

Signal quality of a novel EEG electrode: a simultaneous occipital alpha comparison against a commercial wet electrode

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Single-subject bench test, 11 September 2026. Methods and results only.

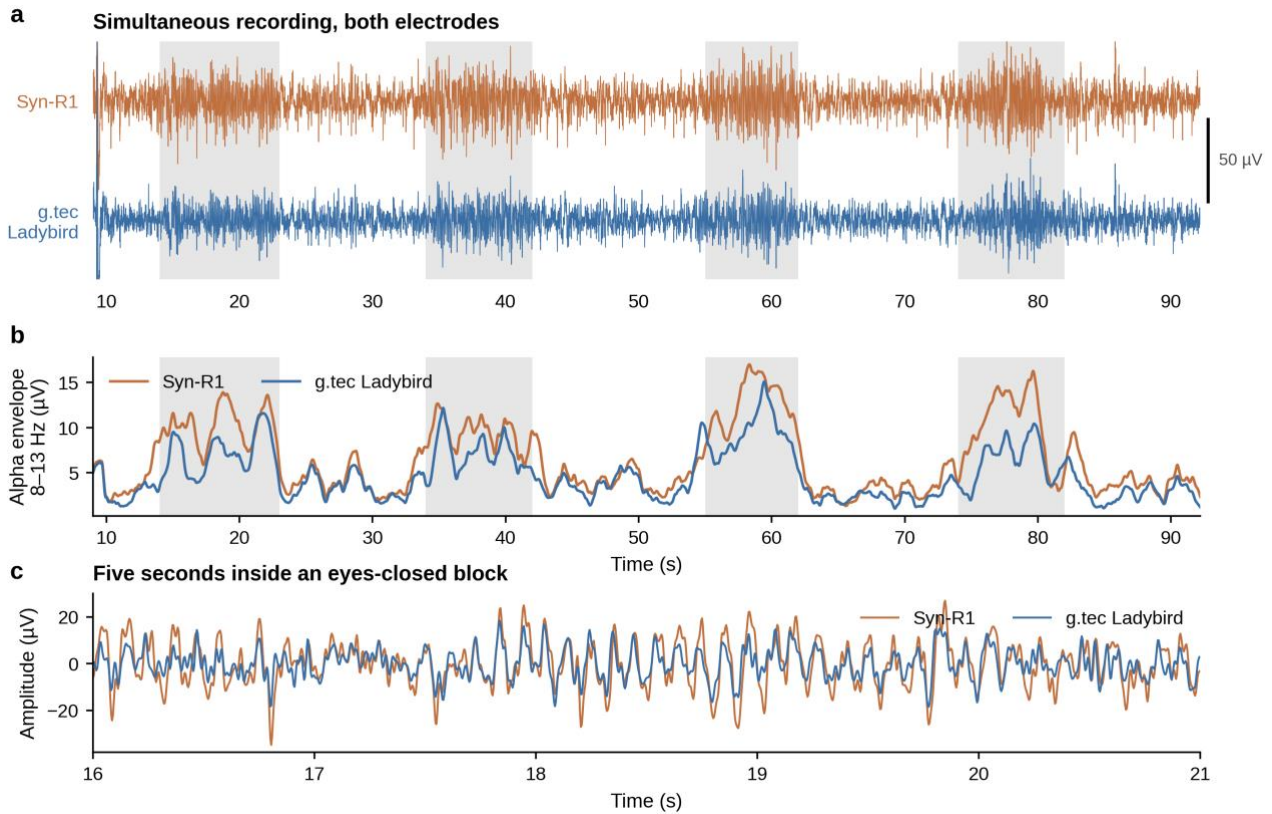


Figure 1. Recording overview. (a) The two occipital channels, 1–45 Hz band-pass with a 50 Hz notch, offset vertically. (b) The 8–13 Hz amplitude envelope of each channel, smoothed over one second. Shaded bands in (a) and (b) mark the eyes-closed blocks. (c) Five seconds inside the first eyes-closed block, both channels overlaid on the same axis; $r = 0.80$ over 1–45 Hz for the whole recording.

