Options for studying human motion: neurophysiological program sLORETA

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ABSTRACT

Evaluation of motions is the basis for the diagnosis of human locomotor system disorders. Analyses are usually focused on the performance components of this system, i.e. on the skeleton and muscles. However, where comprehensive diagnosis is to be obtained, the motor system must be evaluated as a whole, without omitting any of its parts. So, evaluation of the control function is very important to body motion evaluation. The method that is normally used to evaluate the activity of brain is electroencephalography, which is superior to other brain activity-evaluating methods in many respects. However, EEG has also a major drawback, namely, it cannot precisely locate the activated and deactivated brain regions. This drawback can be avoided by using the sLORETA neurophysiological program, a tool that can transform EEG data to 3D brain images and finding application across a wide range of clinical branches of medicine – neurology, neurophysiology, psychiatry, physiotherapy and also in sports.

KEYWORDS

motion evaluation; EEG; sLORETA; physiotherapy; rehabilitation; EMG; kinematic analysis

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INTRODUCTION

Motion is one of the basic manifestations of human life. Movements can be classed into internal movements and external movements. Internal movements occur in the internal body organs and are responsible for body supply logistics. External movements are the result of activity of the locomotor system, serving an individual's self-care and satisfaction of basic human needs and enabling one's contact with the outer environment and communication. Breathing motions are transitory between the two types of motion, contributing both to internal supply logistics and external postural functions. So, movements are vital to humans (Véle, 2006; Kračmar et al., 2016).

In the motor ontogenesis of humans, the development of external movements begins with the simplest holokinetic movements of the newborn baby. They are reflective, general movements of serpent nature, very little differentiated, serving to familiarise the baby with its movement possibilities. Such movements develop slowly into ereismatic movements, more differentiated and serving largely for support. Ideokinetic movements constitute the highest stage, serving to make complex differentiated movements. They are closely related to communication motor activity. Ideokinetic movements are controlled teleologically by the central nervous system responding to stimuli from both the internal and external environment with a view to attaining a specific intended goal. Ideokinetic movements occur through a pyramidal path, are mainly controlled by the cerebral cortex and cerebellum and are dependent on cooperation with the postural-and-locomotor system ensuring preconditions for such movements (Véle, 2006; Kolář, 2009).

The basic human movement patterns are genetically determined in the CNS and serve as a support or building blocks for erection and motion forwards. The motional behaviour of an individual, however, develops and individualises during their whole life and is affected by a number of factors, internal as well as external. So, the motional behaviour of an individual reflects various somatic, mental, social as well as health effects. And conversely, repeated motional behaviour is mirrored by the overall body posture and ultimately also results in structural body changes. Hence, investigation and analysis of human motions is a basis for diagnosis and therapy of locomotor system disorders (Kolář, 2009; Vojta, 2010).

MOTION EVALUATION OPTIONS

The motor system can be divided into components: (i) supportive component, (ii) strength component, (iii) control component and (iv) logistic component. The supportive component provides mechanical support to motion and comprises the skeleton, bones and joints. The strength component is provided by muscles, transforming chemical energy into mechanical energy, thus serving as an energy source for the motion. The control component is provided by the nervous system, controlling the motion, while the logistical component is responsible for setting and maintaining the conditions for the internal environment. The performance part of the locomotor system comprises the supportive and strength components, i.e. the skeleton and muscles. It is onto those 2 components of the locomotor system that stress is laid in locomotor system disorder diagnosis. Still, all the locomotor system components, including the logistic and control component, must be included in the analysis in order to obtain an accurate and comprehensive diagnosis of locomotor system disorders (Véle, 2006).

The motion analysis methods can be classed into instrumental methods and instrument-less methods. An instrument-less examination consists of routine clinical motion examination made within any examination of the locomotor system and providing information both on motion quantity and quality. Quantitative examination serves to evaluate both passive movements, informing us about the boundaries of the motor system, and active movements, informing us about the motor system performance. Passive movement examination includes goniometric measurement of the joint range and assessment of joint play. In fact, an adequate passive movement range in the joints is a precondition for normal movement function. In addition to the angular range of the movement, the nature of the resistance observed during the movement must also be assessed. Active movement measurements include the force each muscle is able to exert. The Janda muscle function test is most frequently used in practice, applying a six-point muscle strength scale. Muscle strength can also be evaluated with a dynamometer, the data obtained from this measurement, however, include only the total force exerted during the movement measured, not the force exerted by a single muscle (Janda, 2004; Véle, 2006).

