An Exploratory Investigation into the EEG Characteristics of the Visual Awareness Negativity

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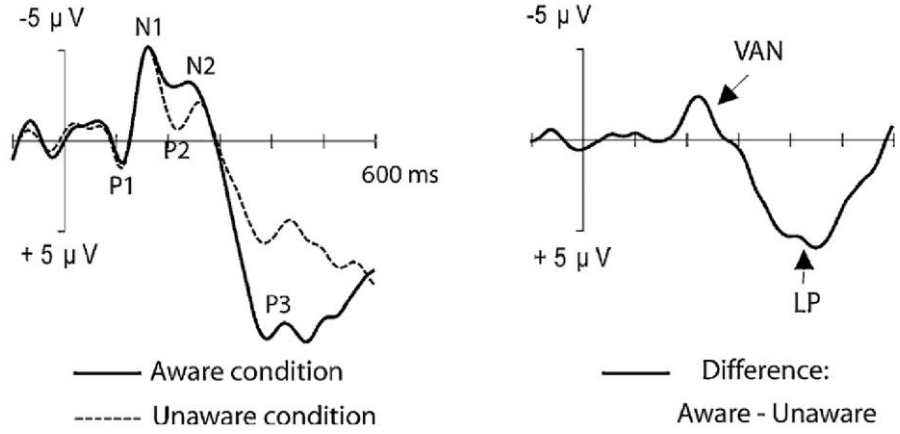
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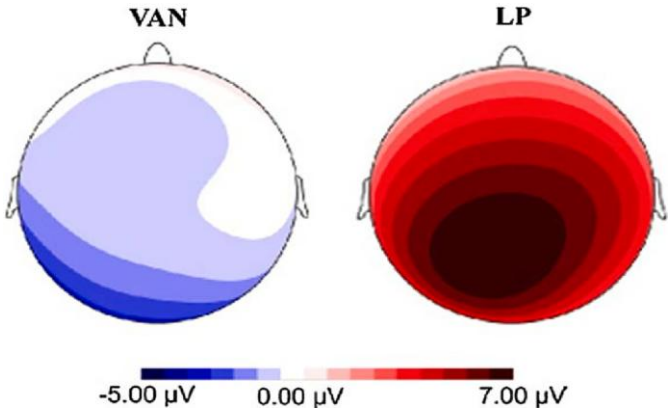
School of Social Work, Texas State University

The Science of Consciousness Conference, October 11–16, 2026



ERP Correlates of Visual Consciousness





Images adapted from Koivisto & Revonsuo (2010).
***Neuroscience and Biobehavioral Reviews, 34*, 922–934**

Visual Awareness Negativity (VAN):

- A posterior negative event-related potential (ERP) shift ~ 200 – 300 ms post-stimulus time range for seen versus not seen visual stimuli

- Sometimes accompanied by a **Late Positivity** response (LP; 300 – 600 ms), which is larger for seen versus not seen stimuli (Förster et al., 2020)

- VAN response likely originates from occipito-temporal cortical sources

- Hypothesized to reflect the onset of recurrent cortical processing of visual information (Förster et al., 2020)

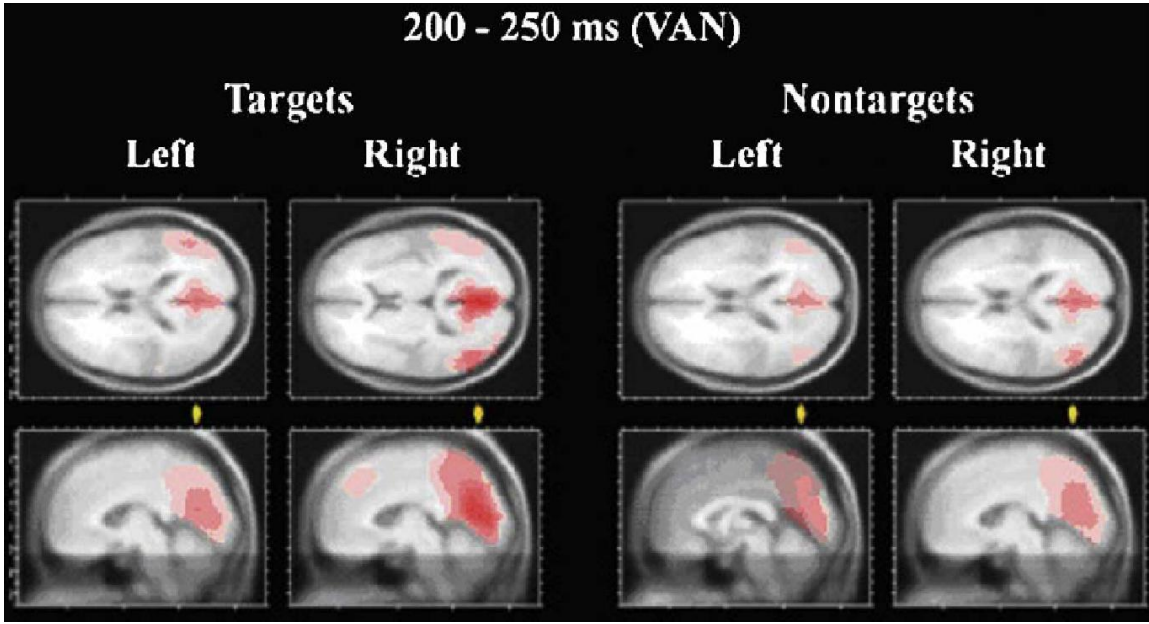


Image adapted from Koivisto & Revonsuo (2010). *Neuroscience and Biobehavioral Reviews, 34*, 922–934

- Relatively insensitive to task-relevance

  => early ERP correlate of phenomenal consciousness

- LP response likely originates from fronto-parietal networks

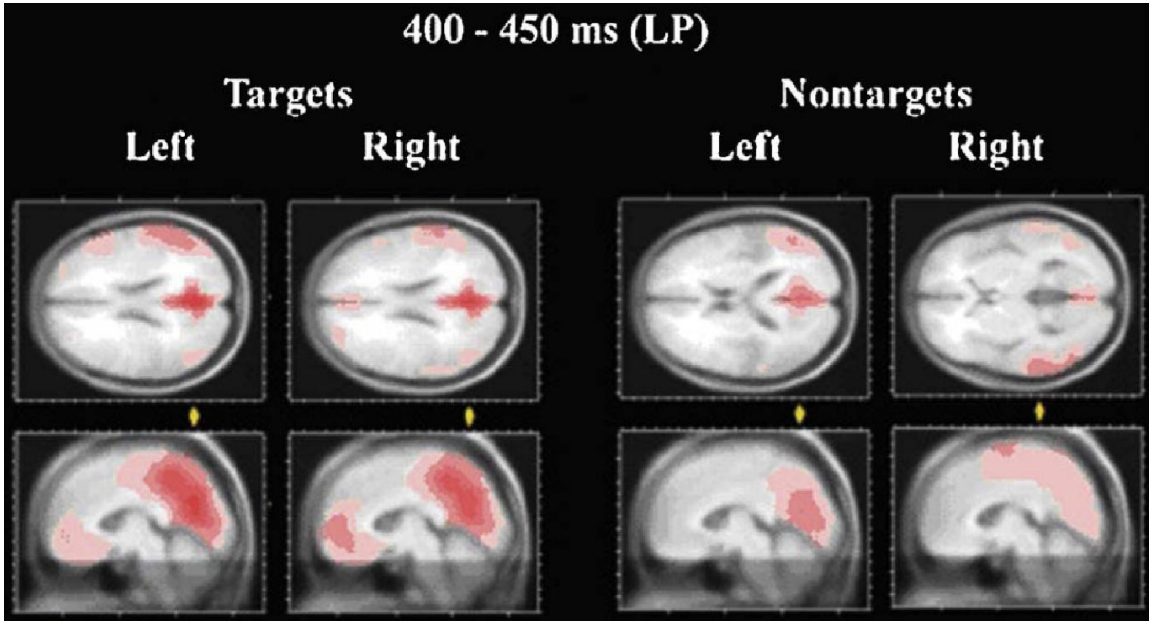


Image adapted from Koivisto & Revonsuo (2010). *Neuroscience and Biobehavioral Reviews, 34*, 922–934

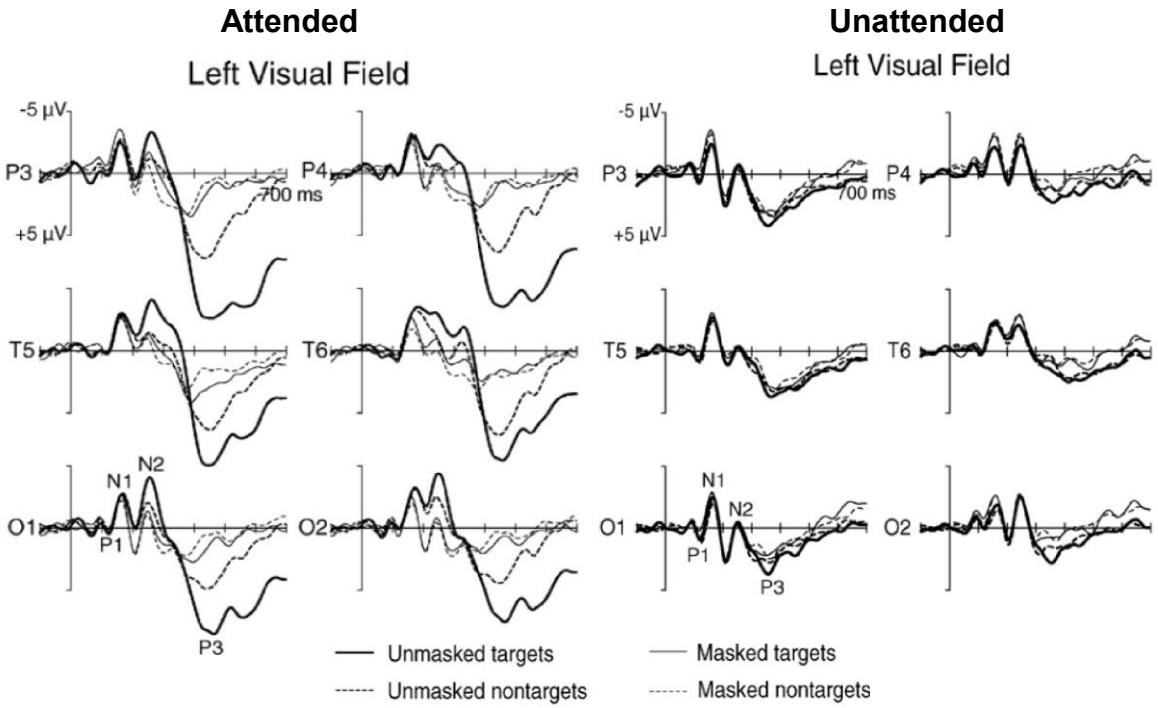
- Sensitive to task-relevance

  => ERP correlate of reflective, access consciousness &/or related post perceptual processing (e.g., “participants’ meta-cognitive evaluations concerning their awareness”; Koivisto & Grassini, 2016, p. 242)

