehabilitation, has been attracting increasing attention worldwide. Electroencephalography (EEG) has been widely used in clinical practice as a tool for the evaluation and treatment of rehabilitation because of its noninvasive and simple measurement of human brain activity. EEG-electromyography coherence is a method to analyze the synchronization between the motor cortex and muscle activity during movement and to quantitatively assess how the motor cortex controls muscle activity. In addition, recent advances in analysis and measurement techniques have made it possible to estimate the source of EEG signals, thus serving as a method to evaluate rehabilitation. The brain-machine interface, which integrates medicine and engineering, has been widely applied in the treatment of rehabilitation and for improving the quality of life. This chapter provides an overview of EEG, and its uses as a tool for rehabilitation assessment and treatment.

Keywords: EEG, non-invasive brain function measurement, rehabilitation, EEG–EMG coherence, EEG mapping, EEG source imaging, brain-machine interface

1. Introduction

Ever since the first human electroencephalography (EEG) [1] and electromyography (EMG) [2] recordings were performed in the 1920s, the theoretical aspects, test techniques, and clinical applications of each have rapidly advanced [3]. Methods for imaging brain function have appeared one after another over the past century beginning with evoked potentials [4] in the 1940s, event-related potential [5, 6] and magnetoencephalography (MEG) [7] in the 1960s, positron emission tomography (PET) [8, 9] in the 1970s, and functional magnetic resonance imaging (fMRI) [10, 11] in the 1990s. Currently, the noninvasive methods available for measuring brain function are broadly divided into two categories: electrophysiological examinations and imaging techniques based on hemodynamic principles. The former includes EEG, MEG, and transcranial magnetic stimulation (TMS), while the latter includes fMRI, PET, single photon emission computed tomography (SPECT), and near-infrared spectroscopy (NIRS) [12].

EEG is widely used in rehabilitation as it is well suited to the field's demands for measurement, which includes simple, safe, and portable equipment. In the past, EEG has primarily been an analysis method used to capture brain activity accompanying a given phenomenon or during a given task as an electric field and subsequently estimates the source of that activity based on the distribution on the scalp. In contrast, recent advancements have led to the development of a method capable of capturing fluctuations in the power of rhythms in a certain frequency band. When this power decreases accompanying a given phenomenon or task, it is called event-related desynchronization (ERD). Conversely, when this power increases accompanying a given phenomenon or task, it is called event-related synchronization (ERS) [13–15]. Thus, electric field analysis is an analysis of the temporal domain, while the second method is an analysis of the frequency domain. In frequency analysis, ERD is thought to reflect a state of increased cortical activity in the region, while ERS is thought to reflect a state of decreased activity or return to a low level. This chapter will outline the clinical applications for treatment and evaluation of rehabilitation using these features of EEG focusing specifically on EEG–EMG coherence, scalp mapping, and brain-machine interface.

2. EEG-EMG coherence

Like brain waves, it has long been known that myoelectric activity—the final output of the motor system—is rhythmic. Since a correlation between EEG and EMG rhythms was first reported, the concept of EEG–EMG coherence has become a field of study attracting much attention [16–18]. As EMG measures the collective firing of a motor unit, if rectified such that the positivity or negativity of individual spikes is irrelevant, EMG signals are thought to correspond to action potentials of spinal motor neurons [19]. At the same time, EEG activity reflects the collective activity of neurons, particularly their postsynaptic potential. Therefore, EEG–EMG coherence is considered capable of measuring the control of spinal motor neurons by the cerebral cortex.

In healthy individuals, EEG–EMG coherence shows a distribution following the somatotopy of the primary sensorimotor cortex contralateral to the muscle for which myoelectric activity was recorded. Research using MEG has found that the source of coherent rhythmic activity can be found in the primary motor cortex [20, 21]. Further, peak coherence has been reported to roughly correspond to hot spots during TMS [17]. Significant coherence is primarily seen in the β frequency band (13–30 Hz) but has also been observed in the lower frequency α band and the γ band near 40 Hz. Thus, coherence in these various frequency bands may be derived from different mechanisms [22].

Research measuring the time lag between EEG and EMG has found that EEG invariably precedes EMG for the β band, yet there is almost no lag for the α band [18]. This suggests that the mechanisms of coherence in the α and β bands differ. One theory to explain this is that a muscle's peripheral centrifugal sensory input is involved in α band coherence. However, a previous study found that coherence in this band was not affected when peripheral sensory input was modified using vibration stimulation [18]. Thus, it appears that the reason there is no time lag between cortical activity and myoelectric activity is that subcortical rhythmic activity contributes to both brain wave rhythms and myoelectric activity. Further, studies have found that intensifying muscle contraction changes the coherence peak frequency from the β band to the γ band [23, 24]. This γ band coherence is thought to contribute to the control of myoelectric activity (piper rhythm) at approximately 40 Hz, as is seen during strong muscle contraction. Interestingly, the coherence peak does not transition smoothly from the β band to the γ band as myoelectric activity changes from weak contraction to strong contraction; rather, it shifts in a step-like manner. This suggests that the mechanism involved in coherence in the γ band differs from that of the β band. However, there is no difference between the two frequency bands when measuring the time lag between brain activity and myoelectric activity; brain activity precedes myoelectric activity for both. Accordingly, coherence in both of these frequency bands is thought to be involved in centrifugal output from the cerebral cortex to spinal motor neurons. This type of coherence is localized to the primary sensorimotor cortex contralateral to the muscle. However, subdural recordings of patients with intractable epilepsy requiring surgical intervention have shown EEG–EMG coherence in other brain areas, such as the premotor cortex and supplementary motor cortex [25]. Anatomically, its well known that there are direct projections from the premotor cortex and supplementary motor cortex to spinal motor neurons [26, 27], suggesting that these brain areas are involved in the control of myoelectric activity.

