SCIENTIFIC ARTICLES

Towards a Coherent View of Brain Connectivity

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ABSTRACT.

Background

. The electroencephalogram provides a myriad of opportunities to

detect and assess brain function and brain connectivity.

Method

. This article describes the relationship between local and non-local brain activation and

synchrony, and discusses the use of appropriate connectivity measures to study and train functional

brain connectivity. Specific connectivity measures are described including coherence, phase, syn-

chrony, correlation, and comodulation. The measures are contrasted and compared in terms of their

ability to detect particular aspects of connectivity and their usefulness for neurofeedback training.

Results

. Connectivity metrics for example EEG data are calculated and shown graphically, to

illustrate relevant principles.

Conclusion

. It is possible to assess brain connectivity and integrated function for both assess-

ment and training, through the use of appropriate metrics and display methods.

KEYWORDS.

Brain connectivity, coherence, EEG, phase QEEG, quantitative electro-

encephalography, spectral correlation, synchrony

The electroencephalogram (EEG) is a

uniquely powerful and revealing indicator of

brain electrical function and one of the best

methods available for assessing and monitor-

ing neural activity in real time. Measurable

scalp EEG is produced by the summation,

through volume conduction, of postsynaptic

potentials of the pyramidal cells within the

cerebral cortex cortex (Burgess & Collura,

1992). When cells polar

ize (or depolarize) in

unison, the resulting potentials are added in

the conducting media, leading to external

fields that can be measured. This phenomenon

is so pronounced that a mere 1% of cortical

cells in a 1 cm

2

area of cortex, when acting in

synchrony, are sufficient to account for more

than 96% of the EEG signal (Shaw, 2003). In

other words, the existence of an EEG potential

implies some degree of local synchrony within

a population of cells lying beneath the affected

sensor. By an extension of this logic, if a mere

1% of cortical cells are coordinated in some

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99

way with 1% of the cells in some other loca-

tion, then 96% of the c

onnectivity might be

accounted for in the EEG. The question is,

how do we define this connectivity and how

do we measure it?

The brain comprises cortical centers, con-

nections between cortical centers, and connec-

tions between cortical centers and subcortical

structures (most notably the thalamus).

Cortical centers are neighboring cells that act

in a synchronize manner measured as an

EEG wave from a single electrode sensor.

The cortical centers of

short-range connections

between close electrode locations and long-

range connections between distant electrode

locations have synchrony or coordinated elec-

trical activity. This relationship of coordinated

electrical activity between EEG signals can be

measured with mathemat

ical calculations or

connectivity measures. The connectivity mea-

sures reveal important differences between

short-range and long-r

ange cortical centers

and are fundamentally d

ifferent from the cor-

tical center activity from a single electrode.

Connectivity measures extend our existing

knowledge to incorporate increasing distances,

thus reflecting whole brain function as exten-

sions and generalizations of the concepts

implicit in localized brain function.

Connectivity can measure the similarity

between channels in one or both of two

important contexts, postprocessed and real

time. In the postprocessed context, the quan-

titative EEG (QEEG) is examined after the

entire QEEG is acquired. Fast-Fourier

Transformation (FFT) and other trans-

form-based methods are sufficient and can

provide a level of precision and understand-

ability that is of value in normative applica-

tions. However, FFT-based methods have

slower time response, owing to the need to

acquire an epoch of data (on the order of 1

sec) before the estimate can be made. Taper-

ing windows further confound this delay by

emphasizing wave components in the center

of the window, thus imposing a firm

delay of half the epoch size, thus incurring

a delay of 500 msec, which maybe detrimen-

tal to EEG biofeedback applications. In

contrast, the digital filters and related

methods including ‘‘complex demodulation’’

and ‘‘joint time-frequency analysis’’ provide

real-time processing while retaining generality

and accuracy (Collura, 1990). The main ‘‘cost’’

of such approaches is the need to predefine the

component band of interest (e.g., 8–12 Hz).

Connectivity is concept in which mathe-

matical calculations can be applied. Like

the concept of intelligence or temperature,

we make assumptions about the measure

with certain understandable limitations.

For example, we never measure temperature

directly. By making assumptions and using

definitions, we measure some other property

such as the length of a column of mercury or

alcohol, the deflection of a metal strip. By

recording such physical entities and inter-

preting them in an agreed-upon way, we

arrive at a measurement that we all agree

to call ‘‘temperature.’’ The situation is not

so different in the case of brain connectivity.

We actually record one or more electrical

potentials that we subject to computations

or an agreed-upon representation. Such

computations produce an estimate of a con-

cept, which we interpret generally as the

similarity between activity in the brain, and

use in the pursuit of brain connectivity

assessment or training. As seen in Figure 1,

any connectivity measure falls within the

realm of system identification and parameter

estimation. By making assumptions, we

derive an ideal property, which we may seek

to measure. Through appropriate definitions,

measurements, and computations, we arrive

at an estimate of a quantifiable property,

which always puts us into an abstract realm.

There are many ways or methods to

measure EEG connectivity. This is alike

to assessing the similarity between any two

FIGURE 1. The relationship between system

properties and measured properties.

100

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