Relationship to Attention

- VAN is dependent on spatial attention & partially dependent on nonspatial attention

=> spatial attention is a prerequisite for phenomenally-experienced internal representations



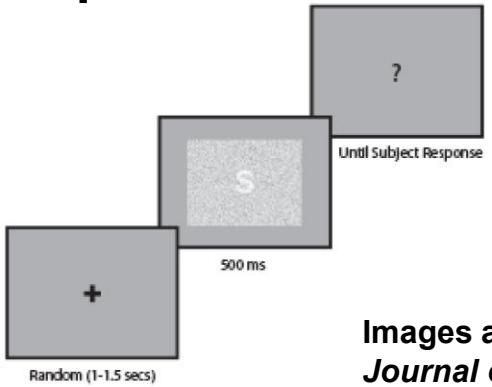
Images adapted from Koivisto et al. (2009). *Neuropsychologia, 47*, 2891–2899

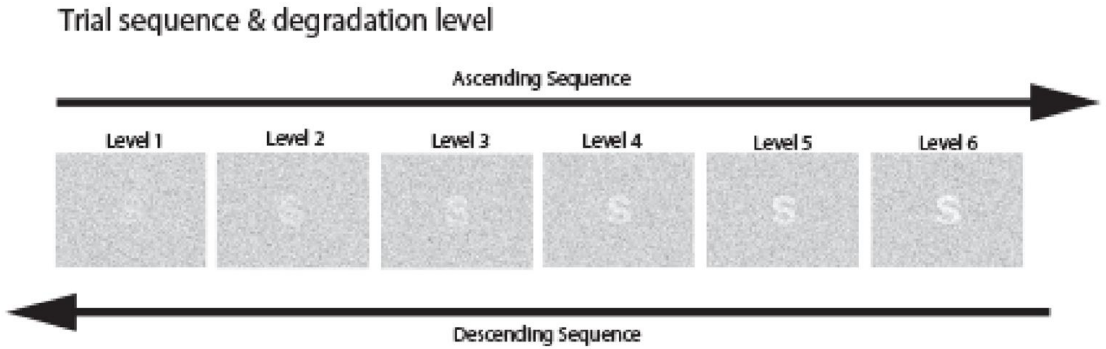
- LP is dependent on both spatial & nonspatial attention

=> consistent with idea that the contents of phenomenal consciousness are input for post-perceptual processing

Role of Expectation: VAN effect increases with influence of predictive expectations

Example: Melloni et al. (2011)

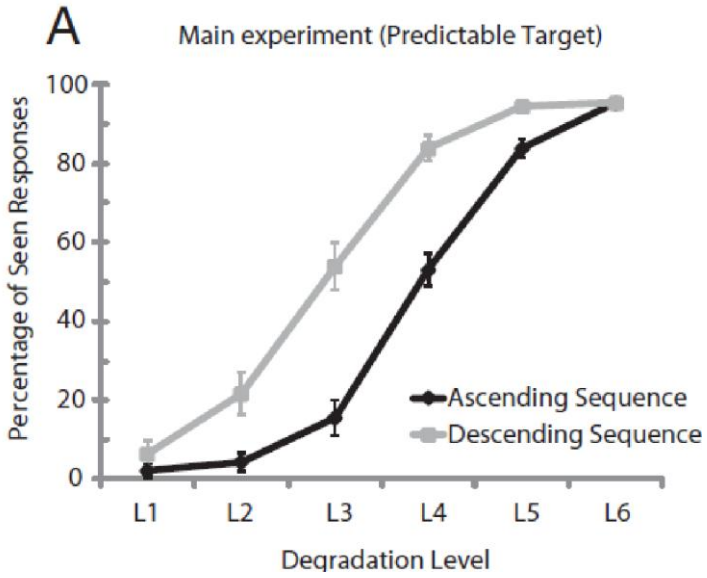




Images adapted from Melloni et al. (2011). *The Journal of Neuroscience, 31(4)*, 1386 –1396

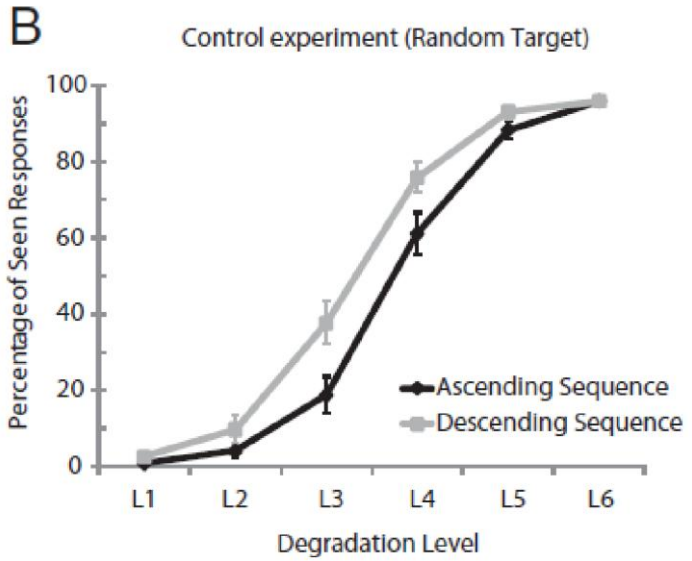
- Repeated symbolic stimuli presented in a “ladder” procedure
  - Step-wise increase in contrast/visibility over six trials (“ascending” sequence)
  - Contrast/visibility decrease over five trials (“descending” sequence)
- Participants reported subjective visibility level of stimuli on a graded perceptual awareness scale

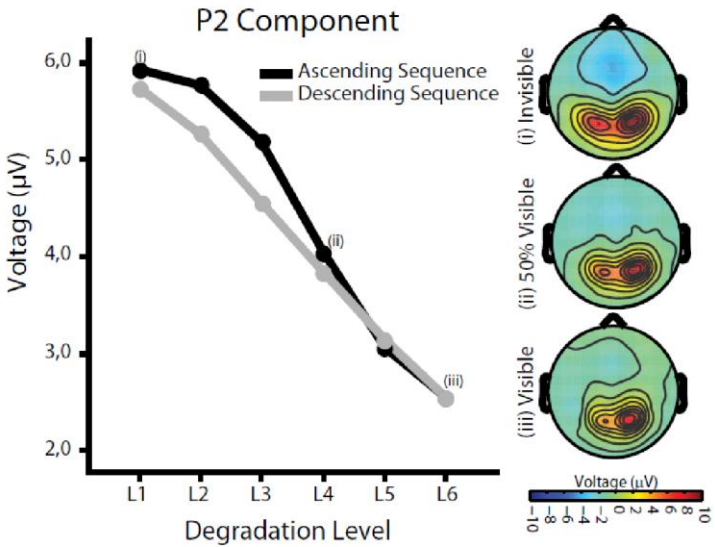
Results: Participants were more aware of stimuli during descending then ascending sequence



Images adapted from Melloni et al. (2011). *The Journal of Neuroscience, 31(4)*, 1386 –1396

- Participants were also more aware of stimuli during descending sequence using predictably versus randomly changing stimuli (control experiment)





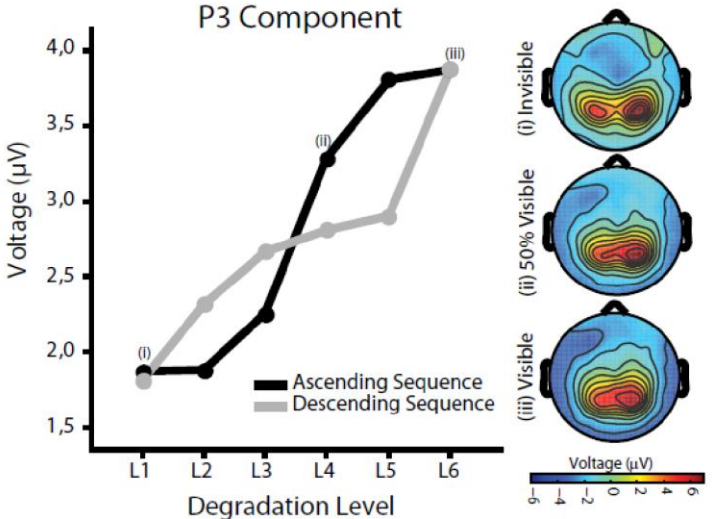
- VAN present during both sequences, but VAN amplitude was larger during descending sequence

=> the presence of participant expectations in the descending sequence, built up during the ascending sequence

Images adapted from Melloni et al. (2011). *The Journal of Neuroscience, 31(4)*, 1386 –1396

- LP amplitude was greater for seen than for not seen stimuli only during the ascending sequence

=> LP is an ERP correlate of visual awareness in the absence of expectations



Measures of Graded Awareness?

Perceptual Awareness Scale (PAS)

- Visibility ratings linearly covary with stimulus duration & probability of a correct answer in a variety of tasks (e.g., shape/color discrimination; stimulus localization) (Ramsøy & Overgaard, 2004; Overgaard, et al., 2006)

- VAN & LP amplitudes correlate linearly & positively with PAS ratings (Tagliabue et al., 2016)

- However, current evidence is unclear if this covariation holds for both simple & complex stimuli (Förster et al., 2020)

PAS
1 = No Experience
2 = Brief Glimpse
3 = Almost Clear Impression
4 = Clear Impression

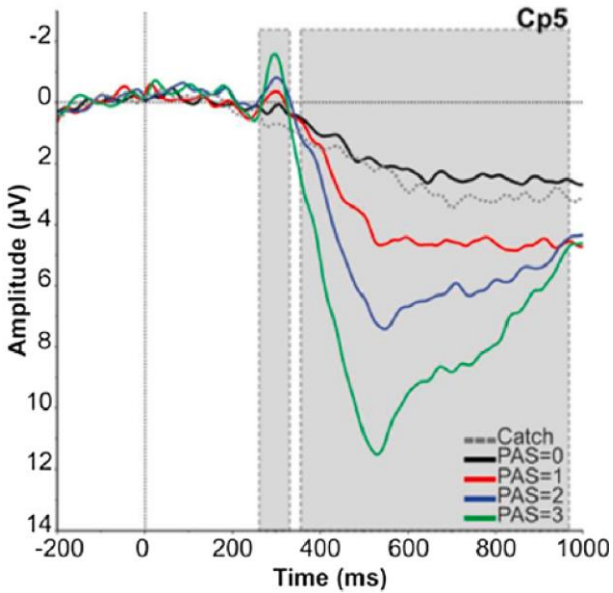


Image adapted from Tagliabue et al. (2016). *Frontiers in Psychology, 7*

EEG Properties of the VAN & LP



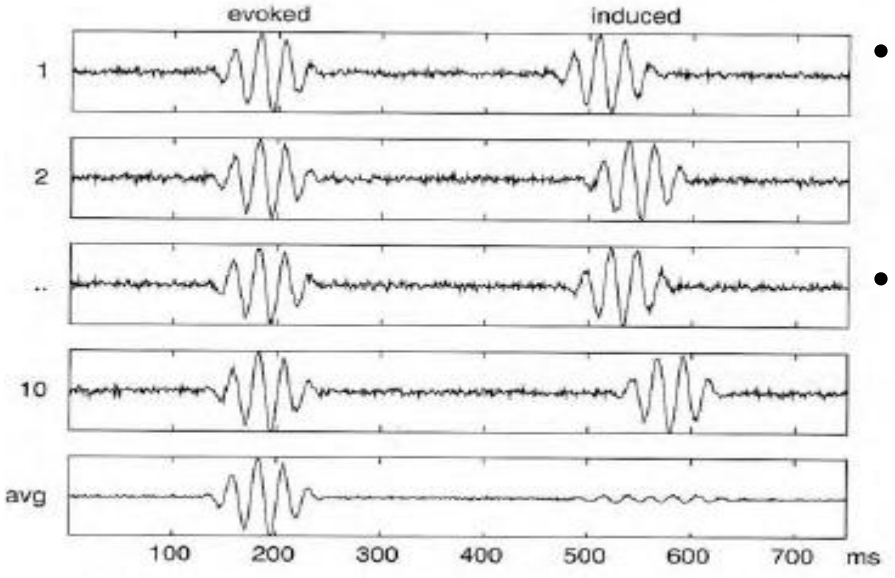
- The focus of the present study is the relationship of the VAN/LP to more general stimulus-related electroencephalographic (EEG) brain responses