Due to its ability to non-invasively measure frequency-specific coupling of the cerebral cortex (specifically the primary motor cortex) and spinal motor neurons, clinical applications of EEG–EMG coherence are ongoing and include illuminating the pathophysiology and evaluation of diseases featuring motor impairment or involuntary movement. A relatively slow resting tremor of 3–6 Hz is one of the core symptoms of Parkinson's disease. While the rhythm of these tremors is thought to originate in the basal ganglia-thalamo-cortical loop, the mechanism of onset remains unknown. One study exploring the EEG–EMG coherence of these resting tremors found that primary sensorimotor cortex activity corresponds to the tremors [28]. As Parkinson's disease patients exhibit EEG–EMG coherence at their tremors' peak frequency or double harmonic frequency, stronger coherence is observed between 5 and 12 Hz, a range that displays low coherence in healthy individuals. At the same time, such patients show reduced coherence in other frequency bands (15–60 Hz) [29]. This abnormal coherence pattern has been found to approach that of healthy individuals (strong coherence for 15–60 Hz) with the use of deep brain stimulation or pharmacotherapy using drugs such as levodopa [30, 31]. Thus, the dopaminergic system may influence the occurrence of this coherence. Studies also report EEG–EMG coherence features resembling those of resting tremors in relation to freezing of gait, a typical gait disorder seen in patients with Parkinson's disease [32, 33]. Accordingly, EEG–EMG coherence is considered widely applicable as a tool for evaluating the effects of rehabilitation interventions and elucidating the pathology of movement disorders in patients with Parkinson's disease.

Reduced EEG–EMG coherence has been reported not only in patients with Parkinson's disease, but also in stroke patients and older adults. One study examining the EEG–EMG coherence of the hemiplegic and non-hemiplegic sides of subcortical infarction patients found that although the EEG and EMG power showed similar patterns for both the hemiplegic and non-hemiplegic sides, the coherence was significantly lower on the hemiplegic side [34]. This reduced EEG–EMG coherence on the hemiplegic side has been shown to improve as the patient's motor function recovers [35], suggesting that this may be a useful biomarker reflecting motor function recovery in stroke patients. Meanwhile, EEG–EMG coherence in older adults is significantly lower than that in younger individuals and has been shown to have a significant correlation with muscle strength [36]. This suggests that lower EEG–EMG coherence in older adults may be one factor in the decline in strength, motor skills, and coordination that accompanies aging.

3. EEG mapping and source imaging

Interpreting an EEG visually requires experience, but a two-dimensional representation of brain electrical activity (topography) is a way to display brain waves more objectively as a planar map of electrical activity on the scalp's surface. Techniques are also being developed to estimate areas of activity within the brain from multichannel EEG data obtained from the scalp, thereby increasing the precision of brain function analysis using EEG.

EEG scalp mapping analyses include spatial analysis (two-dimensional and three-dimensional), coherence, and complexity (Ω). As brain waves consist of multiple frequencies with different physiological significances, it is vital to perform frequency analysis based on a fast Fourier transform (FFT) to consider each frequency independently. It is also integral to select the appropriate analysis and interpretation with consideration to the items to be evaluated and features of each disease using these analysis techniques [37].

A previous study reported the spatial distribution of EEG topography independent of electrode placement by epoch and found that the standard topographies of various intervals were separated by instantaneous transitions [38]. In other words, it was unusual for one shape to slowly change into the next. Different topographies are thought to reflect different regions of neural activity and represent different stages of information processing. In light of this, dividing brain waves according to the temporal similarity of their spatial distribution on the scalp is considered a potentially useful method for studying information processing within the brain as it changes moment to moment. EEG microstate modeling and analysis was developed as a method of microstate segmentation using cluster analysis to determine the optimal topography and number of segments from a sequence of brain electrical activity corresponding to the characteristics of a mental activity [39]. This method is used to efficiently extract data based on the temporal and spatial structure of background EEG activity and explore the pathophysiology of brain function in a number of diseases [40, 41].

