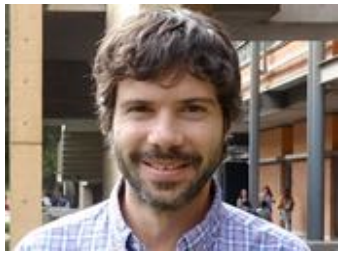
This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Recording & Analysis

Participants, Stimuli, & Task



ORIGINAL ARTICLE

WILEY | PSYCHOPHYSIOLOGY SPR

Event-related potential components as measures of aversive conditioning in humans

Felix Bacigalupo | **Steven J. Luck**

Center for Mind and Brain, University of California, Davis, Davis, California, USA

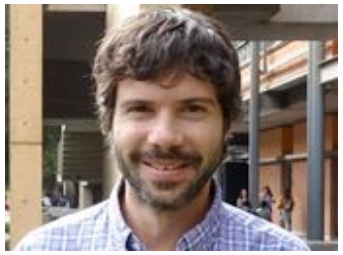
Correspondence
Felix Bacigalupo, Center for Mind and Brain, University of California, Davis, 267 Cousteau Place, Room 133, Davis, CA 95618, USA.
Email: fbacigalupo@ucdavis.edu

Funding information
National Institutes of Health (grants R03MH098119, R01MH076226) (to S. J. L.), Becas Chile-Conicyt scholarship (to F. B.)

Abstract

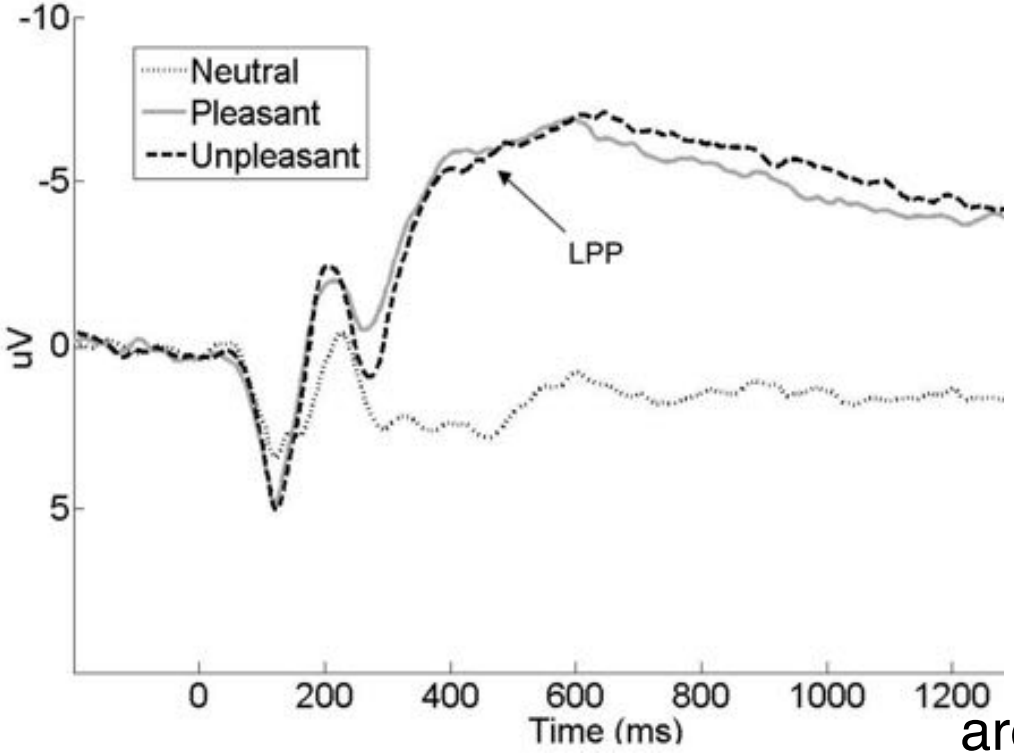
For more than 60 years, the gold standard for assessing aversive conditioning in humans has been the skin conductance response (SCR), which arises from the activation of the peripheral nervous system. Although the SCR has been proven useful, it has some properties that impact the kinds of questions it can be used to answer. In particular, the SCR is slow, reaching a peak 4–5 s after stimulus onset, and it decreases in amplitude after a few trials (habituation). The present study asked whether the late positive potential (LPP) of the ERP waveform could be a useful complementary method for assessing aversive conditioning in humans. The SCR and LPP were measured in an aversive conditioning paradigm consisting of three blocks in which one color was paired with a loud noise (CS+) and other colors were not paired with the noise (CS−). Participants also reported the perceived likelihood of being exposed to the noise for each color. Both SCR and LPP were significantly

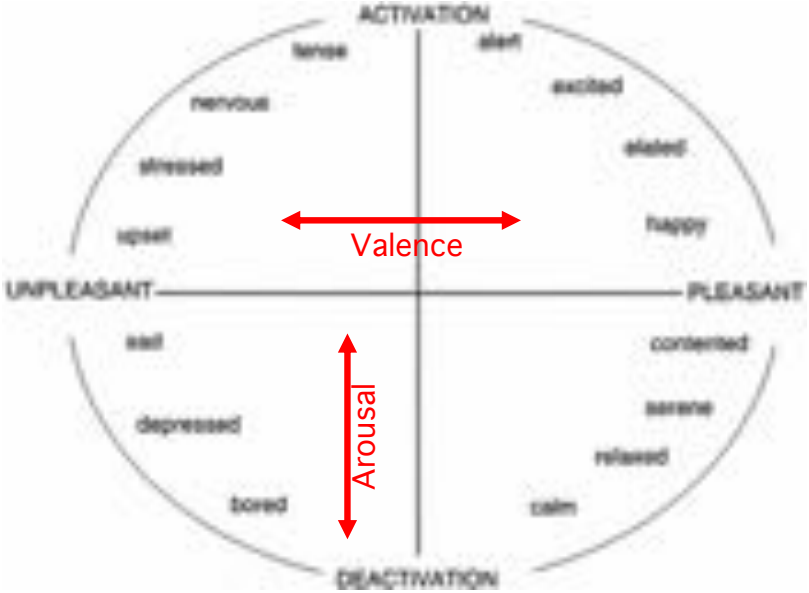
Bacigalupo, F., & Luck, S. J. (2018). Event-related potential components as measures of aversive conditioning in humans. *Psychophysiology*, *55*, e13015.



For decades, researchers have studied aversive conditioning using the skin conductance response, which is related to the sweaty palms you get when you're nervous.

The Late Positive Potential (LPP)





The LPP is elicited by emotionally arousing stimuli, whether they're positive or negative. An LPP would therefore be expected for stimuli that have been associated with negative outcomes.

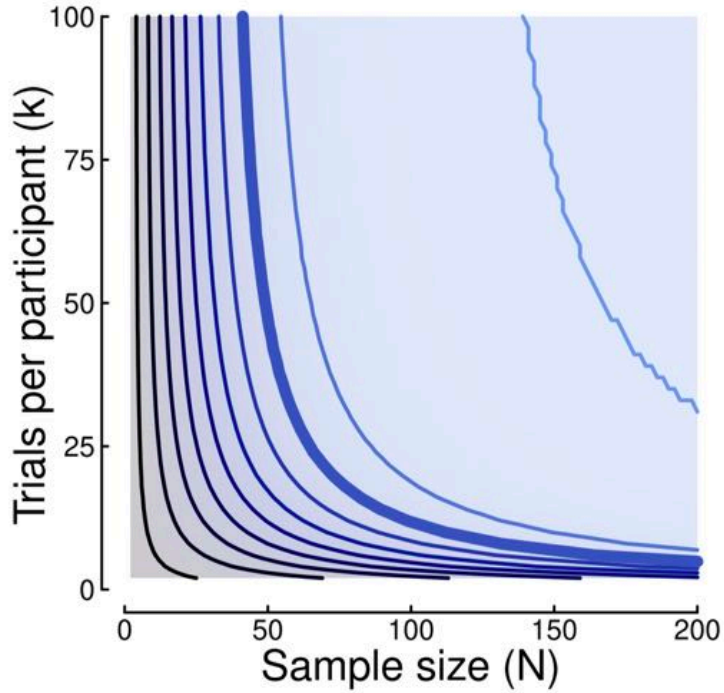
Hajcak et al. (2012, Oxford Handbook of ERP Components)

2 | METHOD

2.1 | Participants

Seventy volunteers from the UC Davis community with no history of neurological or psychiatric conditions participated in this experiment (49 female). All participants were screened with a standard questionnaire for color blindness and visual acuity, and all reported normal color perception and normal or corrected-to-normal visual acuity. The age ranged between 18–29 years with a mean of 21 years. They were originally recruited in two groups of 35 participants for two separate studies, but the analyses presented below were collapsed across all 70 participants.

Statistical power in ERP experiments depends on both the number of subjects and the number of trials per subject.



Baker, D. H., Vilidaite, G., Lygo, F. A., Smith, A. K., Flack, T. R., Gouws, A. D., & Andrews, T. J. (2020). Power contours: Optimising sample size and precision in experimental psychology and human neuroscience. *ArXiv:1902.06122 [q-Bio, Stat]*.

2 | METHOD

2.1 | Participants

Seventy volunteers from the UC Davis community with no history of neurological or psychiatric conditions participated in this experiment (49 female). All participants were screened with a standard questionnaire for color blindness and visual acuity, and all reported normal color perception and normal or corrected-to-normal visual acuity. The age ranged between 18–29 years with a mean of 21 years. They were originally recruited in two groups of 35 participants for two separate studies, but the analyses presented below were collapsed across all 70 participants.

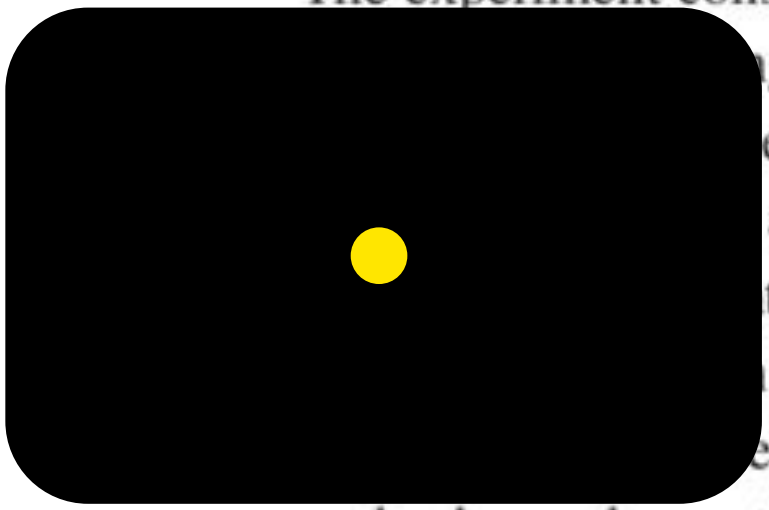
2.2 | Experiment setup

The experiment consisted of three phases: (a) habituation, (b) aversive conditioning, and (c) extinction. In all three phases, participants were seated 100 cm from an HP ZR244Ow LCD monitor with a black background and a continuously visible fixation point at the center. The monitor delay (8 ms) was measured with a photodiode, and the stimulus event codes were corrected accordingly prior to data analysis. In

The problem with LCDs is that there is a delay between when the computer sends them the video signal and when the image actually appears on the screen.

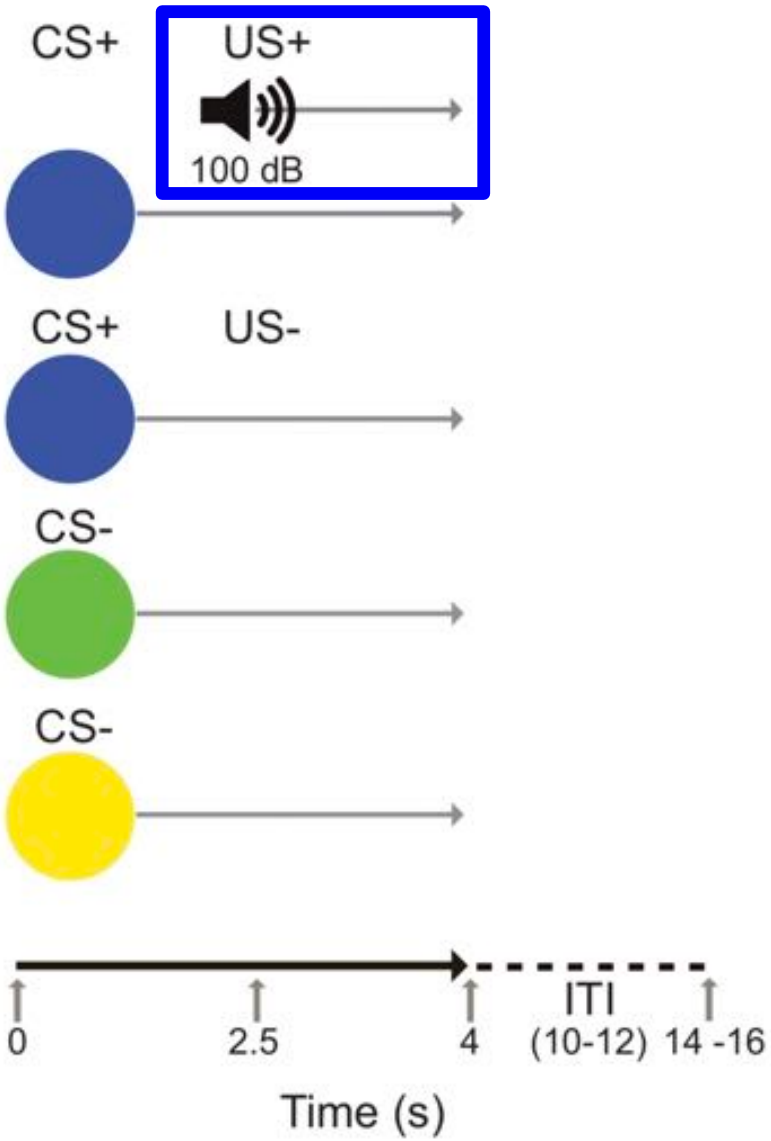
We always measure the delay and shift the event codes accordingly.

2.2 | Experiment setup



The experiment consisted of three phases: (a) habituation, (b) g, and (c) extinction. In all three phases, eated 100 cm from an HP ZR244Ow a black background and a continuously t at the center. The monitor delay (8 ms) a photodiode, and the stimulus event ed accordingly prior to data analysis. In each phase, the participants passively viewed a sequence of trials in which a circle (1.3°) was presented in the middle of the monitor. Stimulus duration was 4 s, and the stimuli were separated by an intertrial interval that varied randomly between 10 and 12 s.

