QEEG markers in stroke, ageing and cognitive decline

*When is “theta” actually alpha?*

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We acknowledge & respect the Traditional owners, the Jagera Nation People of Brisbane (North and South of the Meanjin) and Goori People belonging to the South East Queensland country. We acknowledge the history of this country, Ancestors, Elders and Community Leaders of this country Past, Present and Future.
Overview

• What does EEG measure?
• QEEG: Frequency-specific power measures
• QEEG in acute stroke
• QEEG in healthy aging & cognitive impairment
• QEEG & prediction of post-stroke cognitive impairment
• Implications for EEG neurofeedback training
EEG - electroencephalography
What brain activity does EEG measure?

Figures from M van Putten ‘Essentials of Neurophysiology’ (2009)
What brain activity does EEG measure?

- Ionic potentials summed over large populations of synchronous, aligned neurons

*Primarily:*

- Post-synaptic potentials of cortical pyramidal neurons

*A simple, take-home message:*

- EEG directly measures cortical function
Alpha activity (~8-13Hz)
Alpha vs Delta

Healthy Control (Alpha) - Post-stroke (Delta)

Voltage (microvolts)

Time (ms)
Quantitative EEG – qEEG/QEEG

• Computational analyses of “raw” digital EEG signals → qEEG measures

• Objective measures - analogous to BP, HR, temp, etc.
  – Can be readily compared or monitored over time
  – Albeit may over-simplify complex EEG signals at

• “Power” is a commonly-used qEEG measure
Fourier / power spectrum analyses of EEG

- IT'S TOO SIMPLISTIC!
- IT'S TOO COMPLICATED!
**EEG power spectrum**

- **Healthy Control (Alpha)**
- **Post-stroke (Delta)**
Interchangeable terms

- Power
- Amplitude
- Voltage
- Intensity
- Energy
EEG “scalp topography”
Relative power

- % of power in a given frequency band (e.g., alpha)
- As % of total power (0-30Hz: delta + theta + alpha + beta)

Relative delta power = 30 / (30+20+40+10) = 30/100 = 30%
Ischaemic stroke
Cerebral artery territories

MCA = Middle Cerebral Artery
ACA = Anterior Cerebral Artery
PCA = Posterior Cerebral Artery
EEG: Delta (1-3Hz)

14h, 20min post-stroke
The Impact of Cortical Lesions on Thalamo-Cortical Network Dynamics after Acute Ischaemic Stroke: A Combined Experimental and Theoretical Study

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Fig 2. Topographical distribution of average differences between patients minus controls. Patients suffered a lesion in either of the two hemispheres, and in order to prevent averaging out hemispheric differences, all non-midline electrodes were swapped laterally for patients with a left-hemispheric lesion. Thus, the right hemisphere in the diagram should be considered ipsi-lesional while the left hemisphere is contra-lesional. (A) Average spectral power differences between patients minus controls, organised per electrode and marked with an I for ipsi-lesional and C for contra-lesional, with clear boundaries separating the different bands around 8 and 12 Hz. (B-E) Topographical distribution of binned power differences for the four separate frequency bands: δ, θ, α and β respectively. Differences in the δ and β-band are qualitatively similar, where patients display an increase over the lateral ipsi-lesional electrodes (P6, C4, T4 and T6) together with the contra-lesional electrode T3 and occipital electrodes O1 and O2. There are no differences in the α-band, and the decrease of β-band activity is spread across all scalp electrodes.

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Delta & thalamo-cortical networks

- disconnection between cortical & thalamic regions
- thalamo-cortical dysrhythmia: disruption of “top-down” cortical modulation of thalamic neurons → low-frequency bursting in thalamus, which is propagated to cortical regions → delta activity

van Wijngaarden et al. PLOS Computational Biology. 2016:10;12(8):e1005048
Healthy Control

HEALTHY CONTROL

STROKE PATIENT

14h, 20min post-stroke
Delta/alpha ratio

Delta/alpha ratio = 30/40 = 0.75
Post-stroke delta/alpha ratio (DAR)