- Studying EEG properties provides additional information about neurocognitive processing, such as:
  - Presence & functional role of different brain oscillations
  - Relevance of spatial & temporal dynamics of the brain
- The above are only partially indexed by ERPs; fortunately, there are many other analytical metrics of these EEG properties

Focus of Present Study: 1) EEG power & phase coherence
2) EEG functional integration & topological complexity

1) EEG Power & Phase Coherence

- Indexed using techniques that decompose EEG signals into constituent oscillations across frequency &/or time
- Two basic kinds of EEG oscillations:



- ***Evoked oscillations:*** time-locked to stimulus events
- ***Induced oscillations:*** not time-locked to stimulus events

Image from Hermann et al. (2005). ***EEG oscillations and wavelet analysis. In T. C. Handy (Ed.), Event-Related Potentials (pp. 229–260). Cambridge, MA: MIT Press.***

- ***EEG Power*** = strength of EEG oscillations within specific frequency bands

- Three kinds of EEG power:

Total Power: mixture of evoked & induced oscillations
- Determined by computing power for each individual trial (total power) & then averaging across trials

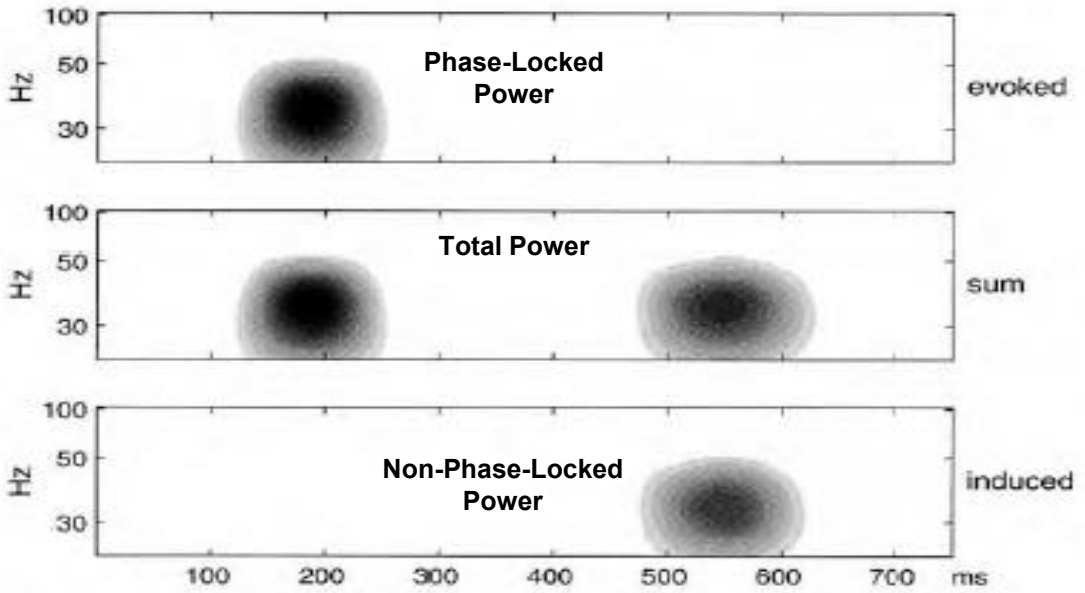
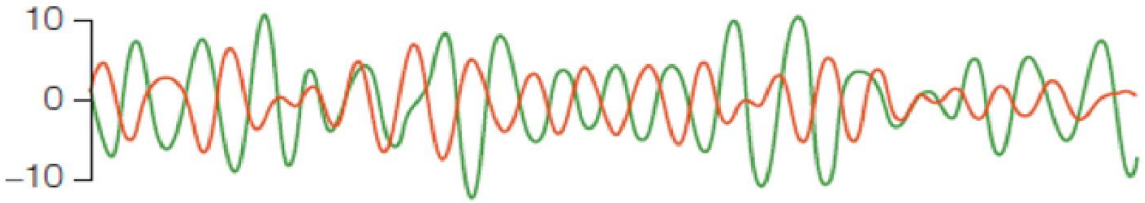


Image from Hermann et al. (2005). *EEG oscillations and wavelet analysis. In T. C. Handy (Ed.), Event-Related Potentials (pp. 229–260). Cambridge, MA: MIT Press.*

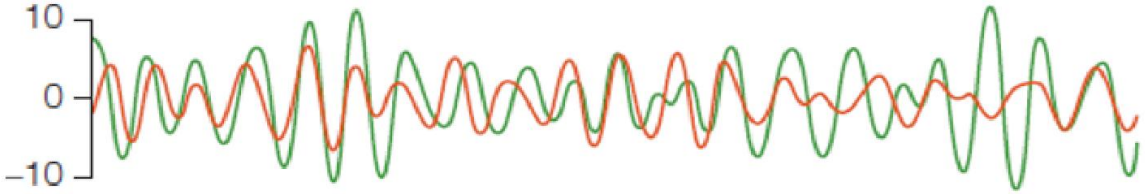
Phase-Locked Power = > Evoked Oscillations
- Computed by averaging EEG trials first before computing power

Non-Phase-Locked Power => Induced Oscillations
- Determined by computing total power & subtracting phase-locked power

EEG Phase Coherence = Phase consistency ("synchronization") of EEG responses within specific frequency bands



Unsynchronized waveforms = Low Phase Coherence

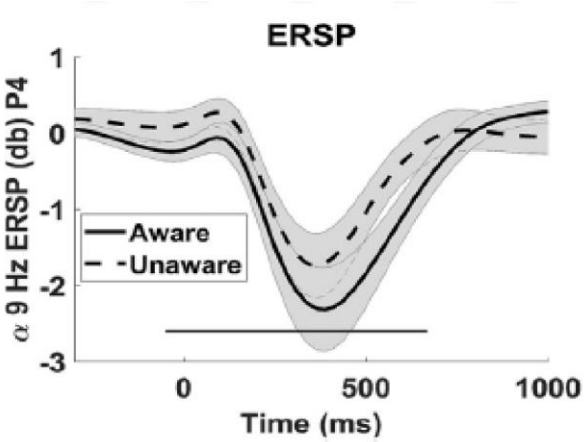


Synchronized waveforms = High Phase Coherence

Image adapted from *Goldstein & Cacciamani (2022). Sensation & Perception 11th Edition.* Cengage Learning.

- Synchronization can occur for a single EEG signal with itself across trials (***Inter-Trial Phase Coherence, ITPC***) or between EEG signals across trials (***Inter-Site Phase Coherence, ISPC***)

- Only three recent studies (Benwell et al., 2017, 2022;Tafuro & Mazzi, 2023) have explicitly examined VAN/LP-related EEG power & phase relationships



Images from Tafuro et al. (2023). *European Journal of Neuroscience, 57,* 2136–2148

General Findings:

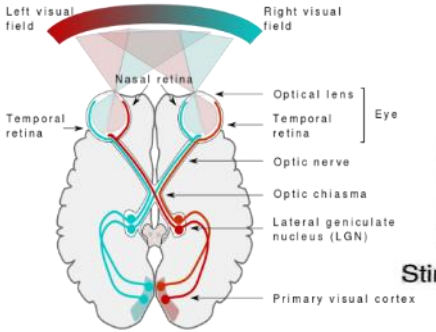
- Wideband (3 – 40 Hz) total EEG power across pre- & post-stimulus intervals inversely-related to subjective awareness of presented stimuli
- EEG phase coherence inversely-related to subjective awareness of presented stimuli across post-stimulus interval

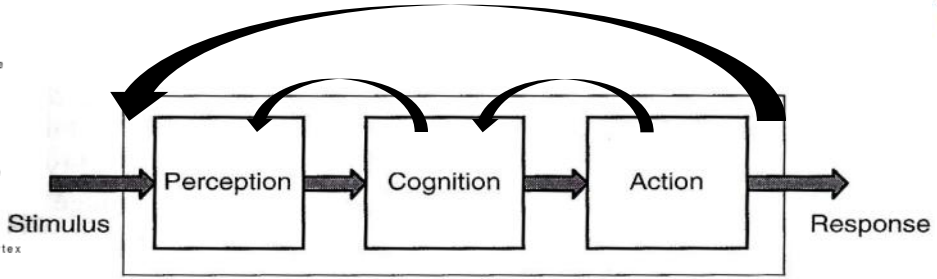
- However, none of these studies separately indexed evoked & induced EEG oscillations

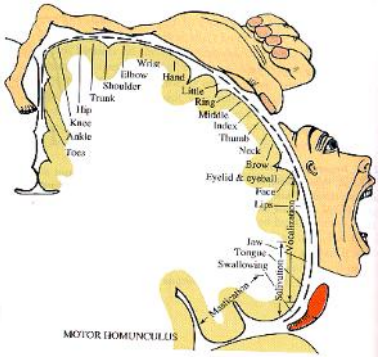
Open Question: Do VAN/LP-related ERP responses reflect evoked oscillations, induced oscillations, or both?