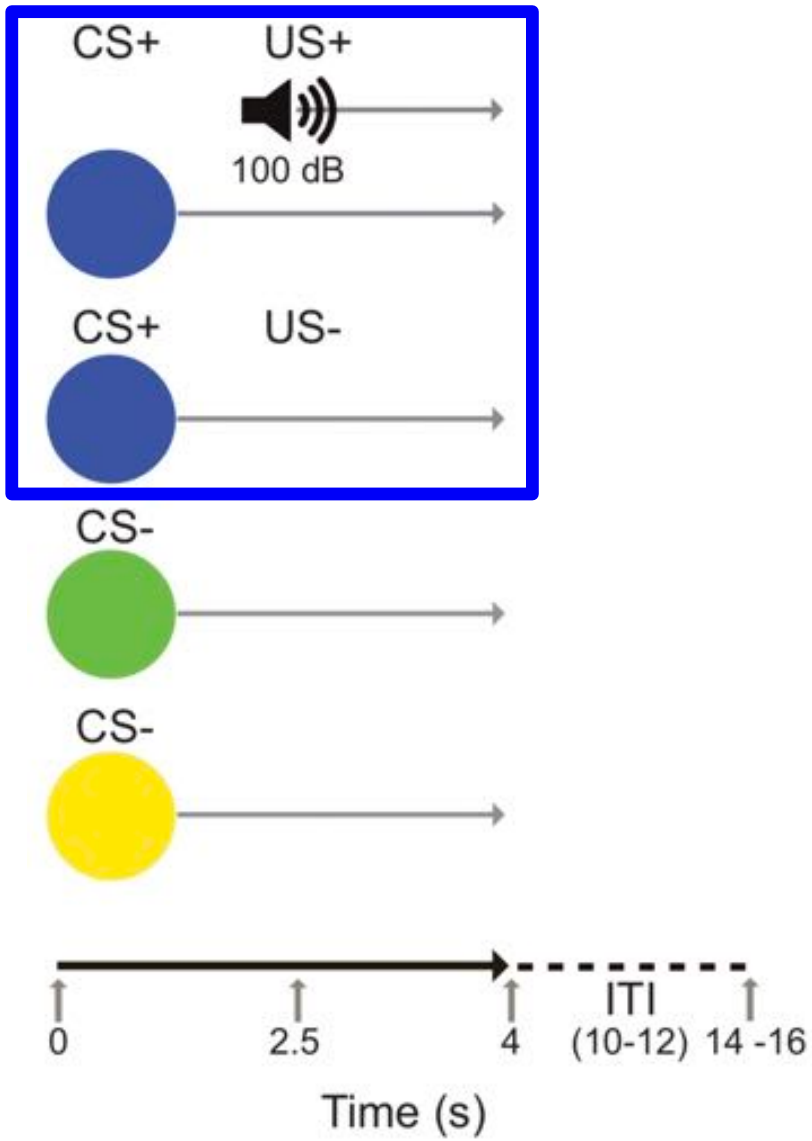
The aversive stimulus was a 1.5-second white noise burst. This is referred to as the unconditioned stimulus or US. It was 100 decibels, which isn't loud enough to damage the ears but was really unpleasant.



One color was the conditioned stimulus or CS+, which was associated with the white noise burst.

When the CS+ was presented, it had a 50% chance of being followed by the noise burst 2.5 seconds after the onset of the CS+. These are CS+/US+ trials.

On the other 50% of CS+ trials, no noise burst was presented. These are CS+/US- trials.



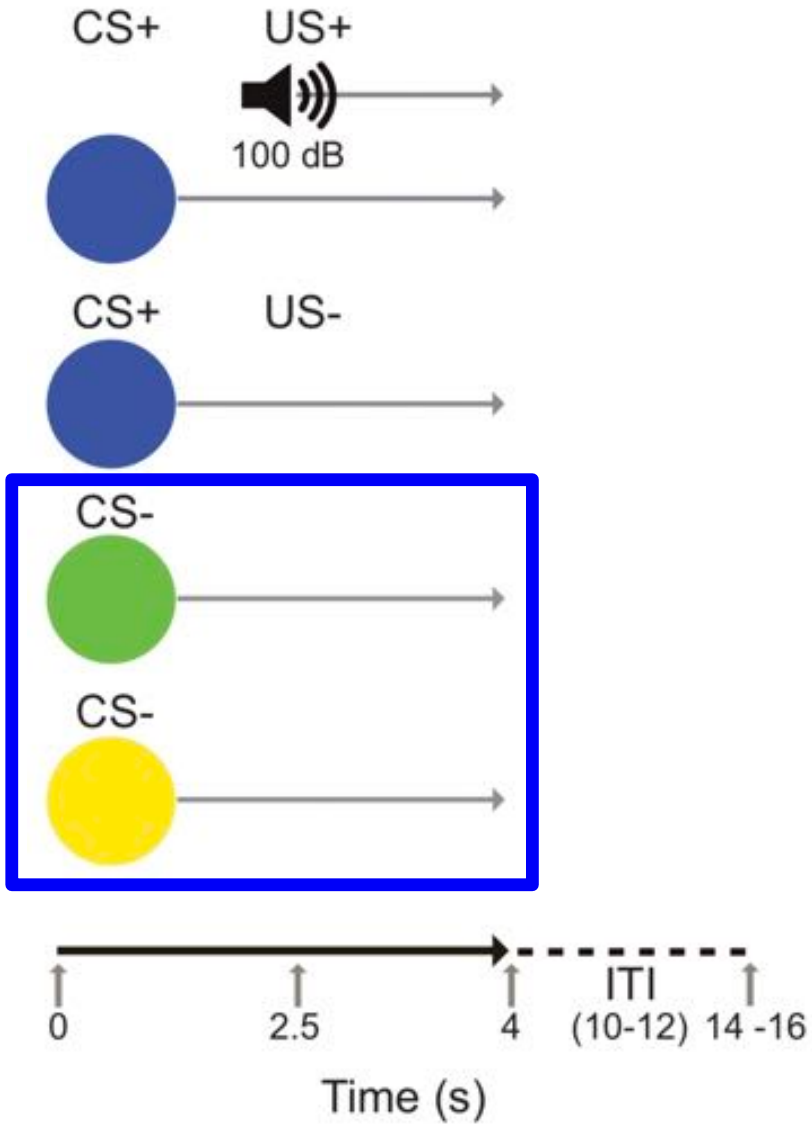
The other two colors were associated with the absence of the noise burst and were called CS- stimuli.

We counterbalanced which color was CS+ and which colors were CS-.

The CS- stimuli were never followed by a noise burst.

<u>Counterbalancing</u>

Subject 1: CS+ = Blue
Subject 2: CS+ = Green
Subject 3: CS+ = Yellow
Subject 4: CS+ = Blue
⋮



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)

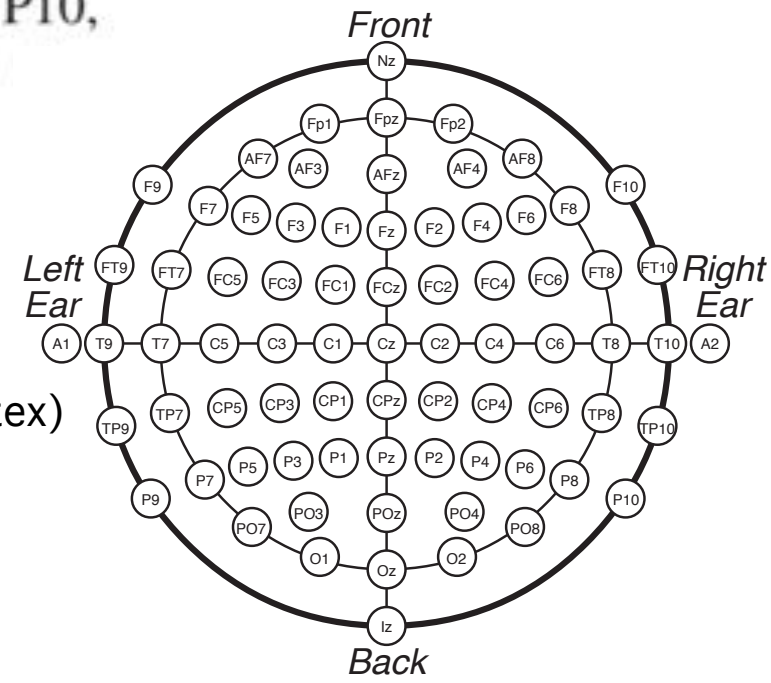
ERP Recording & Analysis

Recording the EEG

2.3 | Psychophysiological recording and analysis

The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz).

The International 10/20 System



Fp: Frontal Pole
F: Frontal
C: Central (Vertex)
P: Parietal
O: Occipital
T: Temporal

How many electrodes do you need?

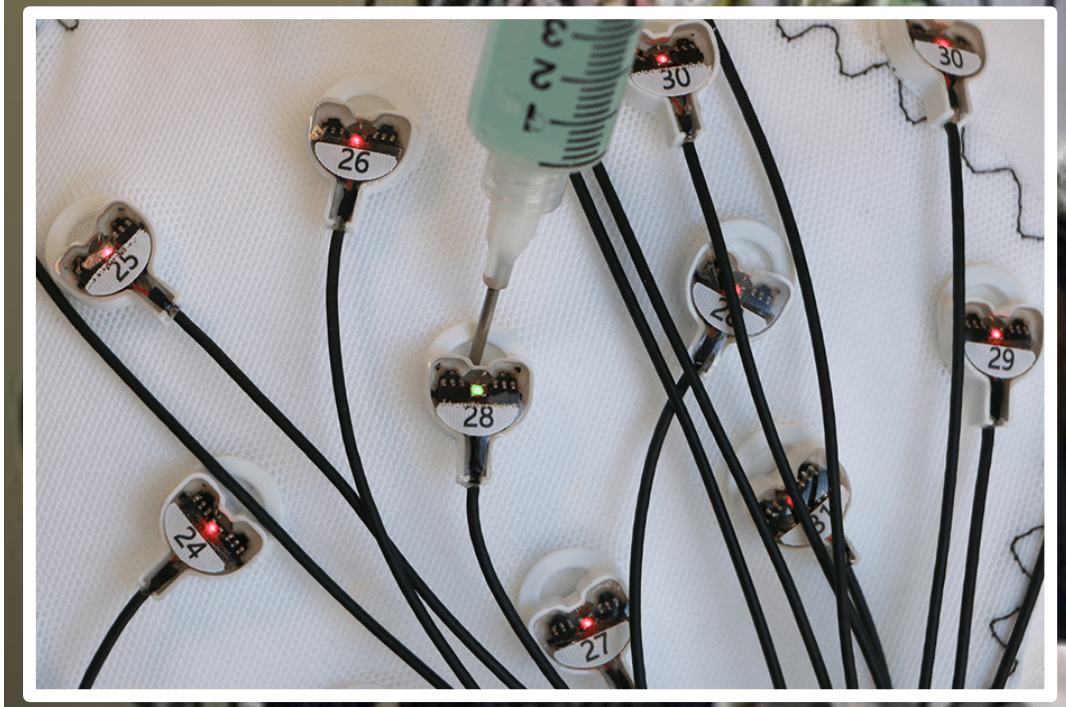
IT DEPENDS

In many studies, all of the analyses focus on just one or two electrodes. It is usually a good idea to have enough electrodes to cover the scalp, you might miss an interesting but unexpected effect

In most cases, 12 electrode sites would be the minimum recommended, and there is not usually a significant benefit to having more than 64 electrodes.

Each electrode is just a little pellet of metal encased in plastic.

The electrode pellet doesn't directly contact the skin. Instead, a conductive gel makes the connection between the skin and the electrode. This results in a more stable connection that isn't as easily disrupted by small head movements.



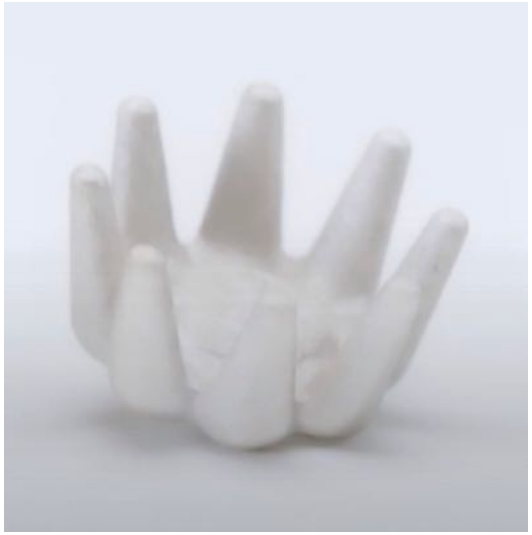
https://pressrelease.brainproducts.com/r-net-2/

Some systems use a sponge soaked with saline as the conductor. This makes the electrodes faster to apply. However, the data are usually noisier.

https://www.cgxsystems.com/

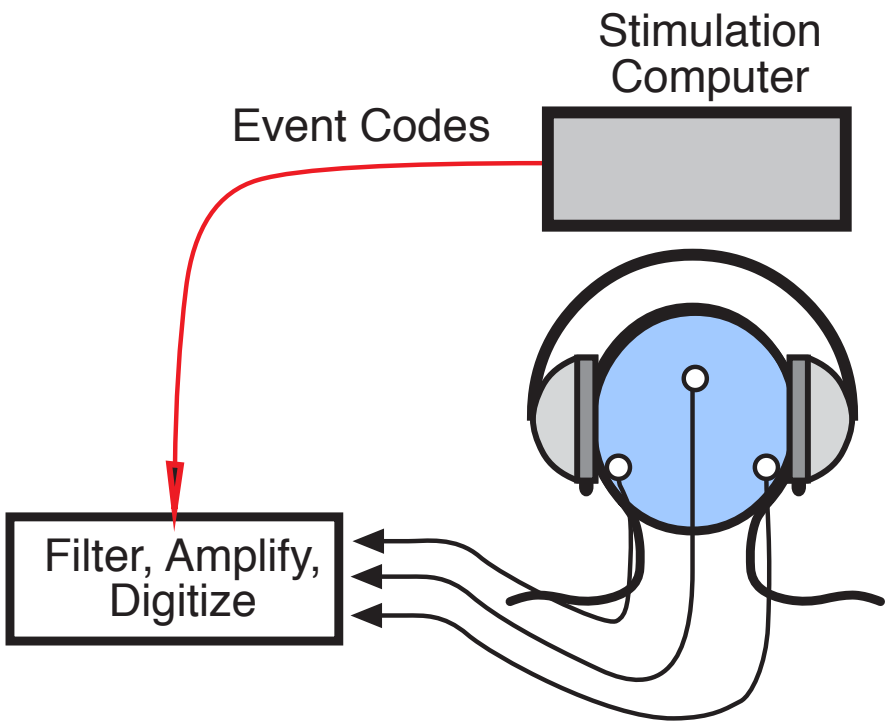
Dry electrodes are popular for real-world applications, like brain-computer interfaces.

The data quality is too poor for most laboratory research.



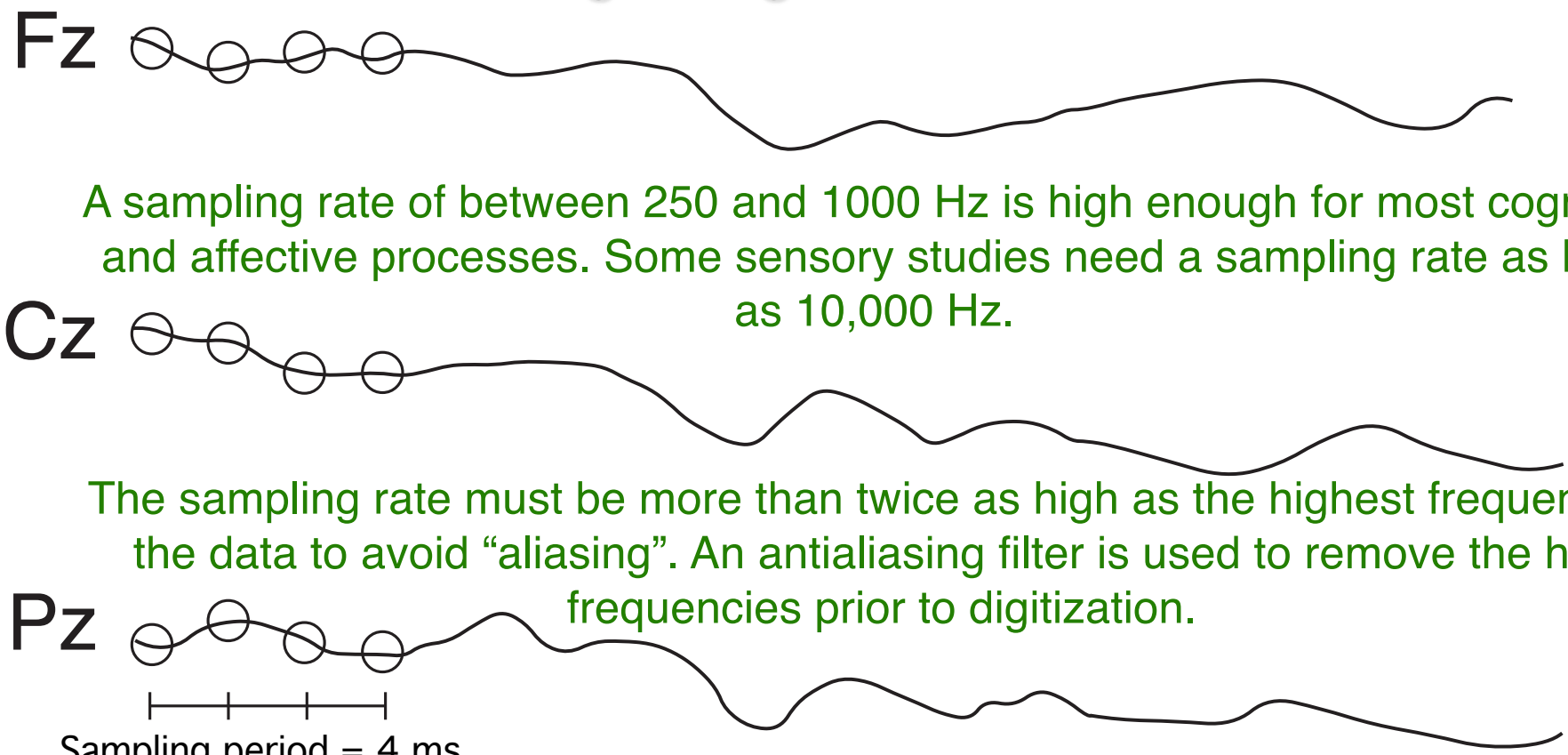
In a typical laboratory system, the outputs of the electrodes are sent to a device that filters and amplifies the voltages and then turns the analog voltages into discrete digital values.

