Quantitative EEG and neurofeedback therapy in the assessment and treatment of psychological disorders

C. Richard Clark BA (Hons) PhD, MACS, BCN, FASSA
Joint Clinical Director, Brain Health Clinics, Adelaide, Australia
Professor, School of Psychology, Flinders University, Adelaide, Australia

richard.clark@brainhealth.com.au
www.brainhealth.com.au

Outline

• Brain dynamics, conscious versus preconscious information processing, and relationship to neurofeedback therapy
• EEG and brain function
• EEG markers of attention and learning difficulties - examples
• Quantitative EEG (QEEG) in the assessment of psychological disorders and an ADHD case example
• Procedures and mechanisms of neurofeedback therapy
• Professional Development and National Certification in the theory and practice of neurofeedback
Brain dynamics, preconscious information processing, psychological function and their relationship to neurofeedback therapy

Treatment modalities affecting brain and psychological function

- **Medication**: modulation of global neurotransmitter systems activity
- **Psychological and behavioural therapies**: reshaping conscious content and behaviour; language, imagery, feelings
- **QEEG/Neurotherapy**: assessing and normalising the preconscious, systemic brain electrical activity required to establish and maintain conscious working memory function

*Synergies can be obtained with multi-modal approaches*
Preconscious processing extends over ~400ms and involves multiple interacting systems

- **Sensory sampling**: A repeated sampling (~10Hz) and processing to cognition of sensory events (thalamocortical system)
- **Valency and feelings**: Parallel evaluation of the valency of such events; generation of related feelings (limbic system)
- **Activation**: direction of attention to distributed cortical representations/associations of valent event (limbic system; brain stem)
- **Working memory binding**: Binding of selected representations as adaptive working memory networks – precursor to conscious awareness and mental operations

Systemic dysregulation impacts on quality and content of conscious function but not directly accessible by conscious function

---

Activity of these systems characterised by distinctive spatial and temporal rhythms seen in the EEG

- **THETA RHYTHMS** (3-7 Hz)
- **GAMMA RHYTHMS** (25-200 Hz)*
- **BETA (14-24 Hz)**
- **ALPHA (8-13Hz)**

Synchronised septo-hippocampal bursts

Limbic inputs influence selection of thalamic material for cortex

Release of reticular inhibition allows material thru to cortex; alpha desynchronises

Thalamocortical bursts seen as alpha rhythms

Lateral inhibition by NRT from causes synchronised thalamocortical bursts

Increased brainstem monoamines decrease NRT inhibition
Thalamocortical system
Cognitive representation of world – cortex as global workspace -

DELTA (1-4 HZ),
ALPHA (8-13 HZ)
BETA (14-25 HZ)

INTRA-CORTICAL
GAMMA (25-200 HZ)

Presenta�on of the Psychology and Neurofeedback Special Interest Group of the Australian Psychological Society by Professor Richard Clark
Modulation of brain activity

**Energetics; regional/systemic arousal and activation**

![Diagram of brain activity](image)

**Radial**
- Thalamocortical
  - Fast and specific
  - Limited domain
  - Information transfer
- Corticolumbic
  - Sensory, semantic, conceptual

**Tangential**
- Monoaminergic
  - Slow, non-specific
  - Large domain
  - Modulatory

**FUNCTIONAL CONVERGENCE OF SYSTEMS DETERMINE LOCAL CONTRIBUTION TO REPRESENTATIONAL PATTERNS**

- Brainstem and basal forebrain modulatory afferents
  - Dopamine, Noradrenaline, Serotonin, Histamine, Acetylcholine

**“Moment to moment seeking of regional mimina”**

Local activation determined by convergent interaction of these systems

Underlies convergent processes of (a) regional priming & activation (SCP: lateral inhibition etc.) (b) cognitive elaboration (Alphals, 2) (c) affective biasing (Theta) and (d) phaselocked, working memory activation (Gamma) of salient information leading to awareness.

Presentation of the Psychology and Neuroscience Special Interest Group of the Australian Psychological Society by Professor Richard Clark
Brain electrical fields & preconscious processes

- Breakdown in these preconscious processes affects conscious awareness
- Such dysregulation not directly accessible to conscious awareness
- Examples of psychological conditions involving such dysregulation: Developmental disorders e.g. ADHD, ASD, language disorders, tics; Anxiety disorders (GAD, Panic disorder); Trauma and stress disorders; OCD; Depressive disorders
- Neurotherapy works on dysfunction through modulation of related brain electrical fields

**Example**

Evolution of brain electrical field activity associated with processing a simple stimulus event

Resulting in standing fields reflecting distributed working memory

Here seen bilaterally over temporal, parietal and frontal regions; and centrally over cingulate regions 400ms post-event

EEG and brain function

Presentation of the Psychology and Neurofeedback Special Interest Group of the Australian Psychological Society by Professor Richard Clark
**EEG reflects brain electrical field activity**

- EEG reflects the electrical component of the open fields of cortical pyramidal cells; organised in notional columns
- Pyramidal neurons most numerous in cortex (>100,000 million)
- Electrical fields capture degree of synchronisation of underlying activity (~1cm radius, ~50 million pyramidal cells) & reveals the oscillatory “rhythms of the brain” or EEG

