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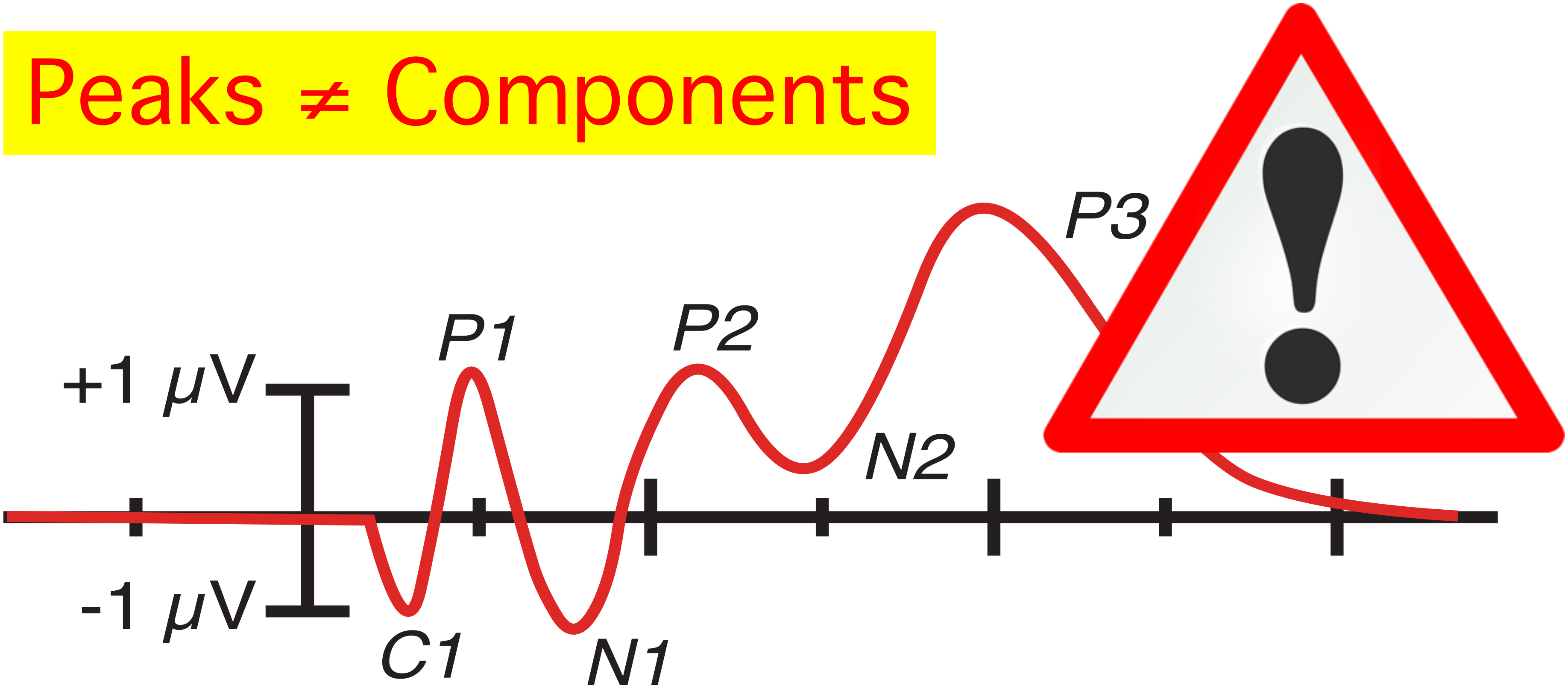
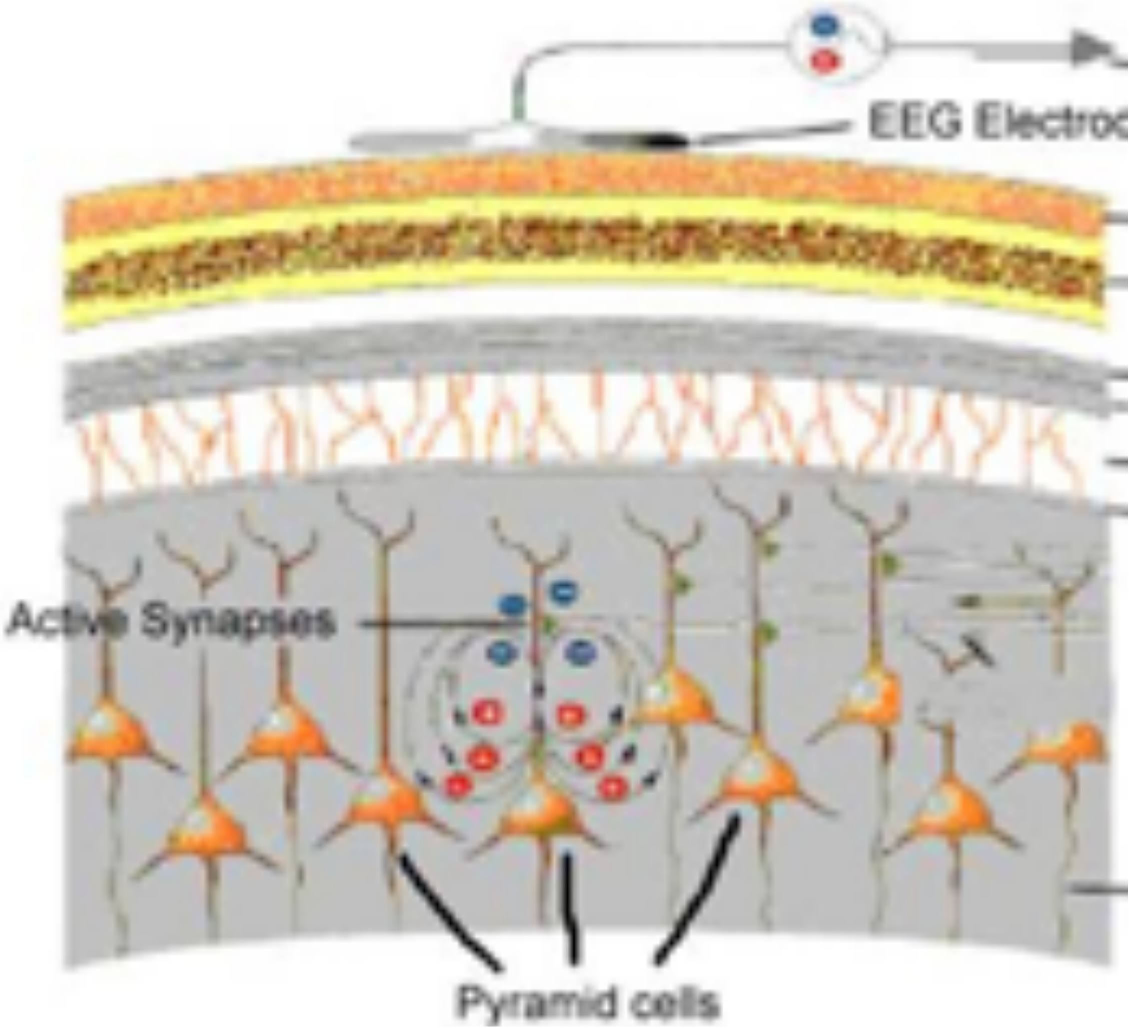
ERP Components

What is an ERP Component?

Peaks ≠ Components



Peaks are things that we observe in our scalp recordings, whereas components occur in the brain and can't be directly observed from scalp electrodes. The observed peaks are the result of the underlying brain components, but the relationship can be complex.

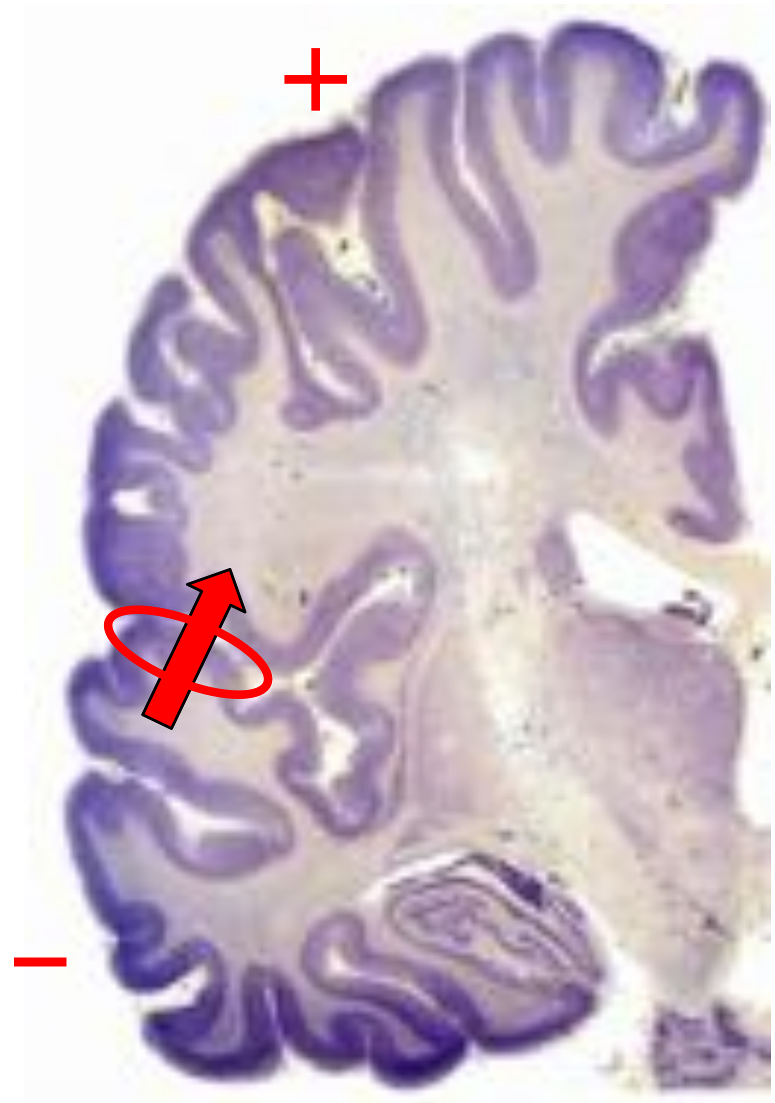


http://www.psych.nmsu.edu/~jkroger/lab/EEG_Introduction.html

With a few rare exceptions, ERPs are generated by cortical pyramidal cells during neurotransmission. To be visible on the scalp, a large number of neurons must be active at the same time.

The extracellular electric fields produced during neurotransmission sum across the neurons in an area, forming an equivalent current dipole that points perpendicular to the active cortical surface.

This will give us a negativity in our scalp EEG electrodes on one side of the dipole and a positivity on the other side.



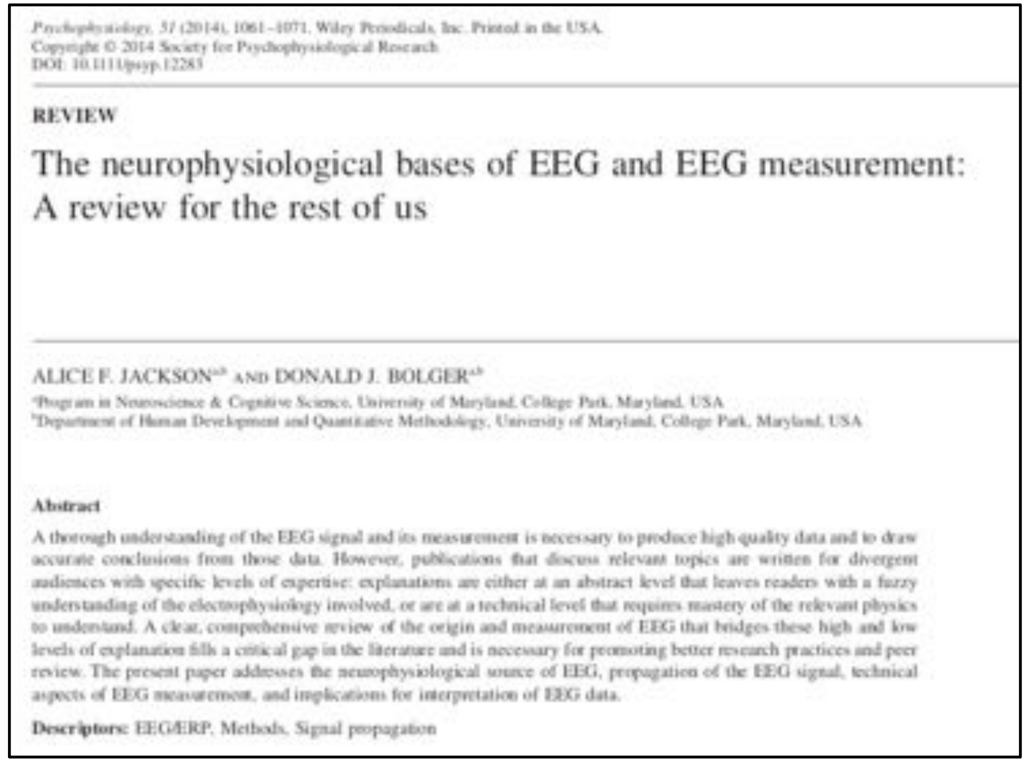
DeFelipe (2022)

nature reviews
neuroscience

The origin of extracellular fields and currents — EEG, ECoG, LFP and spikes

György Buzsáki[1,2,3], Costas A. Anastassiou[4] and Christof Koch[4,5]

Abstract | Neuronal activity in the brain gives rise to transmembrane currents that can be measured in the extracellular medium. Although the major contributor of the extracellular signal is the synaptic transmembrane current, other sources — including Na^+ and Ca^{2+} spikes, ionic fluxes through voltage- and ligand-gated channels, and intrinsic membrane oscillations — can substantially shape the extracellular field. High-density recordings of field activity in animals and subdural grid recordings in humans, combined with recently developed data processing tools and computational modelling, can provide insight into the cooperative behaviour of neurons, their average synaptic input and their spiking output, and can increase our understanding of how these processes contribute to the extracellular signal.



Psychophysiology, *51* (2014), 1061–1071. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/psyp.12283

REVIEW

The neurophysiological bases of EEG and EEG measurement: A review for the rest of us

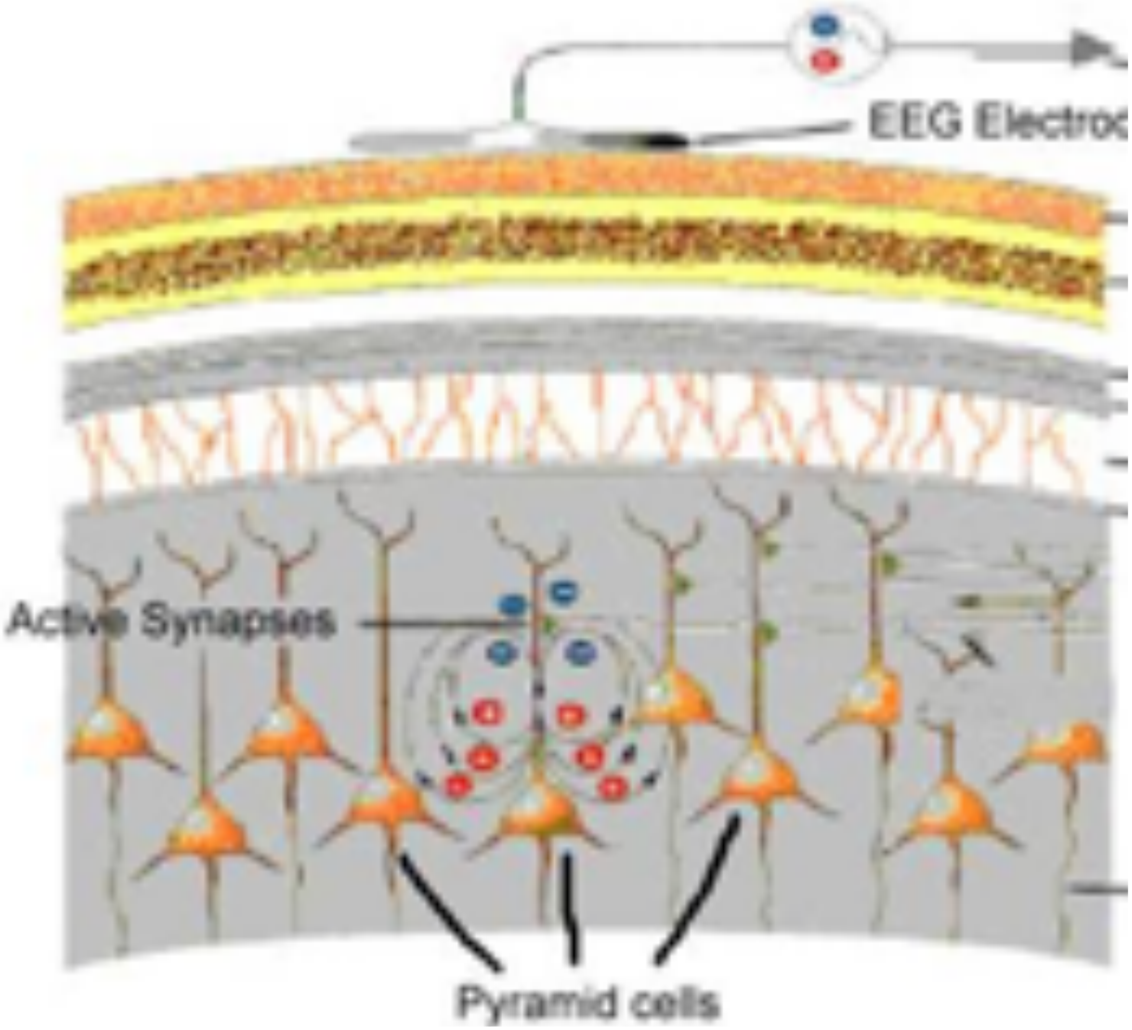
ALICE F. JACKSON[a,b] AND DONALD J. BOLGER[a,b]
[a]Program in Neuroscience & Cognitive Science, University of Maryland, College Park, Maryland, USA
[b]Department of Human Development and Quantitative Methodology, University of Maryland, College Park, Maryland, USA

Abstract
A thorough understanding of the EEG signal and its measurement is necessary to produce high quality data and to draw accurate conclusions from those data. However, publications that discuss relevant topics are written for divergent audiences with specific levels of expertise: explanations are either at an abstract level that leaves readers with a fuzzy understanding of the electrophysiology involved, or are at a technical level that requires mastery of the relevant physics to understand. A clear, comprehensive review of the origin and measurement of EEG that bridges these high and low levels of explanation fills a critical gap in the literature and is necessary for promoting better research practices and peer review. The present paper addresses the neurophysiological source of EEG, propagation of the EEG signal, technical aspects of EEG measurement, and implications for interpretation of EEG data.

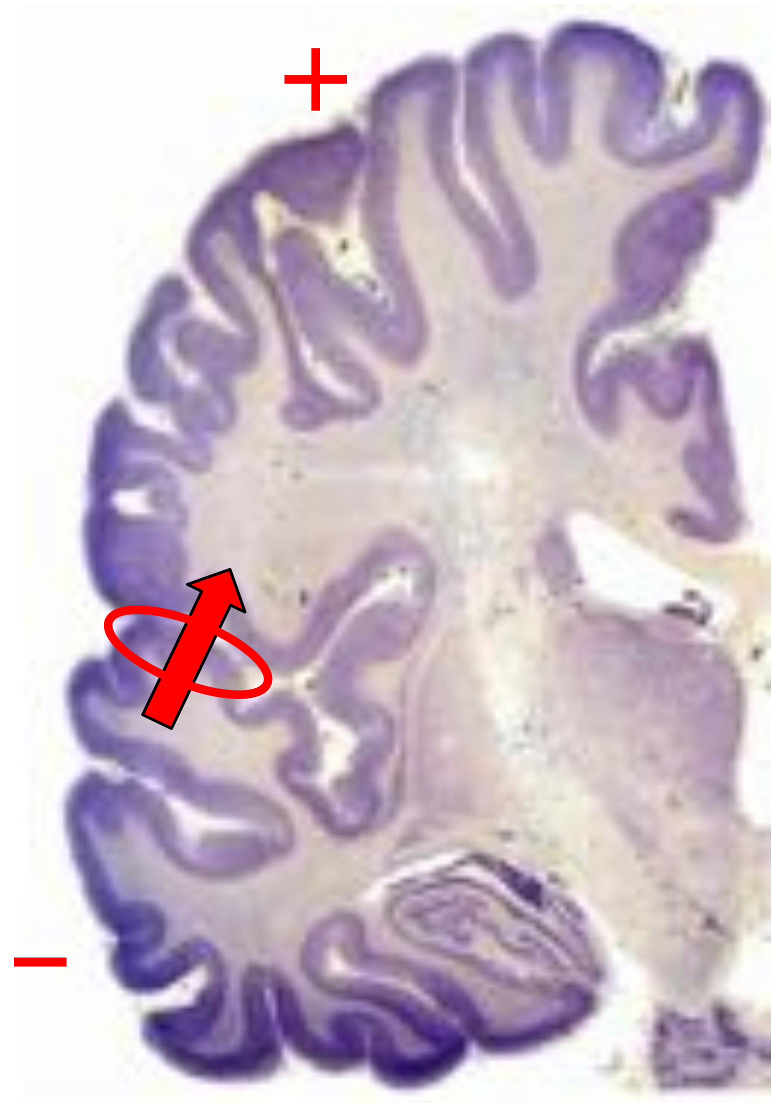
Descriptors: EEG/ERP, Methods, Signal propagation

Buzsáki, G., Anastassiou, C. A., & Koch, C. (2012). The origin of extracellular fields and currents—EEG, ECoG, LFP and spikes. *Nature Reviews Neuroscience*, *13*, 407–420.