• We have found DAR to:
  – Correlate with post-stroke functional outcomes (2007)
  – Be informative about success/failure of acute treatments (2013)
  – Correlate with post-stroke cognitive outcomes (frontal DAR; 2014)
  – Be 100% accurate for determining presence/absence of ischaemic stroke (confirmed by CT imaging; 2016)
  – Normalise within minutes of successful “clot retrieval” treatment (2016)
Reperfusion treatments for acute ischaemic stroke

• If CT brain scan indicates “large vessel occlusion”, &
• Within 6 hours of symptom onset ➔
• Inject clot-dissolving drug (intravenously) then
• Intra-arterial clot retrieval (“thrombectomy”)

![Reperfusion treatment diagram]
Delta/alpha ratio (DAR) normalises within minutes of cerebral blood flow being restored.
Post-stroke qEEG publications

Invited review

EEG in ischaemic stroke: Quantitative EEG can uniquely inform (sub-)acute prognoses and clinical management

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Prognosis
Thrombolytic

HIGHLIGHTS

- Quantitative electroencephalographic (QEEG) abnormality indices sensitive to power of slow relative to faster activity, or to interhemispheric asymmetry, can uniquely inform clinical prognoses and management during (sub-)acute ischaemic stroke.
- Continuous bedside monitoring of these QEEG indices during thrombolytic therapy may instantaneously inform clinicians about the efficacy of same and thereby inform decisions about “bridging” protocols involving intra-arterial interventions.
- Current clinical EEG systems compute and display various QEEG indices, facilitating non-expert EEG interpretation. Hence wider utilization of such technology appears warranted and would address a key stroke management objective proposed by numerous stroke opinion leaders.
Recap: Key points

• EEG directly measures activity of cortical neurons
• EEG power spectrum plots amplitudes associated with various frequencies

• Stroke → increased delta & diminished alpha power
• Delta/alpha power ratio shows promise for various clinical applications (monitoring, prognoses)
Take a ride on a CityCat

to New Farm / Bulimba / Teneriffe (via Riverside / City)

or

to UQ St Lucia (via Milton & Regatta)

(translink.com.au)
qEEG studies of:

Aging
Mild cognitive impairment (MCI)
Dementia
Post-stroke cognitive impairment
Theta activity (~4-7Hz) & cognitive decline

• Several studies indicate that high, *resting-state* theta power in adults is associated with cognitive impairment, or subsequent cognitive decline
  – increased theta power in early dementia (e.g., Coben et al 1985)
  – theta power correlated with cognitive impairments; across controls, MCI & dementia (e.g., Prichep et al., 1994; Jelic et al., 1996)
  – that higher baseline theta power is generally indicative of subsequent cognitive decline (e.g., progression to dementia; Jelic et al., 2000; Moretti et al., 2009; Prichep et al., 2006)

• *However* ....
(Frontal) theta & cognition

- Theta – especially at frontal midline – is an EEG index of healthy cognitive function:
  - Memory; working & episodic
  - Spatial navigation
  - Arithmetic
  - Performance, practice, or meditation
  - “Non-specific, focused or sustained attention or concentration, or resistance to intrusion” are common requirements

- Generated by networks including medial temporal, anterior cingulate & other cortical regions

THETA BURSTS: AN EEG PATTERN IN NORMAL SUBJECTS PRACTISING THE TRANSCENDENTIAL MEDITATION TECHNIQUE

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(Accepted for publication: June 25, 1976)
So is theta activity “good” or “bad” in relation to cognitive function ?!?
Theta power is reduced in healthy cognitive aging

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Theta oscillations are affected by amnestic mild cognitive impairment and cognitive load

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Frontal midline theta: reduced in cognitive aging & MCI

- Frontal midline theta power:
  - Young controls > Older controls > Mild cog impairment (MCI)
  - Differences greatest in EEG during recognition memory task

- MCI categorised by consensus between two neuro-psychologists & neurologist (neuropsych assessment, medical history, clinical examination & MRI)
ABOUT IAN

Ian Robertson is a clinical psychologist and neuroscientist with a unique ability to apply his research to the pressures of everyday life. His previous books, *Mind Sculpture*, *The Mind's Eye* and *The Winner Effect*, have been translated into many languages and he is widely recognised as one of the world's leading researchers in neuropsychology.
BRIEF REPORT

Resting EEG theta power correlates with cognitive performance in healthy older adults