As mentioned above, the quality of the movements must be measured as well because it is this parameter that ultimately governs the overall system performance. Movement quality includes muscle coordination, movement smoothness and movement tactics, metrics and strategy. Additional routinely used instrument-less methods of movement evaluation include aspect examination, movement stereotype examination, and other types of examination (Véle, 2006).

There exist a range of instrumental methods for movement evaluation, which have been enjoying development and modernisation lately owing to the development of physiotherapeutic approaches worldwide. Among frequently used methods are electromyography and kinematic analysis. Electromyography (EMG) is a routine electrophysiological diagnostic method enabling muscle activity to be objectively evaluated by measuring electrical activity. EMG is based on measurements of the action potential of activated motor units. This technique finds wide application in physiotherapy, allowing us to assess the extent of muscle activation, muscle behaviour in time, muscle coordination and muscle fatigue. Either surface EMG or needle EMG is used in practice. Surface EMG is a non-invasive technique measuring electrical signals from electrodes distributed over a reasonably large surface area of the muscle tissue, thereby enabling several muscles to be measured simultaneously. In this respect it differs from needle EMG, an invasive technique during which a needle electrode is introduced directly into a muscle to measure the activity of motor units in the immediate needle surroundings. Needle EMG is used in clinical practice mainly to measure muscle denervation or neuromuscular transmission disorders (Pánek, 2016; Roy et al., 2007; Lorencová et al., 2018; Krobot, 2011).

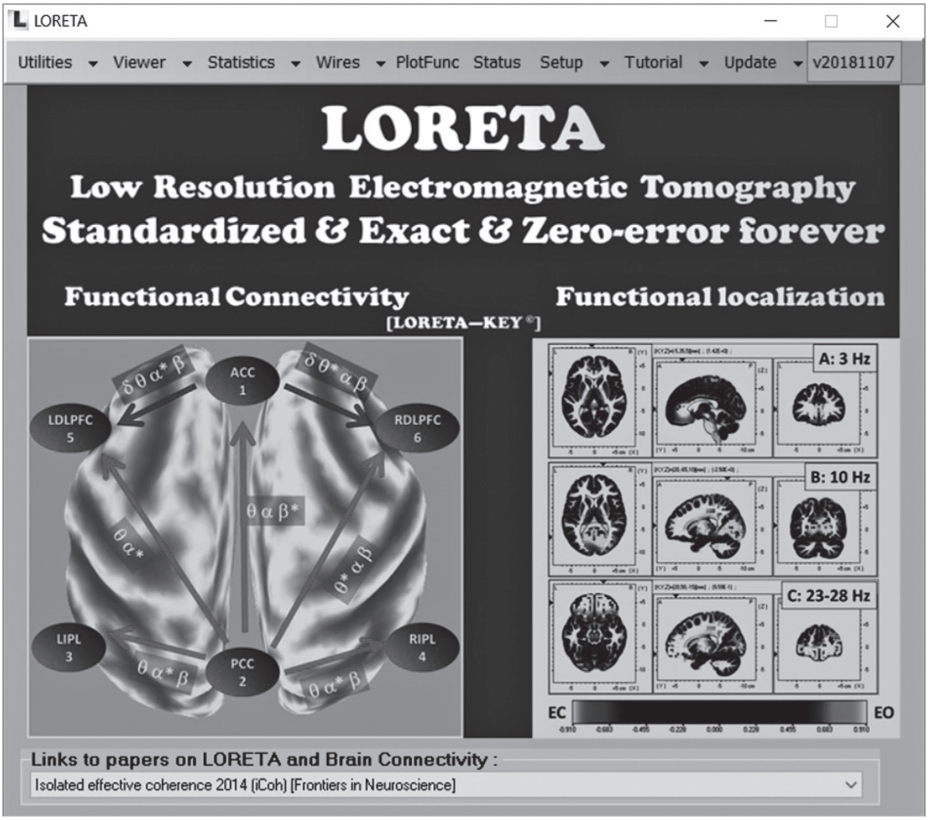
Kinematic analysis is a method describing the position of a point in a plane (2D) or in space (3D) in dependence on time. This method enables us to examine positions, speed, acceleration and angles between segments but not dynamic quantities such as momentum or energy. Angles between segments are measured with goniometers, largely electronic (potentiometers), and the output is a continuous time development curve. The electrical output of the potentiometers can be converted to angles by a simple procedure. Acceleration is measured with accelerometers that are directly attached to the segment and are primarily used to measure sharp movements. A system of adhesive markers attached to the person's skin improves position determination accuracy for a point on the body. Markers can be passive, reflecting infrared radiation emitted from the direction of the cameras, or active, emitting the radiation rather than reflecting it. Kinematic analysis can be used to evaluate both simple movements including mere 1–2 movement segments in a plane, and more complex multi-segmental motions such as walk (Kračmar, 2016; Kolář, 2009; Svoboda, 2010).