Jackson, A. F., & Bolger, D. J. (2014). The neurophysiological bases of EEG and EEG measurement: A review for the rest of us. *Psychophysiology*, *51*(11), 1061–1071.



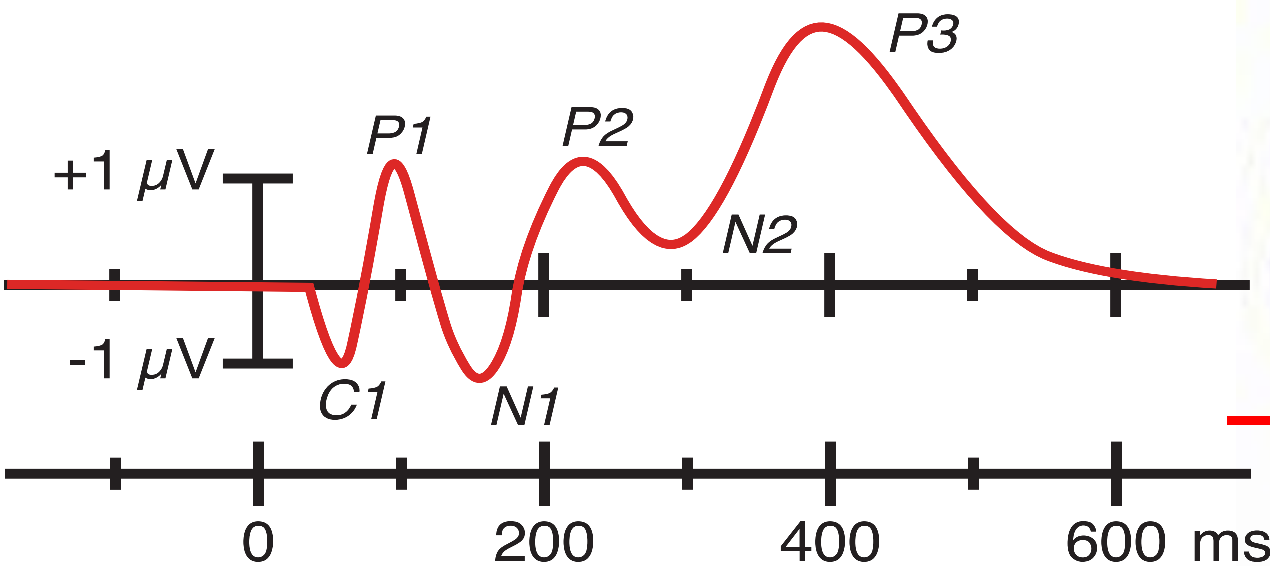
http://www.psych.nmsu.edu/~jkroger/lab/EEG_Introduction.html

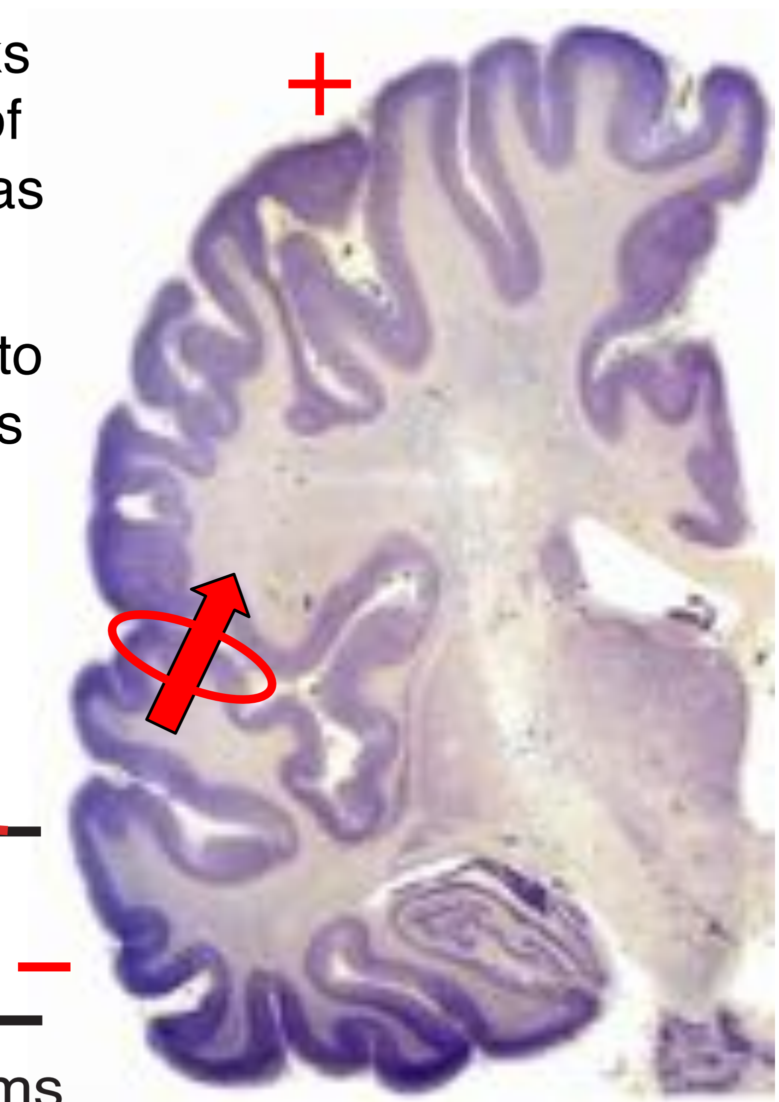


DeFelipe (2022)

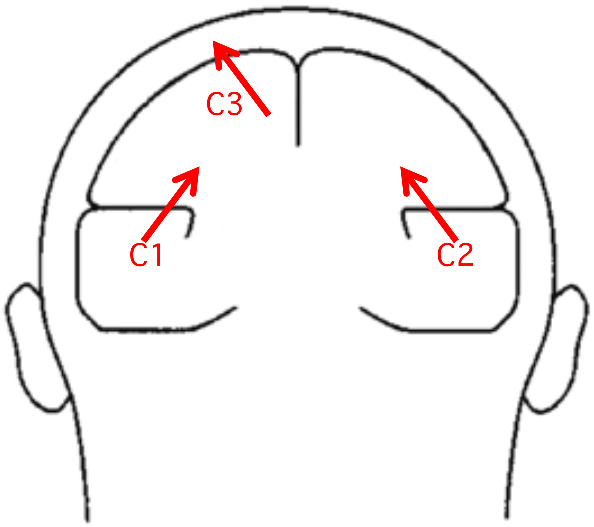
The sequence of positive and negative peaks at a given scalp electrode reflects the sum of many of these components, each of which has its own time course.

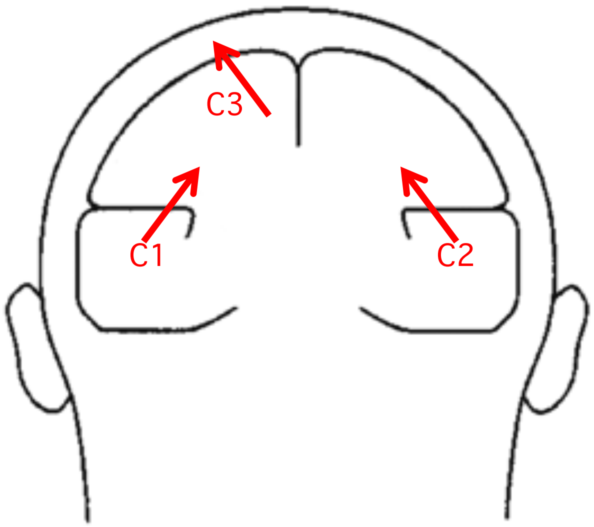
The components overlap in time. It's difficult to tell when a single component actually begins and ends by looking at the ERP waveform.



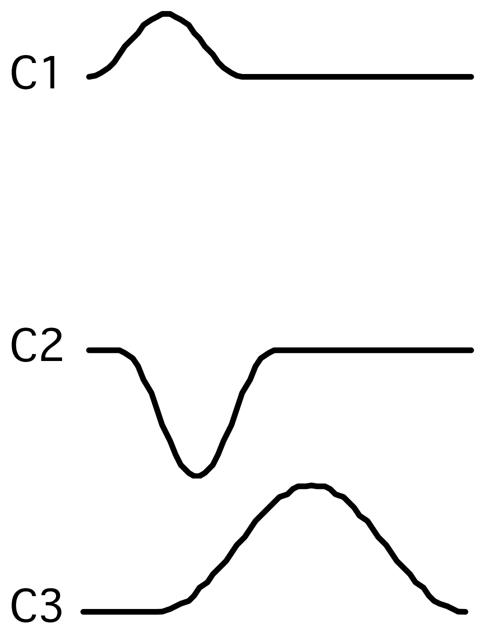


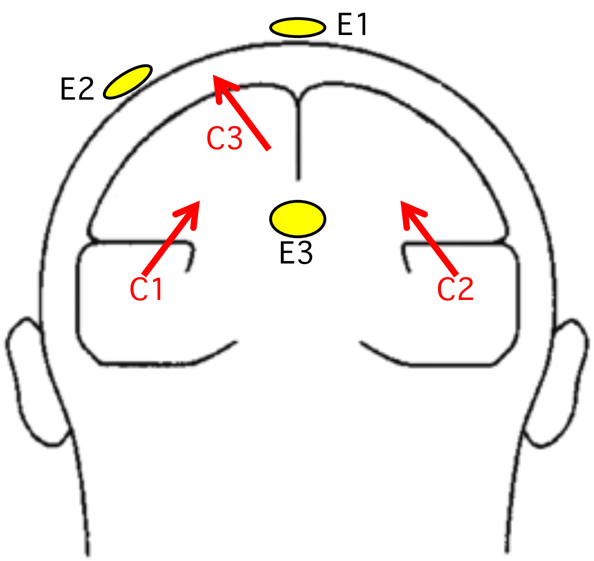
DeFelipe (2022)


C3
C1
C2

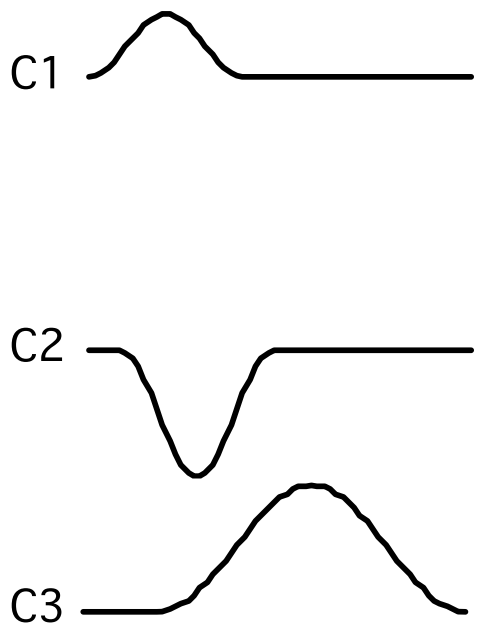


Source Waveforms



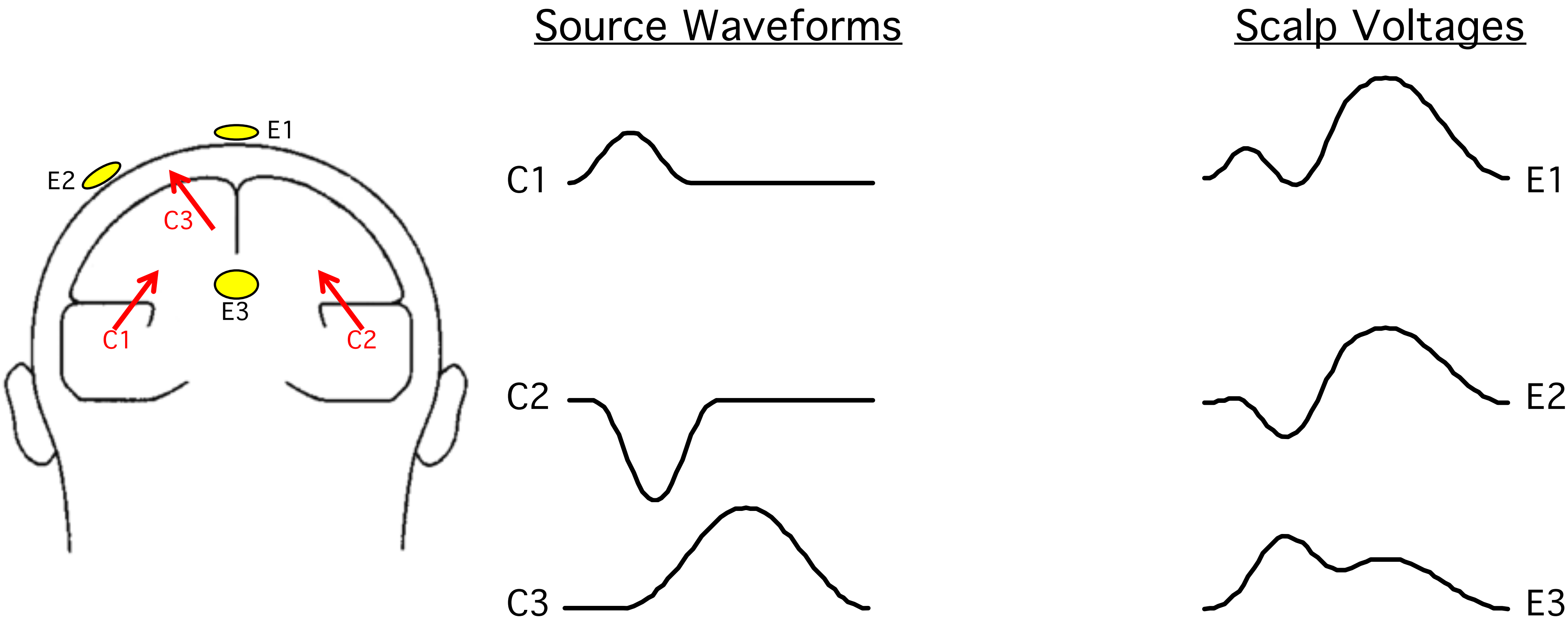


Source Waveforms



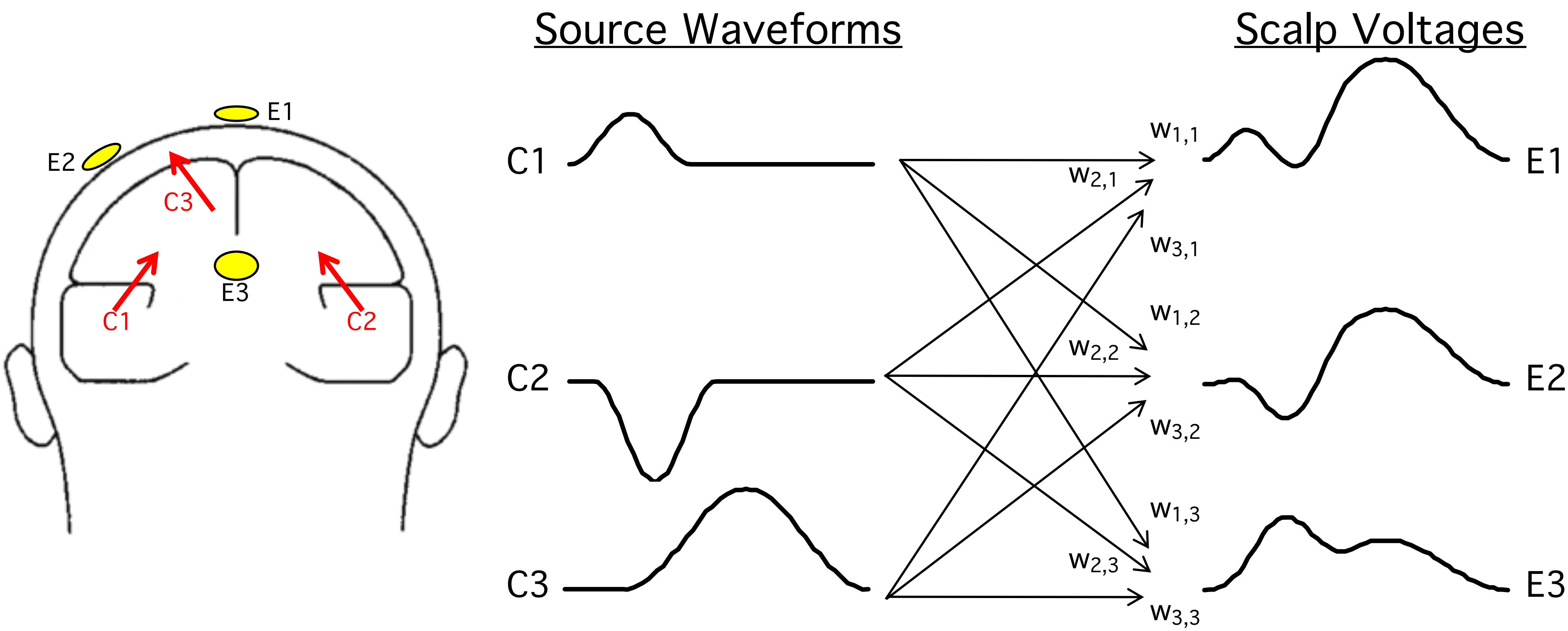
Each internal component is represented by an arrow, showing the location and direction of the dipole for that component.

Each component also has a source waveform, which is the change in voltage over time in that brain area in response to a given event.



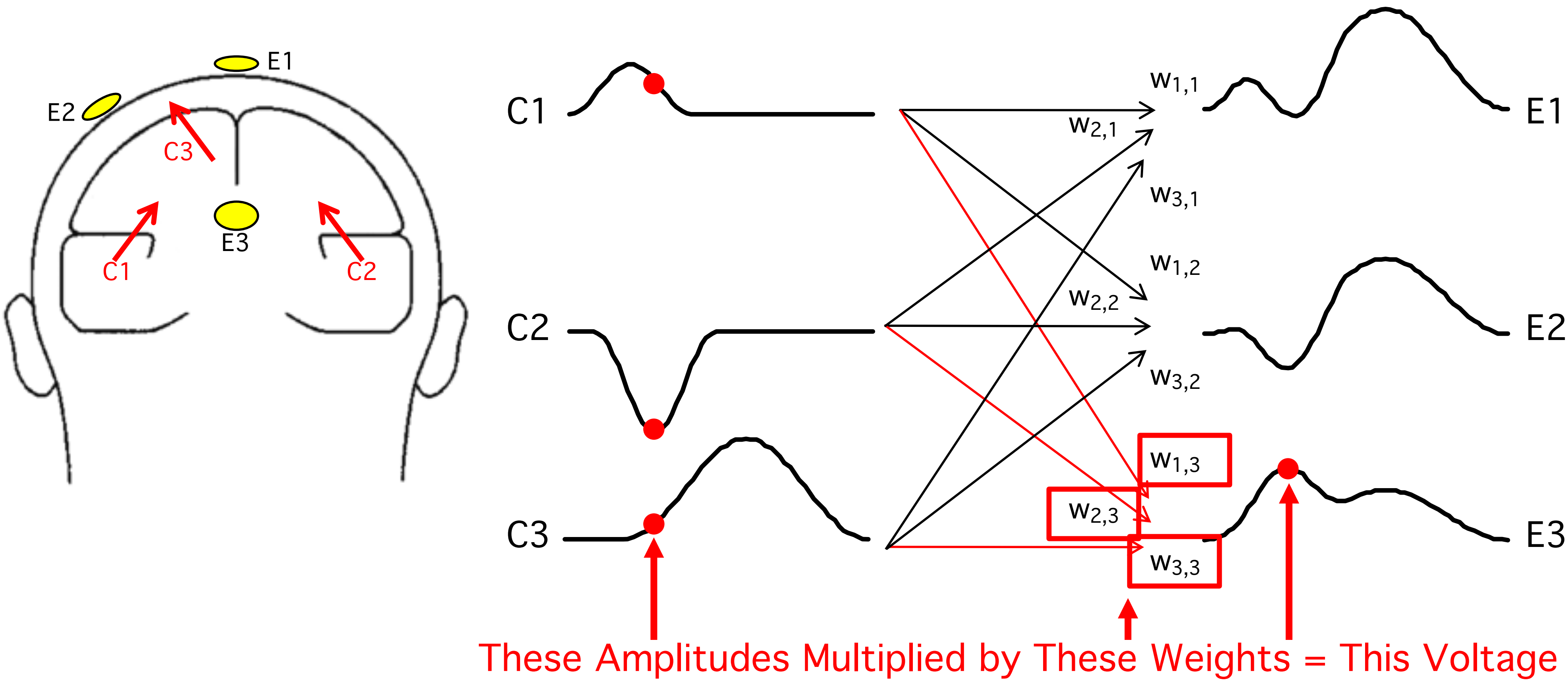
Voltages simply sum together in a conductor. As a result, the voltage recorded at each electrode will be a weighted sum of the underlying source waveforms.

You have a different weight for each combination of component and electrode site.