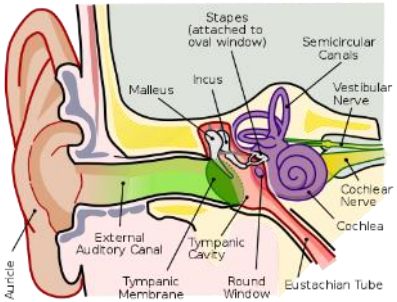
2) EEG Functional Integration & Topological Complexity

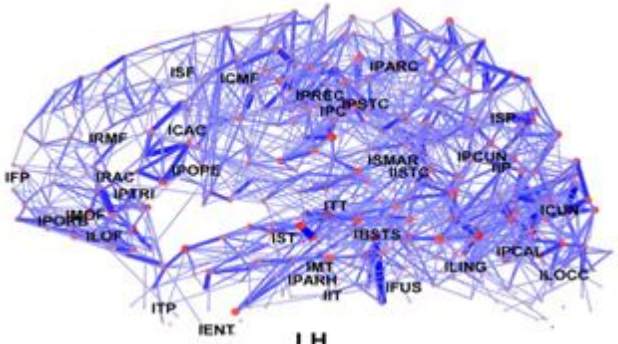
- Motivated by observations that perception, cognition, & behavior are associated with complex spatiotemporal organization of the brain emerging from neural interactions across local & global scales

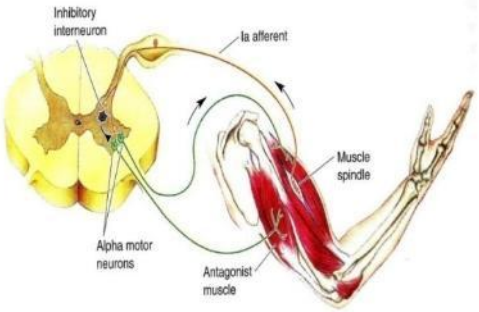








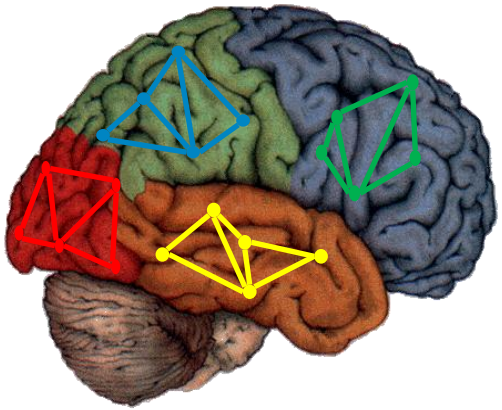




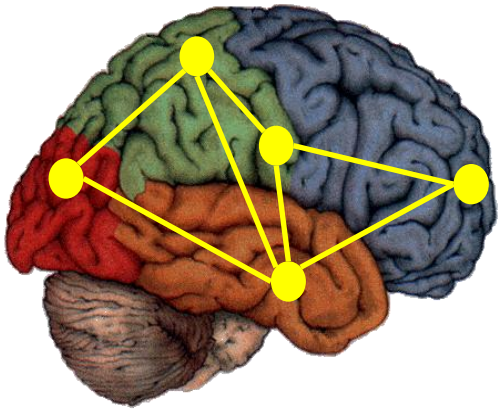
- Topological complexity of the brain arises from the interplay of two key organizational properties of brain networks (Tononi et al., 1994,1996, 1998a,b; Bullmore & Sporns, 2009; Fair et al., 2009; Rubinov & Sporns, 2010)

Segregation: division of information processing across regional clusters within a neural system

High Segregation

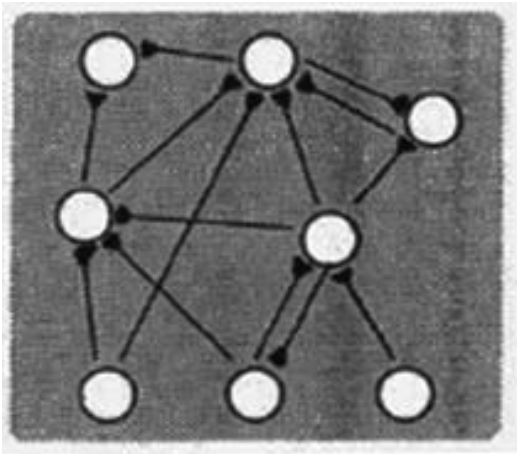


Low Segregation

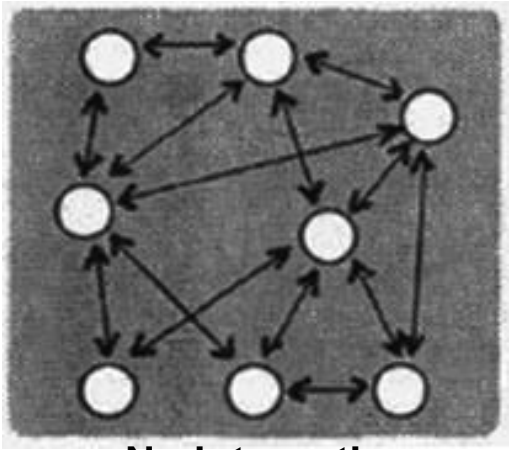


- High segregation => **Differentiation**: a large # of different brain states

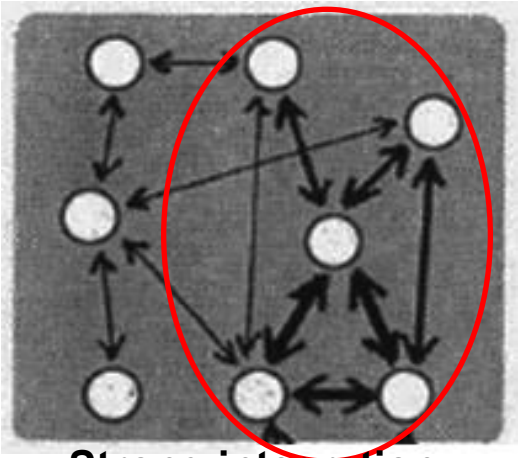
Integration: combination of information processing within & across distributed brain networks



Neural system



No integration (thin arrows)



Strong integration (thick arrows)

Images adapted from *Tononi et al. (1996). PNAS, 93, 3422-3427*

- Integrated subsets of elements within a neural system interact more strongly with each other than the rest of the system
- Integration & segregation have an inverse relationship to each other (i.e., when integration is low, segregation is high & vice-versa)

- **Topological complexity** then reflects the relative balance of segregation & integration

  - Complexity is highest for "patchy" network connectivity, aka long-range connectivity between distinct neural clusters

  - Such "patchy" connectivity reflects coordinated interactions among brain elements engaged in various levels of subordination that are neither fully regular nor random (Tononi et al., 1998)

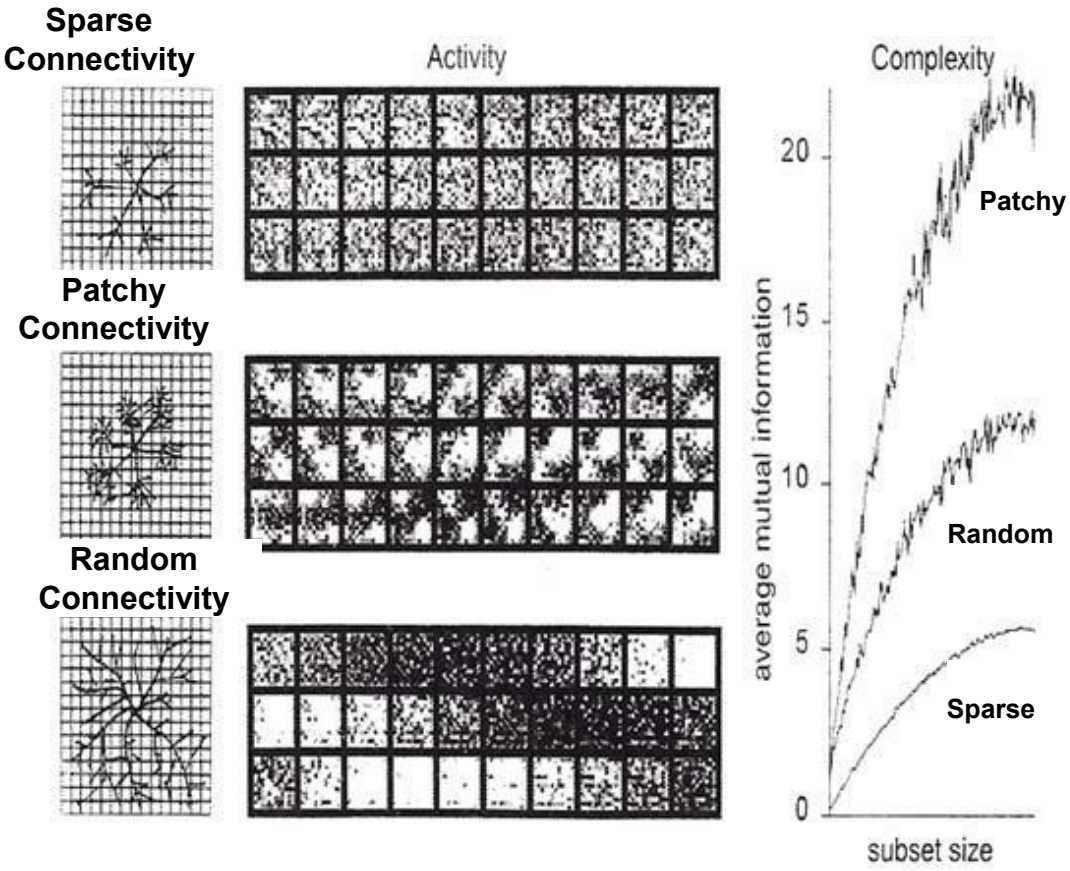


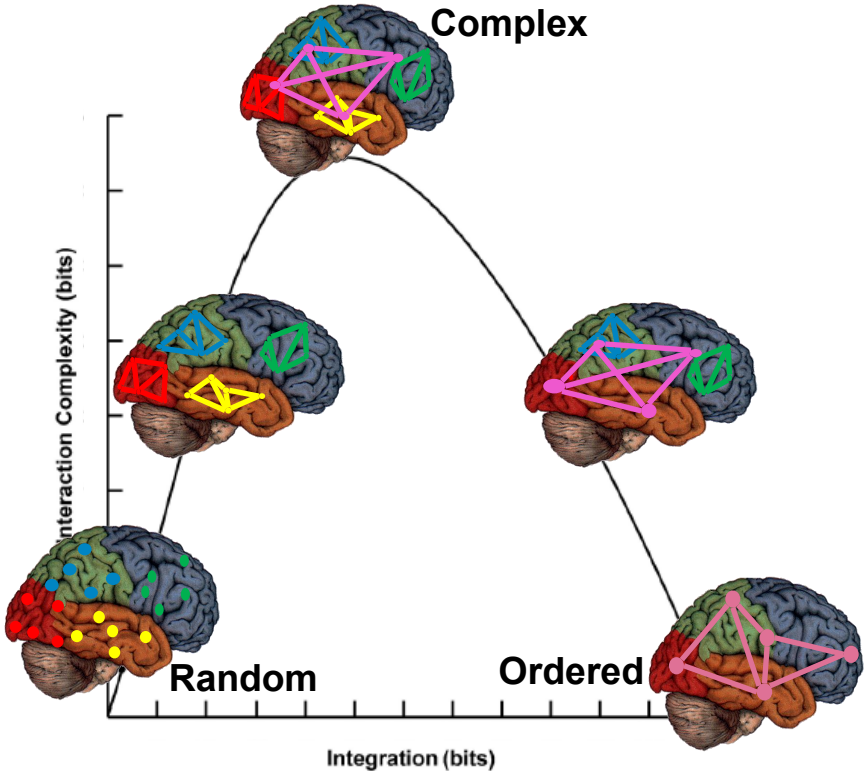
Image adapted from *Tononi et al. (1994). PNAS, 91, 5033-5037*

- One strategy to study the brain's complexity, integration, & segregation is to focus on the relationship between integration & complexity

(Trujillo, et al., 2017; Trujillo, 2019, 2026)

- This approach implicitly captures the segregation of the brain as well

- Integration/complexity relationship has a curvilinear inverted-U shape



Graph image adapted from *Trujillo (2019). Entropy, 21, 61.*

- To date, no studies have investigated the functional integration & complexity associated with the VAN & LP

The Present Study

Research Questions:

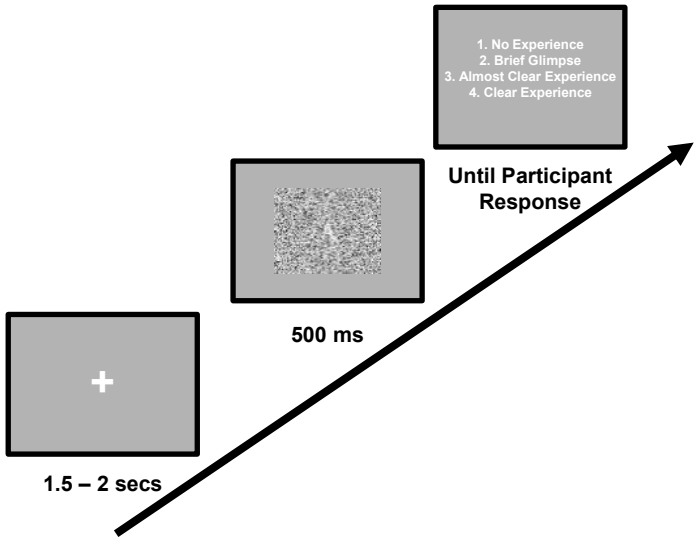
1) Do VAN & LP-related neural responses reflect evoked oscillations, induced oscillations, or both?