Importantly, a three-dimensional approach is necessary when considering actual brain pathology. Estimating the source of brain waves has recently been gaining attention as one approach to three-dimensional EEG analysis. This approach can be broadly divided into equivalent dipole estimation methods [42–44] and low-resolution brain electromagnetic tomography (LORETA) [45–47], a standard method of current density distribution estimation. While there are advantages and disadvantages to each, one challenge faced by the former, for which it is essential to stipulate the number of sources of activity in advance, is the difficulty of selecting which combination of dipoles is valid because different combinations of dipoles result in similar scalp distributions (inverse problem). The latter depicts the spread of neural activity within the brain in three-dimensional tomography using EEG data collected from the scalp based on the hypothesis that adjacent groups of neurons have roughly the same activity. Excluding special cases such as epileptic seizures, actual brain activity is not limited to one specific area, making this method useful in understanding complex brain activity such as higher brain function. More specifically, LORETA excels in primary processing, analyzing raw data to display an image, and secondary processing, carrying out statistical analyses to extract maps and find differences in current density distributions, and is therefore a form of EEG mapping used in diverse branches of neuroscience. As discussed above, LORETA estimates a three-dimensional distribution of brain tissue activity from EEG data measured on the scalp based on the hypothesis that adjacent neuron groups carry out similar activity. In other words, assuming a number of cubic lattices within the cerebral parenchyma, this method generates a three-dimensional blurred image of the current source by selecting the smoothest option from among combinations of three-dimensional current density distributions based on the Laplacian operation. Unlike other programs, the initial location value or number of dipoles is not set in advance. The operation is relatively simple, and while the resolution is low, the result

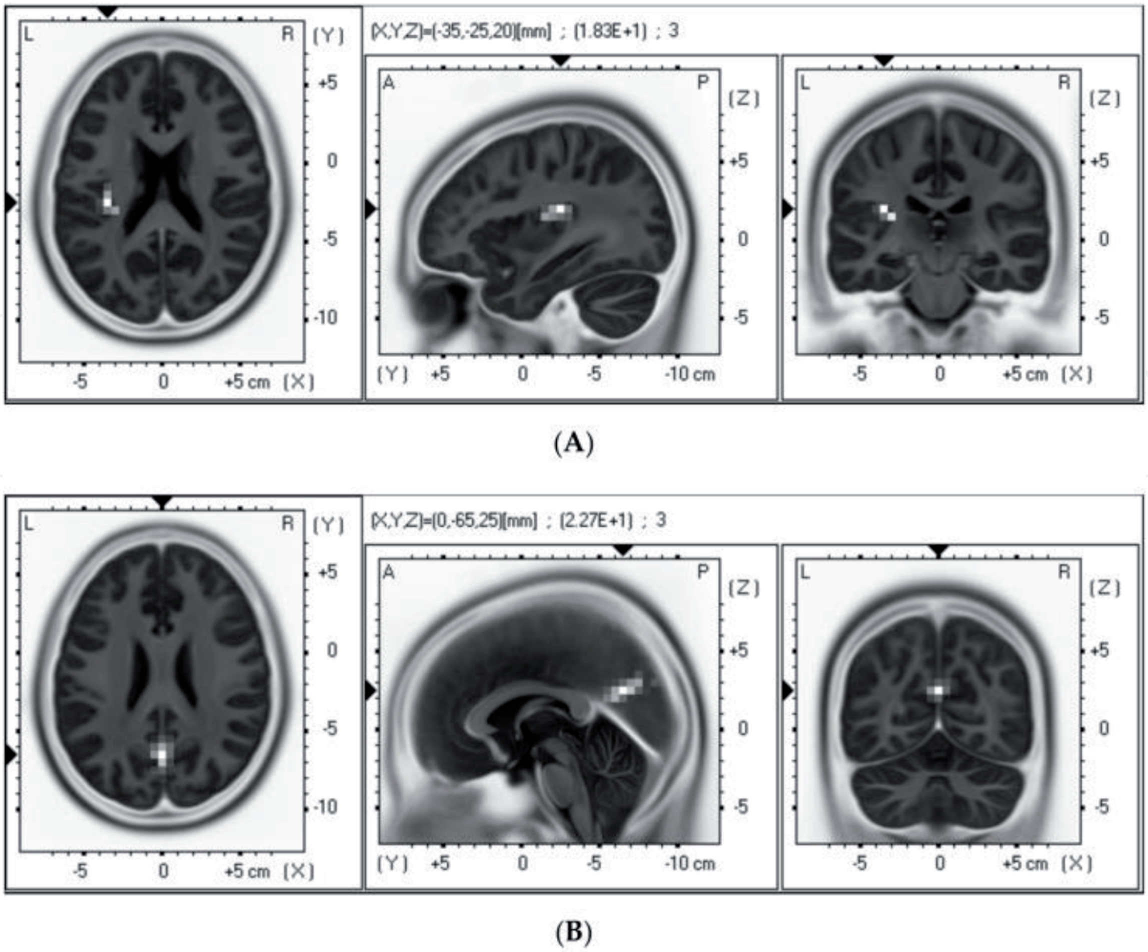

Figure 1.
Statistical non-parametric maps of LORETA of the alpha band comparing pre-rest and post-rest of hand massage (A) and foot massage (B) [48]. White blobs indicate increased activity at post-rest for each massage.

is not a primitive spherical model, but instead a tomographic image superimposed onto Talairach atlas, which can be shown in color and three dimensions (**Figure 1**) [48–50]. LORETA is being improved, and it has recently become possible to evaluate functional lagged connectivity and the directionality of that connectivity (isolated effective coherence; iCoh) between different areas of the brain.

As demonstrated above, delving deeper into background EEG activity by first exploring the time domain using methods such as microstate segmentation, then investigating the frequency domain using FFT, and the spatial domain both two-dimensionally (topography) and three-dimensionally (equivalent dipole estimation, FFT-dipole-approximation, LORETA) has a wide range of clinical applications, including elucidating pathological mechanisms and evaluating rehabilitation.