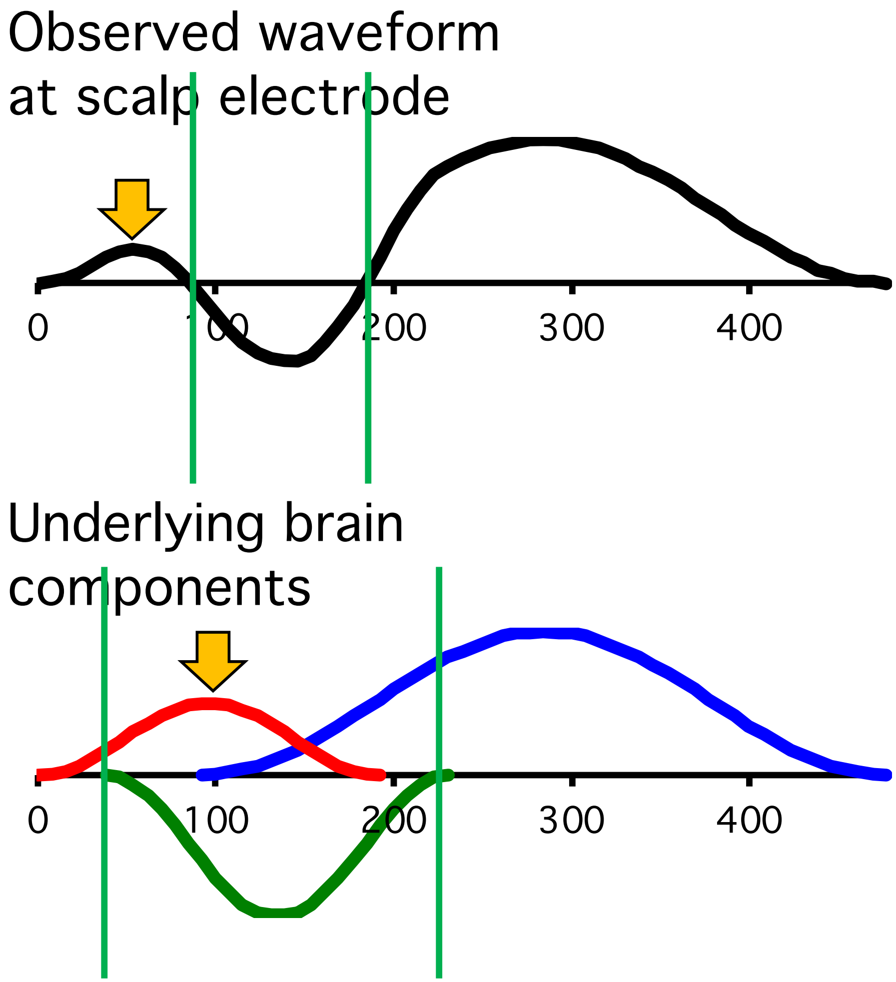


Note: These are arbitrary weights and may not match the actual weights for this combination of components and electrodes.

The contribution of a given source to a given electrode site at a given time is simply the amplitude of the source waveform at that time multiplied by the weight between that component and the electrode site.



Note: These are arbitrary weights and may not match the actual weights for this combination of components and electrodes.

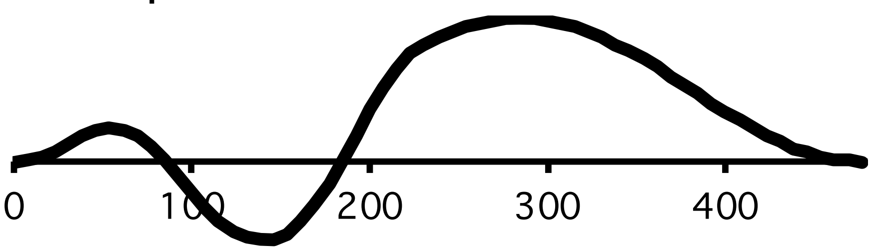


Timing of peaks often differs from timing of components.

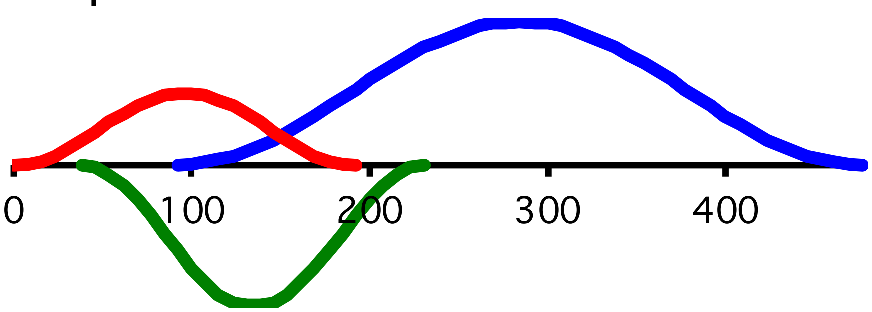
The first component peaks at 100 ms, whereas the first peak in the scalp waveform is at 50 ms.

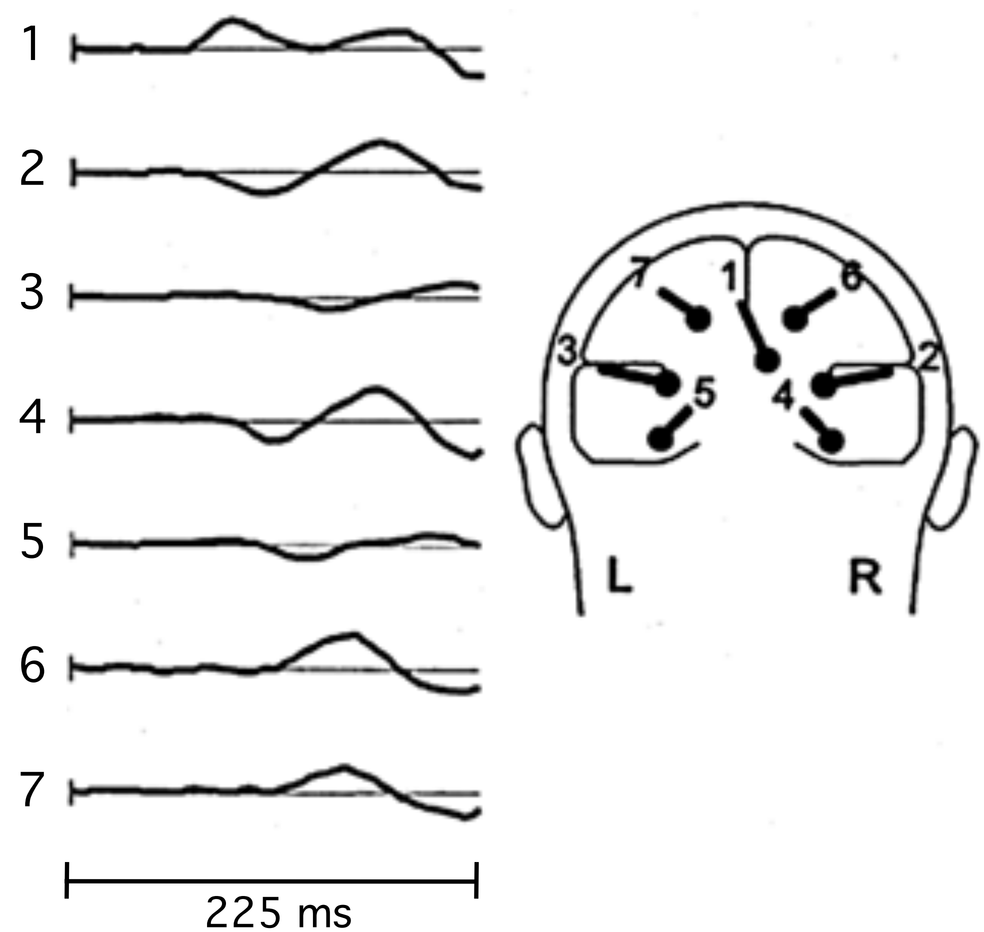
It looks like the second peak goes from about 90 to 180 ms, but the underlying component actually goes from about 50 to 225 ms.

Observed waveform
at scalp electrode



Underlying brain
components

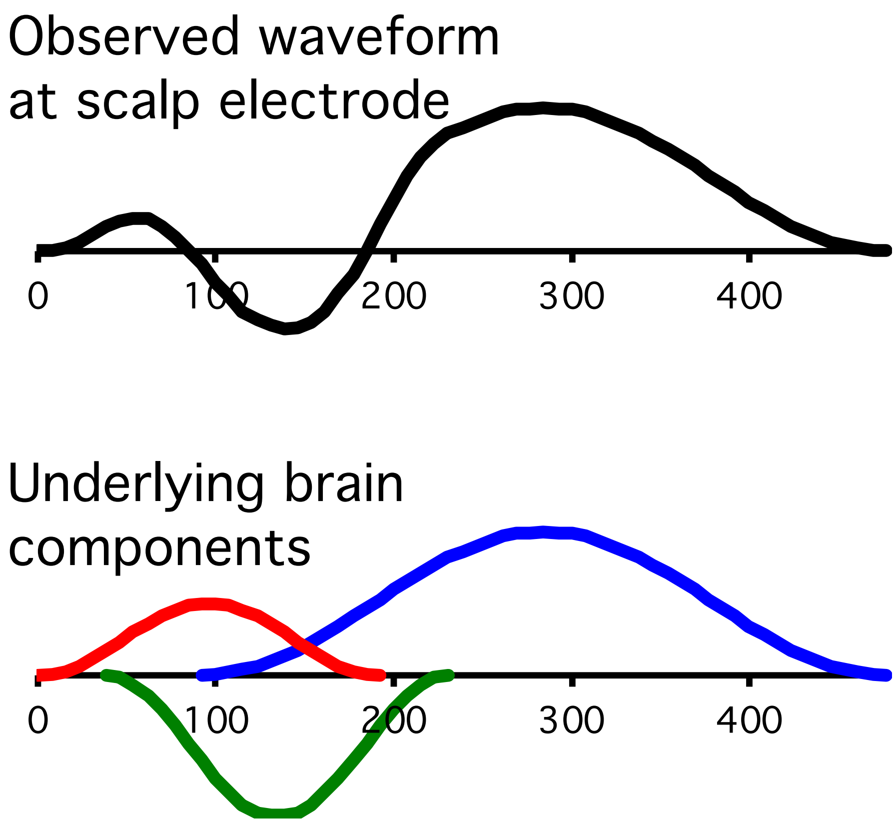


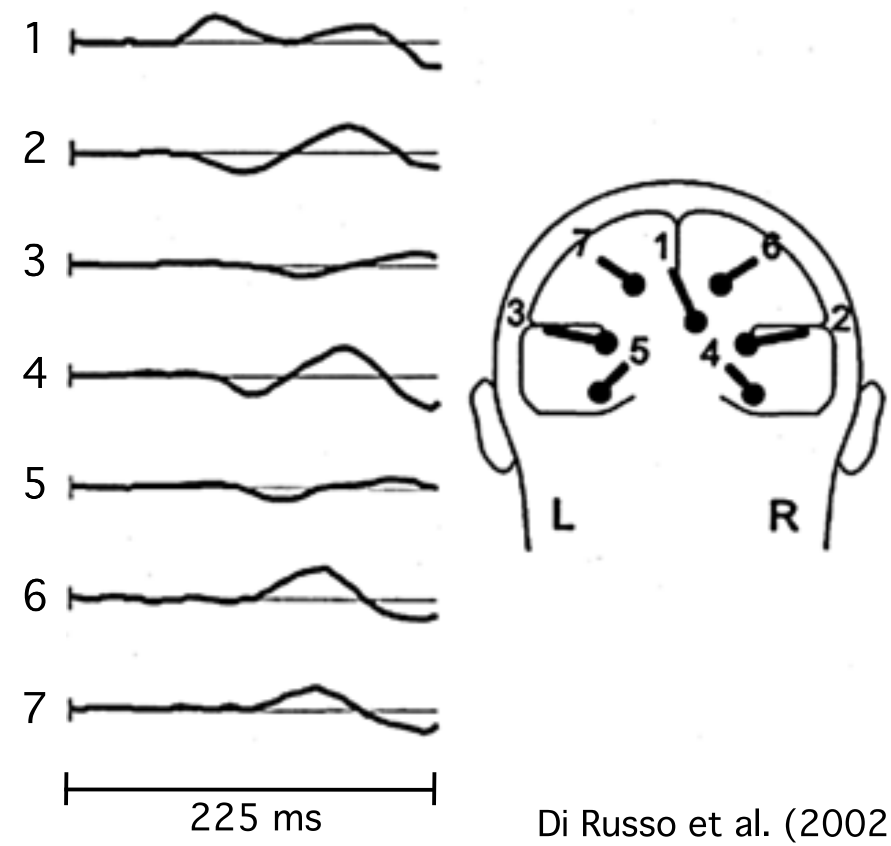


Di Russo et al. (2002)

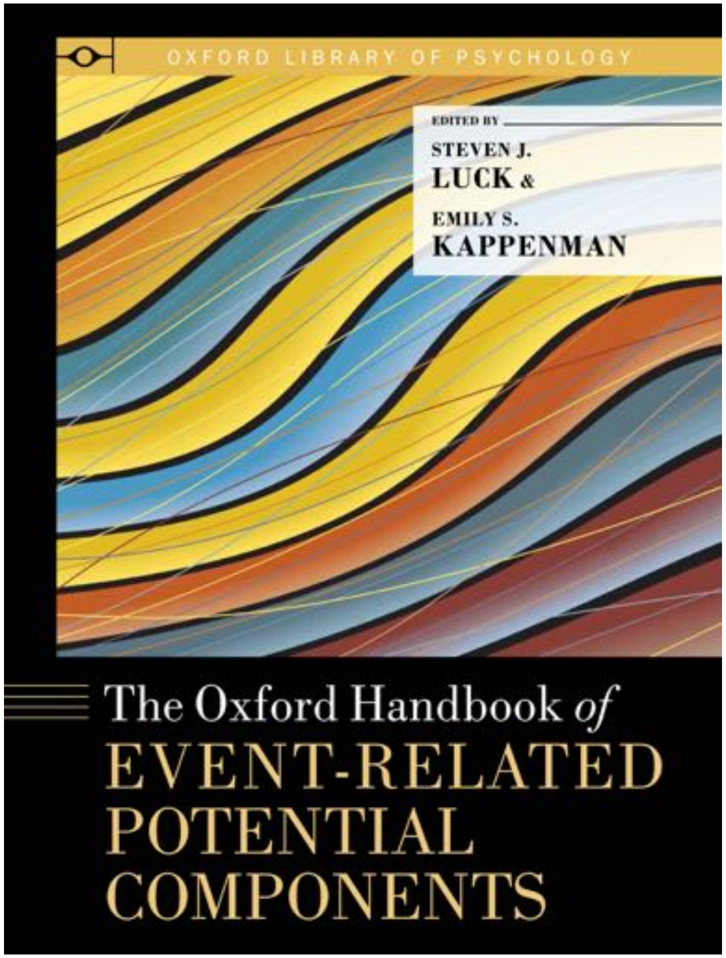
There are usually way more components than there are obvious peaks.

There are at least 10 distinct components active between 50 and 150 ms in the sensory response to a visual stimulus.





Di Russo et al. (2002)



CHAPTER 1

ERP Components: The Ups and Downs of Brainwave Recordings

Emily S. Kappenman *and* Steven J. Luck

Abstract

This chapter provides a framework for understanding, interpreting, and using event-related potential (ERP) components in the broad domain of mind, brain, and behavior sciences. The first section defines the term *ERP component*, describing the neural events that give rise to ERP components and explaining how multiple components sum together to form the observed ERP waveform. The next section describes the problems involved in isolating individual ERP components from the observed waveform, which is often much more difficult than researchers realize. This is followed by a discussion of the challenges involved in linking an ERP component with a specific neural or psychological process and then using this link to answer broader questions about the mind and brain. The chapter concludes with a discussion of what types of questions are most easily answered with ERPs and the approaches that have proven effective in overcoming the challenges of the technique.

Keywords: event-related potential, ERP component, peaks, waves, reverse inference

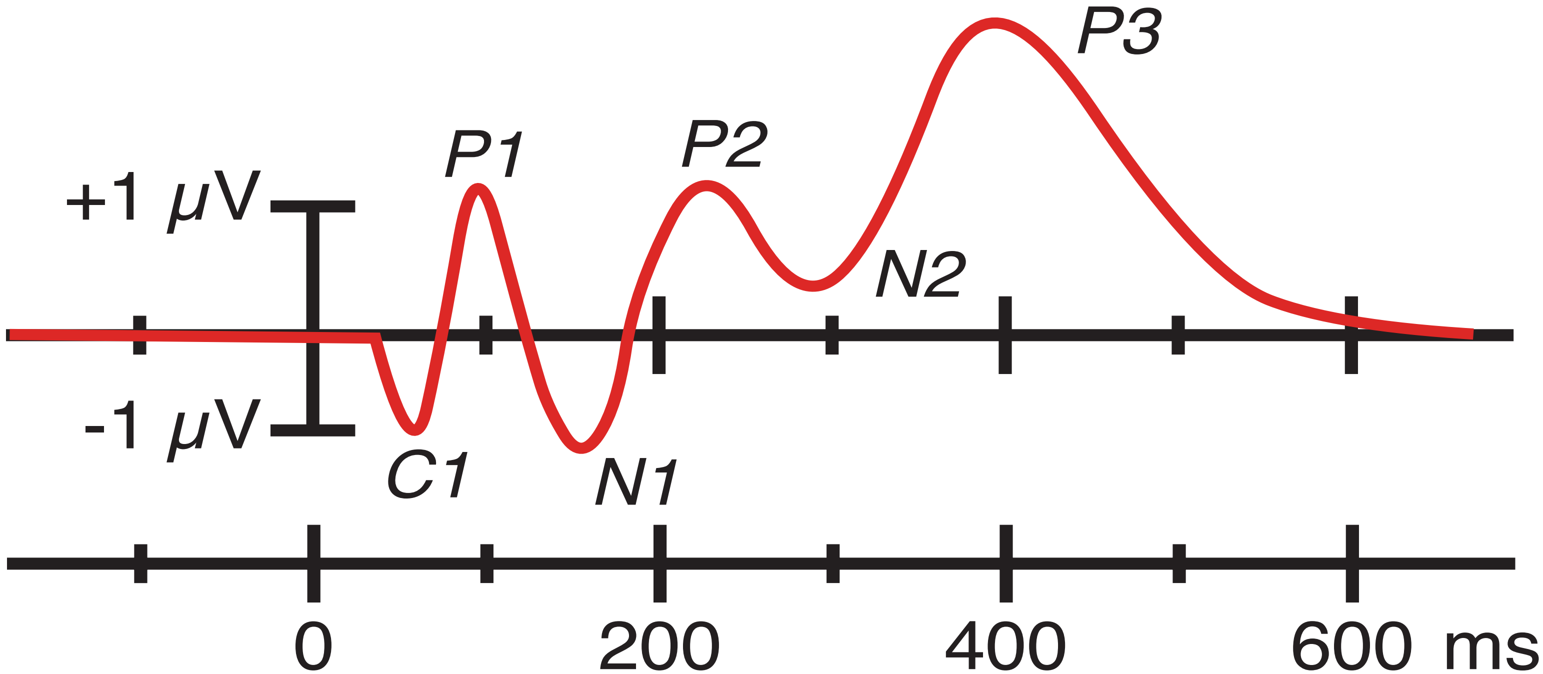
Kappenman, E. S., & Luck, S. J. (2012). ERP components: The ups and downs of brainwave recordings. In S. J. Luck & E. S. Kappenman (Eds.), The Oxford Handbook of ERP Components (pp. 3–30). Oxford University Press.