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Abstract

We address the degree to which resting EEG bandpower is associated with cognitive performance in 73 healthy older adults (aged 56–70). Relative theta (4–6.5 Hz) power was significantly correlated with immediate and delayed verbal recall, attention, and executive function measures. Relative delta and alpha power and peak alpha frequency did not correlate with any cognitive measures. These data indicate that high resting theta power in healthy older adults is associated with better cognitive function and may be a marker of healthy neurocognitive aging. Comparison of these with previous findings suggests that two forms of theta-frequency oscillations may exist; one indicative of healthy neurocognitive function and the other, EEG/alpha slowing linked to (future) substantial cognitive decline. Future EEG investigations of cognitive aging or decline should analyze both relative theta power and degree of EEG/alpha slowing so as not to confound these.
Frontal midline theta & cognition in healthy older adults

• N=73 cognitively healthy older adults (25 male); mean age 60.8 (range 56 to 70)

• Frontal midline theta power correlated significantly with cognitive performance:
  – Rey Auditory Verbal Learning Test (RAVLT) delayed recall
  – Raven’s Standard Progressive Matrices
  – Category Fluency (Animal Naming Test)
  – Sustained Attention to Respond Task (SART; Robertson et al., 1997)
Figure 1. Scatterplots illustrating significant Spearman’s correlations between EEG relative theta power at electrode Fz, and two cognitive measures as labeled. RAVLT: Rey Auditory Verbal Learning Test. Half of Raven's Standard Progressive Matrices were administered.
**Slowing of the alpha rhythm**

- Alpha slowing occurs:
  - in aging
  - with reduced brain metabolism & brain volume,
  - in MCI and dementia
    (e.g. Coben et al, 1985; Buchan et al, 1997; Jelic et al, 2000)

- Peak alpha frequency can shift below 8Hz
  - Some healthy older adults: 7.5 Hz (Finnigan & Robertson, 2011)

- We need to be careful & not confuse theta with slowed alpha activity
Frontal midline theta & cognition in healthy older adults

- Only frontal (not posterior) theta power correlated significantly with cognitive performance.
- Alpha power & peak alpha frequency (Pz) did not correlate.
- These results indicate the correlations involve frontal midline theta, not slowed alpha.
Poststroke QEEG informs early prognostication of cognitive impairment

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Abstract
Cognitive impairment is a common consequence of stroke, but remains difficult to predict. We investigate the ability of early QEEG assessment to inform such prediction, using binary logistic regression. Thirty-five patients (12 female, ages 18–87) suffering middle cerebral artery, ischemic stroke were studied. Resting-state EEG was recorded 48–239 h after symptom onset. Relative power for delta, theta, alpha, and beta bands, delta:alpha ratio, and peak alpha frequency were analyzed. Montreal Cognitive Assessment (MoCA) was administered, where possible, on day of EEG and at median 99 days (range 69–138) poststroke. Eight patients could not complete the baseline MoCA and four the follow-up MoCA, for varying reasons (most commonly, stroke symptoms). Fifteen patients (48%) had cognitive impairment (MoCA score ≤25) at follow-up. One QEEG index was able to correctly predict presence/absence of cognitive impairment in 24/31 patients (77.4%), whereas predischarge MoCA did so in 23 patients. This index, relative theta frequency (4–7.5 Hz) power, was computed from only three posterior electrodes over the stroke-affected hemisphere. Its predictive accuracy (three electrodes) was higher than that of any “global” QEEG measure (averaged over 19 electrodes). These results may signify association between poststroke alpha slowing and cognitive impairment, which may be mediated by attentional (dys)function, which warrants further investigation. Pending further studies, QEEG measure(s)—from a few electrodes—could inform early prognostication of poststroke cognitive outcomes (and clinical decisions), particularly when cognitive function cannot be adequately assessed (due to symptoms, language, or other issues) or when assessment is equivocal.
Post-stroke cognitive impairment

• Cognitive impairment occurs in ~50% of stroke patients
  – 53% (52/99) at 3 months (Srikanth et al, 2003)
  – 46% (50/108) at 6 months (Kelly-Hayes et al, 2003)
  – 58% (189/327) at 3–6 months (Dong et al, 2014)
  – 48% (15/31) at 3 months (Schleiger et al, 2017)