**Brain electrical field activity and the EEG**

- EEG measured using sensing electrodes (1 to 256) placed on scalp; usually 19 channels.
- Scalp impedance preparation necessary
  - Electrode gels generally used to facilitate signal capture
- Signals amplified, digitised (~200-1000 samples/sec) and preprocessed to allow visualisation & analysis
EEG display demonstrating temporal and site variability in oscillatory frequency & power, reflecting composite neurological activity

<table>
<thead>
<tr>
<th>Bandwidth name</th>
<th>Bandwidth range</th>
<th>Causal descriptions</th>
<th>Waveform (3 second epoch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure EEG</td>
<td>0 – 45 Hz</td>
<td>Awake</td>
<td></td>
</tr>
<tr>
<td>Slow and infraslow</td>
<td>&lt; 1 Hz</td>
<td>Vascular, brain stem SCPs</td>
<td></td>
</tr>
<tr>
<td>Delta</td>
<td>0.5 – 4 Hz</td>
<td>Thal-Ctx disconnection</td>
<td></td>
</tr>
<tr>
<td>Theta</td>
<td>4 – 8 Hz</td>
<td>Limbic-Ctx affective</td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>8 – 12 Hz</td>
<td>Thal-Ctx Resting alert</td>
<td></td>
</tr>
<tr>
<td>SMII</td>
<td>12 – 15 Hz</td>
<td>Thal-Ctx Motor alert</td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>13 – 30 Hz</td>
<td>Ctx cognitive</td>
<td></td>
</tr>
<tr>
<td>Gamma</td>
<td>30 – 45 + Hz</td>
<td>Ctx mental processes</td>
<td></td>
</tr>
</tbody>
</table>

Amplitude and frequency characteristics of the EEG

Adapted from Sherlin, 2009
Examples of EEG indicators of attention and learning difficulties

Excessive posterior alpha activity reflecting abnormal thalamocortical function underactivation affecting sensory integration, sensory attention and related learning.
Abnormal midline limbic theta resulting in attentional dysregulation – theta-beta subtype

Excess theta (limbic cortical network) and reductions in beta (intracortical dysregulation) in >50% of ADHD: evaluation issues

Intracortical overactivation resulting in attentional dysregulation – beta spindling subtype

Widespread spindling

High beta spindling related to pre-epileptic auras, epilepsy, cortical irritation and some forms of encephalopathy.
Quantitative EEG in the assessment of psychological disorders

Quantitative EEG (qEEG) quantifies power, frequency and phase of electrical field oscillations
Quantifying & parameterising spectral frequencies in the EEG

Absolute Power by resonance band (Frequency: 1-30Hz)

Measures of test-retest and split half reliability

Spectral plot

Resonant frequency

Normality across resonance bands (z-score)

Quantifying & parameterising spectral frequencies in the EEG

Power

Z-score

Measure of normality across resonant frequency power (z-score)

2sd
ADHD case example
QEEG assessment
Male teenager Case CRC112

EEG traces, spectral values and spectral statistics relative to age matched normative database

Theta bursts over midfrontal regions

Theta excess (5Hz)

Statistical outliers (>4sd) at 5Hz - Limbic

2sd threshold

Z-score

SPECTRAL POWER

SPECTRAL STATS

Frequency

Power

Z-score

SPECTRAL POWER

SPECTRAL STATS

Z-score

Frequency

Power
Localised bilaterally to Brodmann areas 24, 32 and 33 of anterior and middle cingulate gyrI – associated with affective and attentional regulation, and impacting on frontal and parietotemporal recruitment, respectively.

Image source: Hoffstaedter et al 2014

Brain mapping of statistical abnormality using 3D source localisation (LORETA)

PRE-POST ANALYSIS ADHD CASE

<table>
<thead>
<tr>
<th></th>
<th>Pre-treatment</th>
<th>Post-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Speed</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Impulsivity</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>Attention &amp; Concentration</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Information Processing Efficiency</td>
<td>7.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Memory</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Executive Function</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table: STEN SD PRE-PRE POST ANALYSIS
Neurofeedback therapy

- Operant training mediated by feedback of targeted brain activity over multiple sessions
- Complex form of behavioural therapy, with positive and negative feedback determined by related valency of targeted brain activity

Neurofeedback generally involves sensory (auditory, visual, tactile) feedback based on real-time analysis of targeted brain function
Neurofeedback reinforcement process

Realtime derivation from 19 channel EEG of composite training metric, based on activity of system target(s) from QEEG analysis. Training proceeds either in terms of metric or z-score transform based on reference norms

Neural mechanisms underlying reinforcement learning

(see Kandel et al., 2012, Principles of Neural Science)
Neurofeedback therapy

- Single or multiple sites on scalp
- Training of scalp or source rhythms
- Passive (sub-conscious brain activity) or active (slow cortical potentials related to active attention)

Neurofeedback therapy

- Many hardware systems e.g. Mitsar, EEGer, Neuroscan, Lexicor, Q20, PET ...
- Many software systems e.g. EEGer, Neuroguide, Bioexplorer, Thought Technology ...

Neurofeedback generally involves sensory (auditory, visual, tactile) feedback based on real-time analysis of targeted brain function.
Extract of a sample neurofeedback session – here using z-score training of source activity

End of presentation