ERP Components

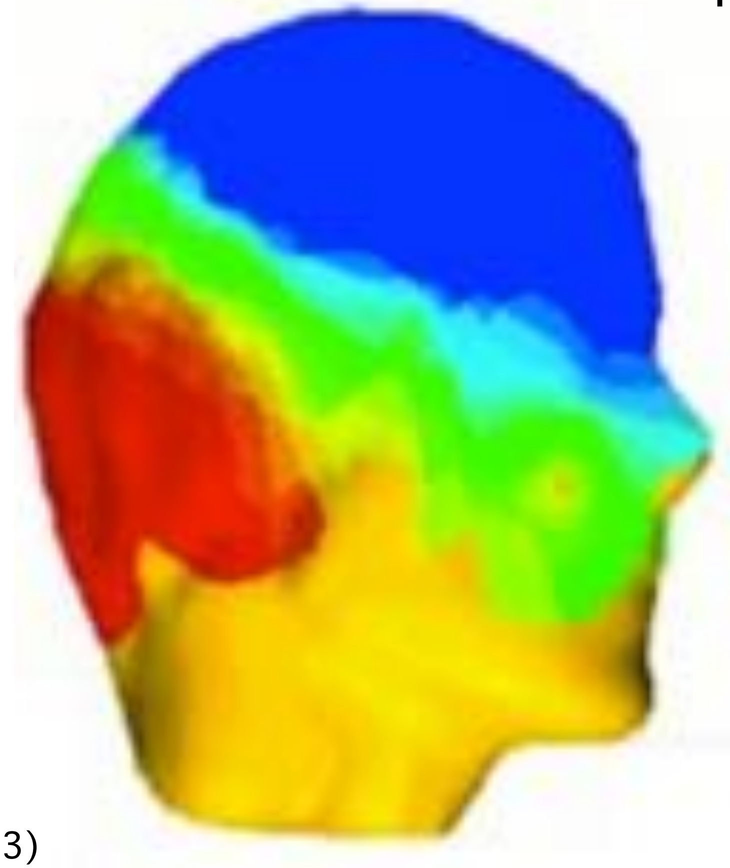
Naming Conventions

P for positive-going
N for negative-going

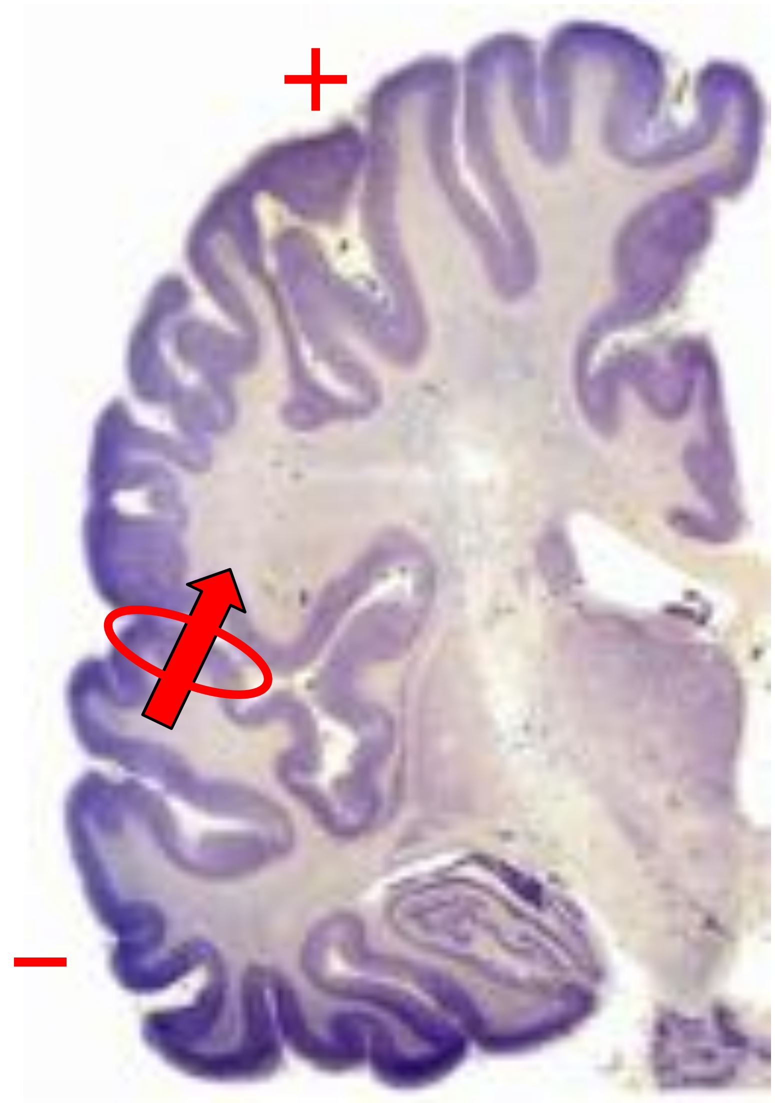
Number: Ordinal position in waveform (if <= 5)
Latency in milliseconds (if > 5)



Every component will be positive on one side of the head and negative on the other (although we might not have electrodes positioned to see both sides of the dipole)

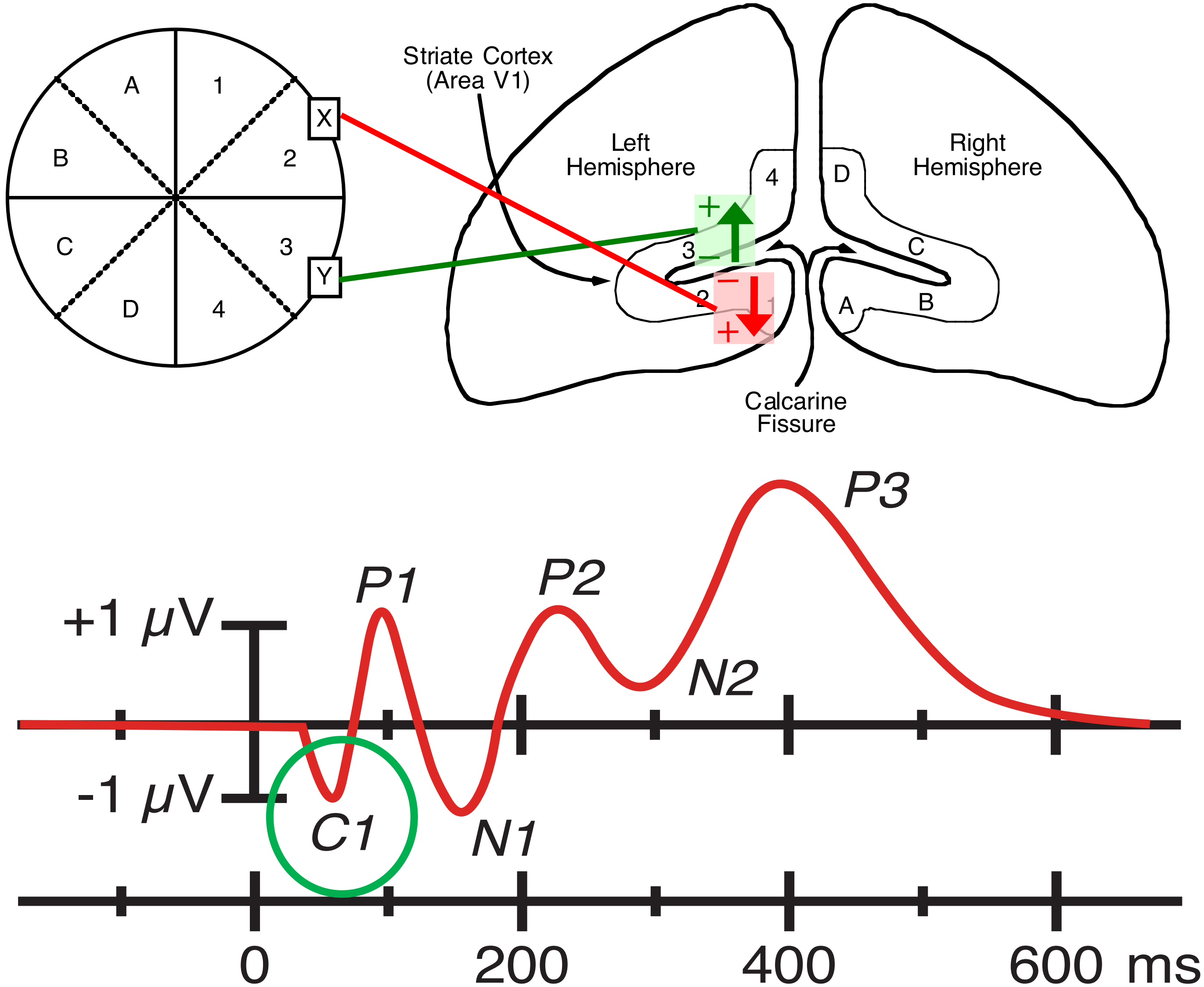


Woldorff et al (1993)



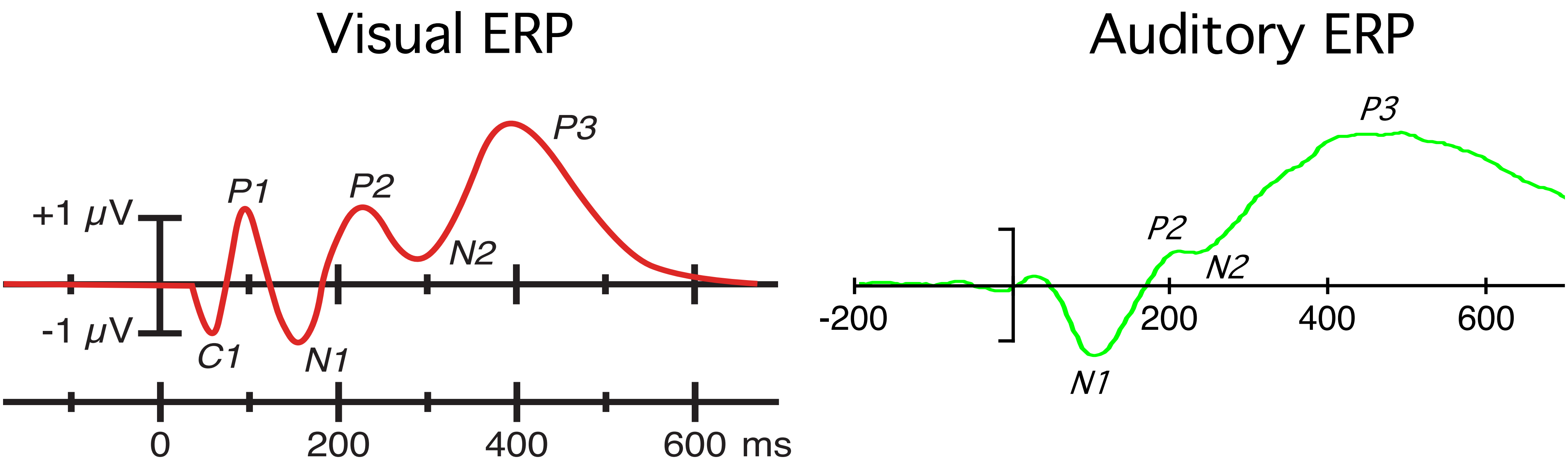
DeFelipe (2022)

Mangun, Hillyard, & Luck (1993)



C1 can be either positive or negative depending on whether the stimulus is presented above or below the point of fixation.

This is because primary visual cortex is folded up in the calcarine fissure, and the upper and lower visual fields project to opposite sides of the fissure.



Visual N1 ≠ Auditory N1

Visual P3 = Auditory P3

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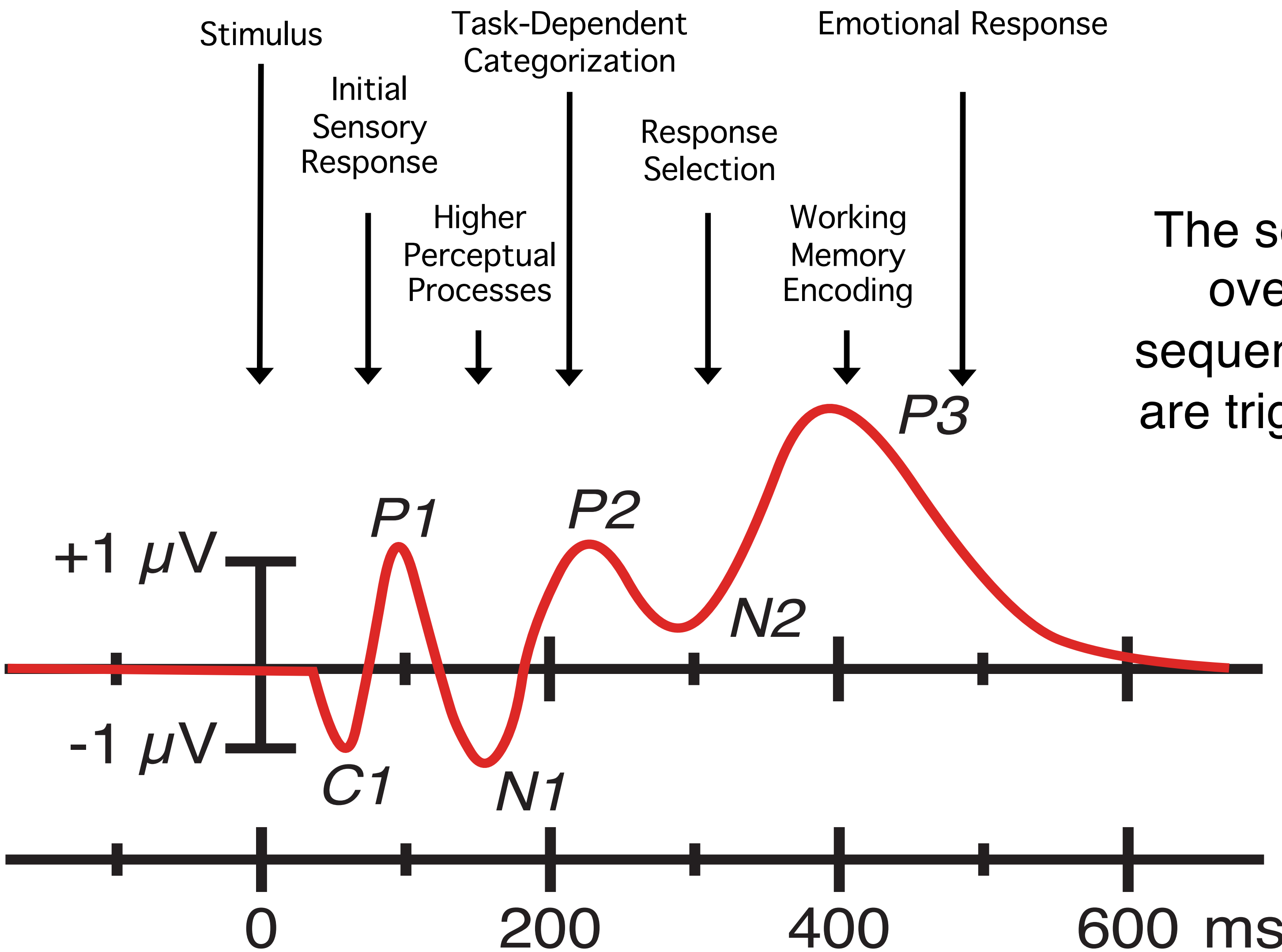
ERP Components

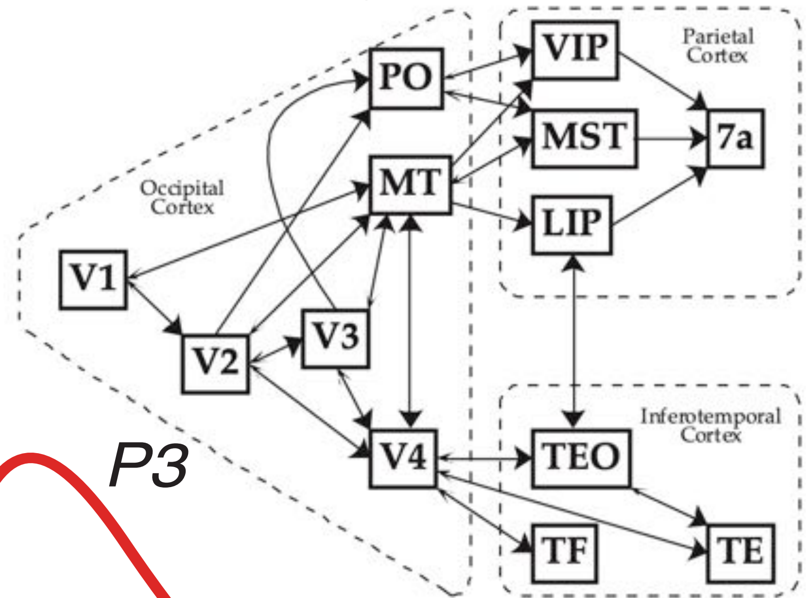
Sensory Components

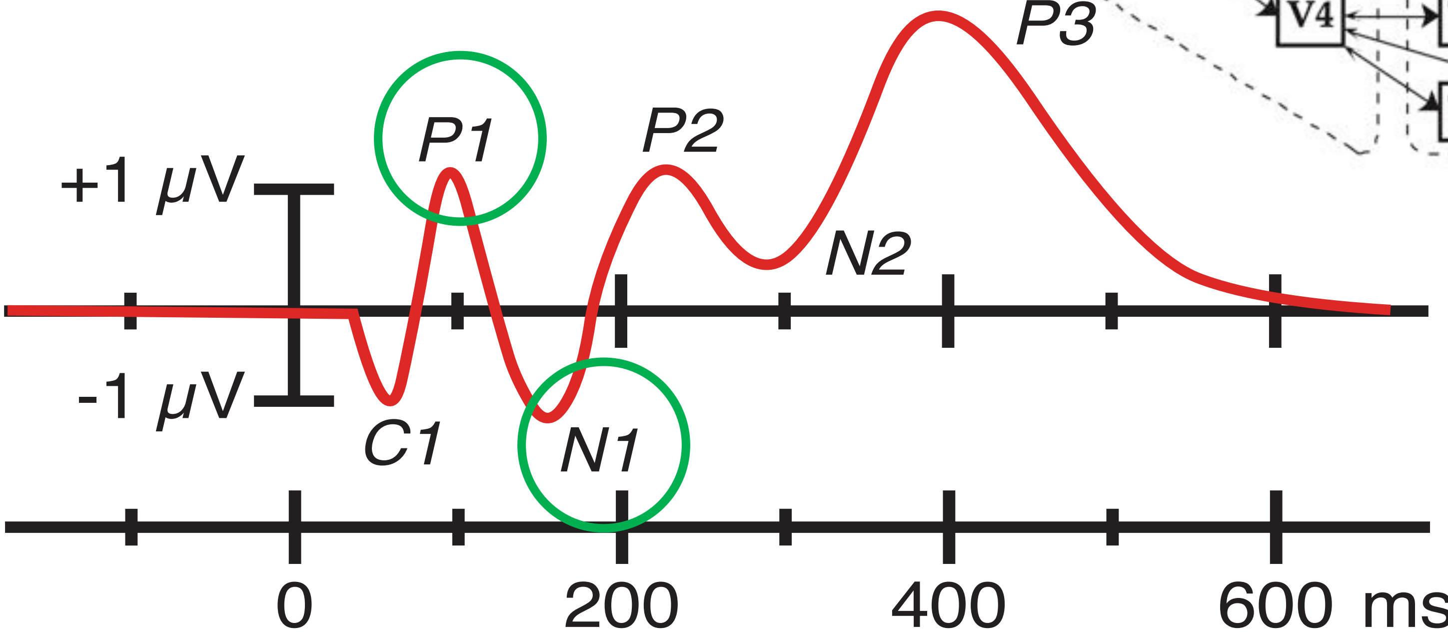


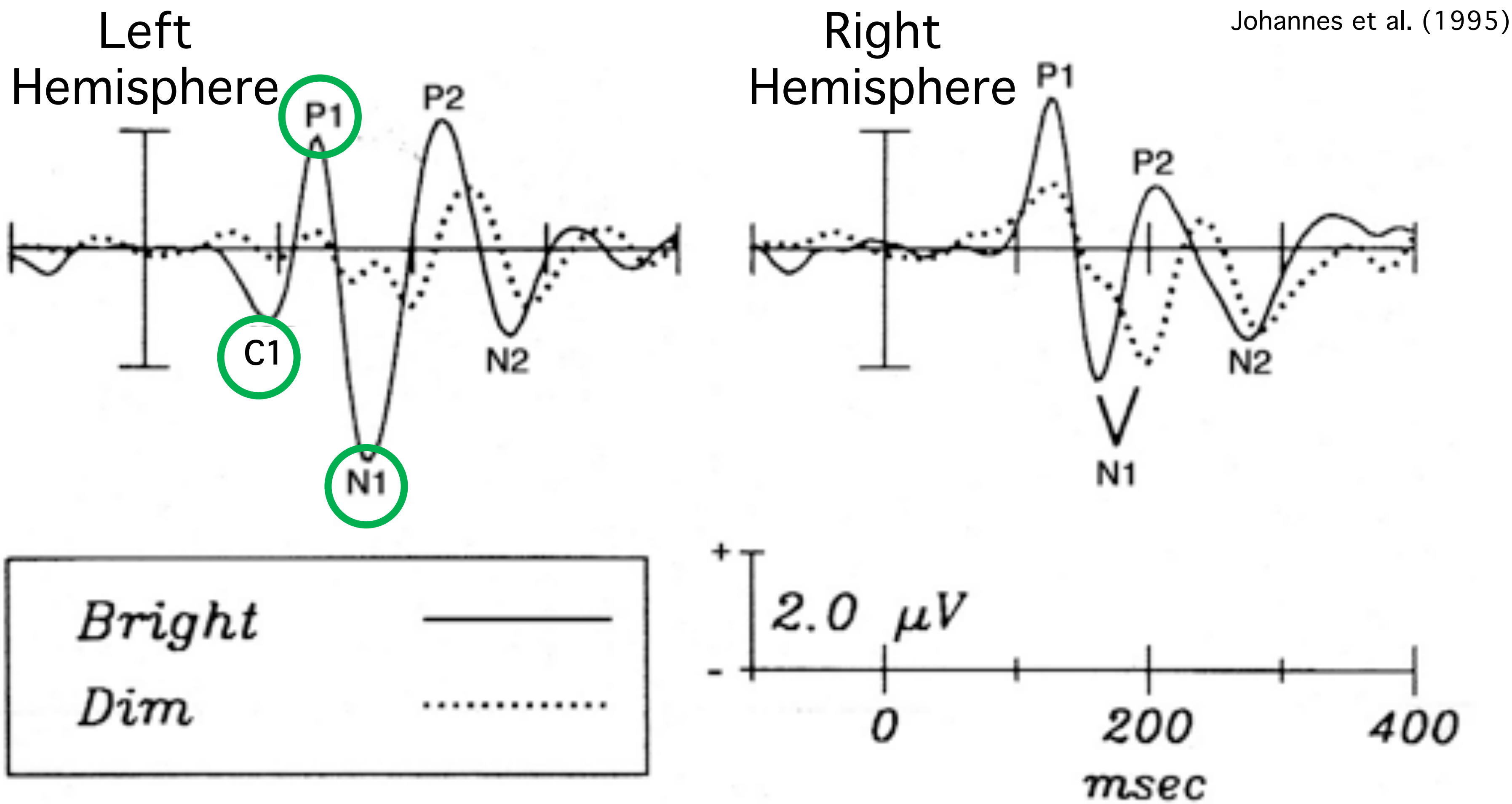
The sequence of voltages over time reflects the sequence of processes that are triggered by a stimulus.