4. Brain-machine interface (BMI)

BMI techniques are methods of connecting the exchange of information between the external world and the brain using artificial electric circuits to restore and supplement its function. In the field of rehabilitation, output-type BMI applications, which read motor intention from brain activity and use this information to operate various devices and computers, are commonly used. Output-type BMI, which interprets motor intention from brain activity to operate external equipment, is classified into invasive and noninvasive types based on the method by which brain activity is measured. The former uses intracranial or epidural electrodes; the latter uses scalp EEG or functional brain imaging techniques. In addition to the conventional methods of restoring function using BMI, such as directly operating a robot arm or environmental control apparatus using brain activity, research geared toward therapeutic BMI applications, which utilize BMI for rehabilitation or reconstruction of functional neural networks, is also underway.

Neurofeedback is a method of learning to voluntarily control one's own brain activity through the presentation of said activity as real-time sensory information (visual, auditory, etc.) (**Figure 2**) [51]. Neurofeedback requires technology that measures brain activity and analyzes the measured data in real time. The technologies involved in brain signal processing and interpretation are shared with those of BMI and, in a broad sense, neurofeedback can be considered a therapeutic form of BMI. In fact, EEG-based neurofeedback is widely used as a tool for improving motor, cognitive, and psychological functions not only in individuals with diseases, but also in healthy individuals ranging from childhood to old age. The delta (<4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (14–30 Hz), and gamma (>40 Hz) frequency bands are most commonly used in evaluation and training [52]. As the functional characteristics of each frequency band differ, it is essential to select the appropriate frequency band for neurofeedback depending on the pathology of the case or the type of function one wishes to improve (**Table 1**) [53].

Neurofeedback is also gaining popularity as a technique for neuromodulation, that is, the regulation of local brain activity. Neurofeedback is considered very safe compared to methods such as repetitive transcranial magnetic stimulation (rTMS) or transcranial direct current stimulation (tDCS), as it does not use external stimulation and therefore avoids the risk of side effects such as seizure or burns that occur with rTMS and tDCS. At the same time, output-type BMI has been gaining interest in recent years as a tool for supporting the daily activities of persons who have difficulty with independent living or spontaneous expression due to disease, disability, or aging. Specifically, it will soon become possible to operate a variety of assistive devices, including wheel chairs, exoskeletons, drones, and communication robots using the operator's EEG signals (**Figure 3**) [54]. Researchers are also

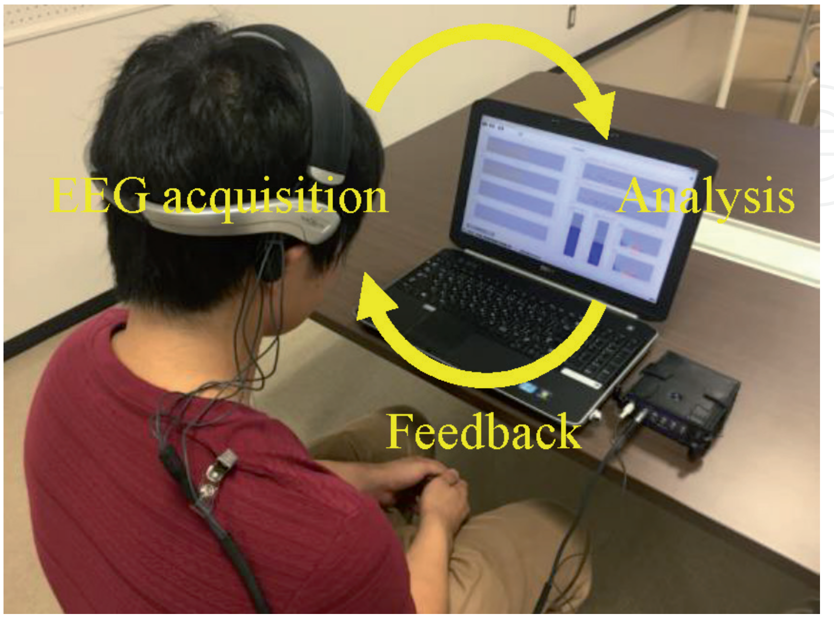

Figure 2.
Motor imagery training using neurofeedback, a therapeutic BMI [51]. EEG activity feedback during motor imagery (μ band EEG activity in the sensorimotor area) is given using sensory modalities such as vision or hearing and the participant is trained to control their own EEG activity.