BRAIN ACTIVITY EVALUATION

As mentioned, the control component is a highly important part of the motional system. Hence, evaluation of motions can also be viewed through brain activity evaluation. Among the amply used and routinely available diagnostic methods is electroencephalography (EEG), which is based on electrical activity measurements of the brain within a band. EEG is a non-invasive method providing highly valuable information about the condition of the central nervous system. The electroencephalogram is a time record of the electrical activity of the brain, predominantly generated by the synchronous synaptic activity of the pyramidal cells of the cortex. The brain activity is measured via surface electrodes embedded in specific EEG caps. A standard EEG cap accommodates 19 electrodes arranged in the international 10–20 system devised by H. Jasper in 1957. This system is based on the percent distribution of the segments for placing the electrodes. The basic method of EEG signal evaluation uses visual analysis, evaluating the occurrences of the various frequencies (alpha, beta, theta, gamma) with respect to the current vigilance conditions. Unlike the morphological methods such as MRI and CT, EEG can be used repeatedly over a reasonably long time span without posing any adverse burden for the patient – this is a major advantage. However, EEG is unable to precisely locate the activated/deactivated brain regions, which is a basic shortcoming of this technique. As to other methods to measure the activity of the brain, functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and single photon emission computed tomography (SPECT) are usable: however, they are much more costly than EEG and exhibit a lower spatial resolving power (Pánek, 2016; Kamarádová, 2015; Faber, 2001).

sLORETA PROGRAM

sLORETA is an acronym for standardized Low-Resolution brain electromagnetic Tomography, a neurophysiological program enabling electrical activity of the brain obtained with EEG to be converted to 3D brain images with a minimal location error, thereby eliminating the basic drawback of surface EEG. The software, created by Roberto Pascual-Marqui of the University Hospital of Psychiatry in Zurich, Switzerland, was introduced in 2002. sLORETA is the standardised version of the initial LORETA code, introduced by the same author 8 years earlier. This is the first method to solve the inverse problem, i.e. the problem of inability of correctly calculating the distribution and amplitudes of the sources from the observed potential. The solution is based on the assumption that adjacent neuronal sources exhibit synchronous activity. Attempts to solve this problem were made earlier by Hämäläinen and Ilmoniemi, who, however, arrived a correct calculation in their solution, referred to as the minimal norm solution, for surface signals only. The current density distribution is calculated in voxels, which are defined in the Talairach Atlas and the corresponding probabilistic brain atlas. In appropriate conditions, sLORETA determines current densities in 6239 voxels at a spatial resolution of 5 mm. sLORETA's major assets include low costs and safety, its spatial resolution, however, is poorer than that of MRI or CT. Among sLORETA's drawbacks is also the fact that it is limited to the cortical brain regions and hence, does not enable imaging of other structures, such as basal ganglia or the cerebellum. The software can be freely downloaded from the website http://uzh.ch/keyinst/loreta and hence, is widely accessible (Pascual-Marqui, 2002; Pánek, 2016; Pascual-Marqui, 1994; Cannon, 2012; Pánek, 2014; Kamarádová, 2015).



Links to papers on LORETA and Brain Connectivity : Isolated effective coherence 2014 (iCoh) [Frontiers in Neuroscience]

Figure 1 sLORETA program – homepage

sLORETA consists of 3 main modules – Utilities, Viewer and Statistics (Fig. 1). Utilities module enables EEG data to be transformed into files with the extension “slor” and hence, displayed visually in the Talairach cortical atlas. The EEG data are first used as input data for calculation based on a parametric model for multichannel EEG to obtain the mutual spectrum for all bands (delta, theta, alpha-1, alpha-2, beta-1, beta-2, beta-3, gamma). The mutual spectrum is then transformed to the desired .slor files by using a transformation matrix obtained by transformation of the electrode coordinates from the native EEG. The “Statistics” module provides statistical data processing, the “Viewer” module enables imaging of statistically significant current density changes in the various Brodmann areas / various frequency bands. The statistically significant differences can be viewed in 2D (Fig. 2), i.e. in the frontal, horizontal and transverse brain cuts, as well as in 3D (Fig. 3) (Pascual-Marqui, 2002; Pánek, 2016).