In some systems, each electrode has a built-in preamplifier. These are called active electrodes, and they produce better data quality.



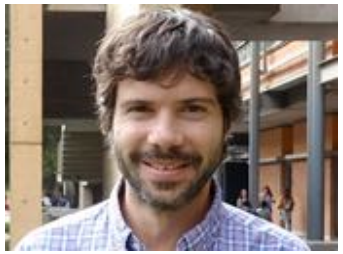
https://www.brainproducts.com/productdetails.php?id=4

Digitizing the EEG



A sampling rate of between 250 and 1000 Hz is high enough for most cognitive and affective processes. Some sensory studies need a sampling rate as high as 10,000 Hz.

The sampling rate must be more than twice as high as the highest frequency in the data to avoid “aliasing”. An antialiasing filter is used to remove the high frequencies prior to digitization.



ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR

Event-related potential components as measures of aversive conditioning in humans

Felix Bacigalupo | **Steven J. Luck**

Center for Mind and Brain, University of California, Davis, Davis, California, USA

Correspondence
Felix Bacigalupo, Center for Mind and Brain, University of California, Davis, 267 Cousteau Place, Room 133, Davis, CA 95618, USA.
Email: fbacigalupo@ucdavis.edu

Funding information
National Institutes of Health (grants R03MH098119, R01MH076226) (to S. J. L.), Becas Chile-Conicyt scholarship (to F. B.)

Abstract

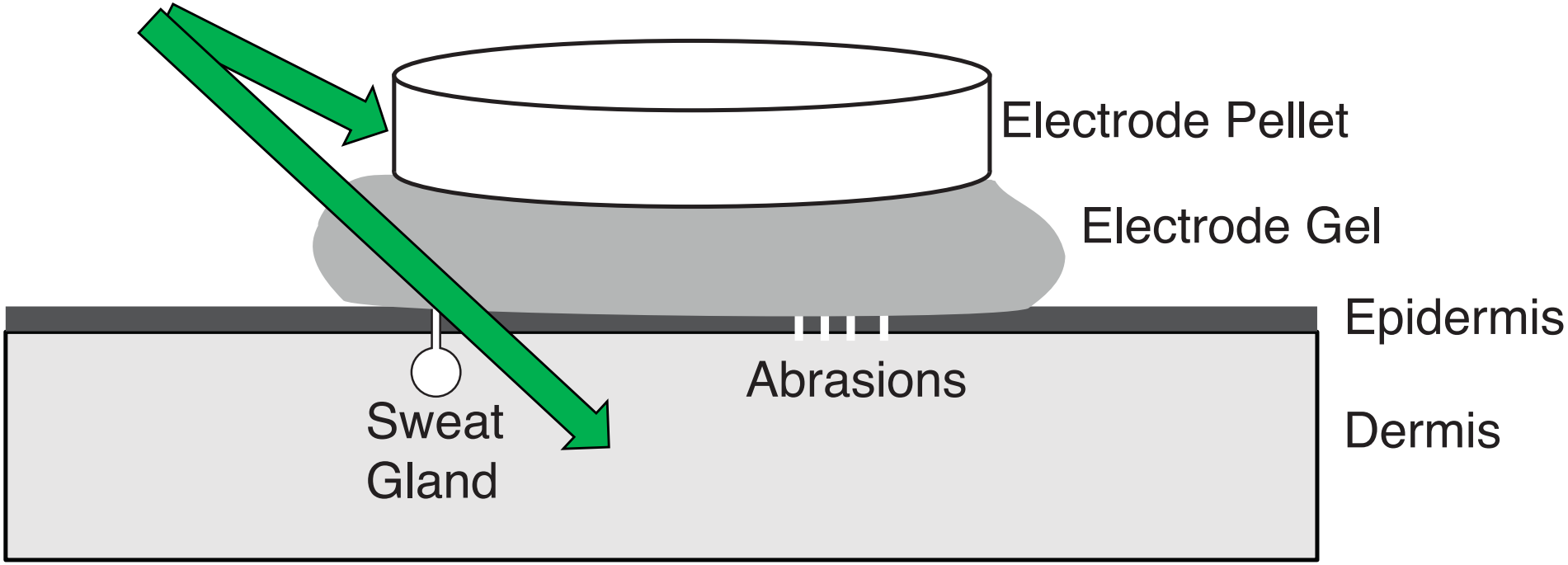
For more than 60 years, the gold standard for assessing aversive conditioning in humans has been the skin conductance response (SCR), which arises from the activation of the peripheral nervous system. Although the SCR has been proven useful, it has some properties that impact the kinds of questions it can be used to answer. In particular, the SCR is slow, reaching a peak 4–5 s after stimulus onset, and it decreases in amplitude after a few trials (habituation). The present study asked whether the late positive potential (LPP) of the ERP waveform could be a useful

All signals were recorded in single-ended mode and digitized at 1000 Hz with a cascaded integrator-comb anti-aliasing filter with a half-power cutoff at 260 Hz. The electrode impedances were kept below 80 KΩ.

Electrode Impedance

Electrode impedance is the extent to which the flow of current between the electrode pellet and the living skin is impeded by the layer of dead skin cells and oils on the surface of the skin

If the impedance is too high, this results in more low-frequency noise from skin potentials. High impedance does not reduce the size of the signal.



Psychophysiology, *47* (2010), 888–904. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2010.01009.x

The effects of electrode impedance on data quality and statistical significance in ERP recordings

EMILY S. KAPPENMAN AND STEVEN J. LUCK
Center for Mind & Brain and Department of Psychology, University of California, Davis, Davis, California, USA

Abstract

To determine whether data quality is meaningfully reduced by high electrode impedance, EEG was recorded simultaneously from low- and high-impedance electrode sites during an oddball task. Low-frequency noise was found to be increased at high-impedance sites relative to low-impedance sites, especially when the recording environment was warm and humid. The increased noise at the high-impedance sites caused an increase in the number of trials needed to obtain statistical significance in analyses of P3 amplitude, but this could be partially mitigated by high-pass filtering and artifact rejection. High electrode impedance did not reduce statistical power for the N1 wave unless the recording environment was warm and humid. Thus, high electrode impedance may increase noise and decrease statistical power under some conditions, but these effects can be reduced by using a cool and dry recording environment and appropriate signal processing methods.

Kappenman, E. S., & Luck, S. J. (2010). The effects of electrode impedance on data quality and statistical significance in ERP recordings. *Psychophysiology*, *47*, 888–904.

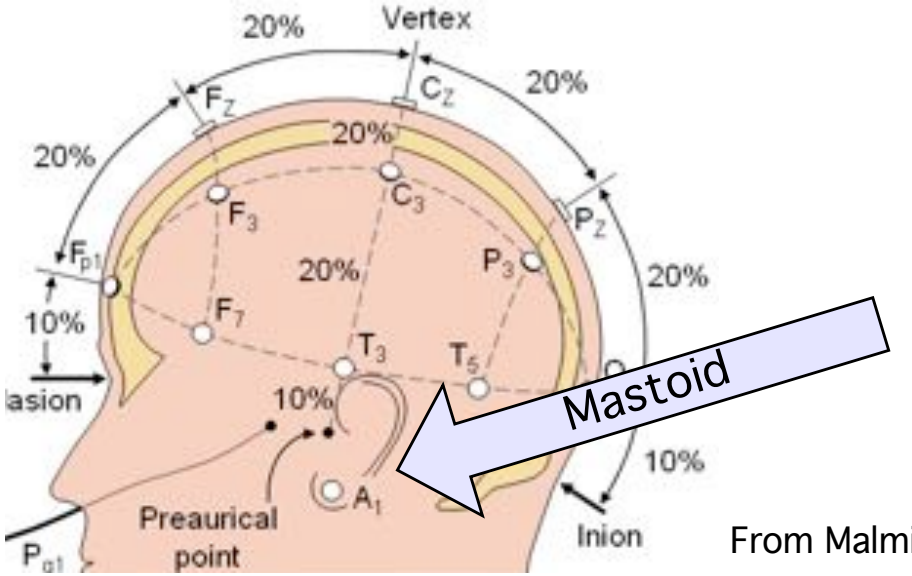
This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Recording & Analysis

Active, Reference, & Ground Electrodes

2.3 | Psychophysiological recording and analysis

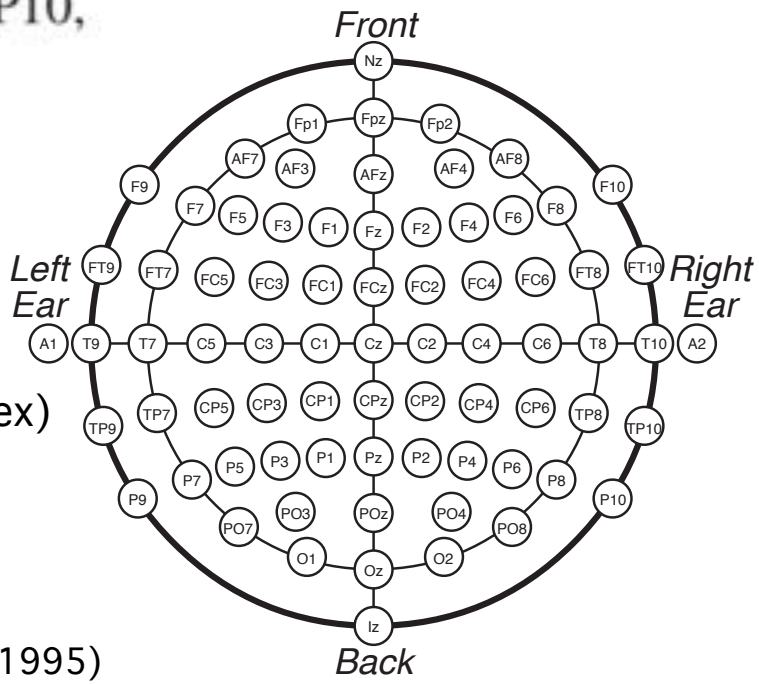
The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz).



Fp: Frontal Pole
F: Frontal
C: Central (Vertex)
P: Parietal
O: Occipital
T: Temporal

From Malmivuo, J. & Plonsey, R. (1995)

The International 10/20 System



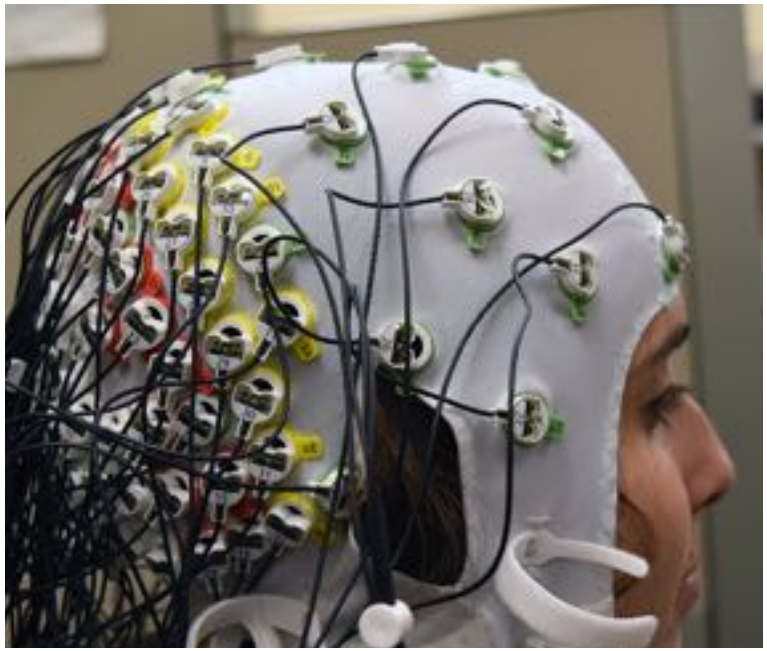
Absolute Voltage-

Potential for current to flow from one site to the average of the whole head

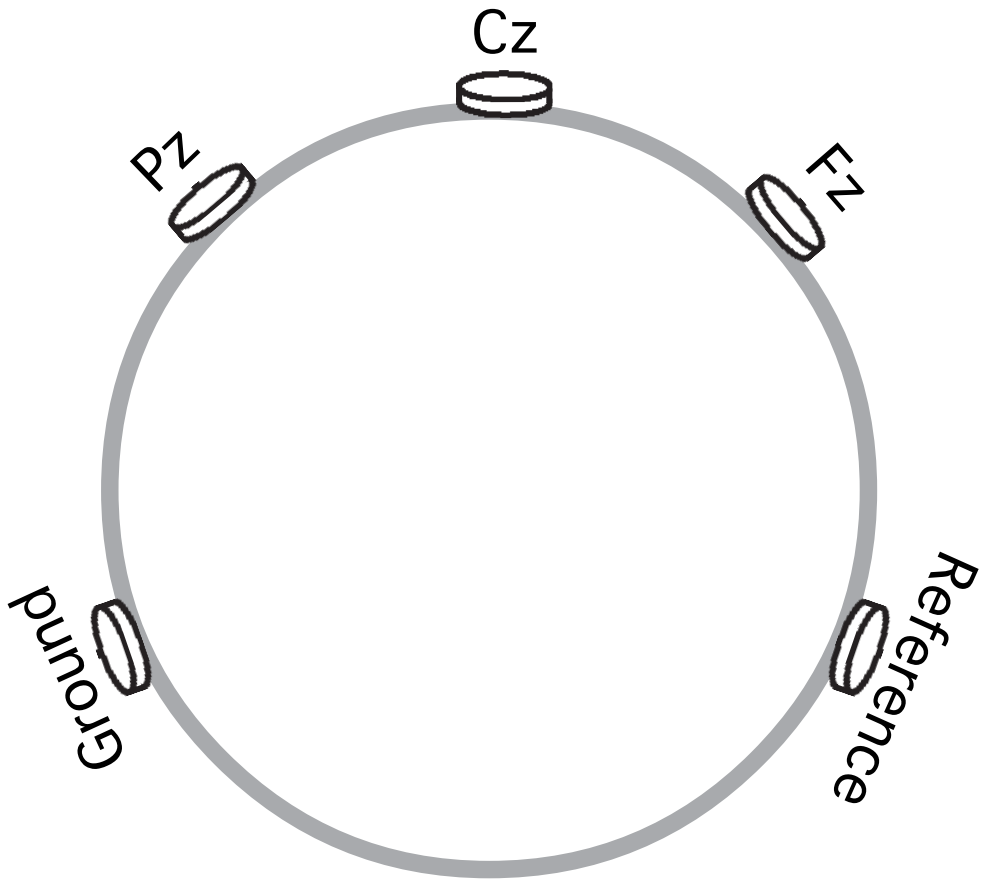
Voltage(A→B) = A - B

Voltage-

Potential for current to flow from one location to another



Active, Reference, & Ground Electrodes



Voltage is measured between ACTIVE and GROUND (A - G)