2) Do VAN & LP-related neural responses reflect functional integration & topological complexity of EEG responses?

- The present exploratory study addressed these questions using a variant of an experimental design previously employed to investigate the VAN (Melloni et al., 2011)

Methods

- Human participants (N = 27) performed a simple visual awareness task

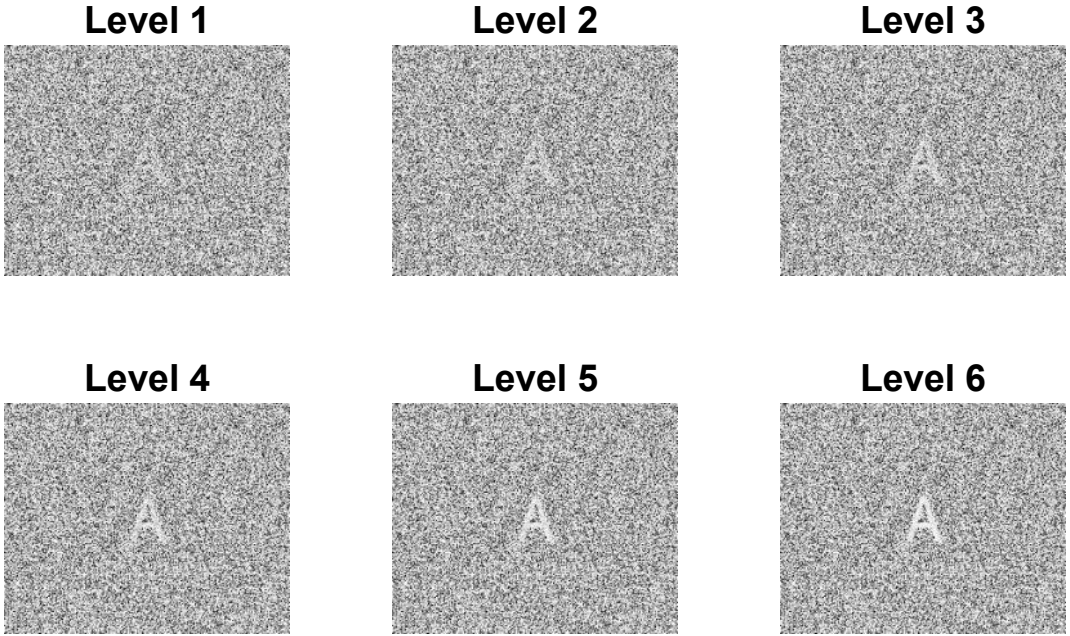


- Participants rated the visibility of letter & number targets overlaid with & surrounded by random visual noise

- 4 experimental blocks of 216 trials for a total of 864 trials

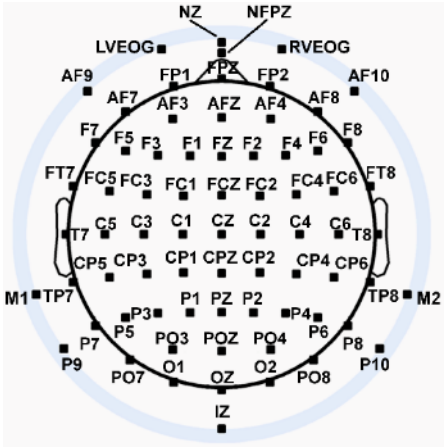
- Stimulus visibility ratings made according to 4-point Perceptual Awareness Scale (PAS; Overgaard, et al., 2004; 2006)

PAS
1 = No Experience
2 = Brief Glimpse
3 = Almost Clear Impression
4 = Clear Impression

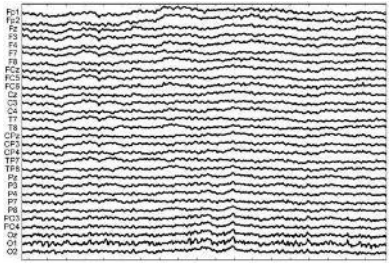


- Six target visibility levels
- Created by altering the transparency of visual noise overlaying targets while keeping background noise constant
  - Stimuli size were 0.65° – 2.35°(W) x 2.64° (H) at 65 cm viewing distance

EEG Recording & Pre-Processing







- 72 channels of scalp EEG signals recorded while Ss performed visual awareness task
  - BioSemi Active II system in 24-bit DC mode
  - 2048 Hz sampling rate down sampled to 512 Hz
  - Common mode sense reference electrode located between sites PO3/POZ
- EEG data pre-processed using standard procedures
  - Bad EEG channels replaced using spherical spline interpolation
  - EEG muscle & signal artifacts identified via visual inspection & manually removed
  - Ocular artifacts rejected via automatic threshold-based algorithm (± 50 mV threshold)
  - EEG data re-referenced to an average reference

ERP Analysis

- ERPs were constructed from trials according to whether the symbolic stimuli were evidently ***SEEN*** (*Almost Clear Experience, Clear Experience*) versus ***NOT SEEN*** (*No Experience, Brief Glimpse*)

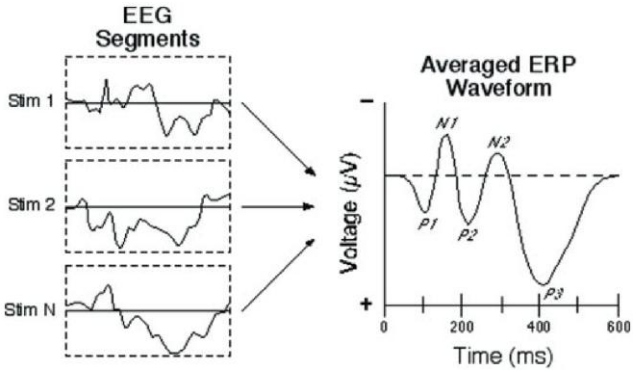


Image adapted from Léger et al. (2014). *Journal of the Association for Information Systems, 15(10),* 651-678

- ERPs constructed using standard procedures
  - EEG data was first bandpass filtered from 0.5 to 30 HZ bandpass (3881-point zero-phase shift finite impulse response filter; 0.44 Hz transition bands)
  - Then EEG divided into 700 ms trials spanning -200 to 500 ms relative to stimulus onset
  - All trials baseline-corrected by subtracting mean value over -200 to 0 ms pre- stimulus interval for each electrode
  - ERP component amplitudes quantified for each participant & condition (***SEEN, NOT SEEN***) as mean amplitude over defined intervals (P2: 150 – 300 ms; LP: 300 – 500 ms)

Time-Frequency Analysis

- Phase-locked & non-phase-locked EEG spectral power & inter-trial phase coherence (ITPC) were computed via a wavelet-based time-frequency analysis

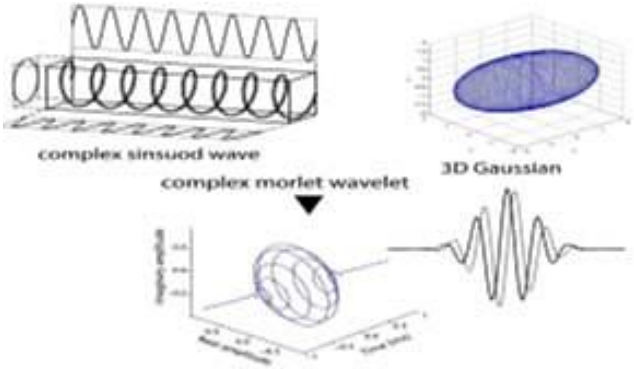
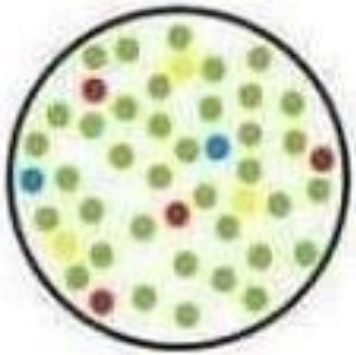


Image adapted from Gabry et al. (2026). *Energies, 19(9),* 2211

- TF analysis performed using standard procedures
- Complex Morlet wavelet with Gaussian temporal-frequency shape (α = 4.7; σ_f = 0.21 – 6.38 Hz, σ_t = 0.025 – 0.75 sec over the 1 – 30 Hz in1 Hz intervals)
- Wavelet transform performed on 2 sec epochs constructed by value-padding the original EEG epochs to reduce edge effects (Addison, 2017)
- Transformed epochs then truncated to the original -500 ms to +500 ms interval relative to stimulus onset
- Spectral measures baseline-corrected to mean pre-stimulus interval (-500 ms to 0 ms) for each electrode, condition (***SEEN, NOT SEEN***), & participant

EEG Functional Integration & Topological Complexity Analysis

- Computed using information-theoretic measures (Tononi et al., 1994; 1998)