• Difficult to assess or prognosticate in many cases
  – Important for planning; e.g. required level of care; return to work

• Is early qEEG informative?
qEEG & post-stroke cognitive impairment

- Resting EEG @ 2-5 days (median 3.5) post-stroke
- Montreal Cognitive Assessment (MoCA) on same day
- Follow-up cognitive assessments @ 69-138 days (median 99)
- Logistic regression modelling & ROC analyses to analyse predictive accuracies of early qEEG & MoCA
Slowed alpha predicts post-stroke cognitive function

- qEEG correctly predicted presence/absence of cognitive impairment in 24/31 patients (77.4%), whereas MoCA did so in 23 patients
- qEEG predictor: slowed alpha power @ occipital electrode on stroke-affected hemisphere
  - This one electrode was more informative than all 19
Alpha slowing

- Alpha slowing, to <8 Hz, has been reported in:
  - Stroke patients (Yuasa et al, 2001)
  - Vascular dementia patients (Moretti et al, 2004; Muresanu et al, 2008)
  - Other neurological insults, e.g. traumatic brain injury (Angelakis et al, 2004; Nuwer et al, 2005; Hebb et al, 2007; Vespa et al, 2002)
- We found some stroke patients had peak alpha frequency as low as 6 Hz (Schleiger et al, 2017)
- Slowed alpha power reliably predicted cognitive outcomes, and peak alpha frequency is also informative (Schleiger et al, 2017)
Fig 1. EEG power spectra. Wavelet convolution power spectra of the resting-state EEG data averaged over time and electrodes. (A) Mean spectra for patients (red) and controls (green), with the shaded area representing the 95%-confidence intervals. (B) Mean spectral energy (MSE) values (±s.e.m.) per frequency band, with significant differences in the δ (1–4 Hz), θ (4–8 Hz), and β (12–30 Hz) band. (C) Locations of the individual dominant α-peaks, showing a significant slowing into a lower frequency for patients (7.9±0.3 Hz) as compared to controls (9.7±0.3 Hz). Statistically significant differences marked as **p < .01, *p < .05, Wilcoxon rank-sum test.

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Two distinct forms of “4-8 Hz” activity

It is important not to confuse these:

• Frontal midline theta
  – Resting & task-state EEG; frontal focus
  – Indicative of healthy neurocognitive function

• Slowed alpha
  – Resting-state EEG; posterior focus
  – In some healthy older adults, those with cognitive impairments or other conditions, e.g. stroke, dementia, TBI

• In these cases, adjusted frequency ranges seem appropriate for theta (e.g. 4-6 Hz) and alpha (e.g. 6-13 Hz)
When classifying EEG activity ...

- **Frequency** is only one part of the story
- It is also important to consider:
  - The *state/s* during which EEG is recorded
    - Resting / task
    - Eyes open / eyes closed
    - Awake / drowsy / asleep
  - Scalp **topography**
  - Other factors
    - e.g. medications, (sub-clinical) conditions e.g. vascular issues, etc.
Implications for neurofeedback with stroke patients

- Cognitive impairment occurs in ~50% of stroke patients
- A study of >200 stroke patients found attention to be the most commonly impaired cognitive domain (Hurford et al, 2013)
- Post-stroke sustained attention seems to be linked to degree of functional recovery (Robertson et al, 1997)
- If neurofeedback can increase alpha frequency, this may aid recovery of cognitive (& perhaps other?) functions
- Is inhibition of delta activity feasible? If yes, this should also be beneficial
Neonatal studies
Thanks 😊

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– National Health & Medical Research Council
EEG: voltage oscillations over time
Alpha activity

• EEG oscillations at ~8-13 Hz
• Most obvious @ posterior electrodes; resting, eyes closed
• Diminished ("blocked") by:
  – Opening eyes
  – Intensive cognitive activity e.g. mental arithmetic
• The above findings are indicative of healthy brain function
Alpha activity