Voltage is measured between REFERENCE and GROUND (R - G)

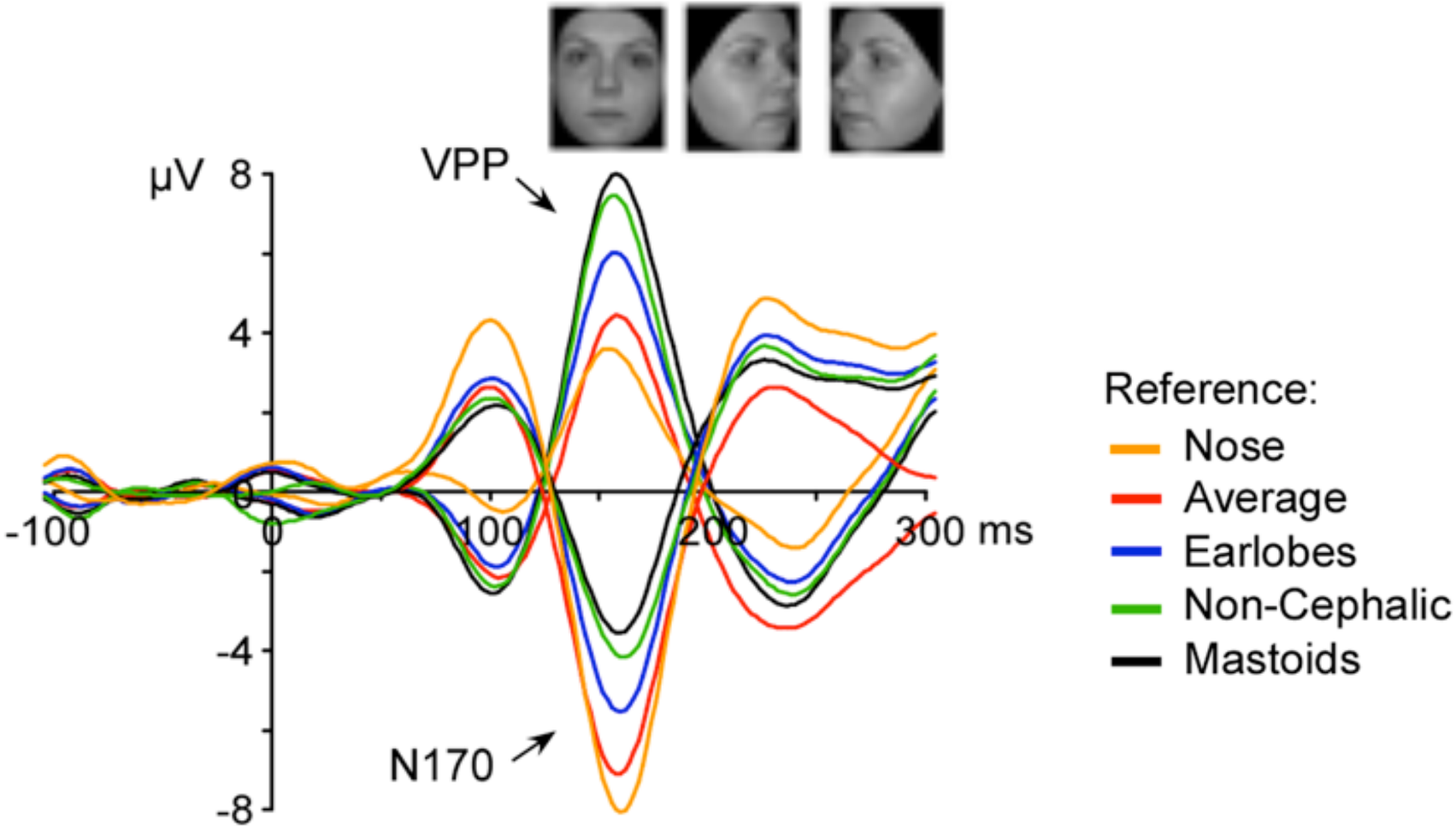
Output is the difference:
(A - G) - (R - G) = A - R

A – R is the voltage between ACTIVE and REFERENCE

Ground location does not matter

Reference location is vitally important!

N170 with Different Reference Sites

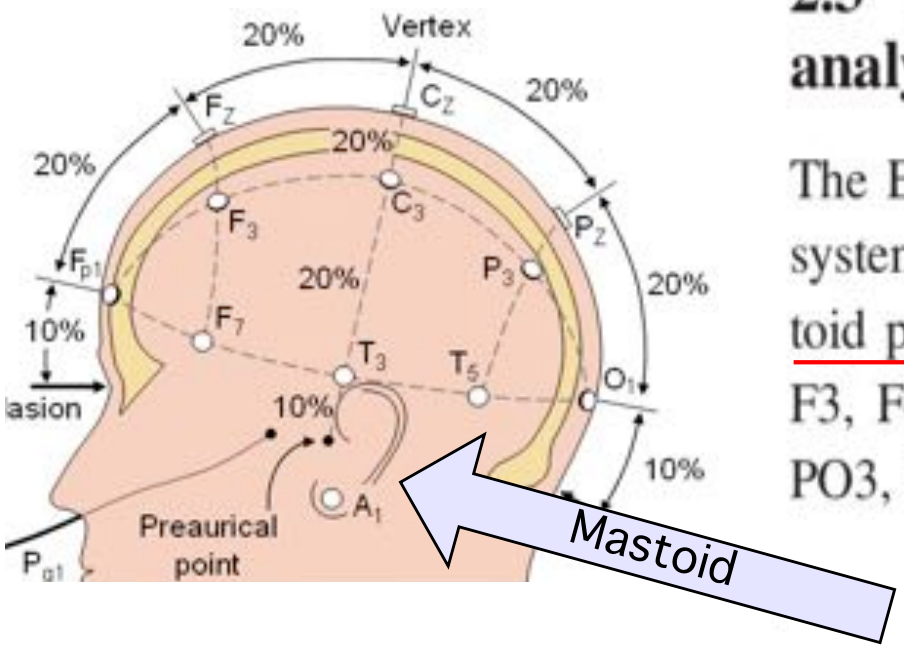


This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Recording & Analysis

Location of the Reference Electrode

From Malmivuo, J. & Plonsey, R. (1995)

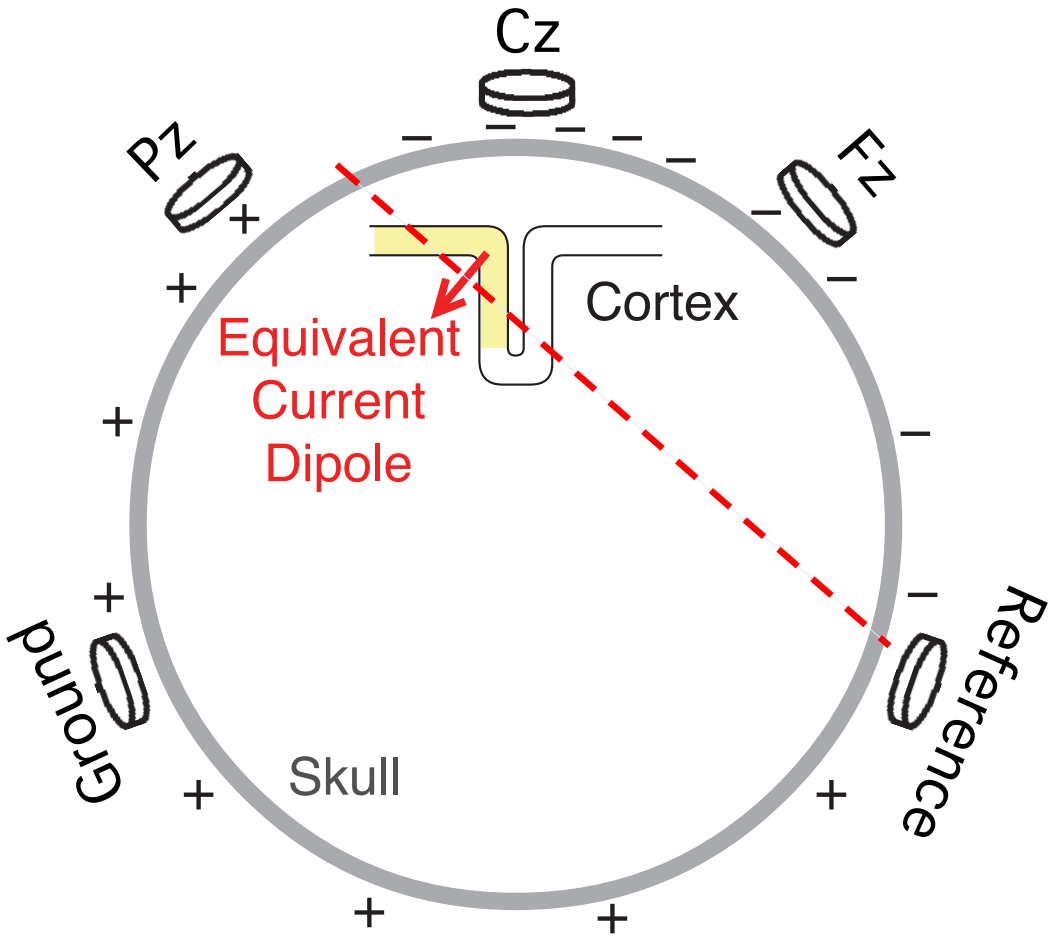


2.3 | Psychophysiological recording and analysis

The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz).

The EEG signals were referenced to the average of the two mastoid electrodes and high-pass filtered using a noncausal Butterworth filter (half-amplitude cutoff = 0.1 Hz, slope = 12 dB/octave).

What to Use as the Reference?



Recorded Voltage = Active - Reference

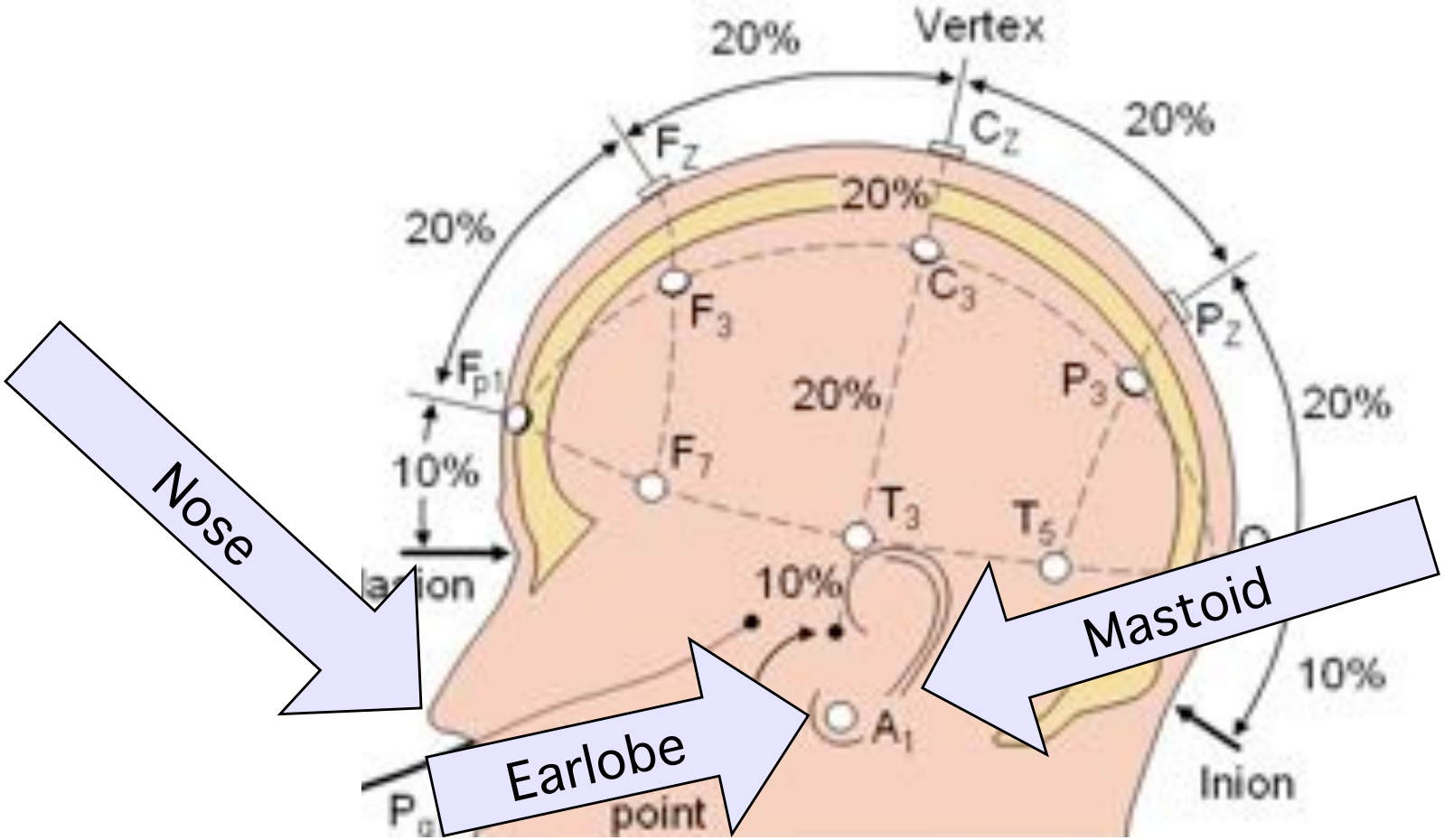
In an ideal world, we'd have our reference electrode somewhere on the zero line.

To know where the zero line is, we'd need to know the location and orientation of all the generator dipoles.

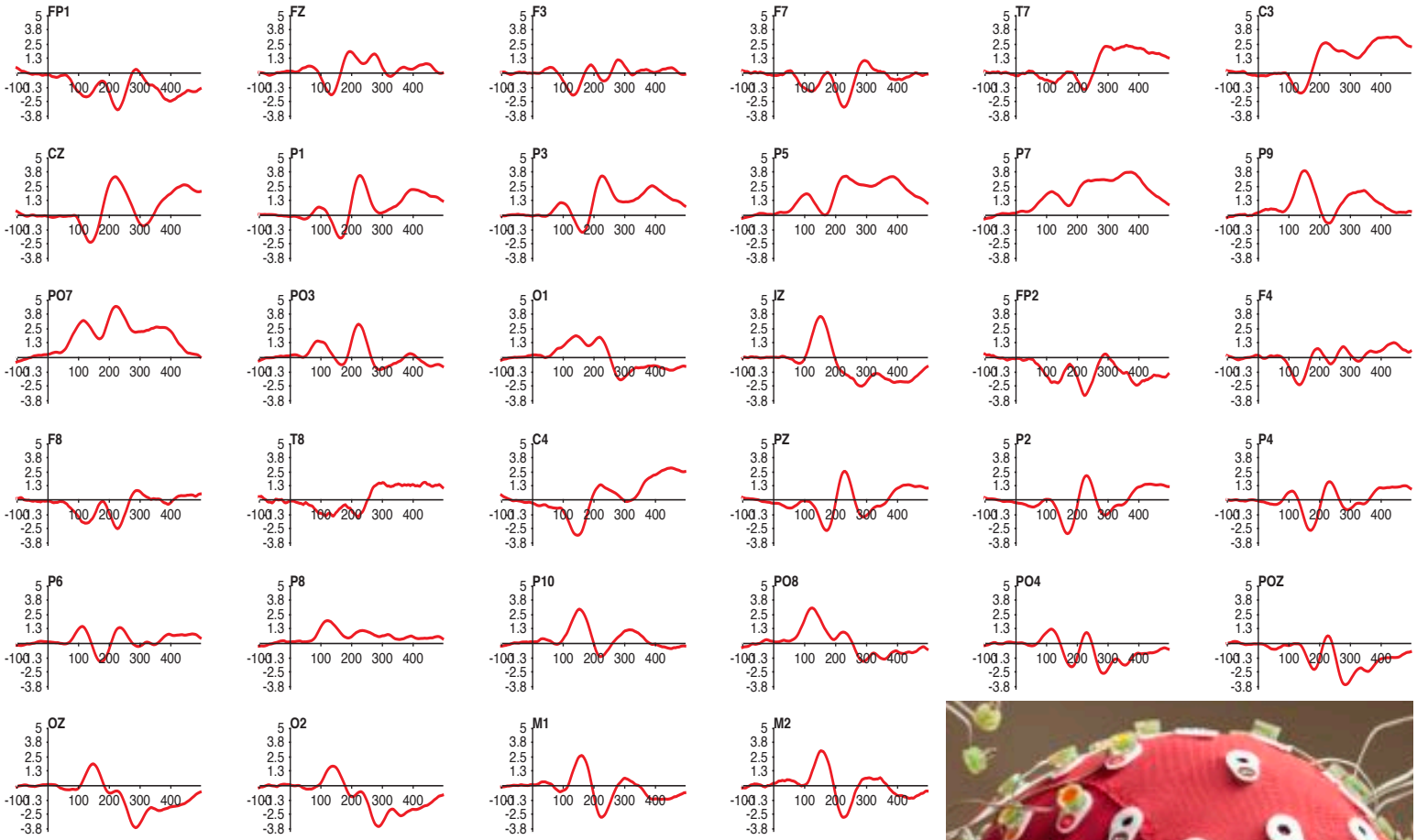
In practice there is no way to find an electrically neutral location for the reference electrode.