1. Methods

1.1 Participant, montage and acquisition

Data were recorded from one adult participant in a single session. Two electrodes were placed simultaneously at the occipital sites O1 and O2 of the international 10–20 system, one of each type under test: the Syn-R1 electrode and a g.tec Ladybird wet Ag/AgCl electrode. A further electrode on the forehead provided a frontal channel, and an earlobe electrode served as the recording reference. Signals were acquired on a g.tec HiAmp amplifier at 256 Hz with a 0.5–100 Hz hardware band-pass, and exported as a MATLAB file containing a single matrix of time and four channels in microvolts.

The session consisted of alternating eyes-open and eyes-closed periods, the standard manipulation for eliciting the occipital alpha rhythm. The recording lasted 97.2 s. Recording both electrodes at once holds brain state, amplifier, reference and environment fixed, leaving electrode and scalp site as the only differences between the two channels (Figure 1).

1.2 Preprocessing

The amplifier settling transient at the start of the recording, and the corresponding transient as the electrodes were removed, were excluded by a fixed rule: the analysed interval begins at the first one-second window whose RMS falls inside three times the median RMS of the recording, plus three seconds of margin, and ends five seconds before the recording does. This gave 9.0–92.2 s.

Two filtered versions were then prepared: a 1–45 Hz fourth-order Butterworth band-pass with a 50 Hz notch for the time-domain and band-power measures, and a 1 Hz high-pass only for the spectral and noise measures, since notching first would mean any assessment of mains rejection measures the notch rather than the electrode. Drift used a 0.1–1 Hz band-pass of the detrended signal. All filters were zero-phase. Neither re-referencing nor artefact rejection was applied; the rate of large excursions is itself one of the quantities compared.

1.3 Epoching and spectral estimation

Statistics were computed on 2 s epochs at 50 % overlap taken from within blocks, with one second discarded at

each block edge so that the transition itself never contributes to a statistic. This gave 20 eyes-closed and 36 eyes-open epochs per channel.

Power spectral densities were estimated by Welch's method using 4 s Hann-windowed segments at 75 % overlap, giving 0.25 Hz resolution, with no segment spanning a block boundary. Segment spectra were combined as a geometric mean, with confidence intervals formed in the log domain, because periodogram estimates are approximately log-normally distributed. The individual alpha frequency was taken as the maximum of the eyes-closed spectrum between 7 and 14 Hz, refined by parabolic interpolation. The aperiodic 1/f background was fitted by least squares to the log-log spectrum between 2 and 45 Hz, excluding 7–14 Hz and 45–55 Hz so that neither the alpha peak nor the mains region biases the fit; alpha SNR is the height of the peak above that fitted background, which makes it independent of any fixed gain difference between the channels.

1.4 Signal-quality measures

The measures separate three questions: how much signal the electrode delivers, how much noise comes with it, and whether it resolves a real physiological change.

Amplitude was summarised as broadband RMS and as conventional band powers. Interface stability was summarised by the RMS of the 0.1–1 Hz band, which captures slow half-cell potential drift, and by the rate of excursions beyond 100 μV ; these degrade first when an electrode is poorly seated, often while the alpha rhythm still looks acceptable. The instrumentation noise floor was taken as the median PSD between 55 and 95 Hz - the recorder applies its own 50 Hz notch before export, a large un-notched 100 Hz harmonic is present, and the anti-alias roll-off begins just above 100 Hz, which leaves that window as the only clean view of the floor.

Function was assessed by alpha reactivity, the eyes-closed to eyes-open power ratio in decibels, with Cohen's d on log power and a one-sided Mann–Whitney U test. Being a within-channel ratio, reactivity is unaffected by a fixed gain difference, which makes it the fair comparison between electrodes at different scalp sites. The same idea was taken to a practical criterion by asking whether a single 2 s epoch suffices to classify eye state from alpha power alone, scored as the area under the ROC curve with a 4000-sample bootstrap interval, alongside d' and the coefficient of variation of eyes-closed alpha across blocks.