Protocol	Purpose
↓ theta	Cognitive training after stroke;
	Cognitive training of healthy adults with a risk for neurodegenerative disorder.
↑ theta	Aiming to increase capabilities of executive functions on healthy students;
	Memory consolidation training.
↑ theta, ↓ alpha	Relaxation training;
	Training to improve creative performance (playing music, dancing), effects on mood.
↓ alpha	Attentional training;
	Frontal alpha-asymmetry self-regulation training to influence mood;
	Training for increased motor performance.
↑ alpha;	Training to reduce anxiety;
	Training to improve cognitive performance;
	Relaxation training for stress reduction.
↑ high alpha	Training to improve cognitive performance.
↑ SMR (12-15 Hz)	Training to decrease epileptic seizures;
	Training to improve declarative learning and sleeping pattern;
	Training to improve cognition and memory in stroke patients;
	Training to enhance golf putting.
↑ SMR, ↓ theta	Training to optimize microsurgical skills;
	Training to minimize ADHD symptoms on a healthy population.
↑ SMR, ↓ theta, ↓ high beta	Training to improve cognitive performance;
	Training to improve Asperger's syndrome and autistic spectrum disorder symptoms.
↑ low beta	Training to improve cognitive performance;
	Training to modulate sleep spindle activity and overnight memory consolidation.
↑ beta, ↓ theta	Typical training for improvement of ADHD symptoms.
↑ beta, ↓ theta, ↓ low alpha	Training of attention.
↑ gamma	Training of cognitive control;
	Training of memory and intelligence.

Table 1.
An overview of already used protocols of frequency EEG-neurofeedback training with the references to exemplary studies and their main therapeutic purpose [53].

developing and exploring the effectiveness of smart homes that incorporate these BMI technologies [55]. Smart homes are equipped with technology that interprets the user's motion intention or emotional state using methods such as EEG, which can easily measure brain activity with no special training or burden on the user. Specifically, smart homes assist with daily life by measuring the brain activity that occurs when the user naturally moves their body accompanying a motion intention, for example, to operate the television or air conditioner, recognizing what kind of motion intention is occurring, and manipulating the environment in accordance with the user's intention. They may also detect when the user is feeling discomfort and modify the environment accordingly using technology that captures an

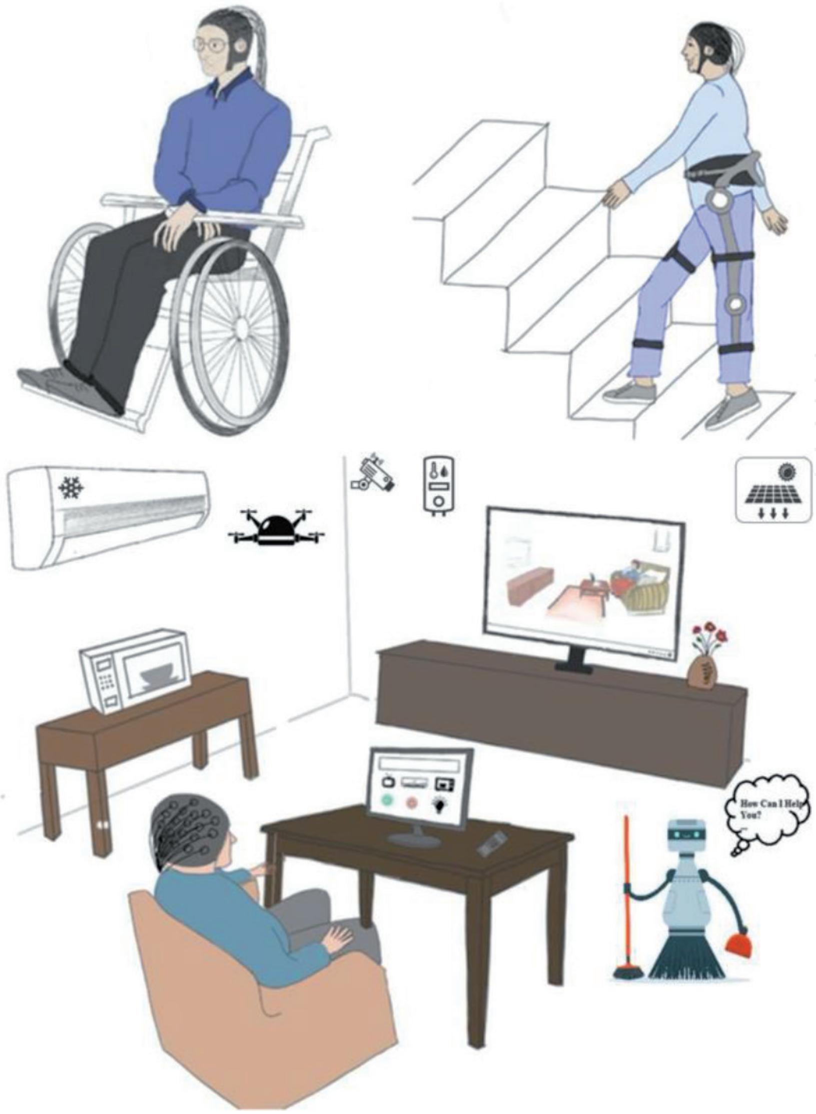

Figure 3.
EEG-based BMI for assisting with daily activities and improving quality of life [54].

emotional state (discomfort) by measuring and analyzing the user's brain activity. This information can further be communicated to family members or caregivers to allow them to provide assistance based on the user's emotional state. In addition to the above, it is also possible to assist a user's own actions in a standard living environment using BMI actuation technology that moves an exoskeleton-type robot actuator linked to brain activity [54, 55]. It is hoped that such BMI technologies will increase communication in a variety of settings and create an environment where people can continue to live independent fulfilled lives.