- Everyone has a characteristic “individual alpha frequency”
  - e.g., 9.5 Hz, 12 Hz, etc.
- Slowing of alpha can occur
  - Common in older adults (e.g., 7-8 Hz)
  - More pronounced in pathologies (e.g., 6-7 Hz in acute stroke)
- Irregularities can be reflected in:
  - Similar alpha amplitudes between eyes closed & eyes open states
  - Similar alpha amplitudes between posterior & frontal electrodes
Alpha is generated by thalamo-cortical networks
Defining abnormal slow EEG activity in acute ischaemic stroke: Delta/alpha ratio as an optimal QEEG index

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Delta activity
Alpha activity

HIGHLIGHTS

• All QEEG indices (sensitive to power of delta, theta, alpha, and/or beta bands) differed highly significantly between acute ischaemic stroke (IS) and control samples.
• Delta/alpha power ratio (DAR) demonstrated maximal accuracy for discriminating between acute IS patients and controls.
• DAR < 3.7 was 100% specific for the absence, and > 3.7 was 100% sensitive for the presence, of a radiologically-confirmed IS lesion.
Fig. 1. Bar graphs plotting relative power values for each of the four classical frequency bands in each individual analysed. (A) Control participants; (B) acute ischaemic stroke cases. Relative delta power was significantly higher in the stroke ($M = 0.58$) than the control sample ($M = 0.29$; $t = 11.63$, $p < 0.0001$), whereas relative alpha power was significantly lower in the stroke ($M = 0.13$) than the control sample ($M = 0.34$; $t = 8.06$, $p < 0.0001$). Such outcomes also relate to the finding that DAR was significantly higher in the stroke ($M = 6.64$) than the control sample ($M = 1.34$; $t = 7.75$, $p < 0.0001$).
Fig. 2. DTABR and DAR values plotted for each individual in the control versus stroke samples. There was substantial overlap of DTABR values between the samples but no overlap for DAR. The horizontal line represents the proposed DAR abnormality threshold value of 3.7.
Delta activity

• Abnormally slow EEG: ~1-3 Hz
• Often indicative of pathology (e.g., acute stroke)
• Evidently reflects pathophysiology in thalamo-cortical networks
  – disconnection between cortical & thalamic regions (physical or functional)
  – thalamo-cortical dysrhythmia: disruption of “top-down” cortical modulation of thalamic neurons → low-frequency bursting in thalamus, which is propagated to cortical regions

(van Wijngaarden et al. PLOS Computational Biology. 2016:10;12(8):e1005048)
Fig. 1. EEG and QEEG data from an acute stroke patient. These data were acquired from a 57-year-old woman, approximately 7 h after the onset of symptoms associated with ischaemic stroke in the left middle cerebral artery territory. The NIHSS score was 7 immediately prior to the EEG recording. (A) Raw EEG trace showing delta activity most particularly at ipsilateral channels incorporating frontal and temporal electrodes. (B) Maps illustrating the topography or distribution of mean delta (left) and alpha (right) power across the scalp (viewed from above). Note the differential power scales for delta versus alpha. (C) Power spectra plotting power (log-transformed) values across the 0–30 Hz range for each electrode of the international 10–20 system. Note the delta activity ‘peak’ at approximately 1.5–2 Hz, particularly at electrodes F7 and T3. Also note alpha power values at some electrodes, e.g., electrode F4, between approximately 9–11 Hz. (D) Delta/alpha ratio (DAR) and (delta + theta)/(alpha + beta) power ratio (DTABR) values plotted for each electrode. Note the relatively highest values at ipsilateral, lateral frontal and anterior temporal electrodes. Note also that even the lowest DAR and DTABR values barely fall below 2.
Theta activity

- EEG oscillations at ~4-7 Hz
- Linked with cognitive activity e.g. memory
  - Often most obvious at frontal electrodes
- Generated by networks including medial temporal, anterior cingulate & other cortical regions

- However abnormally slow alpha can be within theta frequency range
  - Important to consider state (e.g., resting eyes closed vs other), scalp location (e.g., frontal vs posterior), reactivity (blocking)

(Finnigan & Robertson. Psychophysiology. 2011;48:1083-7.)
Methods

Participants and Recruitment
Seventy-three cognitively healthy older adults (48 female) with a mean age of 60.76 years (range 56 to 70) were recruited from the older adult participant panel of the Trinity College Institute of Neuroscience. Participants on this panel were originally recruited via newspaper advertisements. Participants received reimbursement of travel (e.g., taxi) expenses to the maximum value of 20 Euros when relevant. This study was approved by the Ethics Committee of the School of Psychology at Trinity College Dublin, and all participants gave informed consent. All participants completed a detailed questionnaire about their own health and current medications, as well as any relevant health issues in their family. Participants who had a history of head injury, stroke, epilepsy, heart attack, neurological conditions, major psychiatric disorder, or diabetes were excluded from the study.