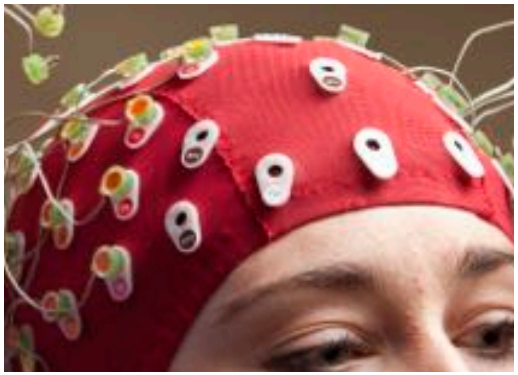
Bottom line: no matter where the reference is located, it is picking up a real signal that is then inverted via the referencing process.

The main value in continuing to use these sites as the reference is that consistency makes it easier to compare the results across studies.



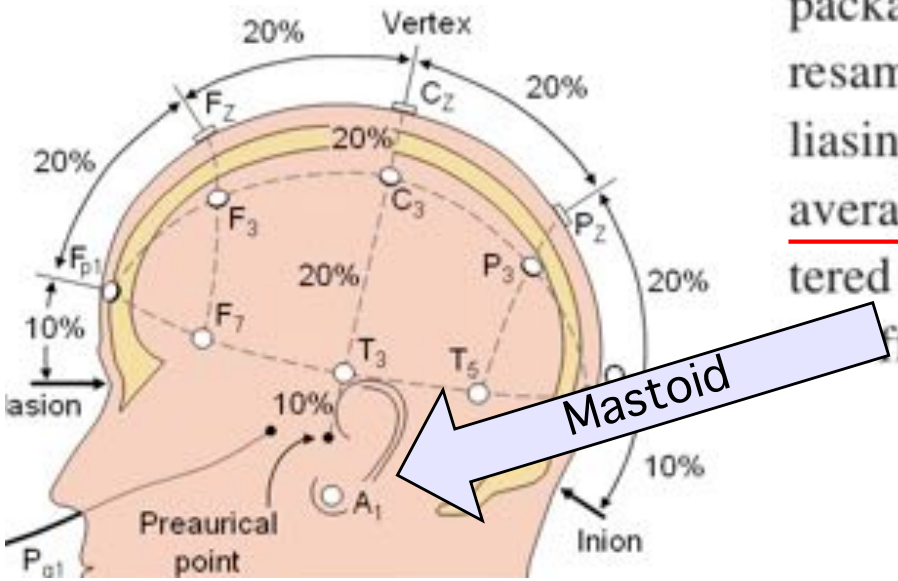
From Malmivuo, J. & Plonsey, R. (1995)





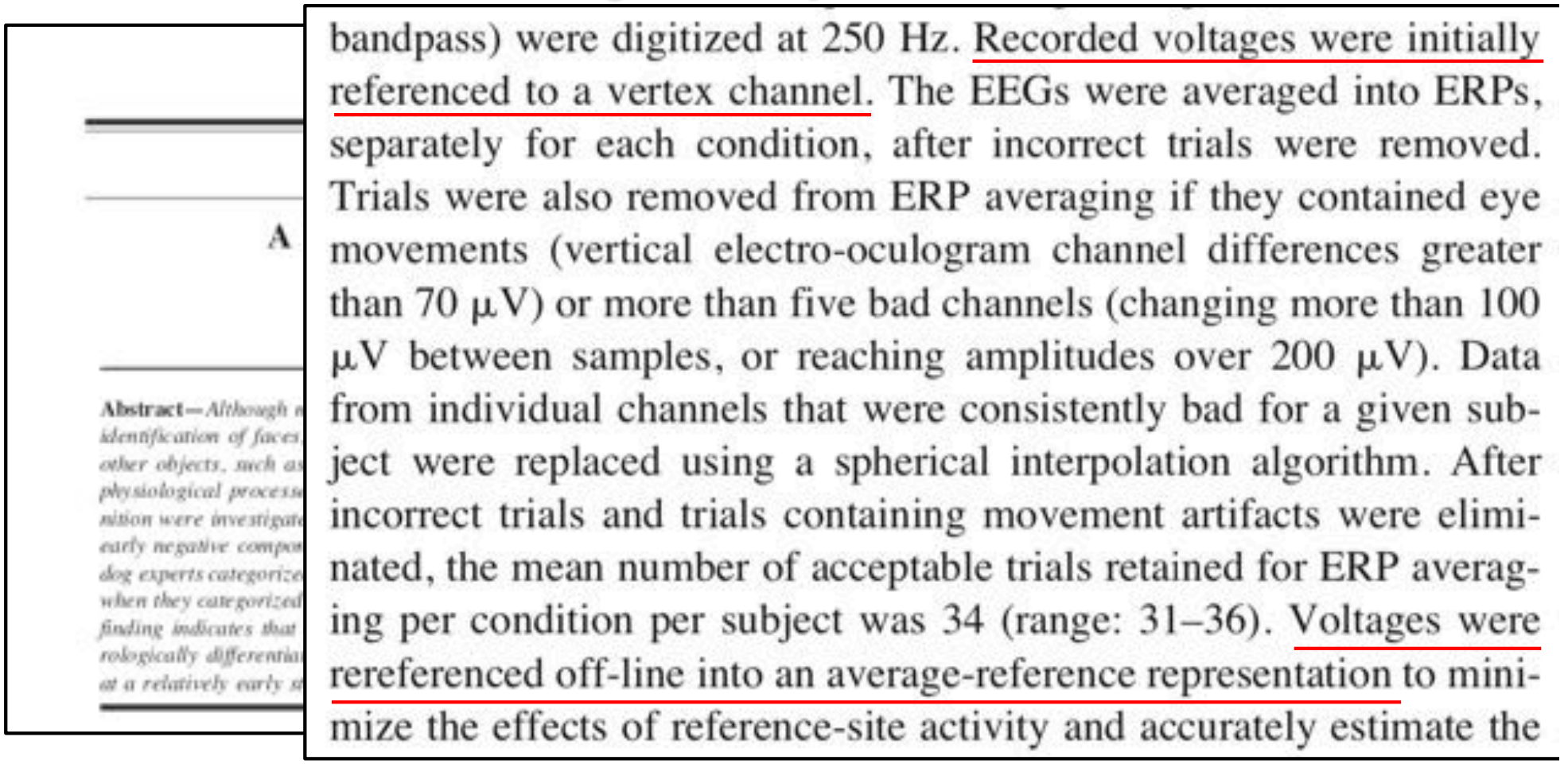
The average across ALL electrode sites can be used as the reference

Some EEG systems compute (A - G) - (R - G) in software (single-ended recording)



All signals were recorded in single-ended mode and digitized at 1000 Hz with a cascaded integrator-comb anti-aliasing filter with a half-power cutoff at 260 Hz. The electrode impedances were kept below 80 KΩ. All data analyses were performed using EEGLAB Toolbox (Delorme & Makeig, 2004) and ERPLAB Toolbox (Lopez-Calderon & Luck, 2014), which are open-source MATLAB packages for EEG/ERP analysis. The signals were resampled offline to 250 Hz (after application of an antialiasing filter). The EEG signals were referenced to the average of the two mastoid electrodes and high-pass filtered using a noncausal Butterworth filter (half-amplitude ff = 0.1 Hz, slope = 12 dB/octave).

The data can be algebraically re-referenced offline



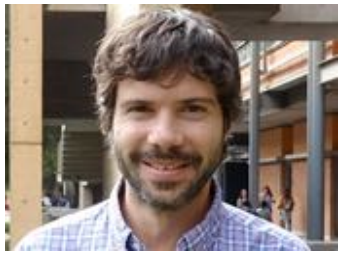
bandpass) were digitized at 250 Hz. Recorded voltages were initially referenced to a vertex channel. The EEGs were averaged into ERPs, separately for each condition, after incorrect trials were removed. Trials were also removed from ERP averaging if they contained eye movements (vertical electro-oculogram channel differences greater than 70 μV) or more than five bad channels (changing more than 100 μV between samples, or reaching amplitudes over 200 μV). Data from individual channels that were consistently bad for a given subject were replaced using a spherical interpolation algorithm. After incorrect trials and trials containing movement artifacts were eliminated, the mean number of acceptable trials retained for ERP averaging per condition per subject was 34 (range: 31–36). Voltages were rereferenced off-line into an average-reference representation to minimize the effects of reference-site activity and accurately estimate the

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science*, *12*, 43–47.

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 Recording & Analysis

Common Artifacts



ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR

Event-related
conditioning i

Felix Bacigalupo |

Center for Mind and Brain, Univ
California, Davis, Davis, Califor

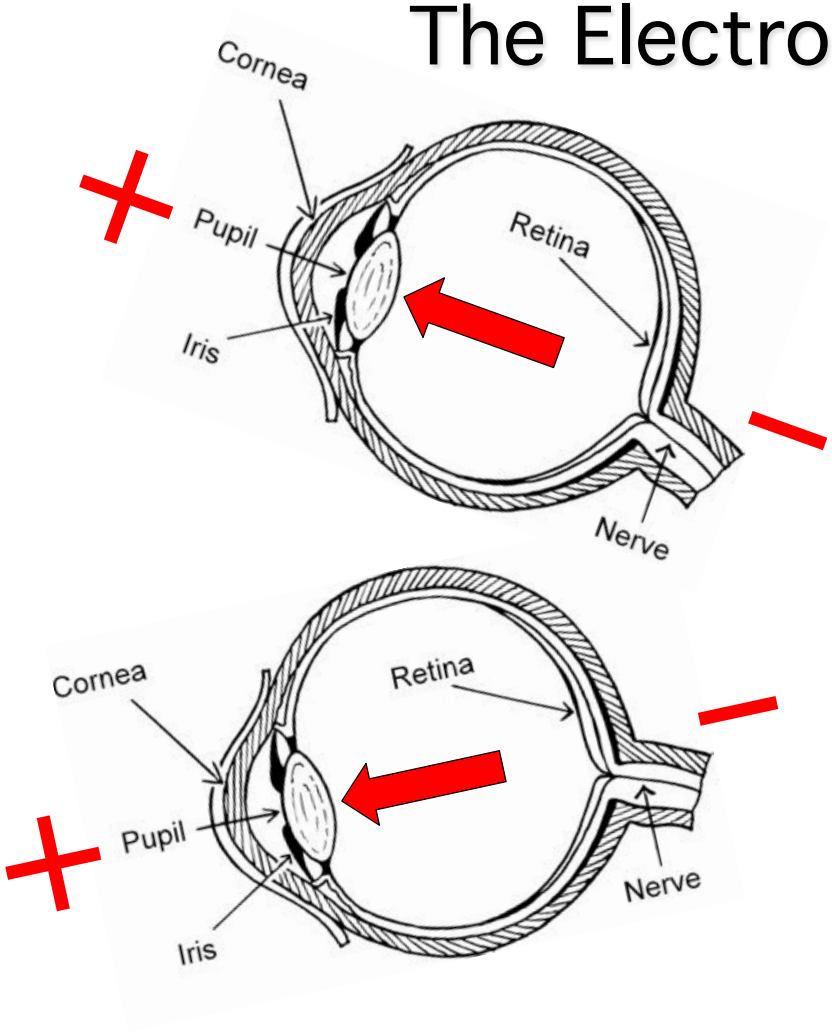
Correspondence
Felix Bacigalupo, Center for Mi
Brain, University of California,
267 Cousteau Place, Room 133,
CA 95618, USA.
Email: fbacigalupo@ucdavis.edu

Funding information
National Institutes of Health (g
R03MH098119, R01MH07622
S. J. L.), Becas Chile-Conicyt
scholarship (to F. B.)

2.3 | Psychophysiological recording and analysis

The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz). The horizontal and vertical electrooculogram (EOG) was measured from electrodes located approximately 1 cm lateral to the outer canthus of each eye and from an electrode placed below the right eye.

The Electrooculogram (EOG)



There is a standing electrical potential between the front and back chambers of the eye, with positive at the front and negative at the back.

This dipole creates a strong voltage field that spreads to the scalp.

The magnitude of the dipole remains constant over time, but as the eyes rotate, this produces a change in the distribution of the voltage field over the scalp.

The corneo-retinal standing potential creates a dipolar voltage field

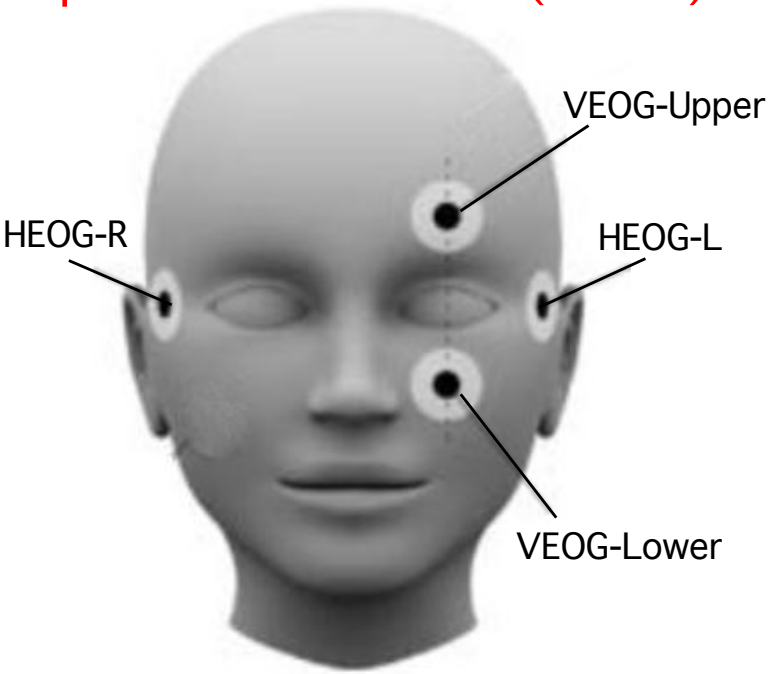
When the eyes blink, the movement of the eyelids over the eyes changes the resistance, which in turn causes a brief change in the magnitude of the EOG over the scalp.

A blink can produce 20 to 40 microvolts at sites like Fz, Cz, and Pz.