The visual P1 and N1 waves reflect the combination of many different brain areas, most of which are in higher-level areas of visual cortex.

Mangun, Hillyard, & Luck (1993)



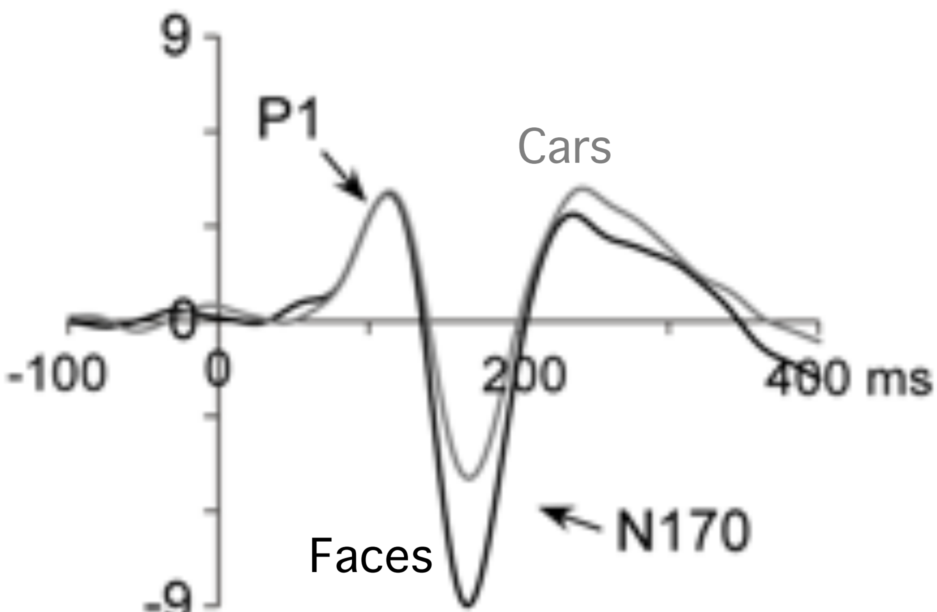


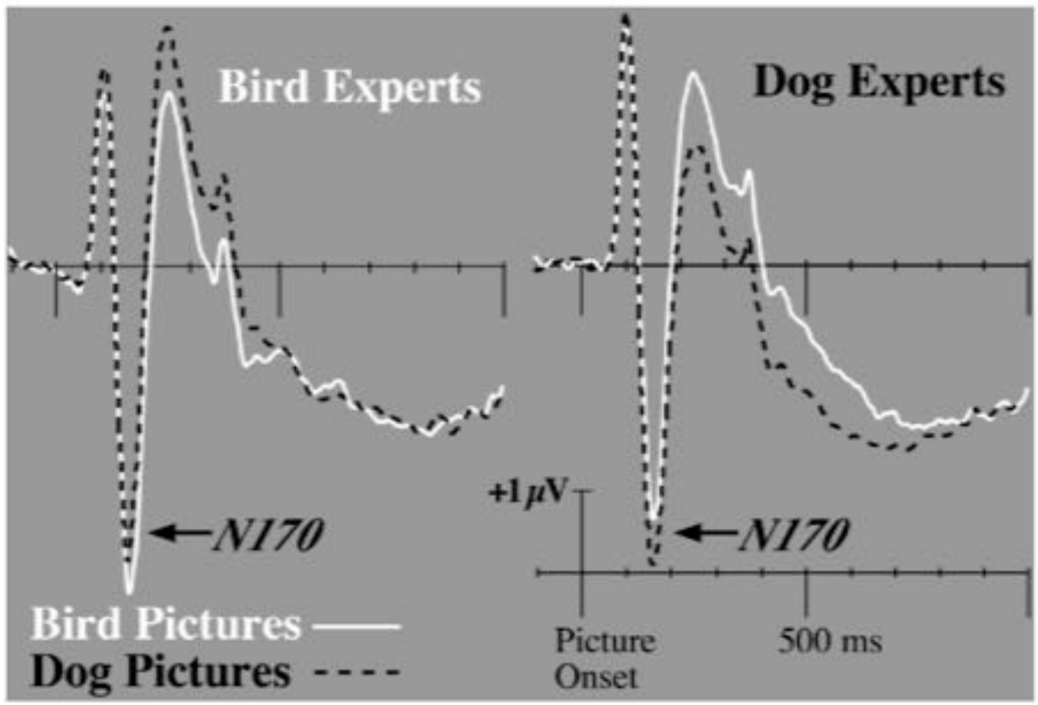


The C1, P1, and N1 waves are highly sensitive to the physical properties of the stimulus, such as brightness.

The N1 wave—often called N170—is bigger for faces than for most other classes of stimuli.

Experience also plays a role: For example, words elicit a large N1 in experienced readers.



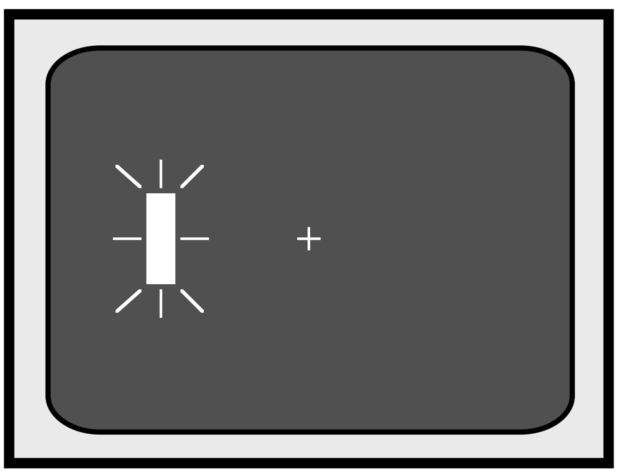


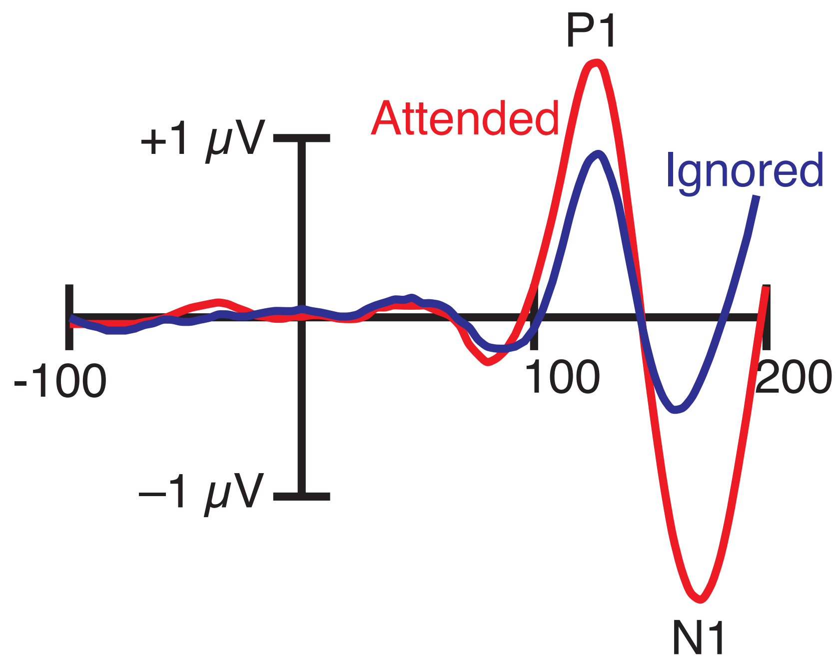
Rossion & Jacques (2012)

Tanaka & Curran (2001)

The P1 and N1 are larger for attended-location stimuli than for ignored-location stimuli. However, these effects are typically observed only for spatial attention, and only when attention has shifted prior to stimulus onset.

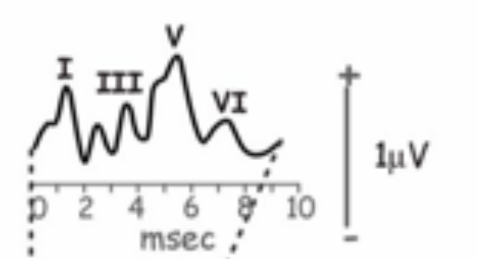
Attend Left or Attend Right in different trial blocks

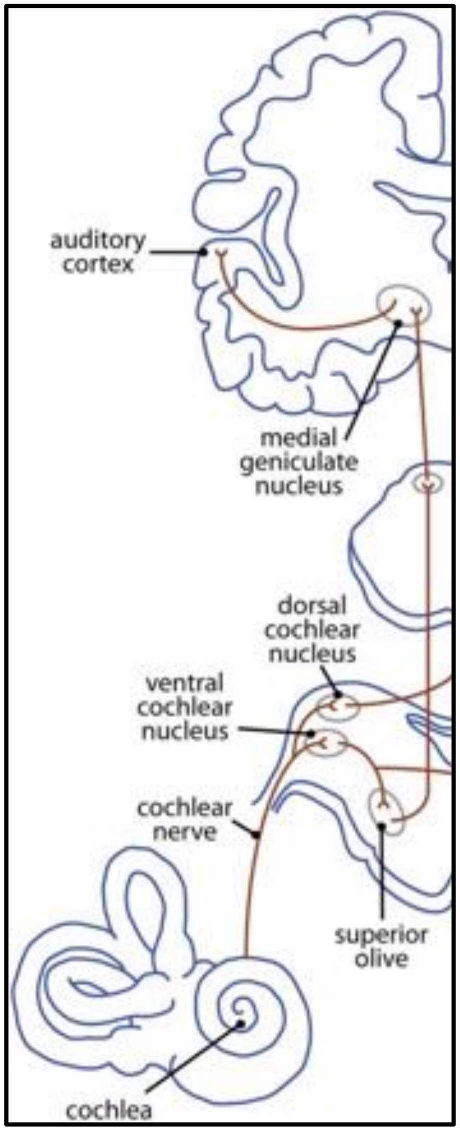




Luck & Kappenman (2012, Oxford Handbook of ERP Components)

Response to Auditory Click





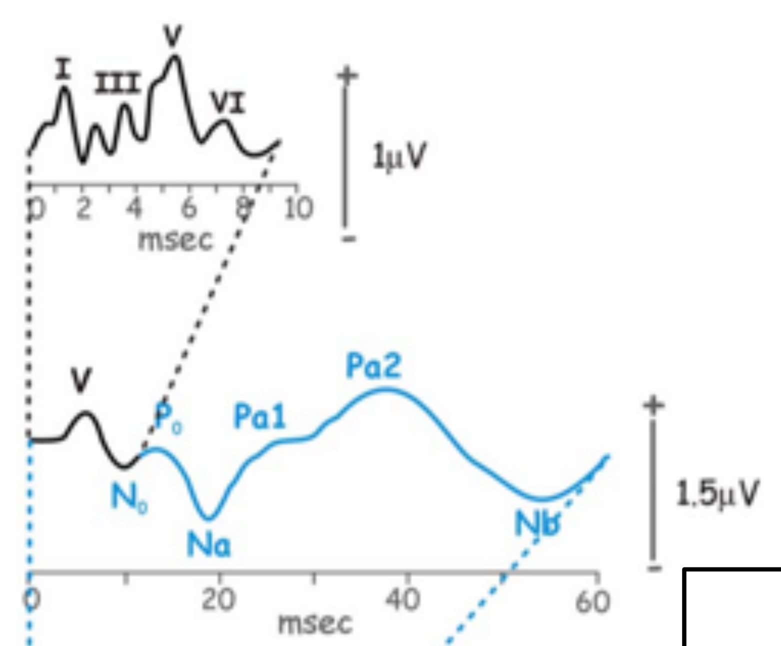
- Auditory brainstem responses (ABRs)
  - Cochlea, cochlear nerve, brainstem nuclei
  - Used for neonatal hearing evaluation

The auditory brainstem responses are the one common exception to the rule that ERPs are ordinarily generated by cortical pyramidal cells.

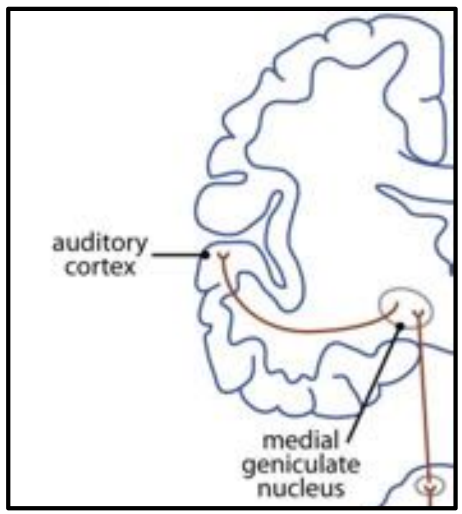
They're used to diagnose hearing impairments in clinical audiology and to screen for hearing problems in newborns.

Pratt (2012, Oxford Handbook of ERP Components)

Response to Auditory Click

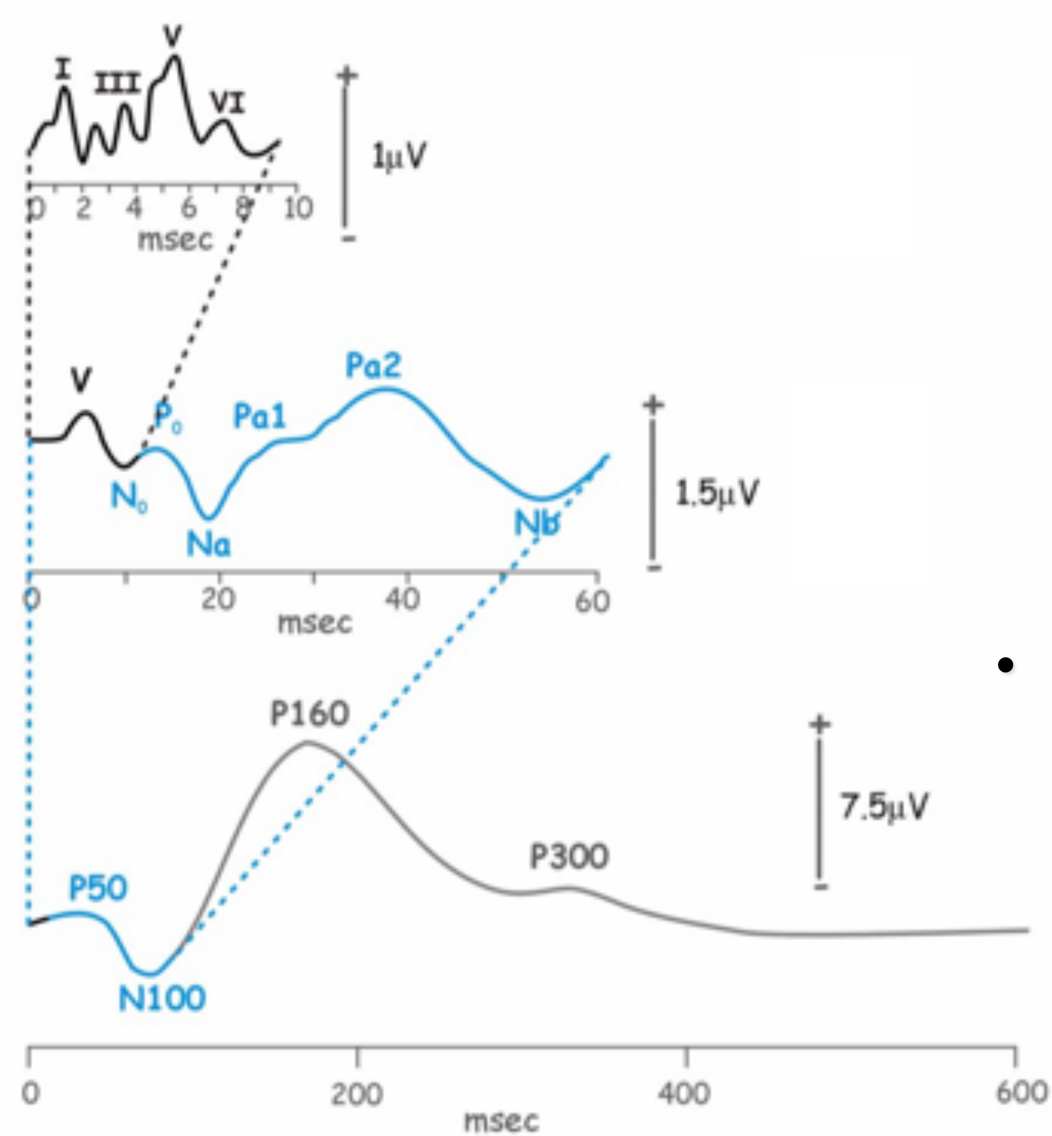


- Midlatency responses (MLRs)
  - Medial geniculate nucleus and primary auditory cortex



Pratt (2012, Oxford Handbook of ERP Components)

Response to Auditory Click



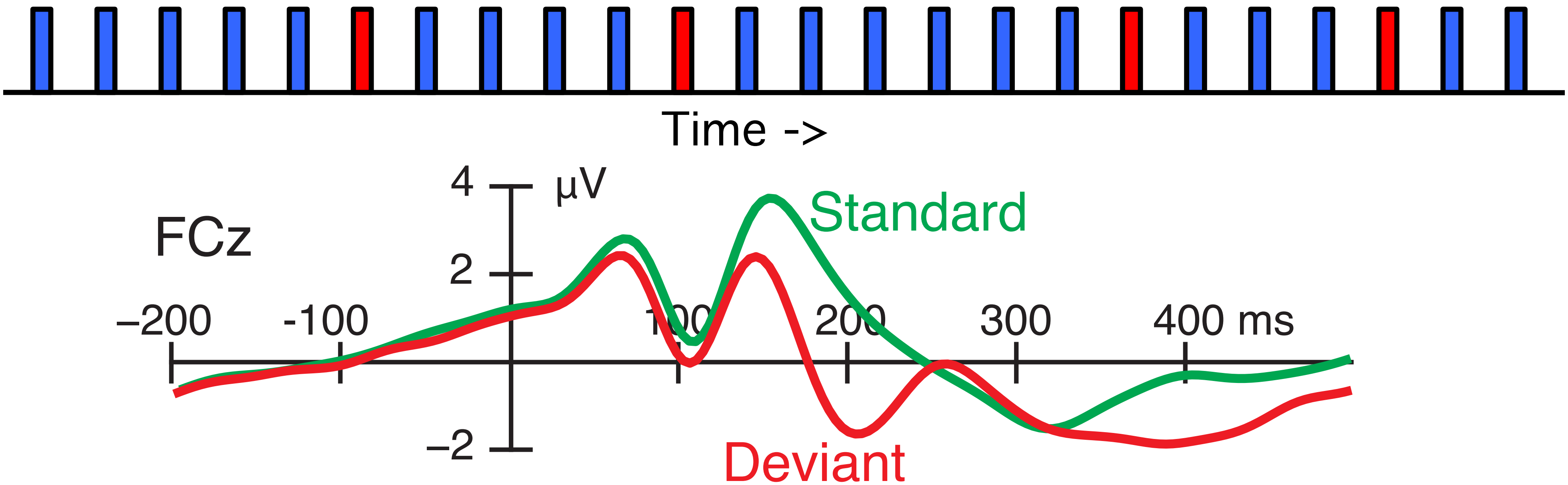
- Auditory "long-latency" sensory responses
  - Multiple cortical areas

Pratt (2012, Oxford Handbook of ERP Components)

Mismatch Negativity (MMN)

One tone every 500 ms
80% 1000 Hz / 20% 1500 Hz

https://erpinfo.org/erp-core



Deviant tones elicit a larger negative response than standards around 200 ms that is called the mismatch negativity or MMN.

The MMN doesn't require the subject to perform a task.

The MMN well suited for use in infants, where it has been used to study the development of phoneme discrimination.

Developmental Science

Developmental Science 14:2 (2011), pp 242–248 DOI: 10.1111/j.1467-7687.2010.00973.x

PAPER

Impact of second-language experience in infancy: brain measures of first- and second-language speech perception

Barbara T. Conboy[1,2] and Patricia K. Kuhl[1]

The MMN can be used to predict which coma patients will recover.