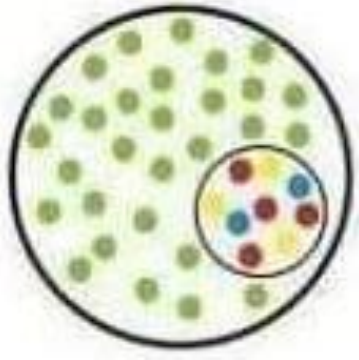


- ***Functional integration*** quantified in terms of "deviations from statistical independence among components of a neural system" (Tononi et al.,1994, p. 5033)

$$I(X) = \sum_{i=1}^{d} H(x_i) - H(X)$$

- Topological complexity indexed via ***interaction complexity*** metric (Tononi et al.,1998) that quantifies the information content resulting from the interactions among the brain's elements

$$C_I(X) = H(X) - \sum_{i=1}^{d} H(x_i|X - x_i)$$



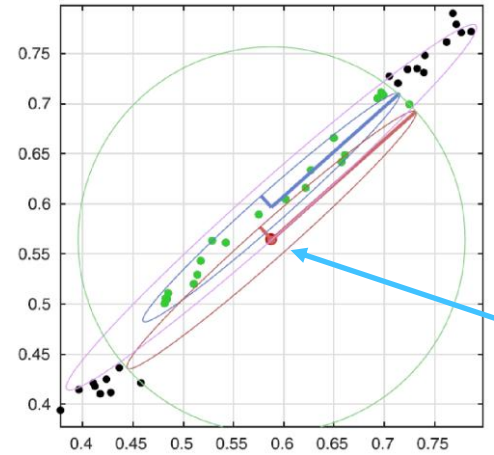
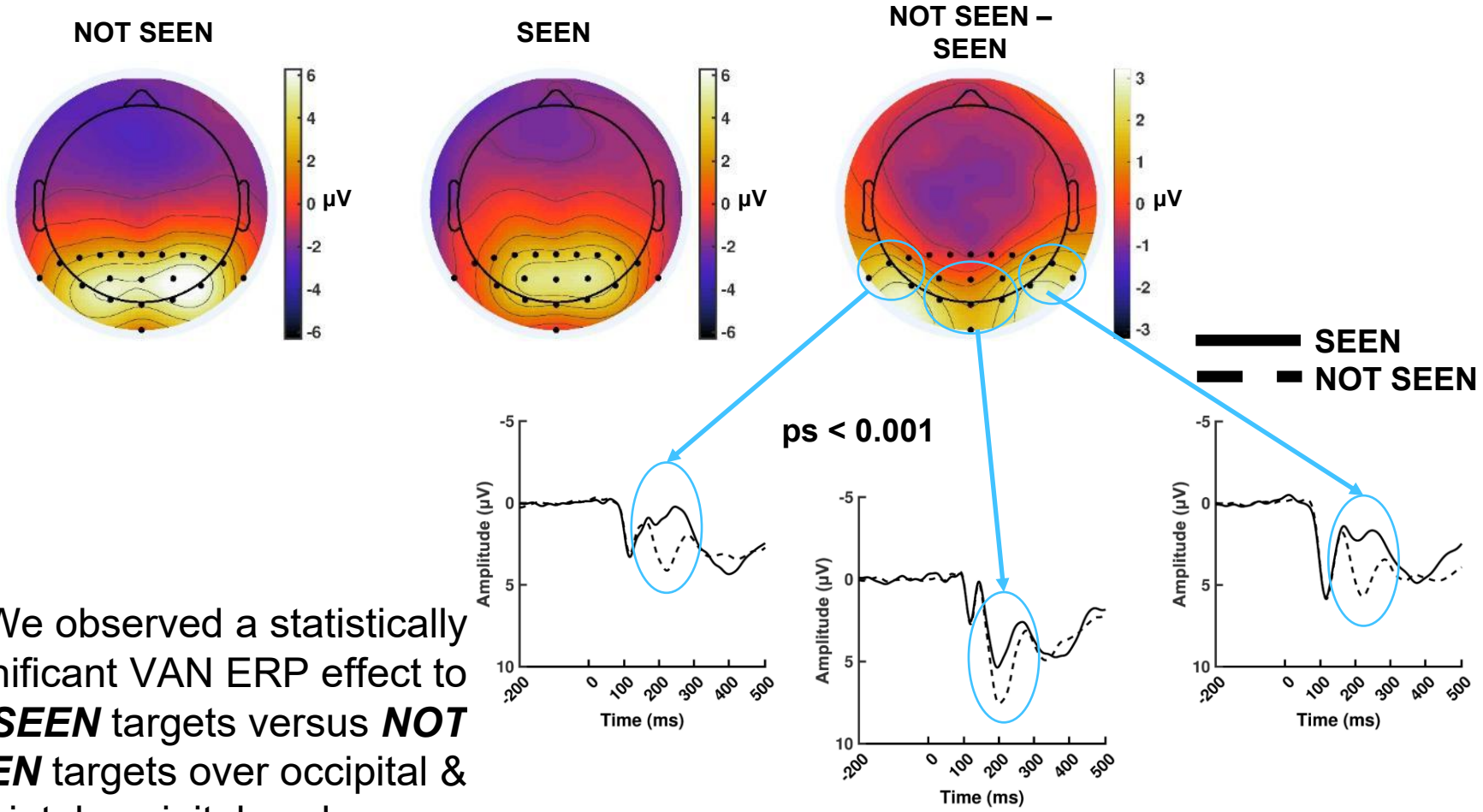


Image adapted from Lord et al. (2018). *Chaos 28,* 033114

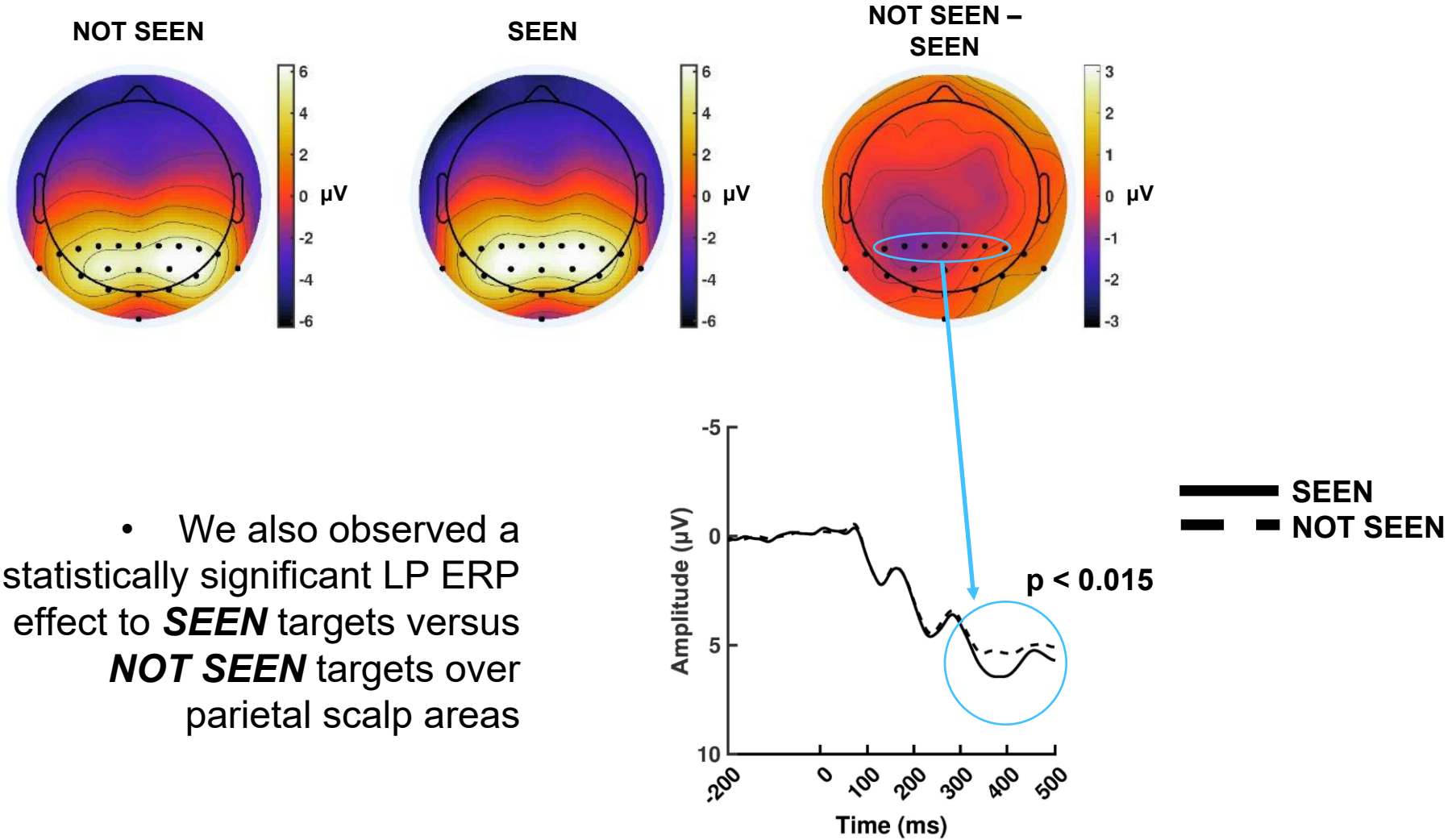
Additional Details

- Data entropy components computed using univariate & multivariate nonparametric geometric k-nearest neighbors (G-KNN) estimator (Lord et al., 2018; Trujillo, 2019 & 2026)
- Achieved by expressing volumes of neighborhoods of data points in terms of distances from each data point to other neighborhood data points (KNN free parameter k = 216 = 3 * # of electrodes)
- EEG data transformed into Laplacian-based current source densities (CSD: $\mu V/m^2$ units) to diminish spatial mixing effects of volume conduction
- Integration/complexity computation performed for mean-centered 500 ms pre-stimulus & post stimulus intervals
- Final integration/complexity measures computed as post- minus pre-stimulus difference, reflecting the stimulus related change in functional integration & interaction complexity
- Analysis restricted to alpha-band (8-12 Hz) frequency range based on previous observations (Trujillo et al., 2018; Trujillo, 2019, 2026) & time-frequency findings of the present study