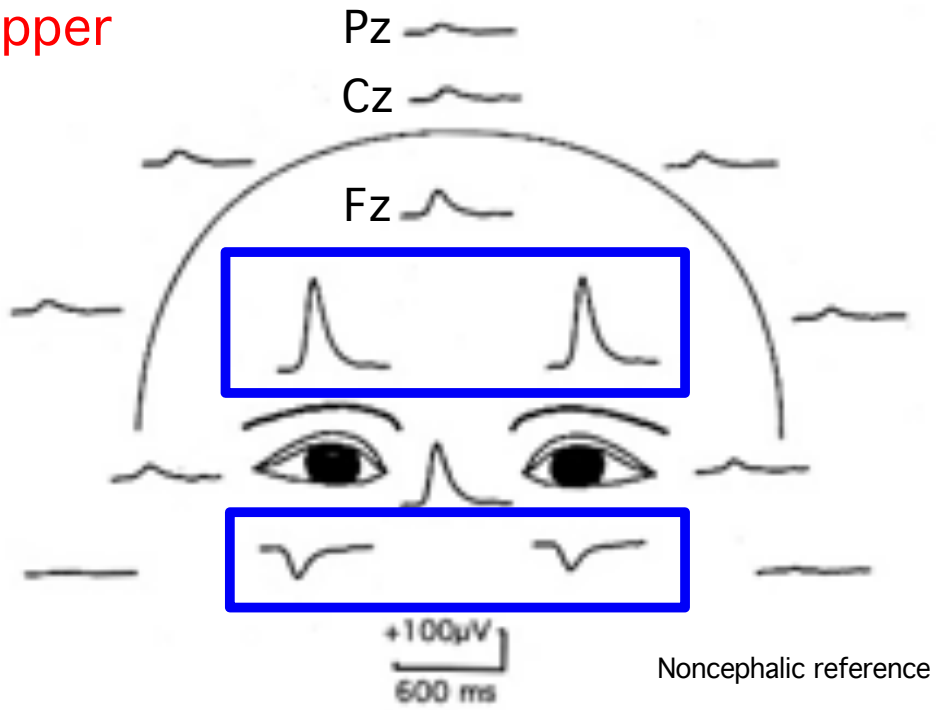
The blink voltage is negative under the eyes and positive over the eyes.

Researchers often take advantage of this by computing a bipolar vertical EOG signal, which is lower minus upper.

Bipolar Vertical EOG (VEOG) = Lower – Upper



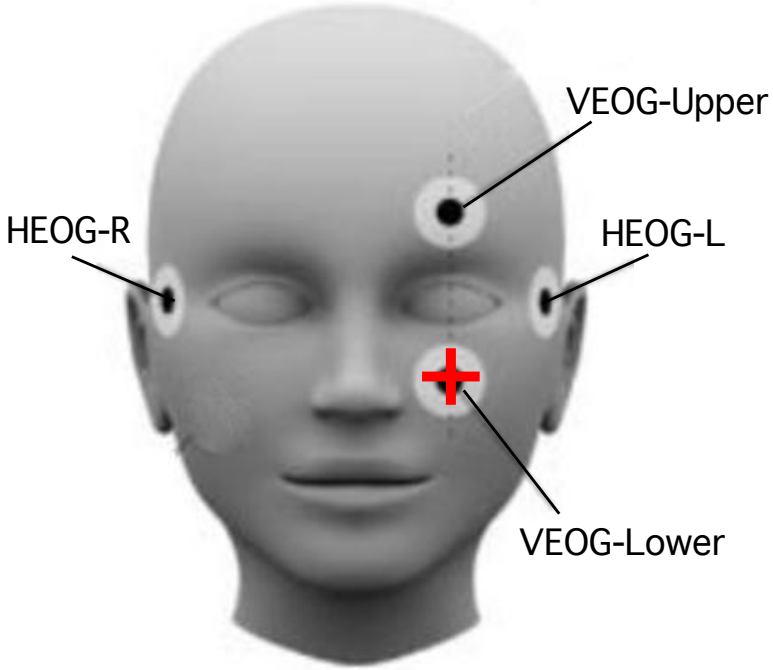
Rogalska et al. (2019, Open Physics)

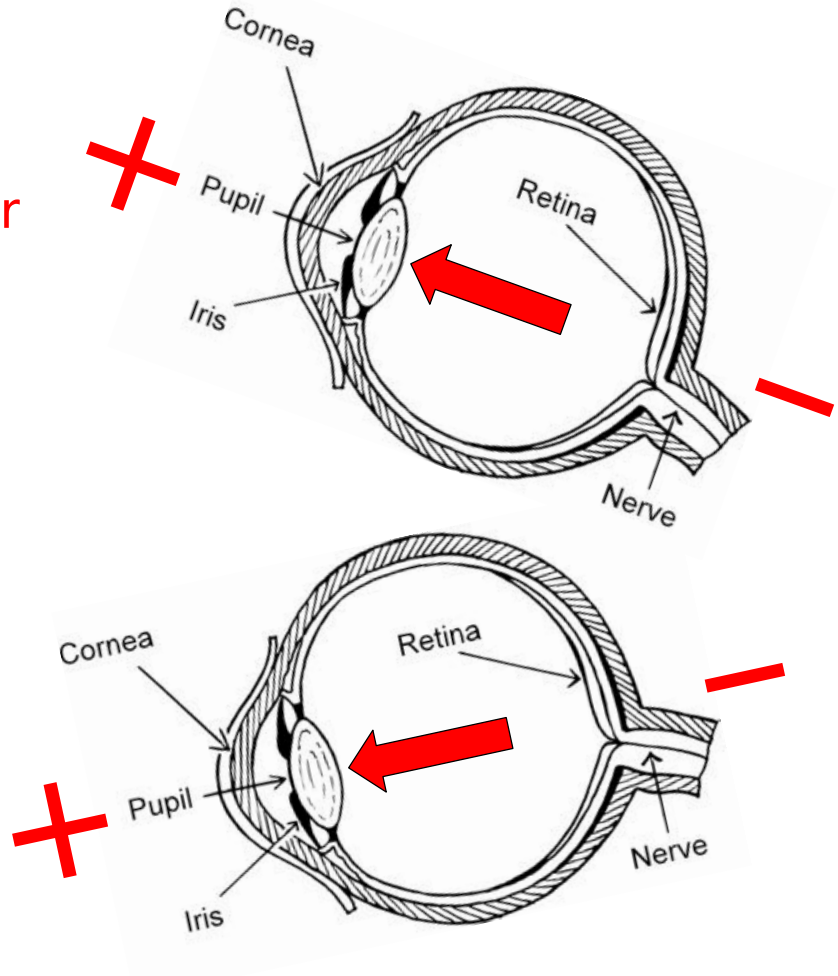


Lins, Picton, Berg, & Scherg (1993)

If the eyes rotate downward, the voltage becomes positive below the eyes.
If the eyes rotate upward, the voltage becomes positive above the eyes.

Bipolar Vertical EOG (VEOG) = Lower – Upper

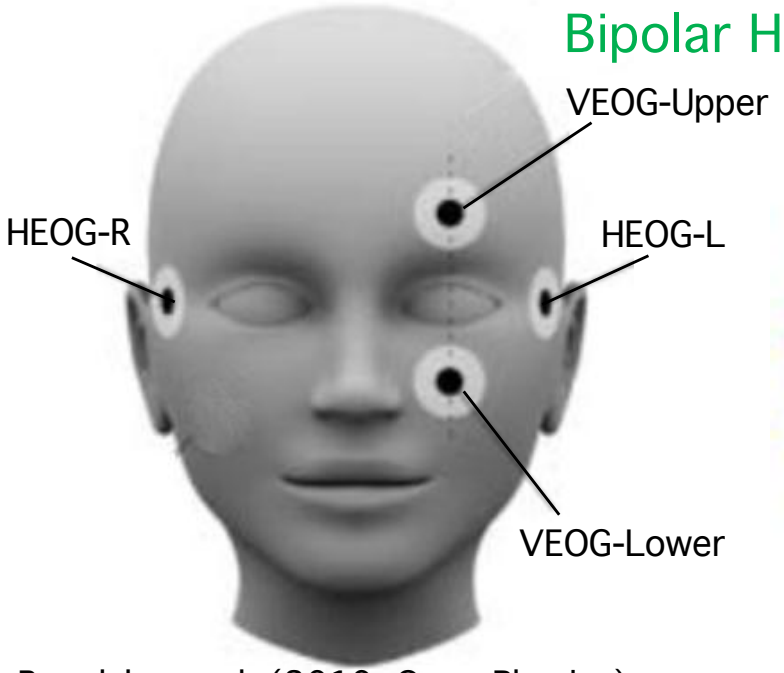




Rogalska et al. (2019, Open Physics)

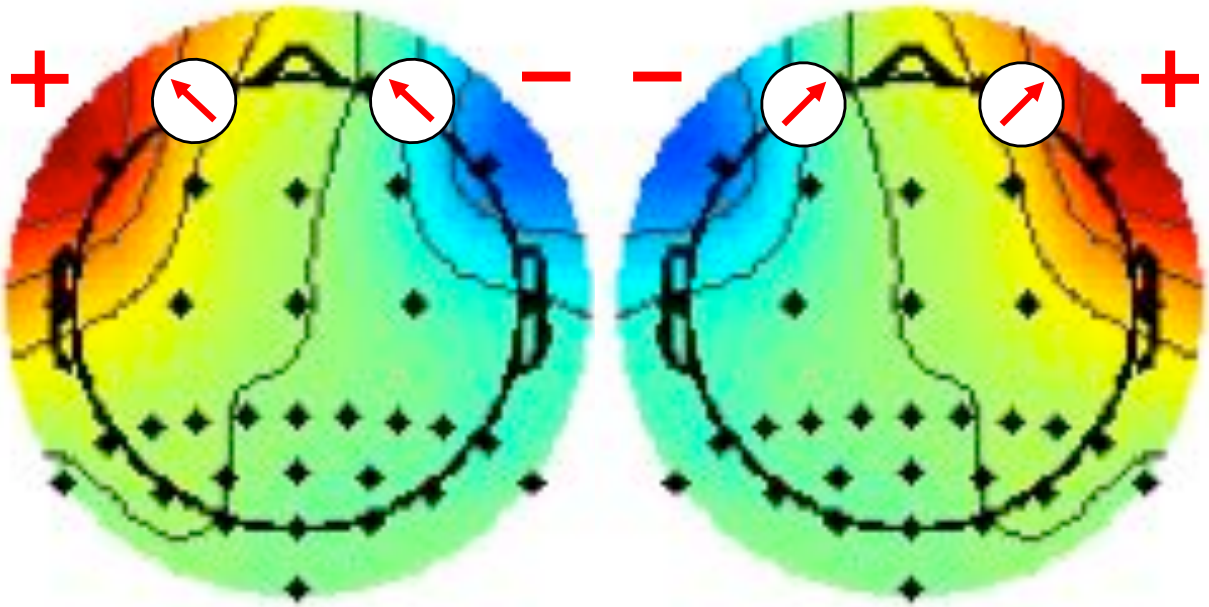
A leftward rotation produces a positive voltage over the left side of the head and a negative voltage over the right side of the head. A rightward rotation produces the opposite polarity.

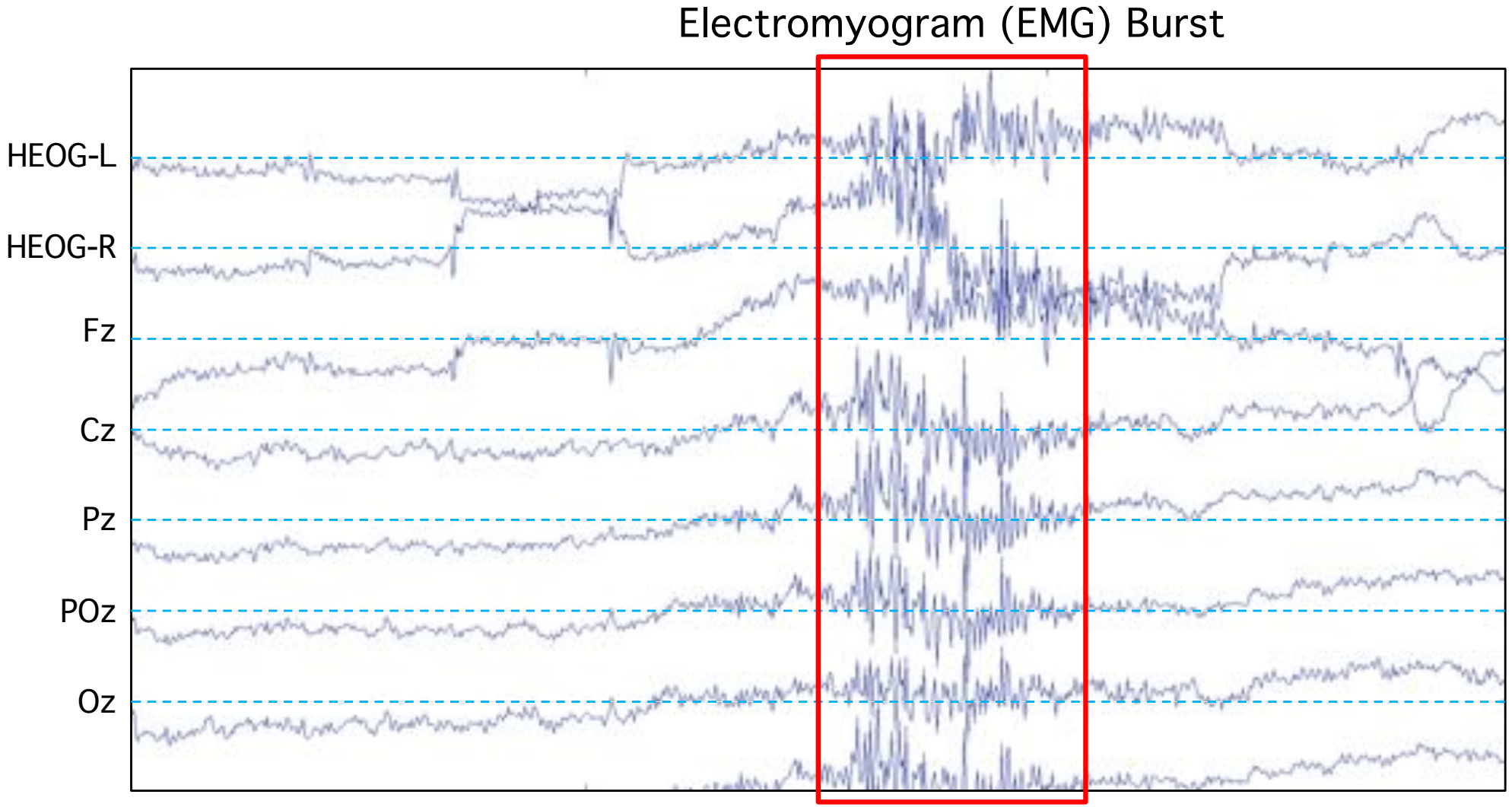
A bipolar HEOG signal (HEOG-Left minus HEOG-Right) doubles the signal and eliminates most brain activity.