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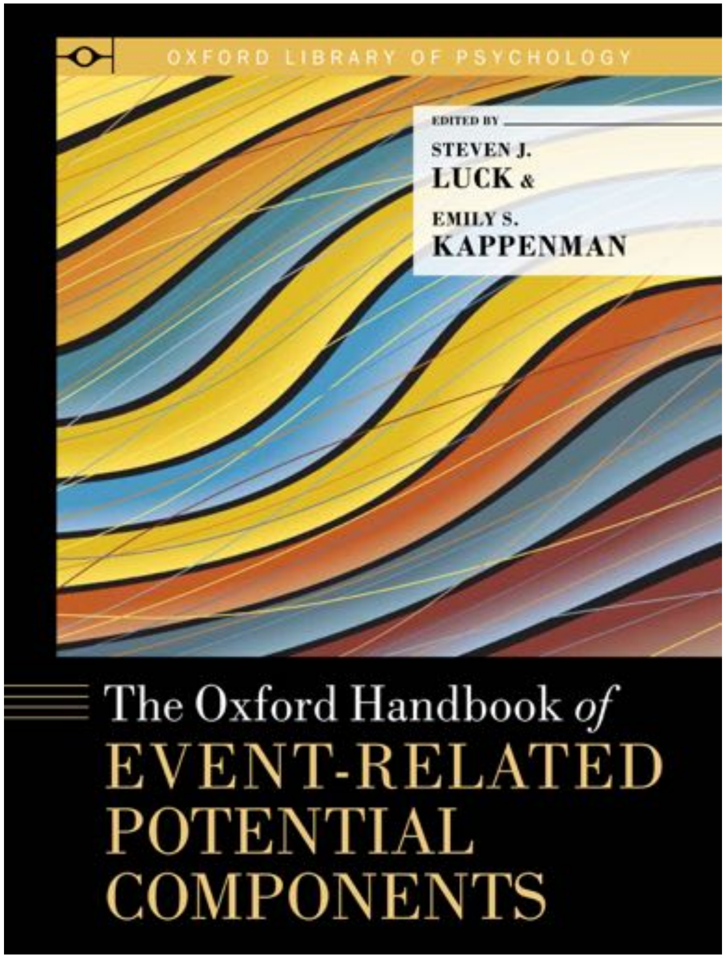
August 24, 2004; 63 (4) ARTICLES

Predictive value of sensory and cognitive evoked potentials for awakening from coma

Catherine Fischer, Jacques Luauté, Patrice Adeleine, Dominique Morlet

First published August 23, 2004, DOI: https://doi.org/10.1212/01.WNL.0000134670.10384.E2



CHAPTER 6

The Mismatch Negativity (MMN)

Risto Näätänen *and* Kairi Kreegipuu

Abstract

The auditory mismatch negativity (MMN) is a change-specific component of the auditory event-related brain potential (ERP) that is elicited even in the absence of attention and can be used as an objective index of sound-discrimination accuracy and auditory sensory memory. The MMN enables one to reach a new level of understanding of the brain processes forming the biological substrate of central auditory perception and the different forms of auditory memory. A review of MMN studies indicates that the central auditory system performs complex cognitive operations, such as generalization leading to simple concept formation (e.g., a rising pair irrespective of the specific frequency values), rule extraction, and the anticipation of the next stimulus at the preattentive level. These findings demonstrate the presence of a cognitive change-detection mechanism in the auditory cortex.

Keywords: mismatch negativity (MMN), auditory event-related potential, sound discrimination, auditory sensory memory

Näätänen, R., & Kreegipuu, K. (2012). The mismatch negativity (MMN). In S. J. Luck & E. S. Kappenman (Eds.), The Oxford Handbook of Event-Related Potential Components (pp. 143–157). Oxford University Press.

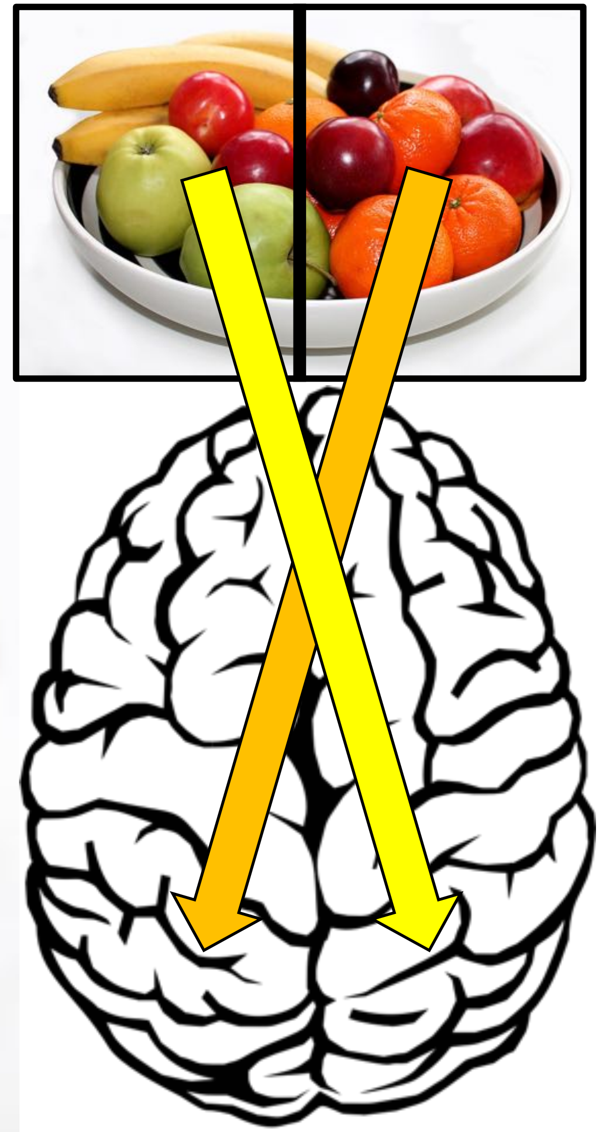
ERP Components

Attention

N2pc
(pc: posterior contralateral)

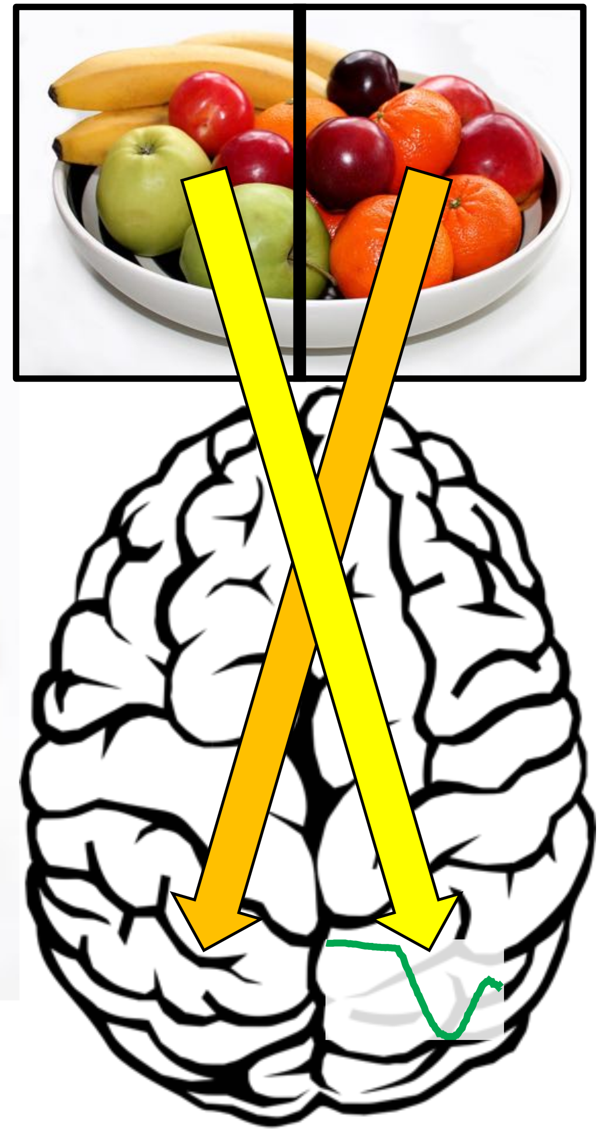
Covert Attention: Shift of mental processing resources
Overt Attention: Shift of eye position

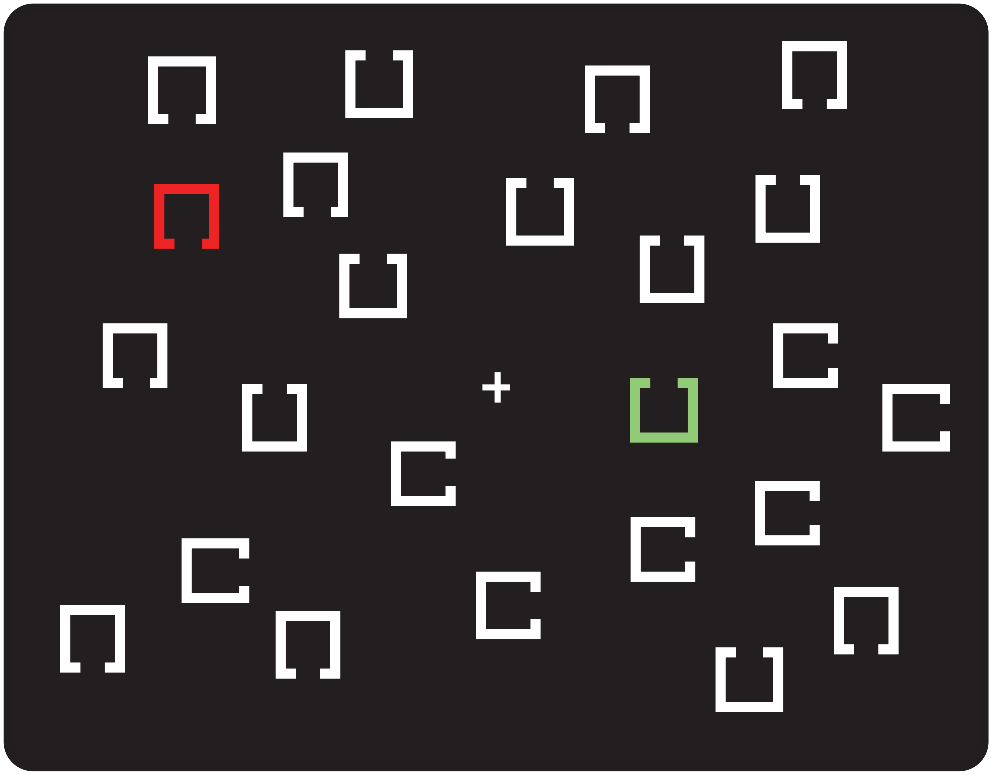
N2pc
(pc: posterior contralateral)



N2pc
(pc: posterior contralateral)

N2pc is a negative-going voltage deflection over posterior electrode sites contralateral to the object being attended.





<u>Task</u>

Attend to red in some blocks and green in other blocks

Press a button to indicate whether gap on attended-color item is on top or bottom

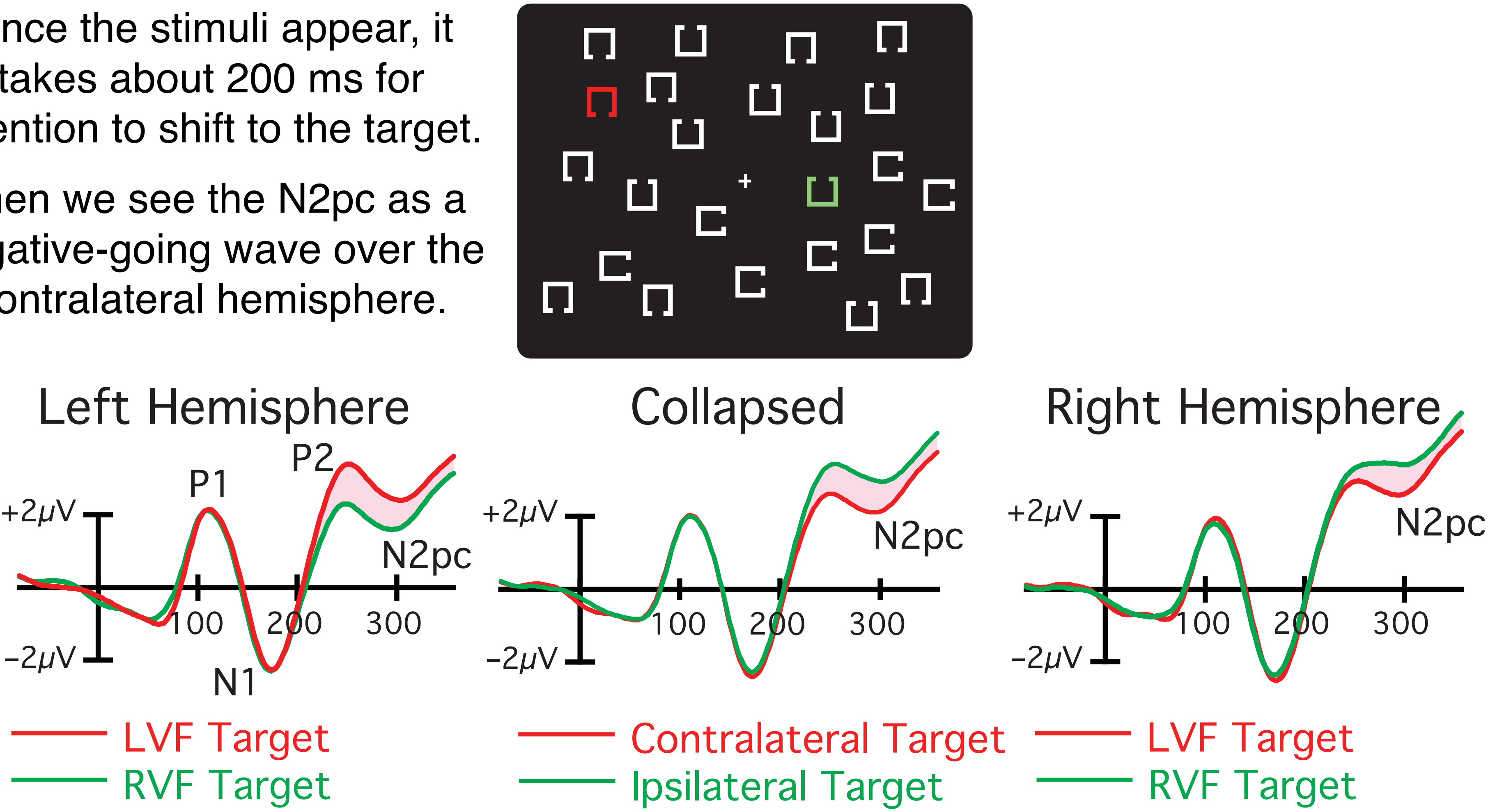
The stimulus locations are randomized from trial to trial, so when the display appears, the subject has to search for the target.

We're studying covert attention, so we have subjects keep their eyes locked on the central fixation point and use their peripheral vision.

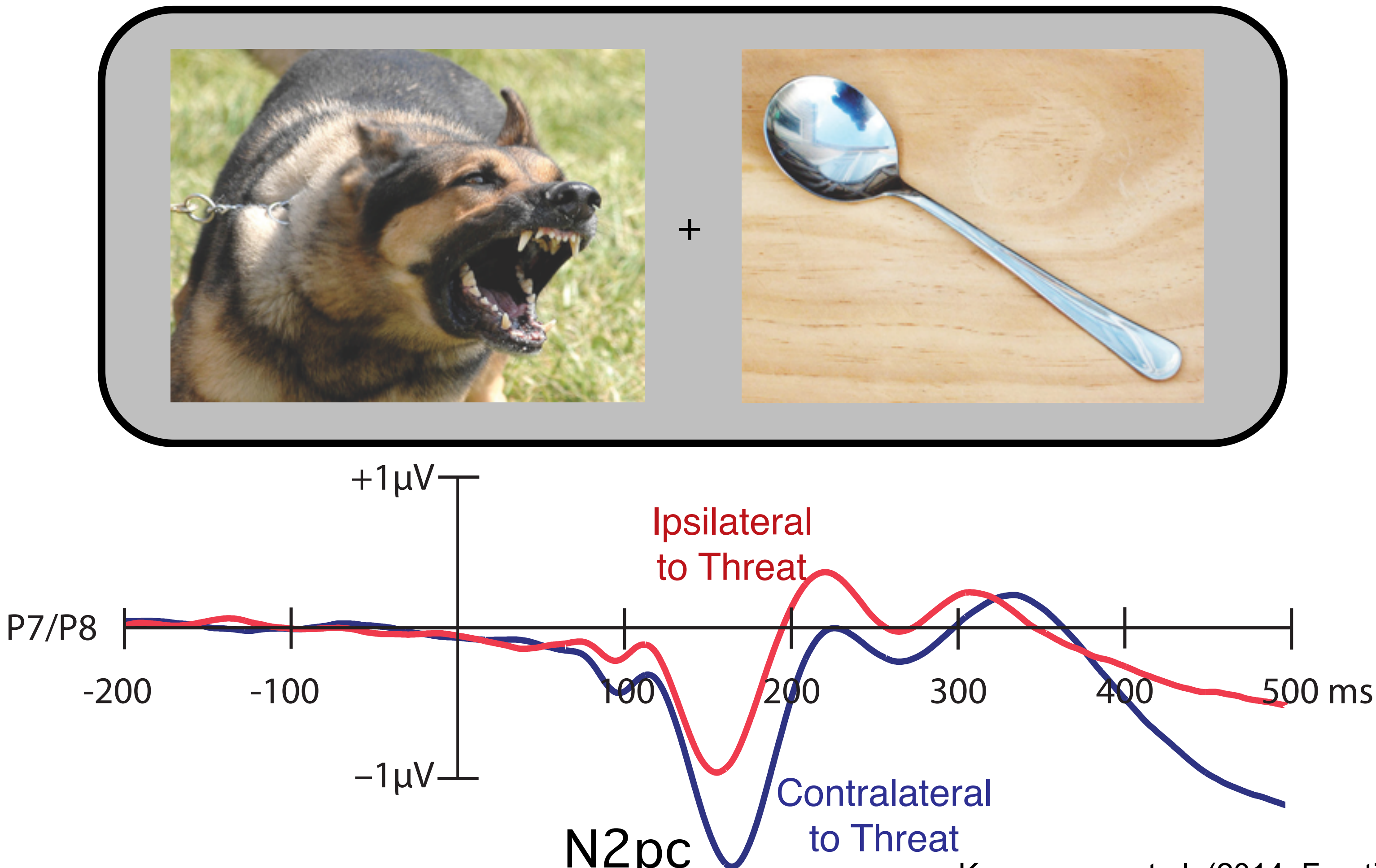
N2pc
(pc: posterior contralateral)

Once the stimuli appear, it takes about 200 ms for attention to shift to the target.

Then we see the N2pc as a negative-going wave over the contralateral hemisphere.



The threat image elicited a robust N2pc: the voltage was more negative contralateral to the threat than ipsilateral to the threat.

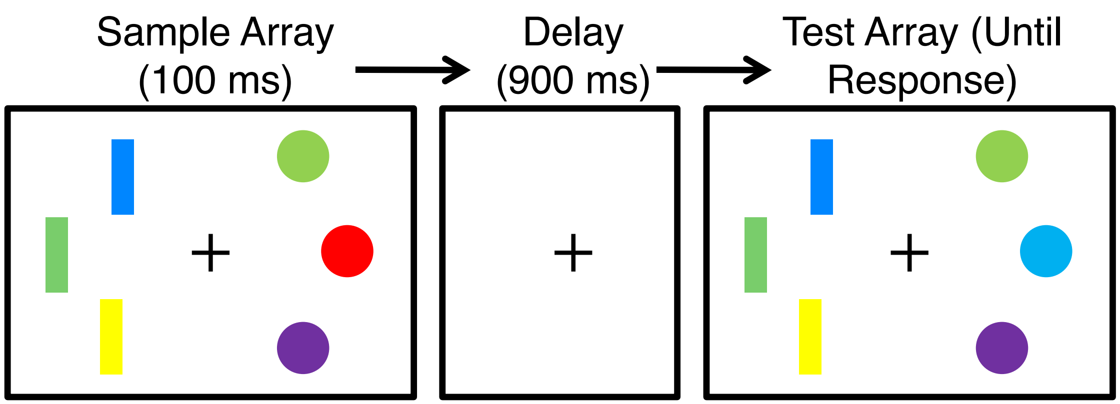


Kappenman et al. (2014, Frontiers in Psychology)

ERP Components

Working Memory

Contralateral Delay Activity (CDA)



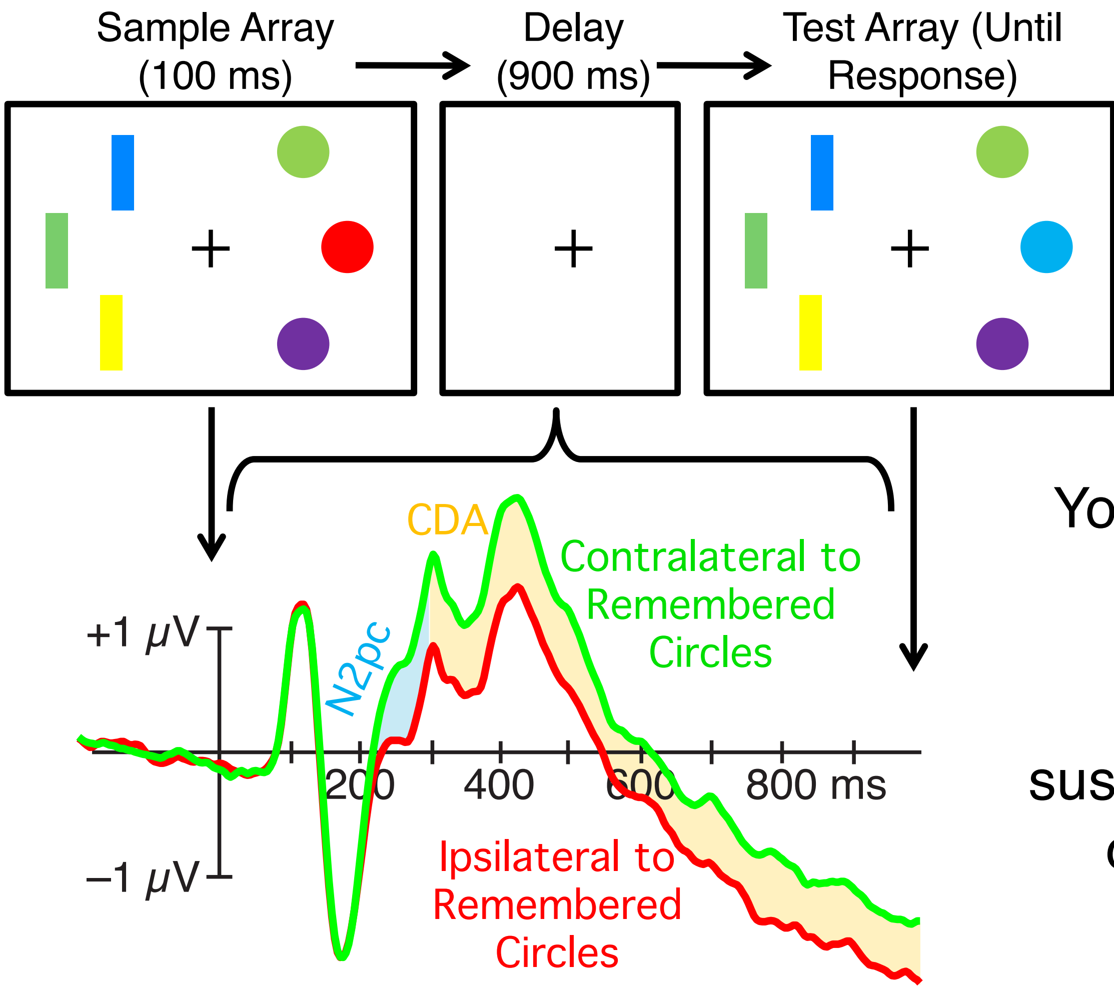
Task: Remember the colors of the circles

Subjects are asked to remember the colors of the circles and ignore the rectangles.