Neuropsychological Test Battery
The battery comprised the Mini Mental State Exam (MMSE), National Adult Reading Test (NART), the Rey Auditory Verbal Learning Test (RAVLT), Rivermead Behavioural Memory Test (RBMT; Prose Recall, immediate and delayed), half of Raven’s Standard Progressive Matrices (RSPM), Category Fluency (Animal Naming Test), the digit-span subtest (forward and backward) of the Wechsler Adult Intelligence Scale (3rd edition). Participants then completed the Hospital Anxiety and Depression Scale (HADS). Following this and prior to EEG set-up, participants performed a computerized version of the sustained attention to respond task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Single digits (1 through 9) appear one at a time on screen and participants are instructed to press a button in response to every digit except “3.” We employed the random version, wherein digits appeared in a pseudorandom order. A total of 225 trials were presented, representing 25 runs of the 1–9 sequence, and lasting approximately 5.5 min total. The task was programmed and run within the Presentation software platform. Each of the above measures was correlated with EEG power measures noted below. Given that normality tests (via normal Q-Q probability plots) indicated that not all of these cognitive and EEG power data were normally distributed, Spearman’s correlation coefficient was used.

4-min, resting-state EEG recording was made with eyes closed. Participants were asked to sit comfortably and to try to minimize body and eye movements as far as was feasible during the recordings. Questioning confirmed that no participants fell asleep during recordings.

EEG Signal Processing
Offline signal processing was performed with Edit 4.3 software (Compumedics-Neuroscan, Melbourne, Australia) using methods we have previously reported (Cummins & Finnigan, 2007; Finnigan, Walsh, Rose, & Chalk, 2007). Data were re-referenced to M1. EOG artifacts were reduced where appropriate using the procedure of Semlitsch, Anderer, Schuster, & Presslich (1986). Each data file was separated into contiguous epochs of 1024 data points (2 s). Epochs in which EEG amplitude exceeded ± 80 μV were automatically rejected. From the first 90 epochs of artifact-free data per participant, EEG power (μV^2) was computed for each electrode and each 0.5 Hz bin using the fast Fourier Transform (FFT) with a cosine window (length: 10%). From the resulting power spectra for each electrode, absolute power was summed across the delta (1–3.5 Hz), theta (4–6.5 Hz), alpha (7.5–12.5 Hz), beta (13–30 Hz) bands. Relative power for each band was computed as the ratio of absolute bandpower to total power across the 1–30 Hz range.

Results
Participant demographics and cognitive performance data are summarized in Table 1, as are key outcomes from the correlation analyses. In EEG acquired during a resting, eyes-closed state, relative theta power at electrode Fz bore significant positive correlations with list A recall scores from the RAVLT (trials 5, 6, 7).

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Table 1. Descriptive Statistics for Cognitive Measures, and Correlations Between These and EEG Relative Theta Power

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<td>Digit-span difference</td>
<td>4</td>
<td>1</td>
<td>11</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>SART comm errors</td>
<td>3</td>
<td>0</td>
<td>12</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>SART RT variability</td>
<td>92.09</td>
<td>52.38</td>
<td>261.34</td>
<td>-0.257*</td>
<td>ns</td>
</tr>
<tr>
<td>HADS Anxiety</td>
<td>5</td>
<td>0</td>
<td>31</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>HADS Depression</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Peak alpha frequency</td>
<td>9.5</td>
<td>7.5</td>
<td>12</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Note: MMSE: Mini Mental State Exam, NART: National Adult Reading Test, RAVLT: Rey Auditory Verbal Learning Test (list A), RBMT: Rivermead Behavioural Memory Test, RSPM: Raven's Standard Progressive Matrices, HADS: Hospitality Anxiety and Depression Scale, SART: sustained attention to respond task, comm.: commission, RT: reaction time.
*indicates p < .05.
Letter to the Editor

Predominant slow EEG activity in healthy neonates: Transient thalamo-cortical dysrythmia?