5. Conclusion

The development of brain function imaging techniques has led to a new understanding of previously unexplained brain functions as well as the creation of clinical applications, scientific techniques, and assistive devices based on these findings. Elucidation of brain function fully utilizing the advantages of EEG is expected to continue as high definition EEG and accompanying analysis methods become more advanced. EEG is also advantageous in that it is relatively easy to record simultaneously with other methods of brain function measurement. Therefore, it is imperative that we do not simply interpret pathology and brain function using EEG results alone but gain a comprehensive picture of the brain's physiological function and dysfunction through the simultaneous use of multiple methods of brain function measurement and by capturing various clinical parameters in a multidimensional manner.

Acknowledgements

This research was funded by the Japanese Physical Therapy Association.

Conflict of interest

The authors declare no conflict of interest.

Appendices

EEG	electroencephalography
EMG	electromyography
MEG	magnetoencephalography
PET	positron emission tomography
fMRI	functional magnetic resonance imaging
TMS	transcranial magnetic stimulation
SPECT	single photon emission computed tomography
NIRS	near-infrared spectroscopy
ERD	event-related desynchronization
ERS	event-related synchronization
FFT	fast Fourier transform
LORETA	low-resolution brain electromagnetic tomography
BMI	brain-machine interface
rTMS	repetitive transcranial magnetic stimulation
tDCS	transcranial direct current stimulation
SMR	sensorimotor rhythm
ADHD	attention-deficit hyperactivity disorder

Author details

Hideki Nakano
Neurorehabilitation laboratory, Graduate School of Health Sciences, Kyoto Tachibana University, Kyoto, Japan

*Address all correspondence to: nakano-h@tachibana-u.ac.jp

References

[1] Berger H. Über das Elektrenkephalogramm des Menschen. Archiv f. Psychiatrie. 1929;**87**:527-570. DOI: 10.1007/BF01797193

[2] Adrian ED, Bronk DW. The discharge of impulses in motor nerve fibres: Part II. The frequency of discharge in reflex and voluntary contractions. The Journal of Physiology. 1929;**67**(2):i3-i151

[3] Shibasaki H. Current status and future of non-invasive studies of human brain functions. Japanese Journal of Clinical Neurophysiology. 2008;**36**(3):114-121

[4] Dawson GD. Investigations on a patient subject to myoclonic seizures after sensory stimulation. Journal of Neurology, Neurosurgery, and Psychiatry. 1947;**10**(4):141-162. DOI: 10.1136/jnnp.10.4.141

[5] Walter WG, Cooper R, Aldridge VJ, Mccallum WC, Winter AL. Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. Nature. 1964;**203**:380-384. DOI: 10.1038/203380a0

[6] Sutton S, Braren M, Zubin J, John ER. Evoked-potential correlates of stimulus uncertainty. Science. 1965;**150**(3700):1187-1188. DOI: 10.1126/science.150.3700.1187

[7] Cohen D. Magnetoencephalography: Evidence of magnetic fields produced by alpha-rhythm currents. Science. 1968;**161**(3843):784-786. DOI: 10.1126/science.161.3843.784

[8] Orgogozo JM, Larsen B. Activation of the supplementary motor area during voluntary movement in man suggests it works as a supramotor area. Science. 1979;**206**(4420):847-850. DOI: 10.1126/science.493986

[9] Roland PE, Larsen B, Lassen NA, Skinhøj E. Supplementary motor area and other cortical areas in organization of voluntary movements in man. Journal of Neurophysiology. 1980;**43**(1):118-136. DOI: 10.1152/jn.1980.43.1.118

[10] Ogawa S, Lee TM. Magnetic resonance imaging of blood vessels at high fields: in vivo and in vitro measurements and image simulation. Magnetic Resonance in Medicine. 1990;**16**(1):9-18. DOI: 10.1002/mrm.1910160103

[11] Ogawa S, Lee TM, Kay AR, Tank DW. Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proceedings of the National Academy of Sciences of the United States of America. 1990;**87**(24):9868-9872. DOI: 10.1073/pnas.87.24.9868

[12] Shibasaki H. Human brain mapping: Hemodynamic response and electrophysiology. Clinical Neurophysiology. 2008;**119**(4):731-743. DOI: 10.1016/j.clinph.2007.10.026

[13] Pfurtscheller G, Aranibar A. Event-related cortical desynchronization detected by power measurements of scalp EEG. Electroencephalography and Clinical Neurophysiology. 1977;**42**(6):817-826. DOI: 10.1016/0013-4694(77)90235-8

[14] Pfurtscheller G. The cortical activation model (CAM). Progress in Brain Research. 2006;**159**:19-27. DOI: 10.1016/S0079-6123(06)59002-8

[15] Pfurtscheller G, Lopes da Silva FH. Event-related EEG/MEG synchronization and desynchronization: Basic principles. Clinical Neurophysiology. 1999;**110**(11):1842-1857. DOI: 10.1016/s1388-2457(99)00141-8

[16] Mima T, Shibasaki H. EEG-EMG coherence: Its application and limitation. Clinical Electroencephalography. 2003;**45**(1):19-25

[17] Mima T, Hallett M. Corticomuscular coherence: A review. Journal of Clinical Neurophysiology. 1999;**16**(6):501-511. DOI: 10.1097/00004691-199911000-00002

[18] Mima T, Steger J, Schulman AE, Gerloff C, Hallett M. Electroencephalographic measurement of motor cortex control of muscle activity in humans. Clinical Neurophysiology. 2000;**111**(2):326-337. DOI: 10.1016/s1388-2457(99)00229-1

[19] Halliday DM, Rosenberg JR, Amjad AM, Breeze P, Conway BA. Farmer SF. A framework for the analysis of mixed time series/point process data-theory and application to the study of physiological tremor, single motor unit discharges and electromyograms. Progress in Biophysics and Molecular Biology. 1995;**64**(2-3):237-278. DOI: 10.1016/s0079-6107(96)00009-0.