They only have to remember the colors for 900 ms, and then they see a test array. They then indicate whether the colors of any of the circles have changed.

Leonard et al. (2013, Cerebral Cortex)

Contralateral Delay Activity (CDA)

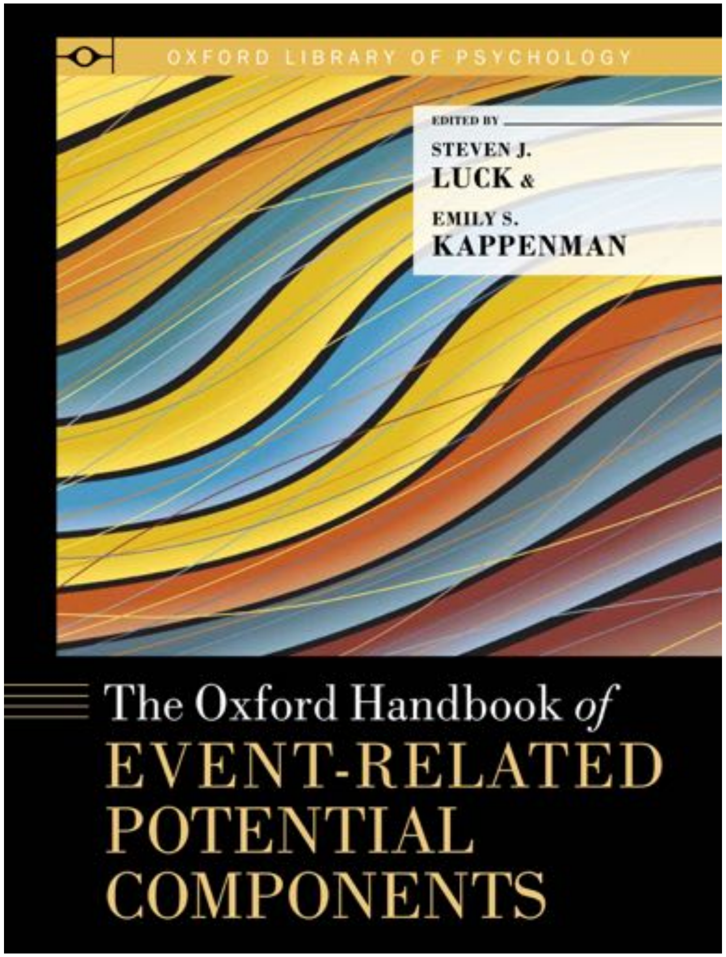


Leonard et al. (2013, Cerebral Cortex)

Task: Remember the colors of the circles

You initially see an N2pc as attention is shifted to the circles.

This is followed by the CDA: a sustained voltage over the hemisphere contralateral to the objects being maintained in memory.

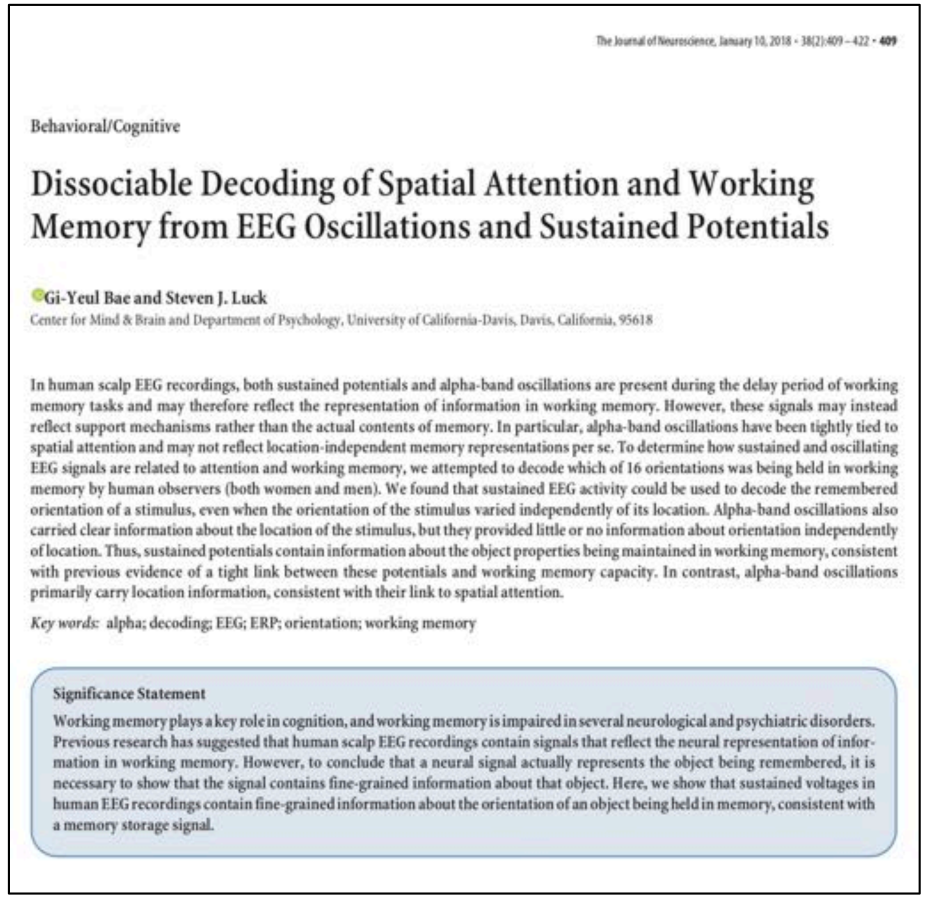


Luck, S. J., & Kappenman, E. S. (2012). ERP Components and Selective Attention (pp. 295–327).

Luck, S. J. (2012). Electrophysiological correlates of the focusing of attention within complex visual scenes: N2pc and related ERP components (pp. 329–360).

Perez, V. B., & Vogel, E. K. (2012). What ERPs can tell us about working memory (pp. 361–372).

Decoding the Contents of Working Memory



The Journal of Neuroscience, January 10, 2018 • 38(2):409–422 • 409

Behavioral/Cognitive

Dissociable Decoding of Spatial Attention and Working Memory from EEG Oscillations and Sustained Potentials

Gi-Yeul Bae and Steven J. Luck
Center for Mind & Brain and Department of Psychology, University of California-Davis, Davis, California, 95618

In human scalp EEG recordings, both sustained potentials and alpha-band oscillations are present during the delay period of working memory tasks and may therefore reflect the representation of information in working memory. However, these signals may instead reflect support mechanisms rather than the actual contents of memory. In particular, alpha-band oscillations have been tightly tied to spatial attention and may not reflect location-independent memory representations per se. To determine how sustained and oscillating EEG signals are related to attention and working memory, we attempted to decode which of 16 orientations was being held in working memory by human observers (both women and men). We found that sustained EEG activity could be used to decode the remembered orientation of a stimulus, even when the orientation of the stimulus varied independently of its location. Alpha-band oscillations also carried clear information about the location of the stimulus, but they provided little or no information about orientation independently of location. Thus, sustained potentials contain information about the object properties being maintained in working memory, consistent with previous evidence of a tight link between these potentials and working memory capacity. In contrast, alpha-band oscillations primarily carry location information, consistent with their link to spatial attention.

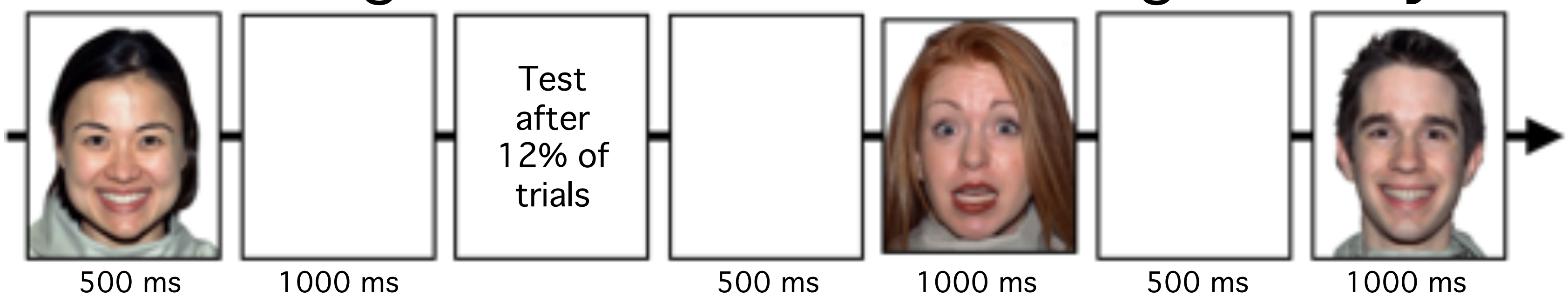
Key words: alpha; decoding; EEG; ERP; orientation; working memory

Significance Statement

Working memory plays a key role in cognition, and working memory is impaired in several neurological and psychiatric disorders. Previous research has suggested that human scalp EEG recordings contain signals that reflect the neural representation of information in working memory. However, to conclude that a neural signal actually represents the object being remembered, it is necessary to show that the signal contains fine-grained information about that object. Here, we show that sustained voltages in human EEG recordings contain fine-grained information about the orientation of an object being held in memory, consistent with a memory storage signal.

Bae, G. Y., & Luck, S. J. (2018). Dissociable decoding of working memory and spatial attention from EEG oscillations and sustained potentials. *The Journal of Neuroscience, 38*, 409–422.

Decoding the Contents of Working Memory



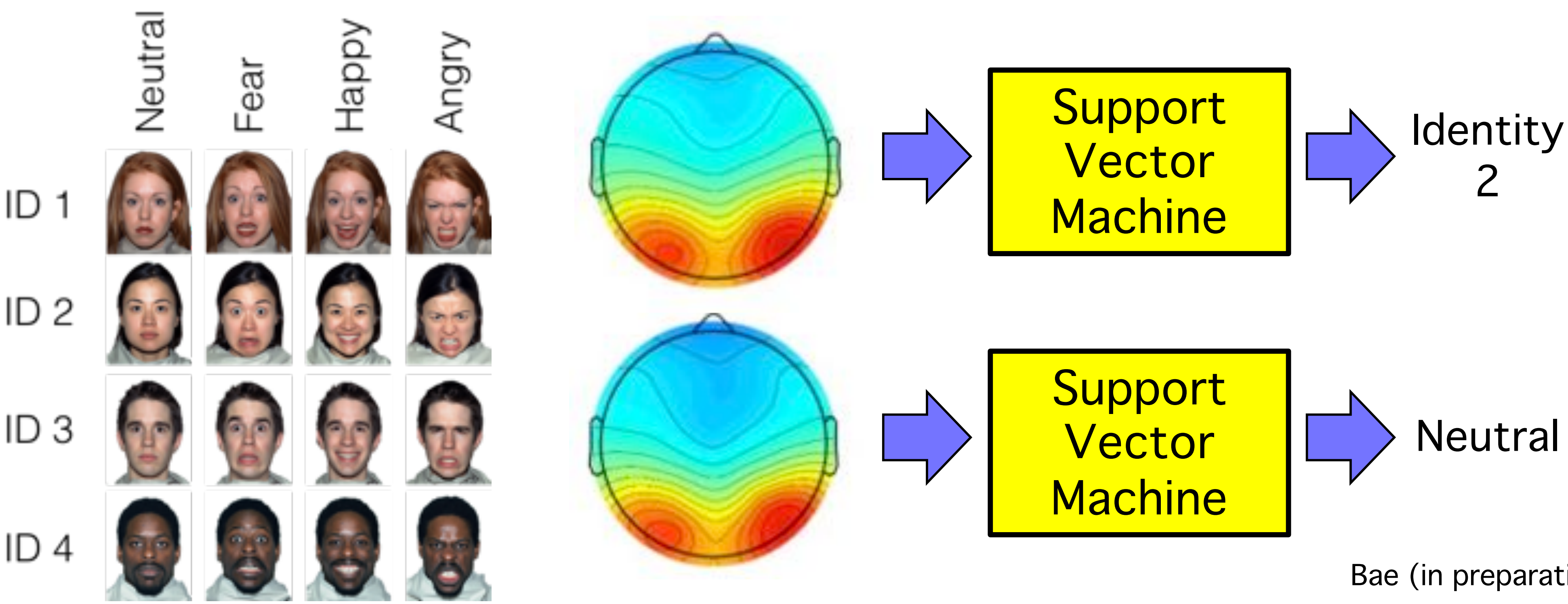
16 combinations of 4 identities and 4 expressions.

Subjects simply had to remember the most recent face. Their memory was tested after a random 12% of faces.

Bae (in preparation)

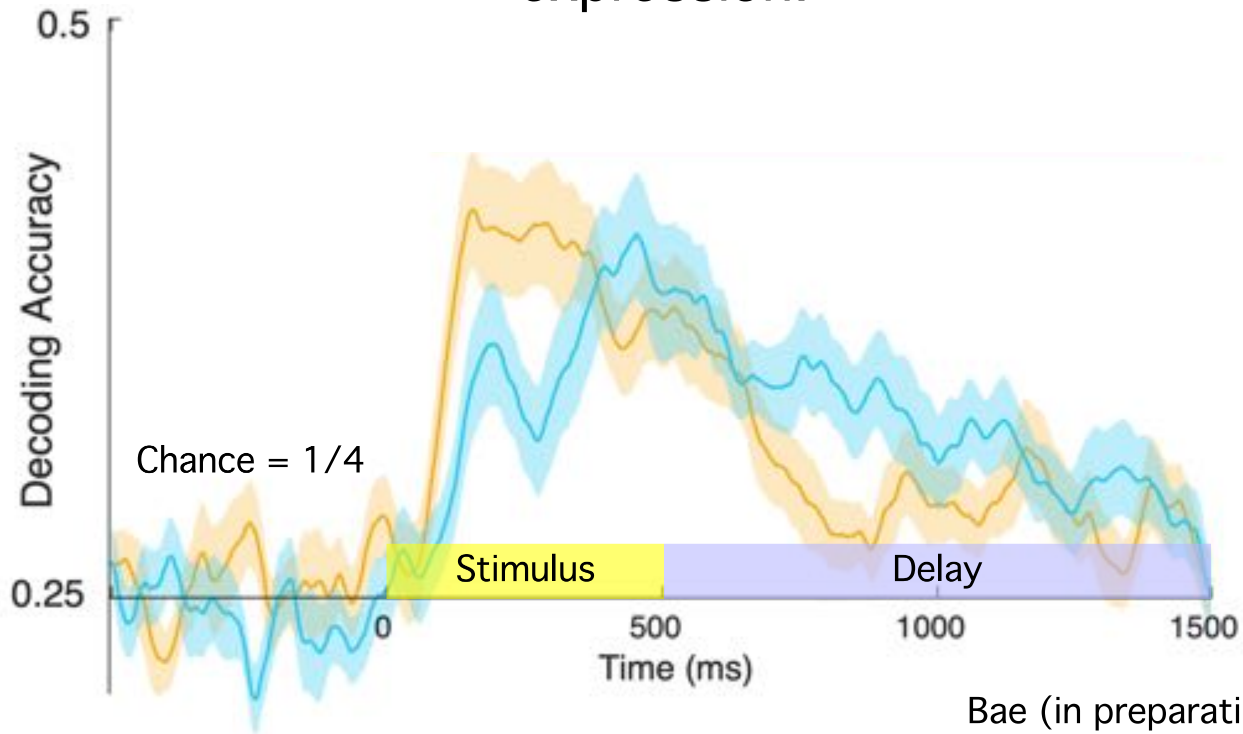
One set of support vector machines was trained to classify the identity of the face independently of the expression.

Another set of support vector machines was trained to classify the expression independently of the identity.



Bae (in preparation)

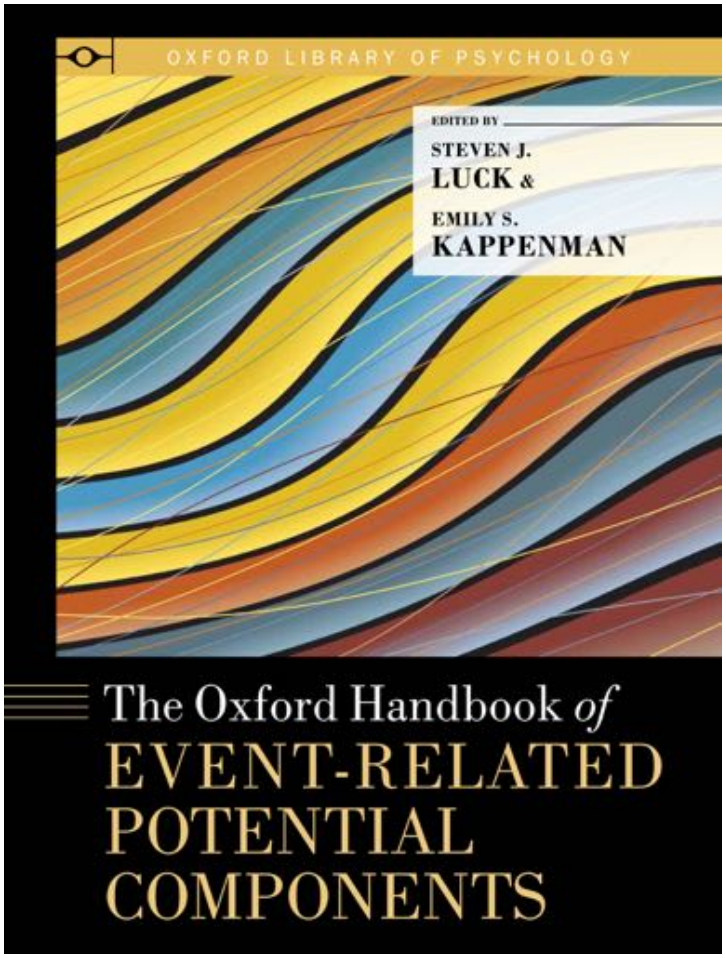
Decoding accuracy was well above chance for both identity and expression.



Bae (in preparation)

ERP Components

Language



CHAPTER

15 Language-Related ERP Components

Tamara Y. Swaab, Kerry Ledoux, C. Christine Camblin, *and* Megan Boudewyn

Abstract

Understanding the processes that permit us to extract meaning from spoken or written linguistic input requires elucidating how, when, and where in the brain sentences and stories, syllables and words are analyzed. Because human language is a cognitive function that is not readily investigated using neuroscience approaches in animal models, this task presents special challenges. In this chapter, we describe how event-related potentials (ERPs) have contributed to the understanding of language processes as they unfold in real-time. We will provide an overview of the many ERPs that have been used in language research, and will discuss the main models of what these ERPs reflect in terms of linguistic and neural processes. In addition, using examples from the literature, we will illustrate how ERPs can be used to study language comprehension, and will also outline methodological issues that are specific to using ERPs in language research.