Development of neuronal connectivity between thalamic and cortical regions critically involves the subplate, a transient structure beneath the developing cortical plate comprising a heterogeneous neuronal population that involutes during the third trimester and disappears soon after birth at term (e.g., see Ramold.

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Active sleep periods were selected for analysis; anterior slow waves have often been reported to occur chiefly during active sleep (e.g., Clancy et al., 2014). These data were filtered (lowpass: 35 Hz,
Fig. 1. Schematic diagram of generalized connections between thalamic, cortical and subplate neurons, leading up to and around term equivalent age (approximately). Circles represent cell bodies of thalamic neurons, diamonds represent cell bodies of subplate neurons and triangles represent cell bodies of cortical pyramidal neurons. Black triangles indicate synapses. The subplate is a transient structure which disappears soon after term age, and only projections represented by vertical lines are central to our current model. At the neurodevelopmental stage illustrated, thalamo-cortical projections are established (represented by the solid vertical line) but cortico-thalamic projections are not yet fully functional (represented by the dashed vertical line; e.g. see Kanold and Luhmann, 2010). We propose this may temporarily result in a state of thalamo-cortical dysrhythmia (TCD) wherein the absence of “top-down” cortical modulation results in low-frequency bursting in thalamic neurons, which in turn is propagated to cortical neurons (via projections represented by the solid vertical line). We propose that such TCD underlies the high relative delta power typical of this neurodevelopmental stage, in healthy preterm- and term-born infants. Under this framework development of functional cortico-thalamic connections would result in disappearance of TCD; this would account for the relative delta power decreases between preterm and post-term periods reported in some studies (e.g., Bell et al., 1991).
Early history of EEG

• Late 1800s: animal studies in Britain & Europe

• 1924: first human EEG, by German psychiatrist Hans Berger
  – Observed alpha activity (the “Berger rhythm”)

• Berger published his first paper in 1929
  – technique for "recording the electrical activity of the human brain from the surface of the head"
EEG electrode positions:
the 10-20 system
EEG reporting, analyses & interpretations

Can focus on various features such as:

• Frequency
• Scalp topography (location e.g., frontal)
• Voltage (e.g., inter-hemispheric symmetry)
• Waveform “morphology” (e.g., posterior sharp waves)
• Synchrony between electrodes (phase)
• Continuity vs discontinuity (e.g., “burst suppression”)
EEG reporting & analyses

• Conventional clinical EEG reporting: qualitative
  – e.g., “alpha activity has a posterior focus. There is also some periodic slow activity at temporal electrodes, more obvious over the left hemisphere ...”
  – Can be subjective

• Quantitative EEG (qEEG) analyses
  – Computational analyses of “raw” digital EEG signals → qEEG measures (analogous to BP, HR, temperature, etc.)
  – Objective measures, albeit may over-simplify EEG at times
  – More commonly used in research; starting to emerge in some clinical settings
Fig. 1. Pre-IV alteplase CTP, post-IV alteplase QEEG and post-thrombectomy QEEG, pre- and post-thrombectomy angiograms (Patient B). (A) Pre-IV alteplase CTP. (B) QEEG-DAR measures over time. Each DAR measure was computed from 2 min of EEG, and the respective median times of these are noted below the X-axis. QEEG indicated that IV alteplase had been unsuccessful as the DAR worsened (increased) during infusion. Clinical assessment during and after the intra-arterial clot retrieval procedure was impossible as the patient was sedated and ventilated. However, DAR significantly improved (decreased) within 2 h of the procedure indicating successful reperfusion. After 48 h of sedation clinical assessment was possible and revealed symptoms had substantially improved. (C) Cerebral angiograms pre- and post-clot retrieval, indicating that clot retrieval was successful, with reperfusion occurring at 5.5 h. IV, intravenous; CTP, computed tomography perfusion; QEEG, quantitative electroencephalography; DAR, Delta/alpha power ratio; CBF, cerebral blood flow; MTT, mean transit time; NIHSS, National Institutes of Health Stroke Scale.