Results: ERPs

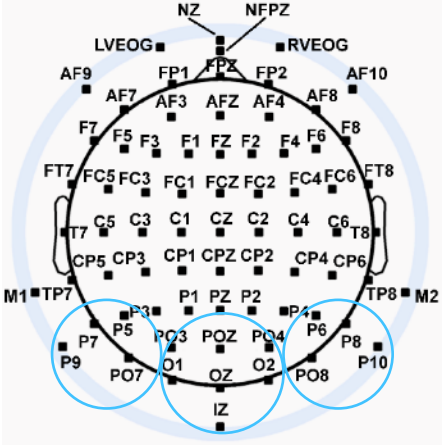


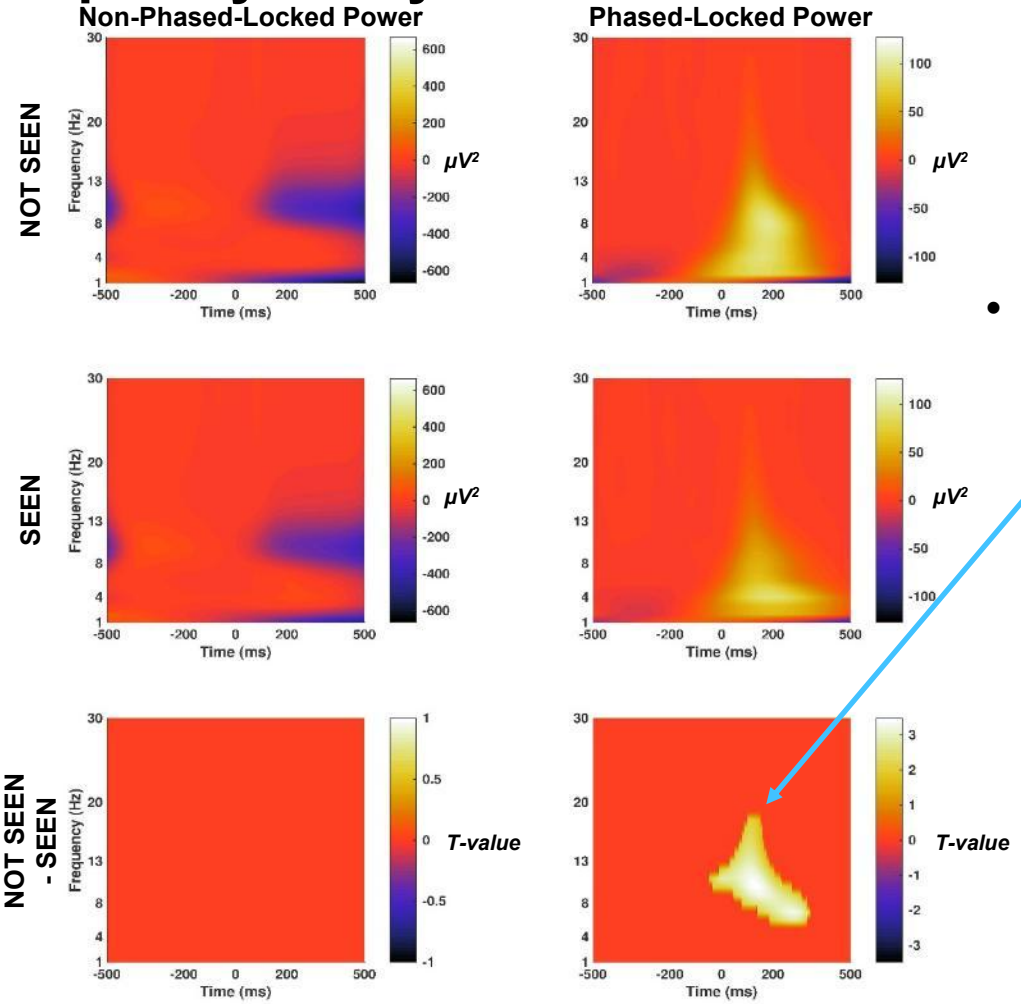
- We observed a statistically significant VAN ERP effect to ***SEEN*** targets versus ***NOT SEEN*** targets over occipital & parietal-occipital scalp areas



- We also observed a statistically significant LP ERP effect to ***SEEN*** targets versus ***NOT SEEN*** targets over parietal scalp areas

Results: Time-Frequency Analysis

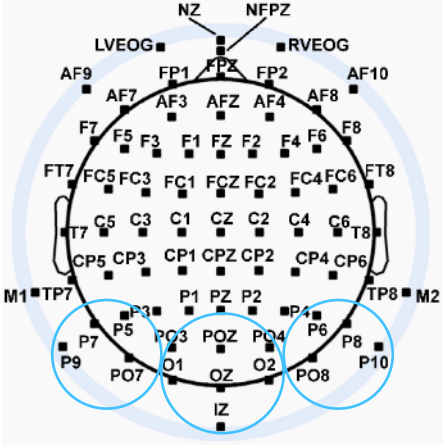


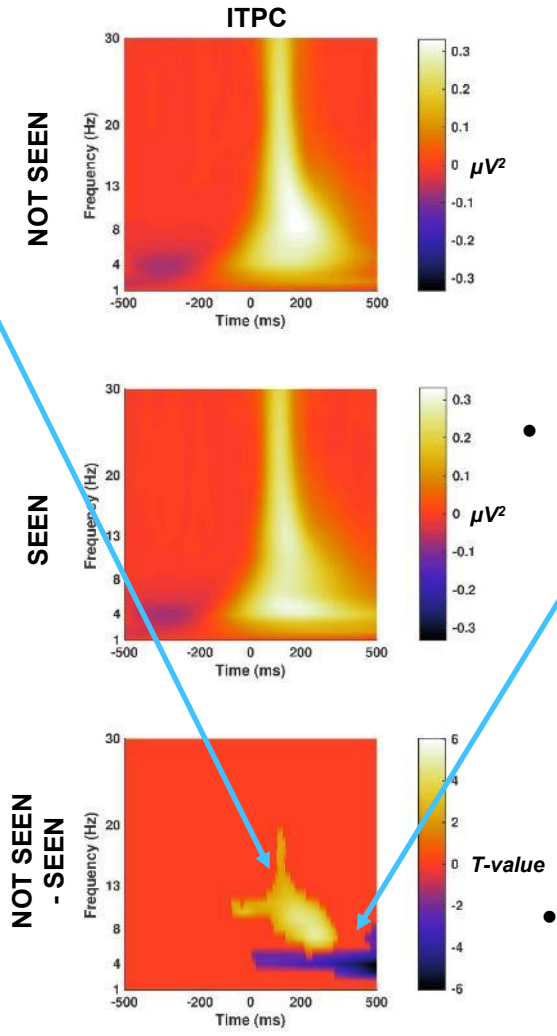


- Greater alpha-band (8 – 12 Hz) phase-locked EEG power within the VAN time range over occipital/parietal-occipital scalp for ***NOT SEEN*** versus ***SEEN*** targets

- Greater alpha-band (8 – 12 Hz) ITPC within the VAN time range over the occipital/parietal-occipital scalp for ***NOT SEEN*** versus ***SEEN*** targets

=> across-trial phase-consistency differences consistent with presence of evoked oscillations

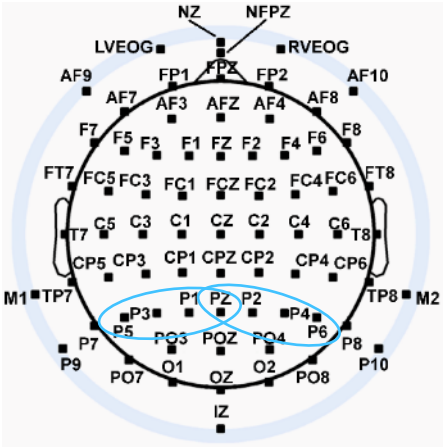


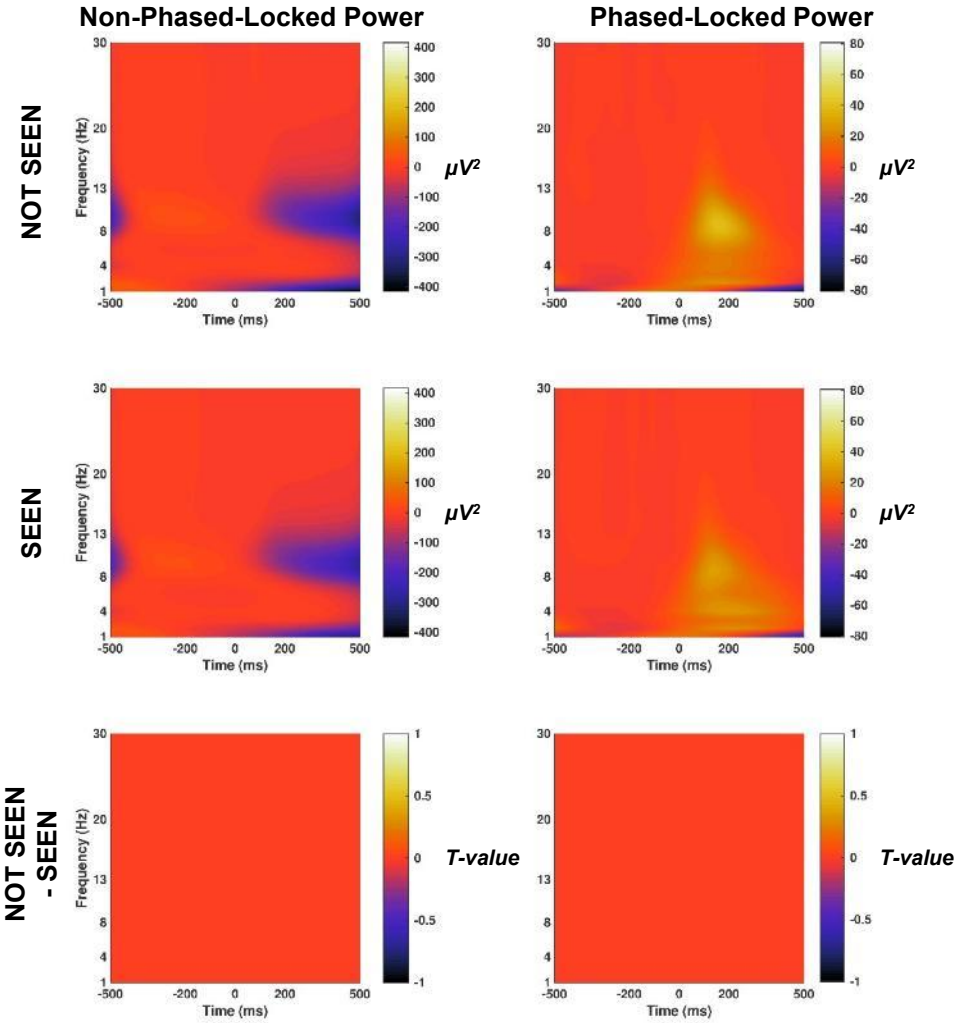


- Smaller delta/theta (3 – 7 Hz) ITPC over the occipital/parietal-occipital scalp for ***NOT SEEN*** versus ***SEEN*** targets across a longer time range that included the LP

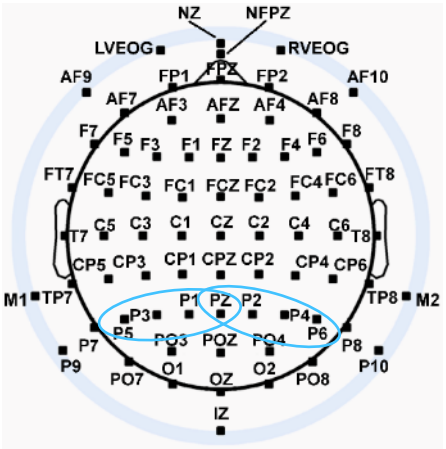
- This effect likely reflects LP differences