Keywords: llexical processing, sentence processing, discourse processing, non-literal language, event-related potentials, N400, P600, Nref

Swaab, T. Y., Ledoux, K., Camblin, C. C., & Boudewyn, M. (2012). Language-related ERP components. In S. J. Luck & E. S. Kappenman (Eds.), *The Oxford Handbook of Event-Related Potential Components* (pp. 397–439). Oxford University Press.

The N400 Component

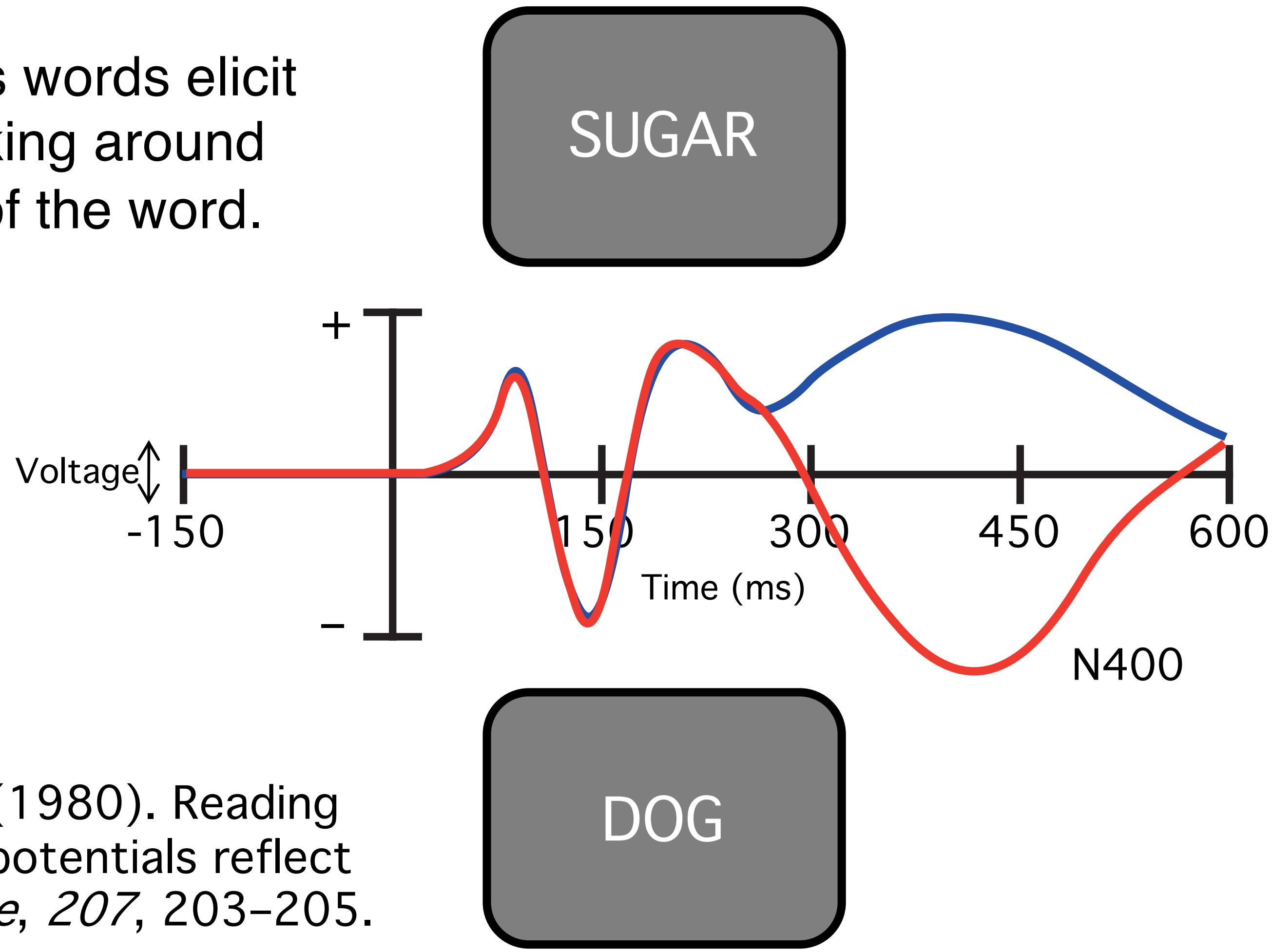
Reading Senseless Sentences: Brain Potentials Reflect Semantic Incongruity

Abstract. *In a sentence reading task, words that occurred out of context were associated with specific types of event-related brain potentials. Words that were physically aberrant (larger than normal) elicited a late positive series of potentials, whereas semantically inappropriate words elicited a late negative wave (N400). The N400 wave may be an electrophysiological sign of the "reprocessing" of semantically anomalous information.*

Kutas, M., & S. A. Hillyard. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*, 203–205.

I take my coffee with cream and _____.

Semantically incongruous words elicit a large N400 wave peaking around 400 ms after the onset of the word.



Kutas, M., & S. A. Hillyard. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*, 203–205.

N400

"I placed my keys on the kitchen floor" (medium N400)
"I placed my keys on the kitchen table" (small N400)

"Tree" -> "Nurse" (large N400)
"Doctor" -> "Nurse" (small N400)

"Life is what happens when you're busy making other plans." -John Lennon

The size of the N400 for a given word reflects the extent to which that word can be predicted from the preceding context.

"Life is what happens when you're busy make other plans."

↑

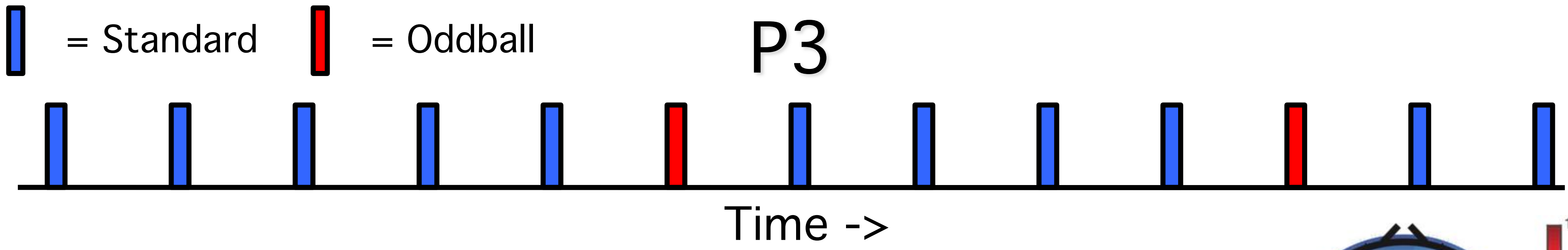
P600 instead of N400 for syntactic violations

This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Components

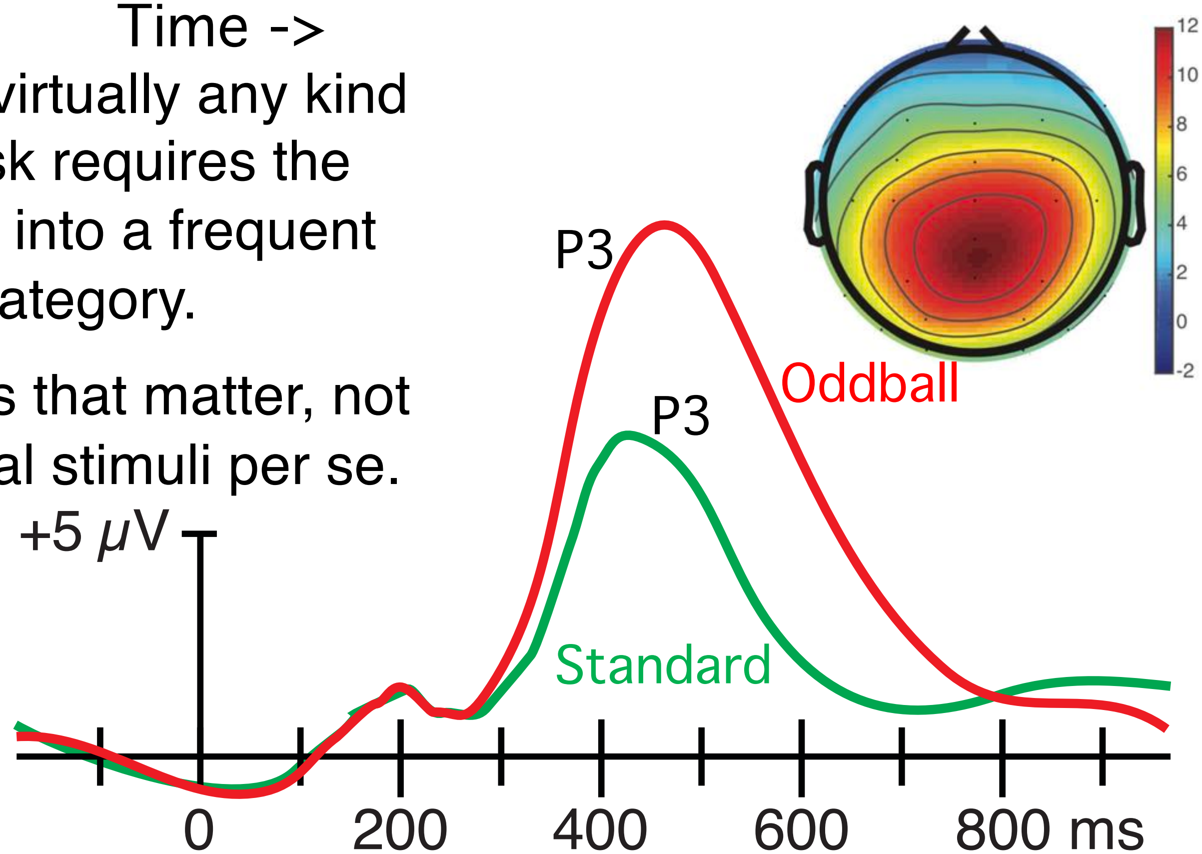
Categorization & Emotion

P3

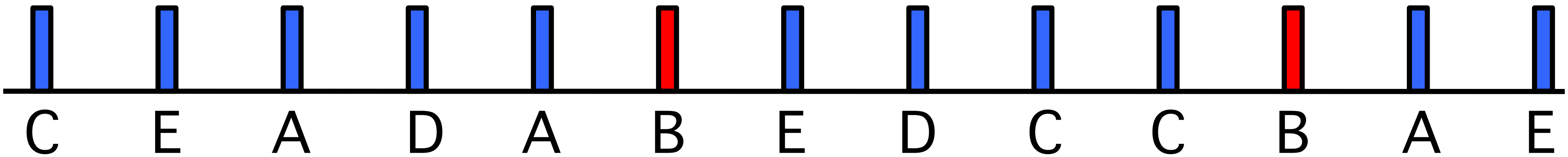


You can get this P3 effect for virtually any kind of stimuli, as long as the task requires the subject to classify the stimuli into a frequent category and a rare category.

It's the task-defined categories that matter, not the probabilities of the physical stimuli per se.



P3



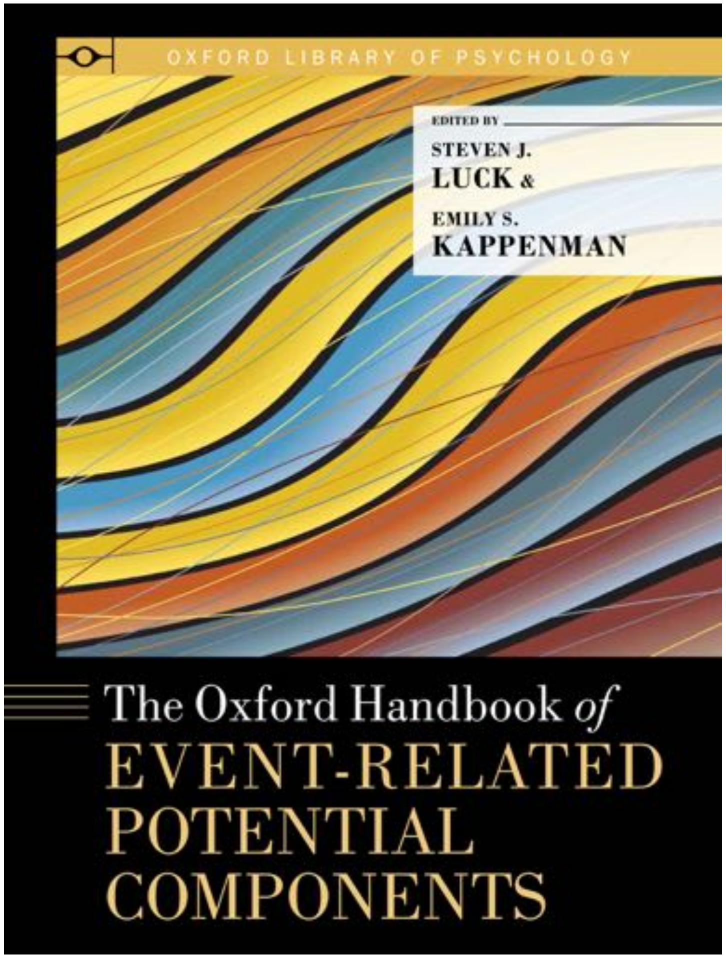
Press button 1 for B (oddball) Press button 2 for A, C, D, E (standard)

Probability of oddball category = 20%

Probability of standard category = 80%

Block 1: Target = B, Standards = {A, C, D, E}
Block 2: Target = E, Standards = {A, B, C, D}
Block 3: Target = A, Standards = {B, C, D, E}
Block 4: Target = D, Standards = {A, B, C, E}
Block 5: Target = C, Standards = {A, B, D, E}

https://erpinfo.org/erp-core



CHAPTER 7

Neuropsychology of P300

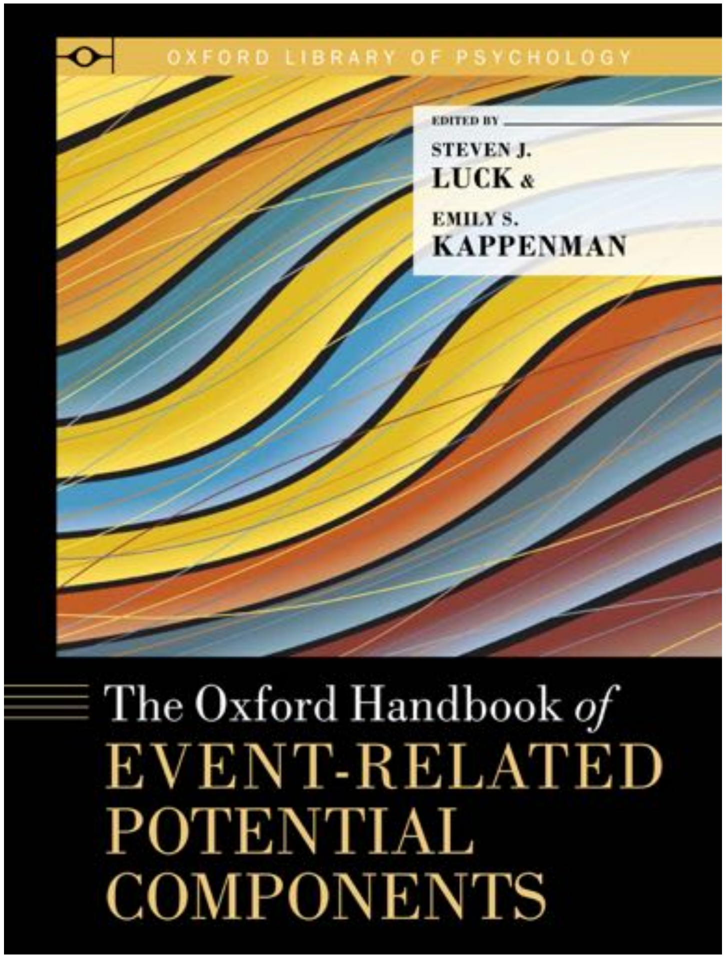
John Polich

Abstract

The discovery of the P300 event-related potential (ERP) stimulated the use of brain recording methods to assess human cognition. This chapter reviews the background and develops an integrated interpretation of P300. First, empirical issues and a theoretical overview are presented. Second, applied uses of P300 are reviewed, with normative and clinical studies highlighted. Third, the neuropsychological background and neurophysiological foundations of the P3a and P3b subcomponents are outlined. Fourth, neuropharmacological processes related to these constituent potentials are sketched to suggest how neurotransmitter systems may contribute to P300 production. Fifth, the P3a and P3b are proposed to result from neuroinhibition that is engaged when incoming stimuli garner attentional processes to facilitate memory encoding.

Keywords: P300, event-related potential, neuroinhibition, memory, cognition

Polich, J. (2012). Neuropsychology of P300. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford Handbook of ERP Components* (pp. 159–188). Oxford University Press.



CHAPTER

16 ERPs and the Study of Emotion

Greg Hajcak, Anna Weinberg, Annmarie MacNamara, *and* Dan Foti

Abstract

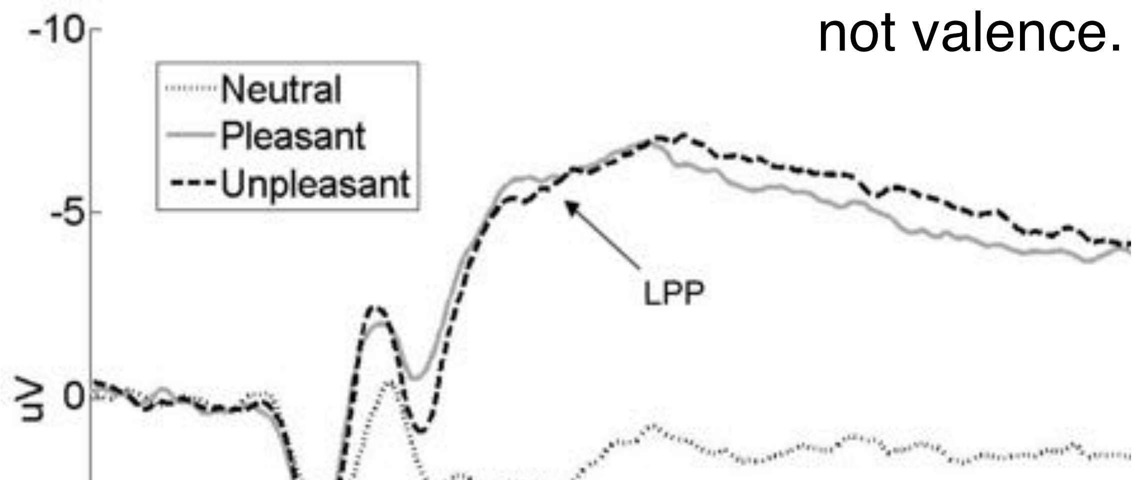
Interest in the neuroscience of emotion has increased dramatically over the course of the last two decades. The rapid growth and popularity, however, have come with a definitional imbroglio, as there seem to be as many conceptualizations of emotion as there are emotion researchers. This chapter begins by presenting an increasingly common conceptualization of emotion and emphasizes key distinctions used in emotion research. Next, multiple event-related potential (ERP) components sensitive to emotional content and the time course of emotional processing are highlighted. Then, how that time course can be clarified through data reduction techniques is examined, with examples provided. Subsequently, methodological issues are outlined, with the key decisions about ERP elicitation and measurement specified. Event-related potential findings related to clinical, developmental, and aging applications in the psychology of emotion are summarized. Finally, speculation on the future of emotion research using ERPs is proffered in terms of key questions to be answered.

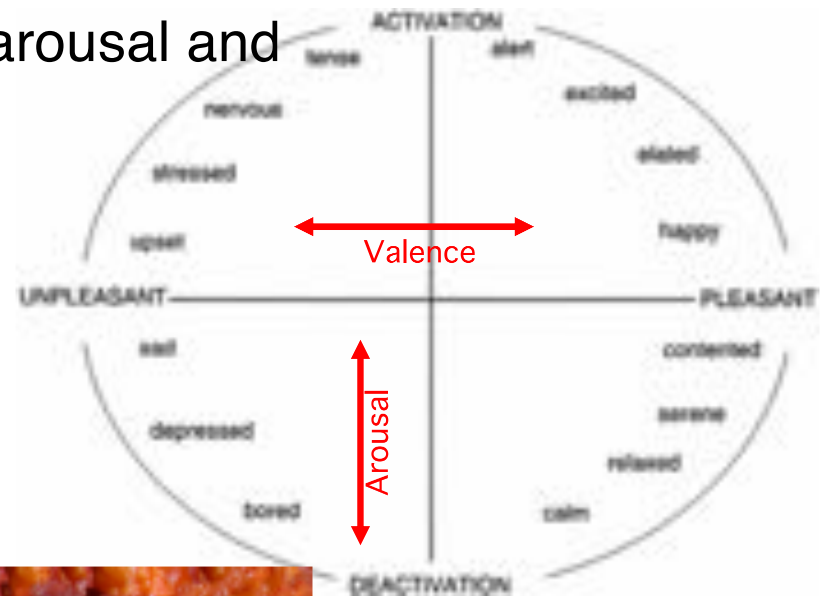
Keywords: event-related potentials, emotion, emotion research, ERP components

Hajcak, G., Wienberg, A., MacNamara, A., & Foti, D. (2012). ERPs and the study of emotion. In S. J. Luck & E. S. Kappenman (Eds.), *The Oxford Handbook of ERP Components* (pp. 441–472). Oxford University Press.

The Late Positive Potential (LPP)

The LPP primarily reflects arousal and not valence.





Hajcak et al. (2012, Oxford Handb