1.5 Agreement between the two electrodes

Correlation alone is a weak claim of equivalence: two channels can correlate perfectly while differing by an arbitrary gain, and correlation is inflated by the wide range of true values an eyes-open/eyes-closed design guarantees. Agreement was therefore reported four ways. Association: Pearson correlation of the two time series, broadband and by band, magnitude-squared coherence over 4 s segments, and the alpha-band phase lag from the cross-spectrum. Absolute agreement, which penalises a fixed offset where correlation does not: ICC(2,1) on log epoch alpha power. Proportionality: Deming regression with unit error ratio, since both variables carry measurement error and ordinary least squares would bias the slope towards zero. Bias and spread: Bland–Altman analysis of the per-epoch difference

in decibels. Equivalence was tested directly, by two one-sided t-tests against bounds of ± 3 dB and ± 5 dB, rather than inferred from a non-significant difference.

1.6 Software

Python 3 with NumPy, SciPy, h5py and Matplotlib. All constants are declared in one shared module and no step involves manual editing or hand-selected time windows, so the analysis and this document regenerate from the raw file.

2. Results

2.1 Spectral characteristics

Both channels showed a clear alpha peak on eye closure at essentially the same frequency, 9.06 Hz on the Syn-R1 channel and 9.03 Hz on the Ladybird, a difference of 0.03 Hz and well inside one frequency bin (Figure 2a, b). Individual alpha frequency is a property of the rhythm rather than of the sensor, so agreement here indicates both electrodes are recording the same neural source rather than similar-looking noise.

The peak stood 16.5 dB above the fitted aperiodic background on the Syn-R1 channel and 16.0 dB above it on the Ladybird (Figure 2c), with aperiodic slopes of -0.71 and -0.56. A distorted 1/f background is a common signature of a compromised electrode interface; neither channel shows one. Across 1–45 Hz the two eyes-closed log spectra correlated at $r = 0.91$.

2.2 Functional performance

Alpha power rose on eye closure from 1.95 to 15.94 $\mu\text{V}^2 \text{Hz}^{-1}$ on the Syn-R1 channel and from 1.29 to 7.38 $\mu\text{V}^2 \text{Hz}^{-1}$ on the Ladybird, giving reactivities of +9.3 dB and +8.2 dB with effect sizes of $d = 4.11$ and $d = 2.94$ (Figure 3a); both differences were significant at $p < 10^{-9}$.

Single 2 s epochs sufficed to classify eye state from alpha power alone on both channels: AUC = 1.000 (95 % CI 1.000–1.000) and 0.992 (0.967–1.000), with d' of 4.30 and 3.15 (Figure 3b). Eyes-closed alpha varied across the four blocks with coefficients of variation of 33 % and 37 %, the two channels rising and falling together from block to block (Figure 3c).