sLORETA has been used in a number of experiments since 2002. One of them was the study by Villafaina et al. (2019) examining the effect of depressions on brain activity in women with fibromyalgia. The enrolled 28 women with fibromyalgia were divided into 3 branches: (i) 9 women with depressions who were on antidepressants; (ii) 7 women with depressive feelings on no antidepressants; and (iii) 12 women with no depressive feelings. Electrical activity of the brain was measured by EEG and the data were processed by sLORETA. Hypoactivation of the left hemisphere was detected in the women with untreated depressions. sLORETA was also used in the study by Dvořáčková et al. (2019) examining brain activity changes during walk affected by visual or auditory cueing in Parkinson’s disease patients. Electrical activity of the brain was recorded in 11 Parkinson’s disease patients in 3 situations – normal walk, walk with auditory cueing and walk with visual cueing. Two paired groups were compared by the statistical module. The one paired group was processed to obtain comparison between walk affected by visual cueing and normal comfortable walk, the other paired group was processed to obtain comparison between walk affected by auditory cueing and normal comfortable walk. Statistically significant ($p \leq 0.05$) current density increase was found in Brodmann areas 9, 10 and 32 in the beta-3 frequency band in the former group (visual cueing vs. normal walk).

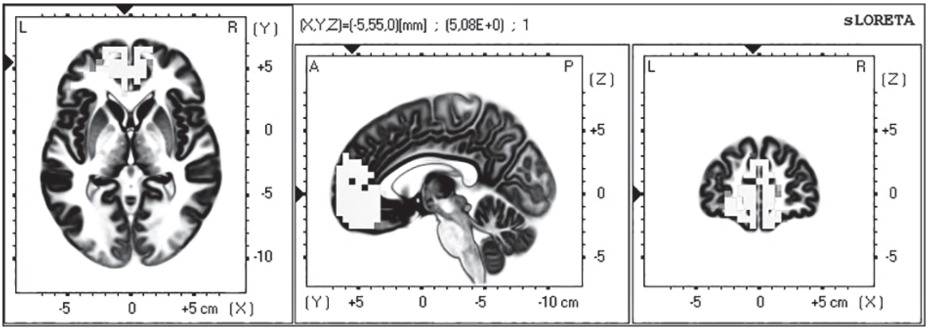


Figure 2 Statistically significant current density changes displayed in 2D by sLORETA software (illustrative picture)

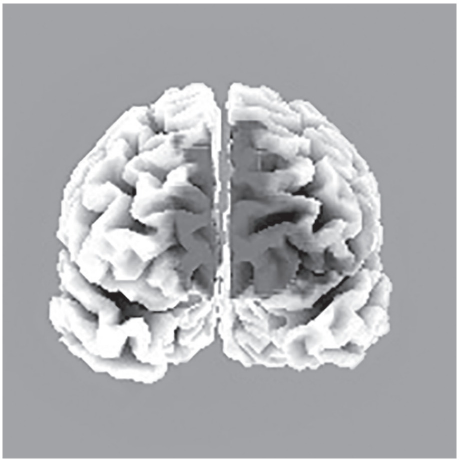


Figure 3 Statistically significant current density changes displayed in 3D by sLORETA software (illustrative picture)

DISCUSSION

As mentioned above, motion is a basic manifestation of humans and is indispensable for them. The motion of each individual is different and is affected by a number of internal and external factors. An individual's motion reflects their social and mental influences as well as health effects. Repeated motional behaviour affects the individual's posture and results in structural changes in the body. Analysis of motion is thus one of the basic tools in locomotor disorder diagnosis. Specific emphasis is frequently put on the condition of the myoskeletal system. However, comprehensive diagnosis requires all motional system components to be analysed, including the nervous system and the logistic function.

Electroencephalography is amply used to analyse the activity of the brain. This technique uses a system of surface electrodes embedded in specific EEG caps to measure electrical activity of the brain. The major assets of EEG include safety and availability, the main drawback is the inability to accurately locate the activated/deactivated brain regions. This drawback is eliminated in the neurophysiological program sLORETA, transforming EEG data into 3D images of the brain.

CONCLUSION

The neurophysiological program sLORETA, transforming EEG data into 3D images of the brain, allow changes in the source activity to be evaluated in various conditions, both at rest and in motion. It is a low-cost tool which is readily available and safe. The field of sLORETA applications is extremely wide, encompassing a broad range of clinical branches – neurology, neurophysiology, psychiatry, physiotherapy, as well as various sports.

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