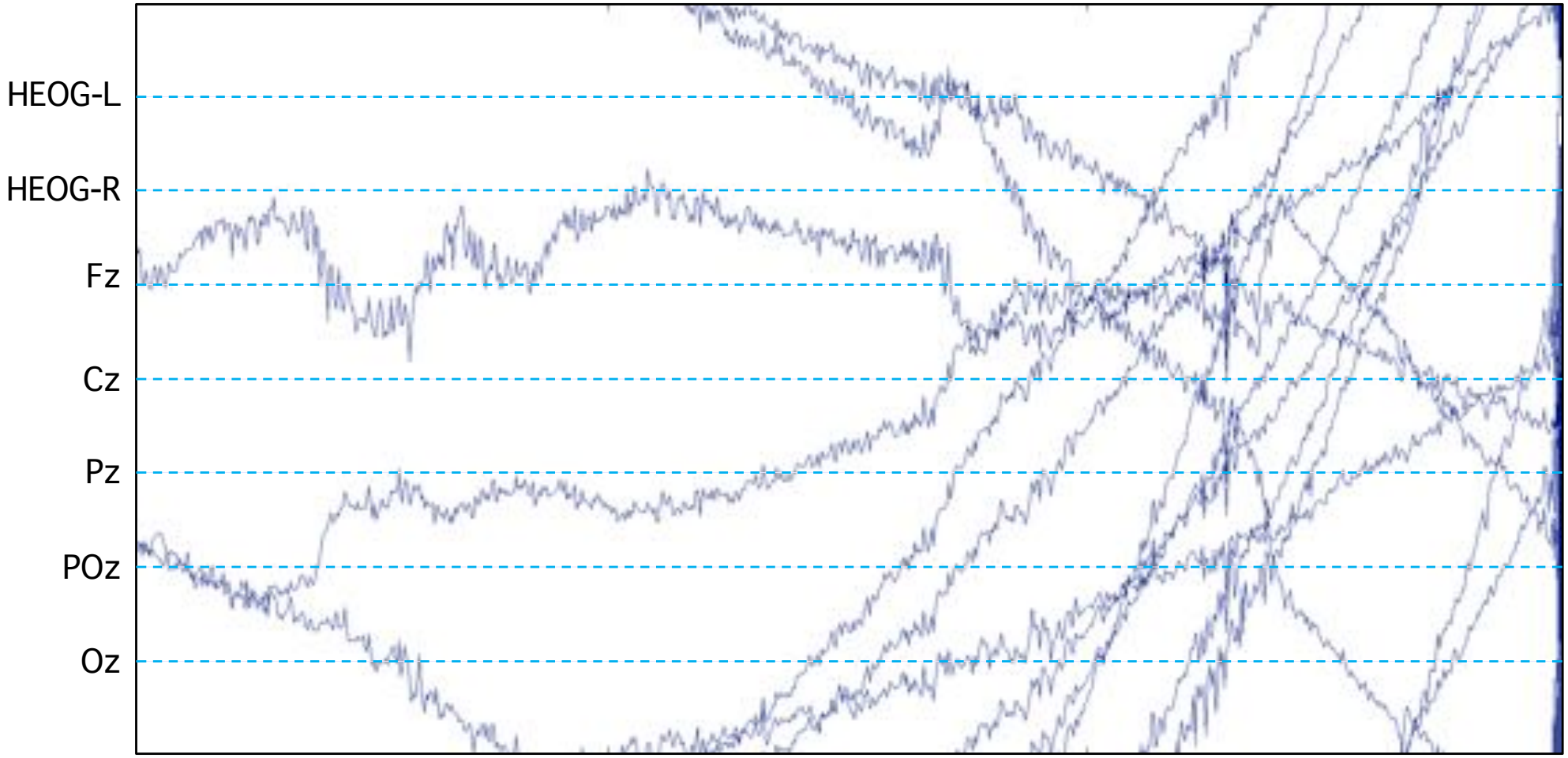
Rogalska et al. (2019, Open Physics)

Bipolar Horizontal EOG (HEOG) = Left – Right




Electromyogram (EMG) Burst
HEOG-L
HEOG-R
Fz
Cz
Pz
POz
Oz

Movement Artifacts



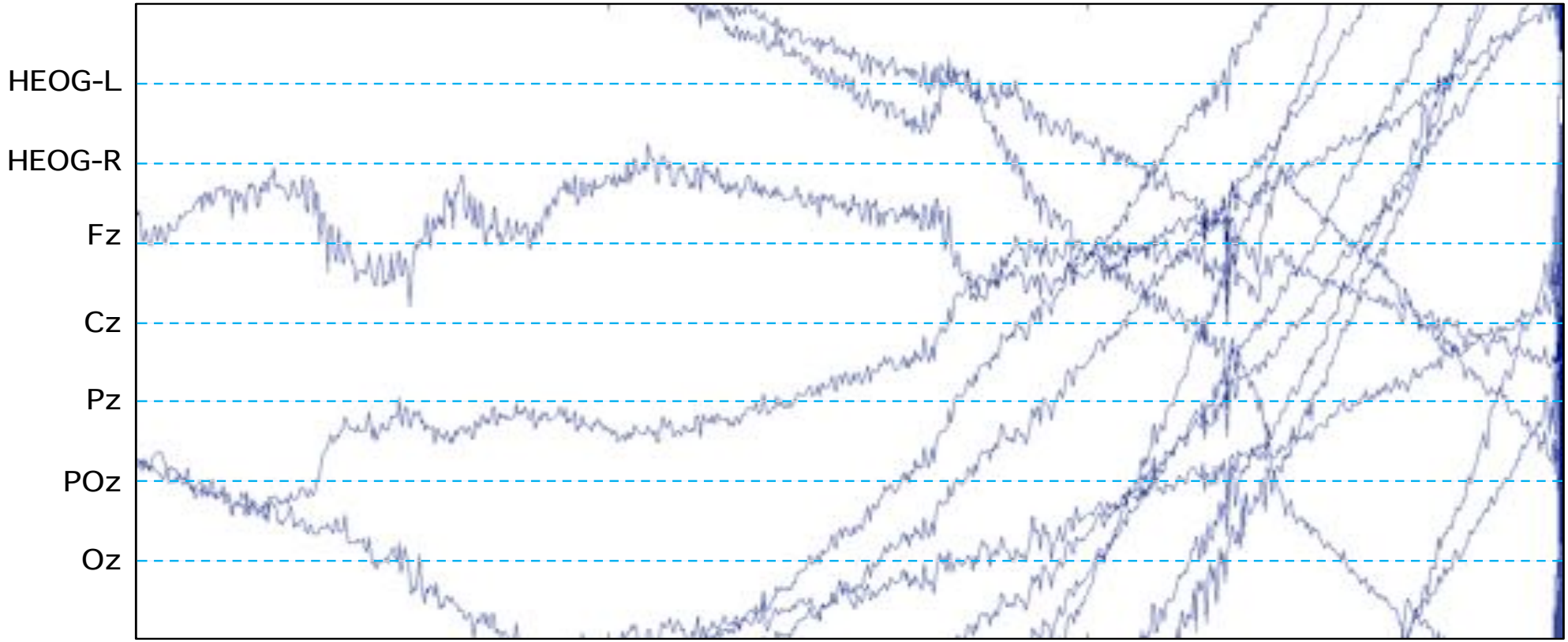
This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Recording & Analysis

Artifact Rejection & Correction

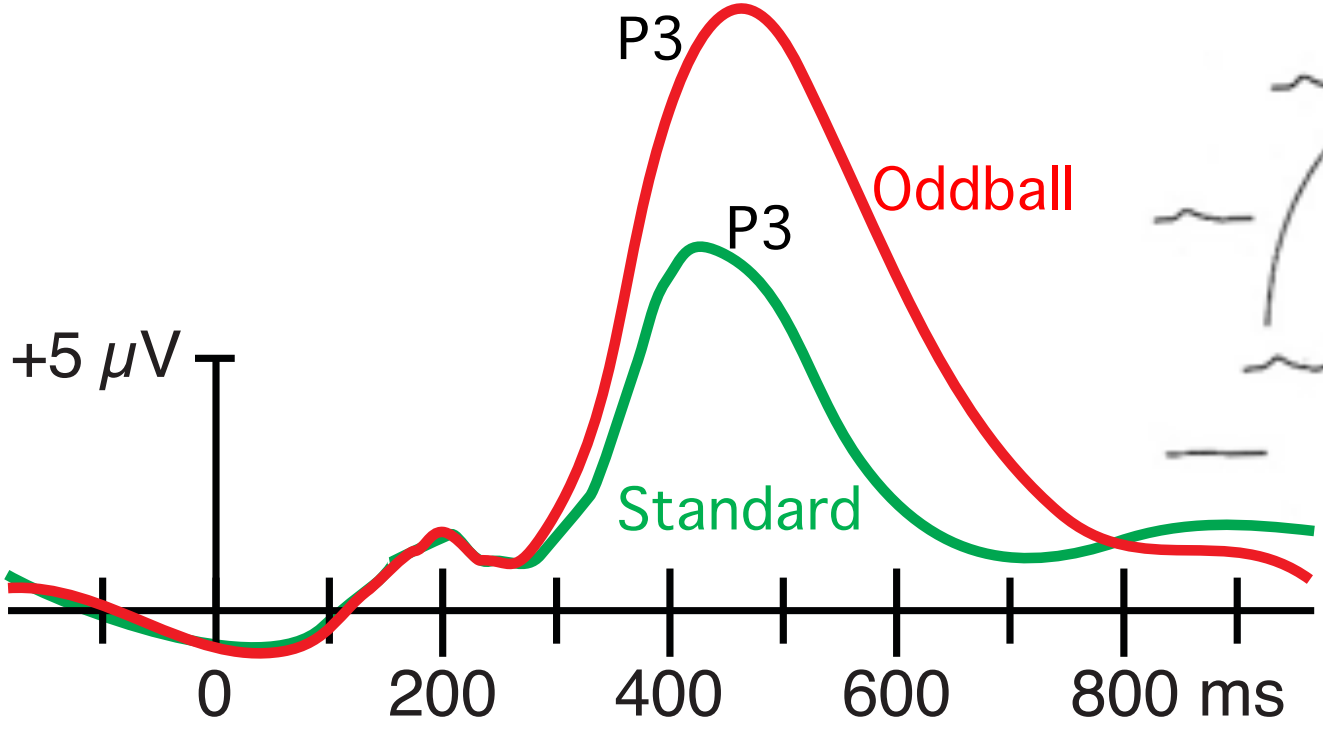
It is important to deal with artifacts that are large enough to add significant random variation to the data.

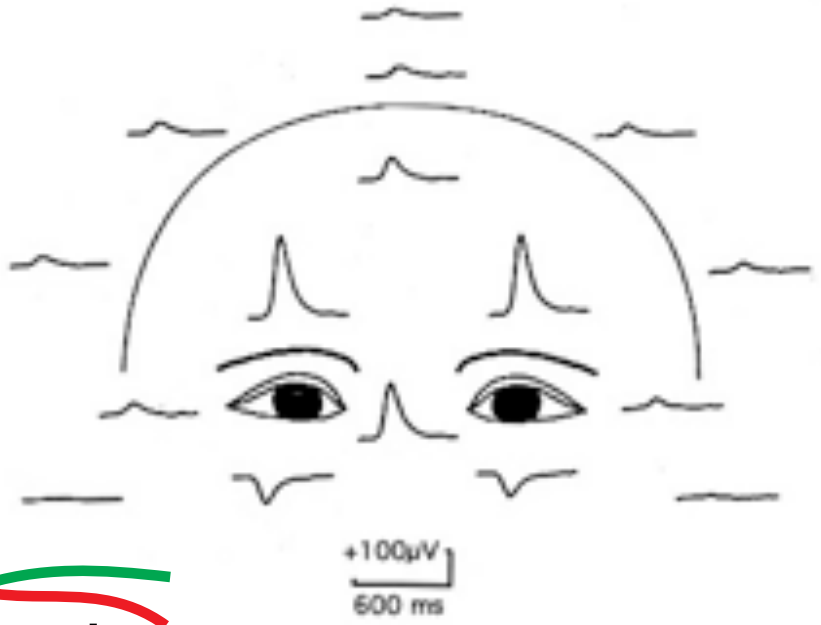
If the EEG contains huge crazy artifacts, more trials must be averaged together to produce a stable, reliable ERP waveform.



It is important to deal artifacts that are not random and may cause a systematic confound in the data.

For example, subjects in tend to blink more for rare oddball stimuli than for frequent standards.



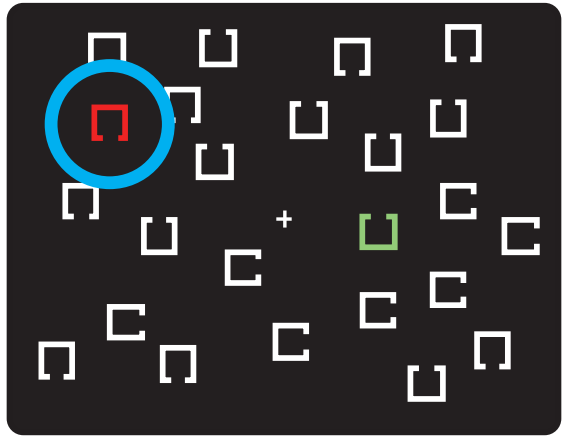


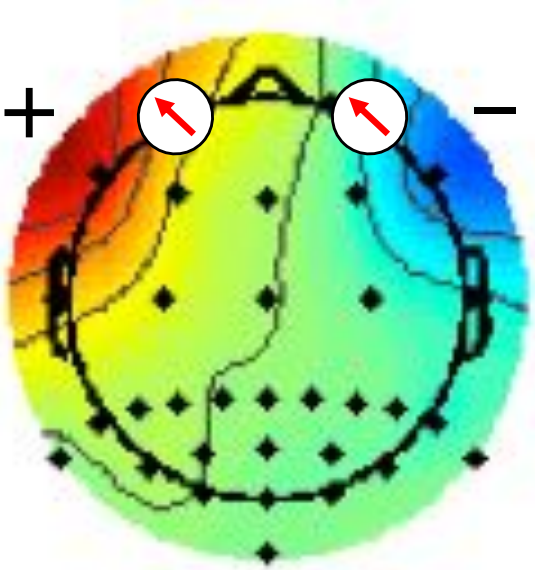
Lins, Picton, Berg, & Scherg (1993)

Moving the eyes toward the target produces a contralateral negativity, just like the N2pc

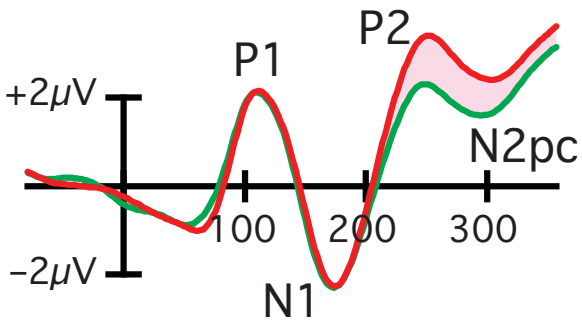
N2pc

(pc: posterior contralateral)