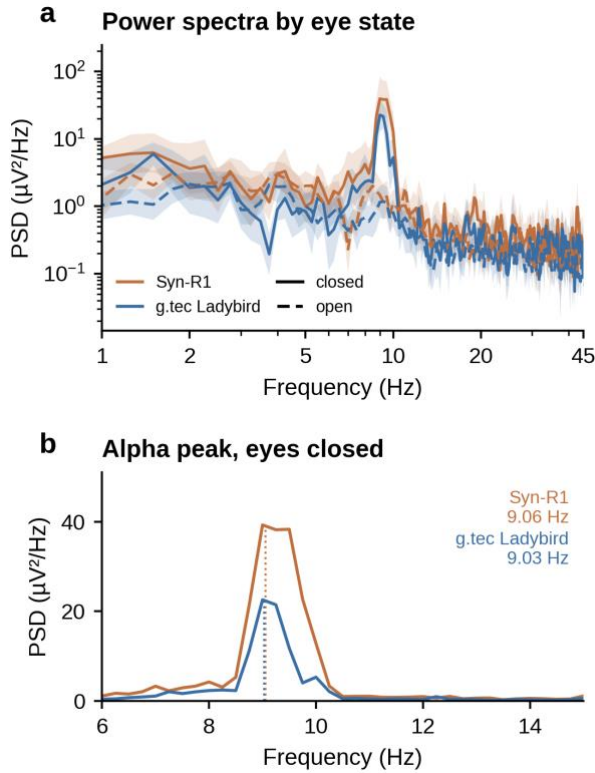


Figure 2. Spectral characteristics. (a) Power spectra by eye state; colour identifies the electrode, line style the condition, shading the 95 % confidence interval of the geometric mean across segments. (b) The eyes-closed alpha peak on a linear scale, with the interpolated individual alpha frequency of each channel.

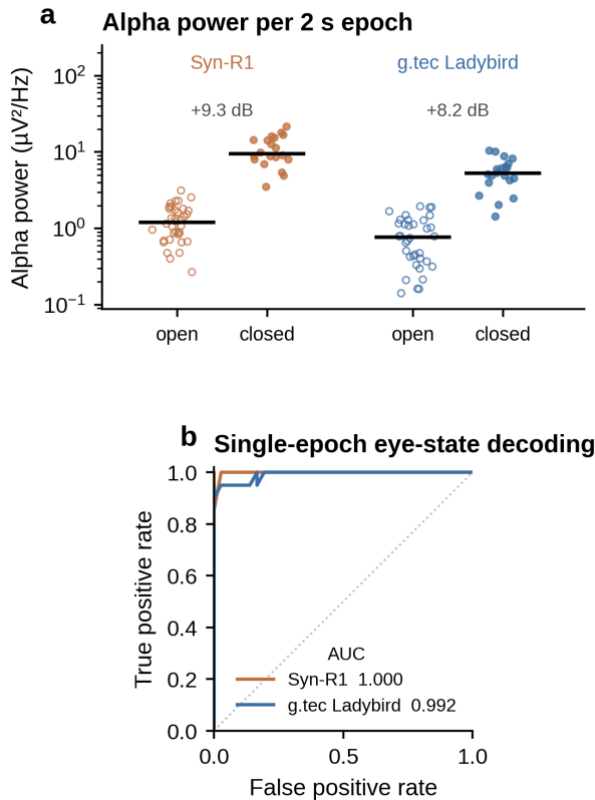


Figure 3. Functional performance. (a) Alpha power in every 2 s epoch, by electrode and eye state; horizontal bars are medians and filled markers eyes-closed epochs. (b) Receiver operating

characteristic for classifying eye state from the alpha power of a single 2 s epoch.

2.3 Agreement

The two waveforms tracked each other sample by sample, at $r = 0.80$ across 1–45 Hz and 0.78 within the alpha band (Figure 1c). Coherence averaged 0.51 in the alpha band with a phase lag of 5.4° , i.e. no meaningful timing offset; coherence below unity is expected for electrodes at different sites, which see partly different cortical sources.

Epoch by epoch, alpha power on the two channels correlated at $r = 0.91$, with $\text{ICC}(2,1) = 0.80$ and a Deming slope of 0.99 (Figure 4a). Bland–Altman gave a bias of +2.63 dB with 95 % limits of agreement of -1.8 to +7.0 dB (Figure 4b). The two channels were equivalent within ± 5 dB (TOST, $p < 0.001$) but not within ± 3 dB ($p = 0.11$).

The Syn-R1 channel recorded 2.63 dB more alpha power than the Ladybird, a broadband RMS ratio of 1.34. The Deming slope of 0.99 places this as a fixed offset rather than a difference in how the two respond: the ratio between them does not change with signal level. The electrodes occupied different occipital sites and alpha amplitude falls off steeply with distance from its generators, so site asymmetry is sufficient to account for an offset of this size, and this recording cannot separate it from an electrode effect. The measures that do not depend on absolute amplitude all agree closely.