[20] Salenius S, Portin K, Kajola M, Salmelin R, Hari R. Cortical control of human motoneuron firing during isometric contraction. Journal of Neurophysiology. 1997;**77**(6):3401-3405. DOI: 10.1152/jn.1997.77.6.3401

[21] Gross J, Kujala J, Hamalainen M, Timmermann L, Schnitzler A, Salmelin R. Dynamic imaging of coherent sources: Studying neural interactions in the human brain. Proceedings of the National Academy of Sciences of the United States of America. 2001;**98**(2):694-699. DOI: 10.1073/pnas.98.2.694

[22] Mima T, Hallett M, Shibasaki H. Coherence, cortico-muscular. In: Hallett M, editor. Handbook of Clinical Neurophysiology. Elsevier; 2003. pp. 87-94. DOI: 10.1016/S1567-4231(09)70155-8

[23] Brown P, Salenius S, Rothwell JC, Hari R. Cortical correlate of the piper rhythm in humans. Journal of Neurophysiology. 1998;**80**(6):2911-2917. DOI: 10.1152/jn.1998.80.6.2911

[24] Mima T, Simpkins N, Oluwatimilehin T, Hallett M. Force level modulates human cortical oscillatory activities. Neuroscience Letters. 1999;**275**(2):77-80. DOI: 10.1016/s0304-3940(99)00734-x

[25] Ohara S, Nagamine T, Ikeda A, Kunieda T, Matsumoto R, Taki W, et al. Electrocorticogram-electromyogram coherence during isometric contraction of hand muscle in human. Clinical Neurophysiology. 2000;**111**(11):2014-2024. DOI: 10.1016/s1388-2457(00)00448-x

[26] Dum RP, Strick PL. Spinal cord terminations of the medial wall motor areas in macaque monkeys. The Journal of Neuroscience. 1996;**16**(20):6513-6525. DOI: 10.1523/JNEUROSCI.16-20-06513.1996

[27] He SQ, Dum RP, Strick PL. Topographic organization of corticospinal projections from the frontal lobe: Motor areas on the medial surface of the hemisphere. The Journal of Neuroscience. 1995;**15**(5 Pt 1):3284-3306. DOI: 10.1523/JNEUROSCI.15-05-03284.1995

[28] Hellwig B, Häussler S, Lauk M, Guschlbauer B, Köster B, Kristeva-Feige R, et al. Tremor-correlated cortical activity detected by electroencephalography. Clinical Neurophysiology. 2000;**111**(5):806-809. DOI: 10.1016/s1388-2457(00)00248-0

[29] Salenius S, Avikainen S, Kaakkola S, Hari R, Brown P. Defective cortical drive to muscle in Parkinson's disease and its improvement with levodopa. Brain 2002;125(Pt 3):491-500. DOI: 10.1093/brain/awf042.

[30] Brown P, Marsden J, Defebvre L, Cassim F, Mazzone P, Oliviero A, et al. Intermuscular coherence in Parkinson's disease: Relationship to bradykinesia. Neuroreport. 2001;**12**(11):2577-2581. DOI: 10.1097/00001756-200108080-00057

[31] Marsden J, Limousin-Dowsey P, Fraix V, Pollak P, Odin P, Brown P. Intermuscular coherence in Parkinson's disease: Effects of subthalamic nucleus stimulation. Neuroreport. 2001;**12**(6):1113-1117. DOI: 10.1097/00001756-200105080-00013

[32] Günther M, Bartsch RP, Miron-Shahar Y, Hassin-Baer S, Inzelberg R, Kurths J, et al. Coupling between leg muscle activation and EEG during Normal walking, intentional stops, and freezing of gait in Parkinson's disease. Frontiers in Physiology. 2019;**10**:870. DOI: 10.3389/fphys.2019.00870

[33] Roeder L, Boonstra TW, Kerr GK. Corticomuscular control of walking in older people and people with Parkinson's disease. Scientific Reports. 2020;**10**(1):2980. DOI: 10.1038/s41598-020-59810-w

[34] Mima T, Toma K, Koshy B, Hallett M. Coherence between cortical and muscular activities after subcortical stroke. Stroke. 2001;**32**(11):2597-2601. DOI: 10.1161/hs1101.098764

[35] Krauth R, Schwertner J, Vogt S, Lindquist S, Sailer M, Sickert A, et al. del R. Millán J, Hinrichs H, Heinze HJ, Sweeney-Reed CM. Cortico-muscular coherence is reduced acutely post-stroke and increases bilaterally during motor recovery: A pilot study. Frontiers in Neurology. 2019;**10**:126. DOI: 10.3389/fneur.2019.00126