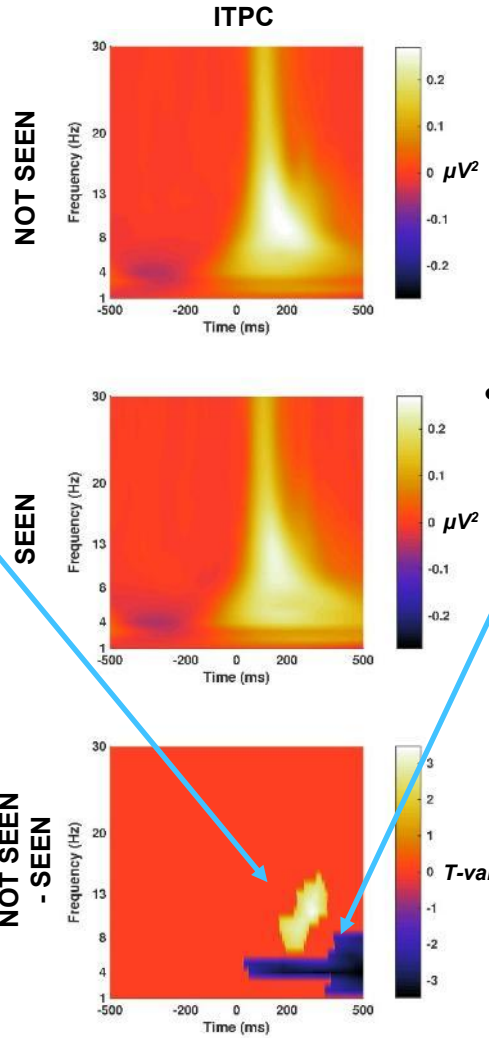
- No significant EEG power differences within the LP time range over the parietal scalp for ***NOT SEEN*** versus ***SEEN*** targets





- Greater alpha/beta-band (8 – 15 Hz) ITPC within the VAN time range over the parietal scalp for ***NOT SEEN*** versus ***SEEN*** targets

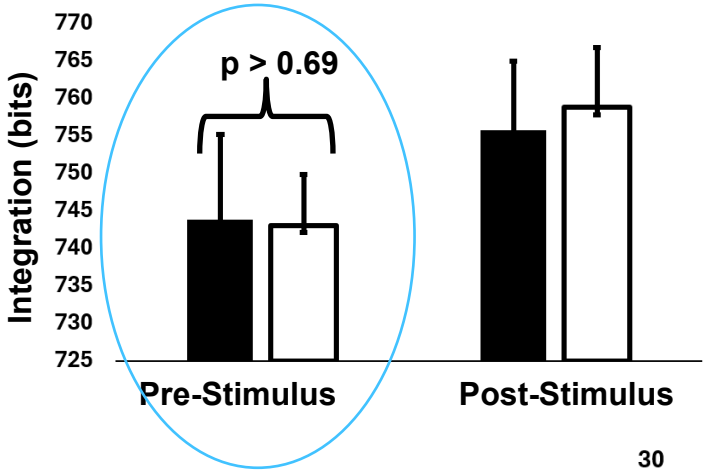




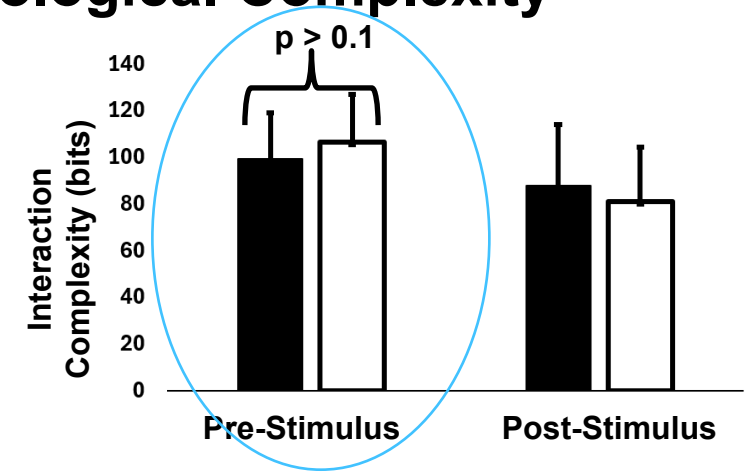
- Smaller delta/theta (1 – 7 Hz) ITPC for ***NOT SEEN*** versus ***SEEN*** targets over parietal scalp across a longer time range that included the LP

- Indicates across-trial phase-consistency differences consistent with presence of evoked oscillations

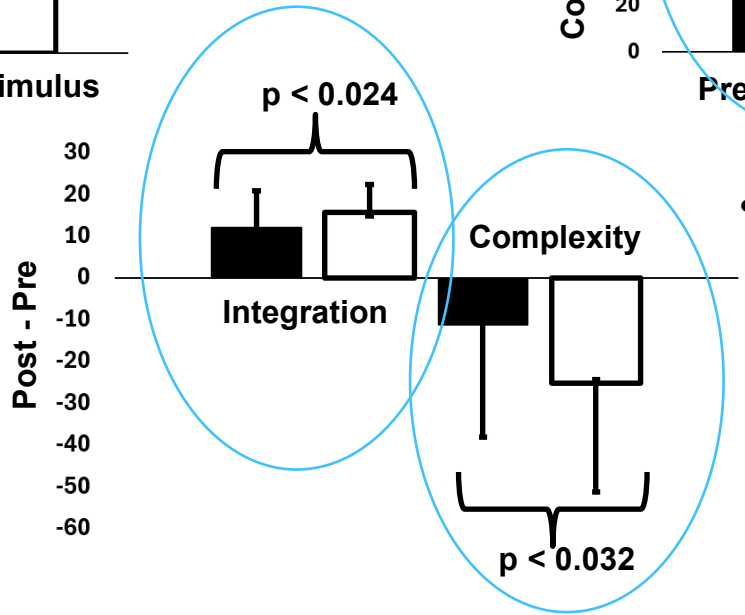
Results: Functional Integration & Topological Complexity







- Stimulus-related increase in integration of alpha-band (8 – 12 Hz) phase-locked EEG signals was smaller for SEEN versus NOT SEEN targets



- Stimulus-related decrease in interaction complexity was smaller for SEEN versus NOT SEEN targets

- No non-phase-locked integration/complexity effects, ps > .1

Summary

- This study investigated the relationship of the VAN & LP to more general stimulus-evoked EEG brain responses

Basic Findings

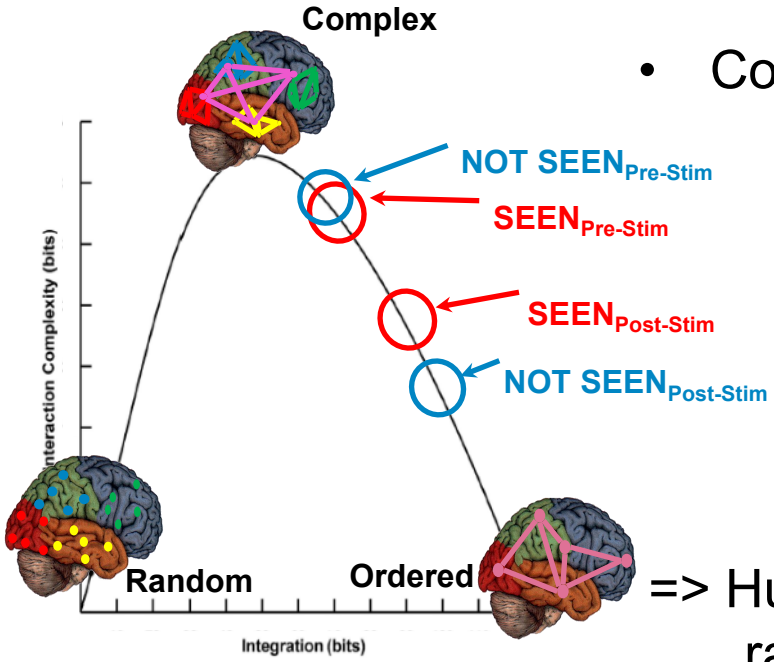
1) VAN & LP related to evoked oscillations but not induced oscillations in alpha-band range

- Consistent with observation that evoked oscillations typically present during early low-level stimulus processing (Hermann et al., 2005)

- Lack of significant LP induced oscillations is surprising because they are traditionally thought to reflect high-level stimulus processing (Haenschel et al., 2000; David et al., 2006; Chen et al., 2012) that may be present during reflective, access consciousness

2) Stimulus-related increase/decrease in integration & interaction complexity of alpha-band (8 – 12 Hz) phase-locked EEG signals was larger for NOT SEEN versus SEEN targets

- No integration/complexity effects for non-phase-locked alpha-band EEG



Graph image adapted from *Trujillo (2019). Entropy, 21, 61.*

- Consistent with findings of VAN & LP relationship to evoked, but not induced, oscillations

- Direction of stimulus-related integration & complexity changes consistent with previous observations (Trujillo, et al., 2017; Trujillo, 2019, 2026)

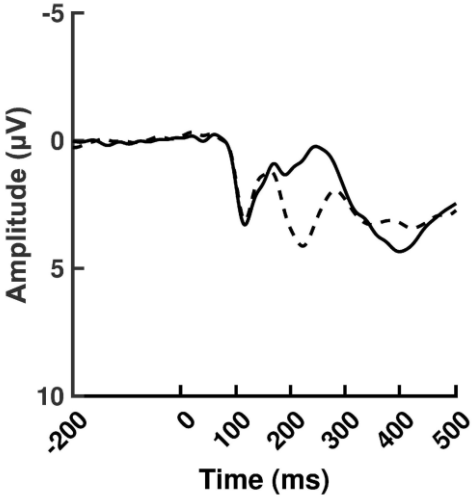
=> Human conscious vision related to medium-high range of functionally integrated & topologically complex brain dynamics (Edelman & Tononi, 2000)

Study Limitations

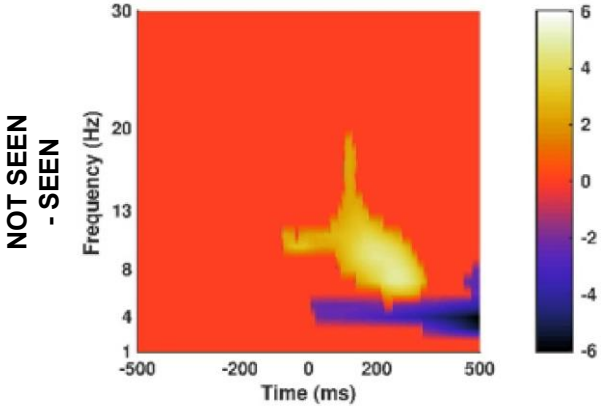
- LP results should be interpreted with caution
  - Experimental design may have affected later stimulus processing (short presentation time, no high-level stimulus evaluation)
  - Will be addressed in a follow-up experiment
- Cannot conclude from current analysis if integration & complexity changes reflect VAN, LP, or both due to temporal resolution limits of G-KNN entropy method
  - Can be investigated by
  - i) parametrically changing G-KNN k parameter
  - ii) restricting analysis to smaller time windows
  - iii) increasing EEG sampling rate in follow-up experiment

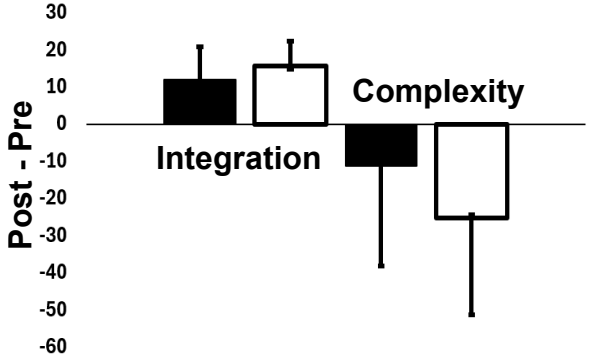
General Conclusion

- The consciousness-related neural processes underlying the VAN & LP are more multifaceted than indicated by previous research & warrant further study









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