2.4 Noise and mains

The noise floor between 55 and 95 Hz was $0.522 \mu\text{V Hz}^{-1/2}$ on the Syn-R1 channel and $0.482 \mu\text{V Hz}^{-1/2}$ on the Ladybird. Drift in the 0.1–1 Hz band measured $8.65 \mu\text{V}$ and $6.91 \mu\text{V}$, and excursions beyond $100 \mu\text{V}$ occurred at 0.008 and 0.011 per minute, a handful of samples in the whole recording on either channel.

Mains rejection cannot be assessed here. The recorder applied a 50 Hz notch before export, visible as a three-decade hole spanning 49–51 Hz on every channel, so residual 50 Hz power reflects the notch rather than the electrodes. The 100 Hz harmonic was not notched and was large and near-identical on both channels (+26.0 dB and +26.1 dB above neighbouring frequencies), placing it in the recording environment.

Table 1. Signal-quality measures for the two electrodes, computed from the same 20 eyes-closed and 36 eyes-open epochs. Residual 50 Hz power is omitted because the recorder notched it before export.

Measure	Syn-R1	Ladybird	Unit
<i>Amplitude</i>			
Broadband RMS, closed	11.32	8.45	μV
Alpha power, eyes closed	15.94	7.38	$\mu\text{V}^2/\text{Hz}$
Alpha power, eyes open	1.95	1.29	$\mu\text{V}^2/\text{Hz}$
<i>Spectral</i>			
Alpha frequency	9.06	9.03	Hz
Aperiodic slope	-0.71	-0.56	—
Alpha SNR over 1/f	16.5	16.0	dB
<i>Noise</i>			
Noise floor, 55–95 Hz	0.522	0.482	$\mu\text{V}/\sqrt{\text{Hz}}$
Drift, 0.1–1 Hz	8.65	6.91	μV
Excursions > 100 μV	0.008	0.011	min^{-1}
<i>Function</i>			

Measure	Syn-R1	Ladybird	Unit
Alpha reactivity	+9.3	+8.2	dB
Effect size, Cohen's d	4.11	2.94	—
Single-epoch AUC	1.000	0.992	—
Block-to-block CV	33	37	%
<i>Agreement</i>			
Epoch alpha power, r	0.91		—
ICC(2,1), alpha power	0.80		—
Deming slope	0.99		—
Bland–Altman bias	+2.63		dB

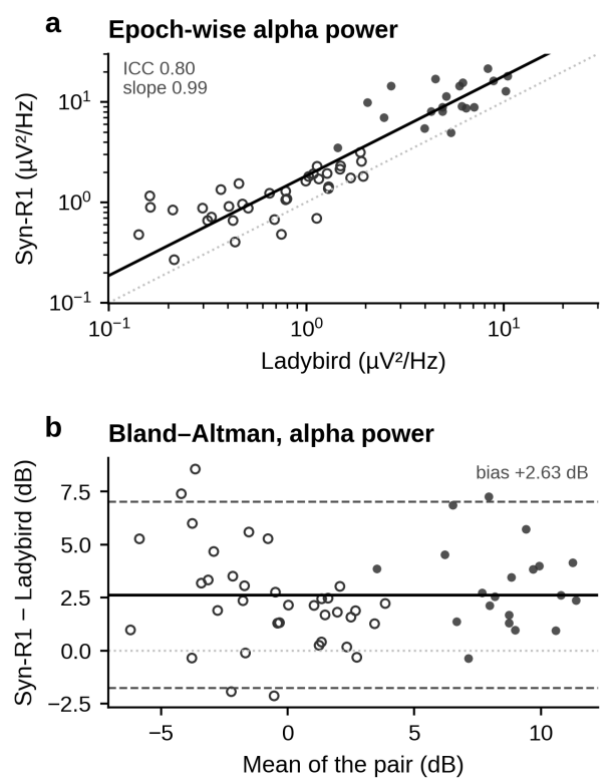


Figure 4. *Agreement between the two electrodes.* (a) Epoch-wise alpha power of one channel against the other, Deming regression solid and identity dotted. (b) Bland–Altman plot of the per-epoch difference, mean bias solid and 95 % limits of agreement dashed.