[36] Bayram MB, Siemionow V, Yue GH. Weakening of Corticomuscular signal coupling during voluntary motor action in aging. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences. 2015;**70**(8):1037-1043. DOI: 10.1093/gerona/glv014

[37] Tanaka H. Brain mapping of electroencephalogram: Clinical application. Japanese Journal of Clinical Neurophysiology. 2008;**36**(6):658-666

[38] Lehmann D. EEG assessment of brain activity: Spatial aspects, segmentation and imaging. International Journal of Psychophysiology. 1984;**1**(3):267-276. DOI: 10.1016/0167-8760(84)90046-1

[39] Koenig T, Lehmann D, Merlo MC, Kochi K, Hell D, Koukkou M. A deviant EEG brain microstate in acute, neuroleptic-naive schizophrenics at rest. European Archives of Psychiatry and Clinical Neuroscience. 1999;**249**(4):205-211. DOI: 10.1007/s004060050088

[40] Khanna A, Pascual-Leone A, Michel CM, Farzan F. Microstates in resting-state EEG: Current status and future directions. Neuroscience and Biobehavioral Reviews. 2015 Feb;**49**:105-113. DOI: 10.1016/j.neubiorev.2014.12.010

[41] Michel CM, Koenig T. EEG microstates as a tool for studying the temporal dynamics of whole-brain neuronal networks: A review. Neuroimage. 2018;180(Pt B):577-593. DOI: 10.1016/j.neuroimage.2017.11.062.

[42] He B, Musha T. Equivalent dipole estimation of spontaneous EEG alpha activity: Two-moving dipole approach. Medical & Biological Engineering & Computing. 1992;**30**(3):324-332. DOI: 10.1007/BF02446971

[43] Bai X, He B. On the estimation of the number of dipole sources in EEG source localization. Clinical Neurophysiology. 2005;**116**(9):2037-2043. DOI: 10.1016/j.clinph.2005.06.001

[44] Musha T, Okamoto Y. Forward and inverse problems of EEG dipole localization. Critical Reviews in Biomedical Engineering. 1999;**27**(3-5):189-239

[45] Pascual-Marqui RD, Michel CM, Lehmann D. Low resolution electromagnetic tomography: A new method for localizing electrical activity in the brain. International Journal of Psychophysiology. 1994;**18**(1):49-65. DOI: 10.1016/0167-8760(84)90014-x

[46] Pascual-Marqui RD. Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. Methods and Findings in Experimental and Clinical Pharmacology. 2002;24 Suppl D:5-12.

[47] Pascual-Marqui RD, Lehmann D, Koukkou M, Kochi K, Anderer P, Saletu B, et al. Assessing interactions in the brain with exact low-resolution electromagnetic tomography. Philosophical Transactions of the Royal Society A. 2011;**369**(1952):3768-3784. DOI: 10.1098/rsta.2011.0081

[48] Nakano H, Kodama T, Ueda T, Mori I, Tani T, Murata S. Effect of hand and foot massage therapy on psychological factors and EEG activity in elderly people requiring long-term care: A randomized cross-over study. Brain Sciences. 2019;**9**(3):54. DOI: 10.3390/brainsci9030054

[49] Nakano H, Kodama T, Sakamoto M, Ueda T, Tani T, Mori I, et al. Effect of hand massage on occupational leg swelling and resting-state electroencephalographic activity: A randomized cross-over study. International Journal of Clinical Research & Trials. 2018;**3**:125. DOI: 10.15344/2456-8007/2018/125

[50] Nakano H, Osumi M, Ueta K, Kodama T, Morioka S. Changes in electroencephalographic activity during observation, preparation, and execution of a motor learning task. The International Journal of Neuroscience. 2013;**123**(12):866-875. DOI: 10.3109/00207454.2013.813509

[51] Nakano H, Kodama T, Murata S, Nakamoto T, Fujihara T, Ito Y. Effect of auditory neurofeedback training on upper extremity function and motor imagery ability in a stroke patient: A single case study. International Journal of Clinical Research & Trials. 2018;**3**:126. DOI: 10.15344/2456-8007/2018/126

[52] Noachtar S, Binnie C, Ebersole J, Mauguière F, Sakamoto A. Westmoreland B. a glossary of terms most commonly used by clinical electroencephalographers and proposal for the report form for the EEG findings. The international federation of clinical neurophysiology. Electroencephalography and Clinical Neurophysiology. Supplement. 1999;**52**:21-41

[53] Omejc N, Rojc B, Battaglini PP, Marusic U. Review of the therapeutic neurofeedback method using electroencephalography: EEG neurofeedback. Bosnian Journal of Basic Medical Sciences. 2019;**19**(3):213-220. DOI: 10.17305/bjbms.2018.3785.

[54] Belkacem AN, Jamil N, Palmer JA, Ouhbi S, Chen C. Brain computer interfaces for improving the quality of life of older adults and elderly patients. Frontiers in Neuroscience. 2020;**14**:692. DOI: 10.3389/fnins.2020.00692

[55] Jamwal R, Callaway L, Winkler D, Farnworth L, Tate R. Evaluating the use of smart home technology by people with brain impairment: Protocol for a single-case experimental design. JMIR Research Protocols. 2018;**7**(11):e10451. DOI: 10.2196/10451