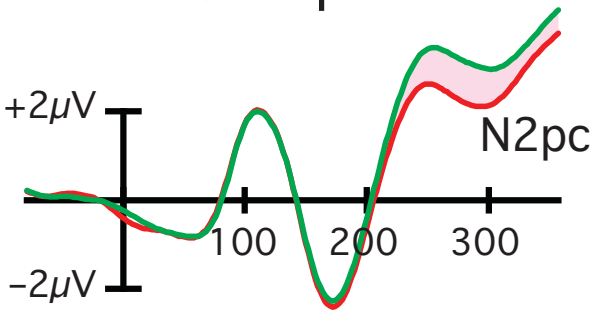


Left Hemisphere



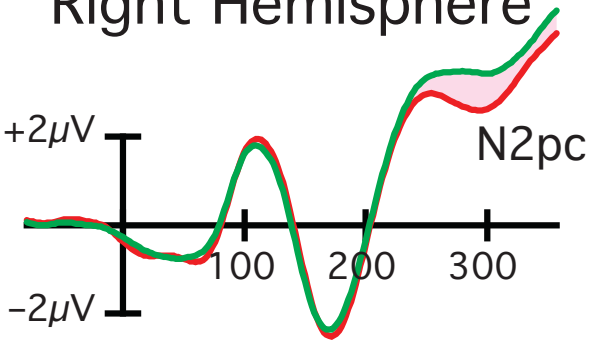
LVF Target
RVF Target

Collapsed



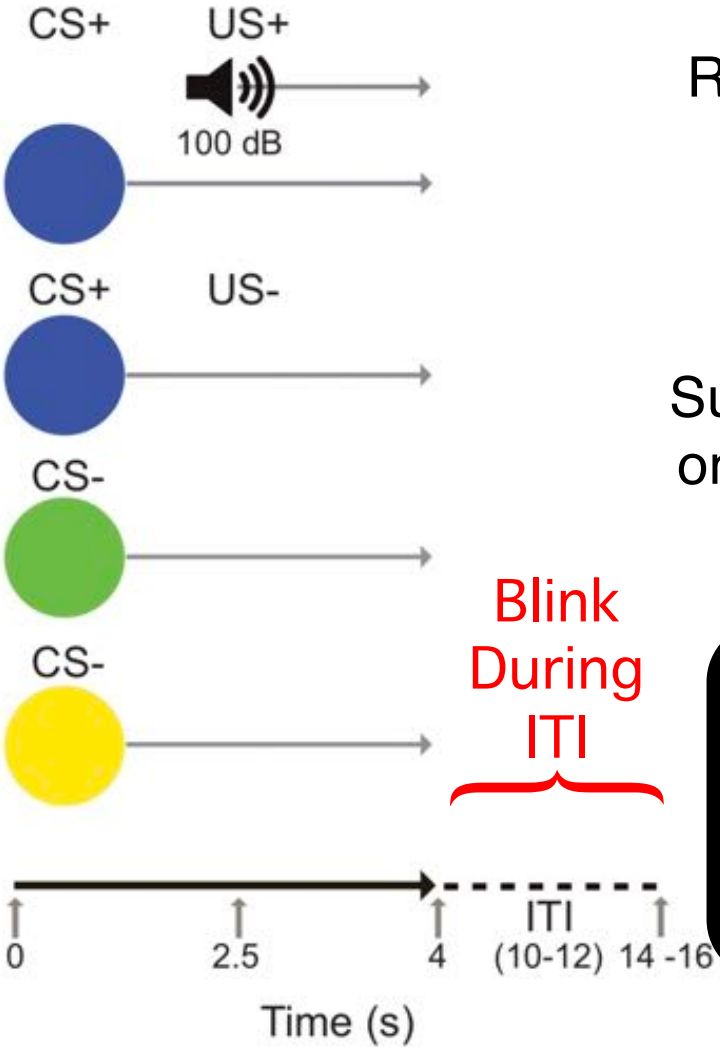
Contralateral Target
Ipsilateral Target

Right Hemisphere



LVF Target
RVF Target

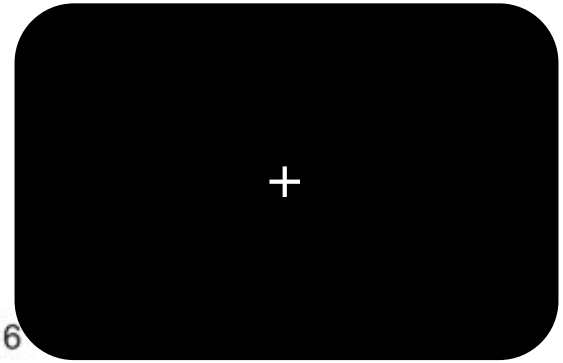
Dealing with Artifacts



Researchers often try to minimize the occurrence of the artifacts.

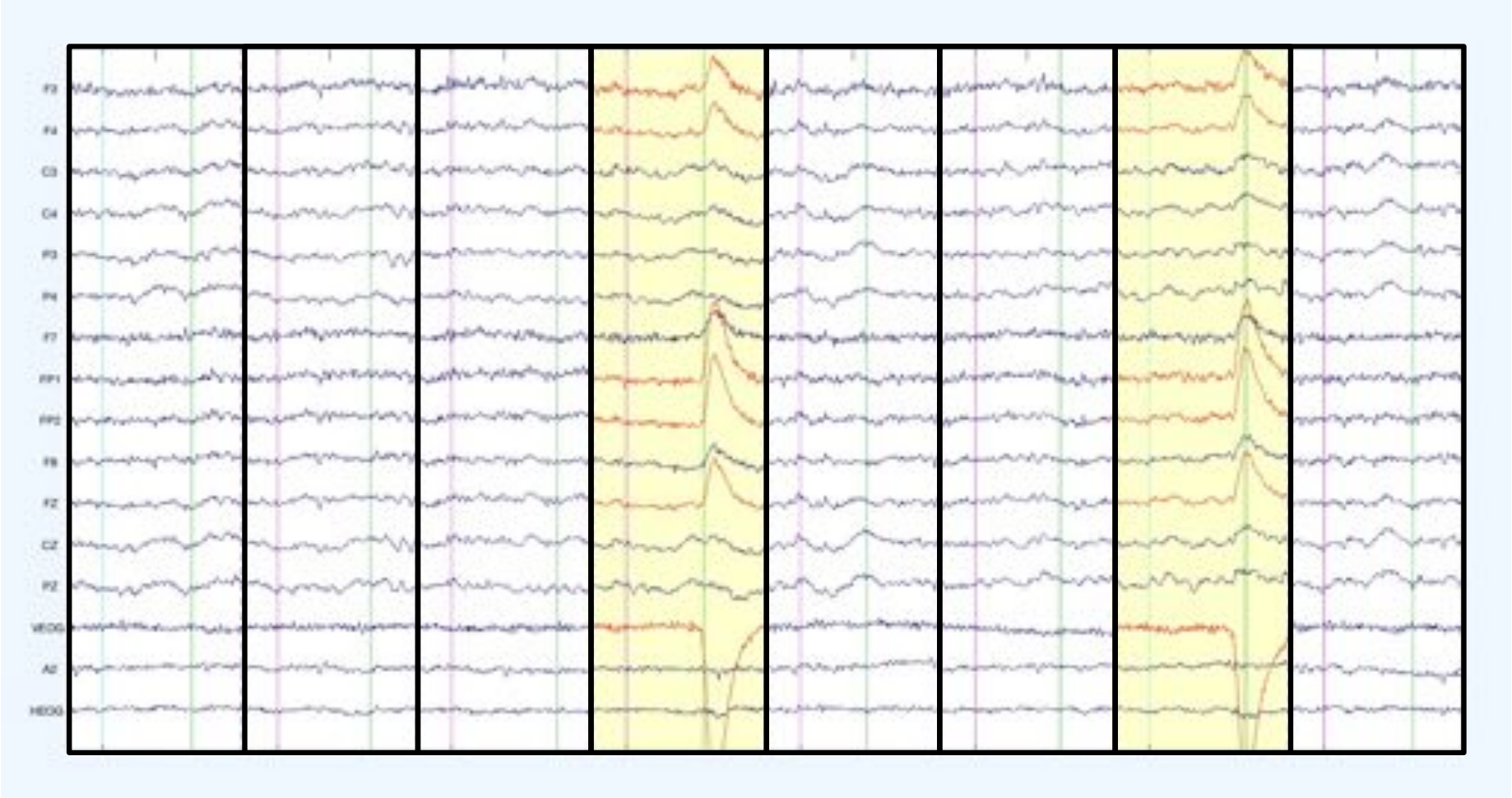
Subjects might be told to blink only at certain times, like the ITI.

Subjects might be instructed to maintain their gaze on a central fixation point, and an eye tracker may be used to ensure compliance.

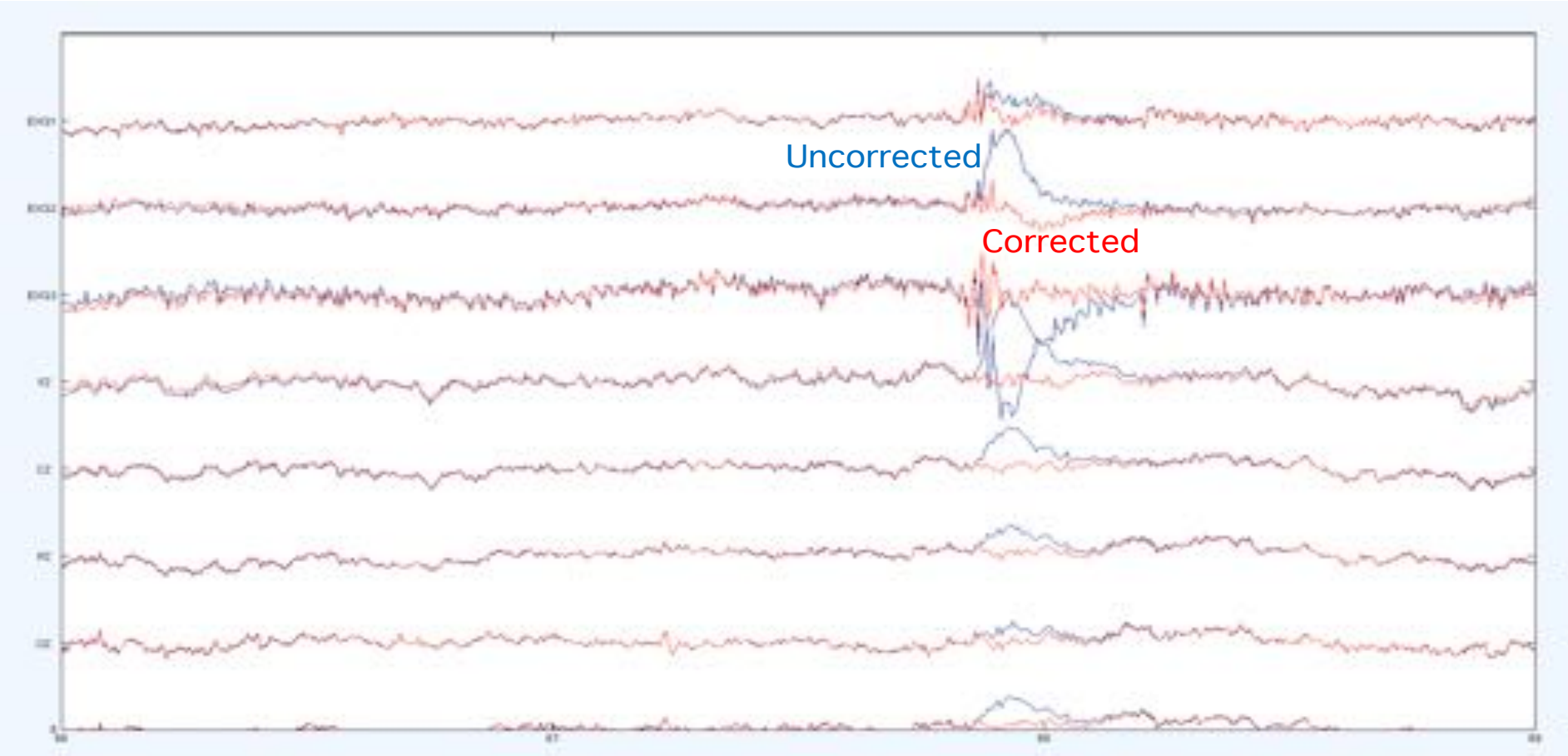


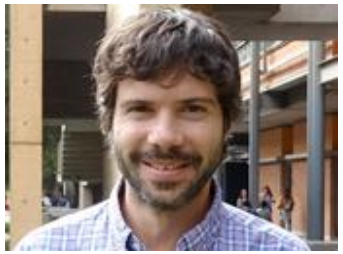
https://www.sr-research.com/eyelink-brainproducts-integration

Artifact rejection: Trials containing artifacts are excluded from the averages.



Artifact correction: The artifactual voltage is estimated (usually with independent component analysis) and subtracted from the EEG at each electrode site. This works particularly well for blinks.





ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR

Event-related potential components as measures of aversive conditioning in humans

Felix Bacigalupo | **Steven J. Luck**

Center for Mind and Brain, Univ
California, Davis, Davis, Californ

Correspondence
Felix Bacigalupo, Center for Mi
Brain, University of California,
267 Cousteau Place, Room 133,
CA 95618, USA.
Email: fbacigalupo@ucdavis.edu

Funding information
National Institutes of Health (g
R03MH098119, R01MH07622
S. J. L.), Becas Chile-Conicyt
scholarship (to F. B.)

To correct the EEG for eyeblinks and horizontal eye movements, ICA was conducted using EEGLAB's BIN-ICA routine. The criterion for component rejection was the consistency between the shape, timing, and spatial location of a given component compared to the single-trial EOG data. For eyeblinks, one or two components were identified per participant, whereas for horizontal eye movements, one component was selected for correction in each participant.

The artifact correction process was supplemented with artifact rejection to eliminate trials with clearly artifactual voltage deflections. Specifically, trials were excluded if the peak-to-peak voltage within the EEG epoch was greater than 300 μV in any 200-ms window in any channel. An average of 0.69% of trials was rejected in the participants (range = 0–5.6%). One volunteer completed only two of the three conditioning blocks and was therefore not considered for the block-by-block SCR/ERP analysis, but was included in all other analyses.

Even when artifact correction is used for blinks and/or eye movements, rejection is often used for other miscellaneous artifacts.

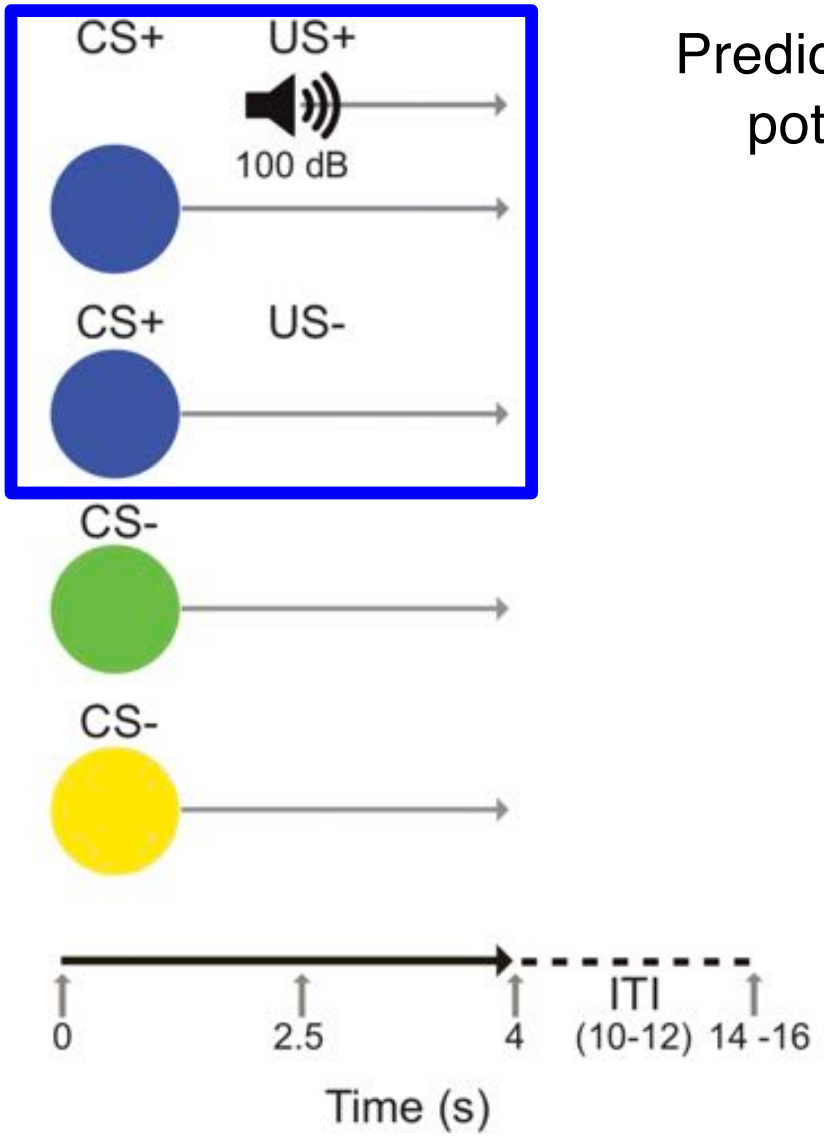
In studies that do not use artifact correction, but rely solely on rejection, a larger percentage of trials is rejected. That's OK as long as enough valid trials are available for averaging.

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)

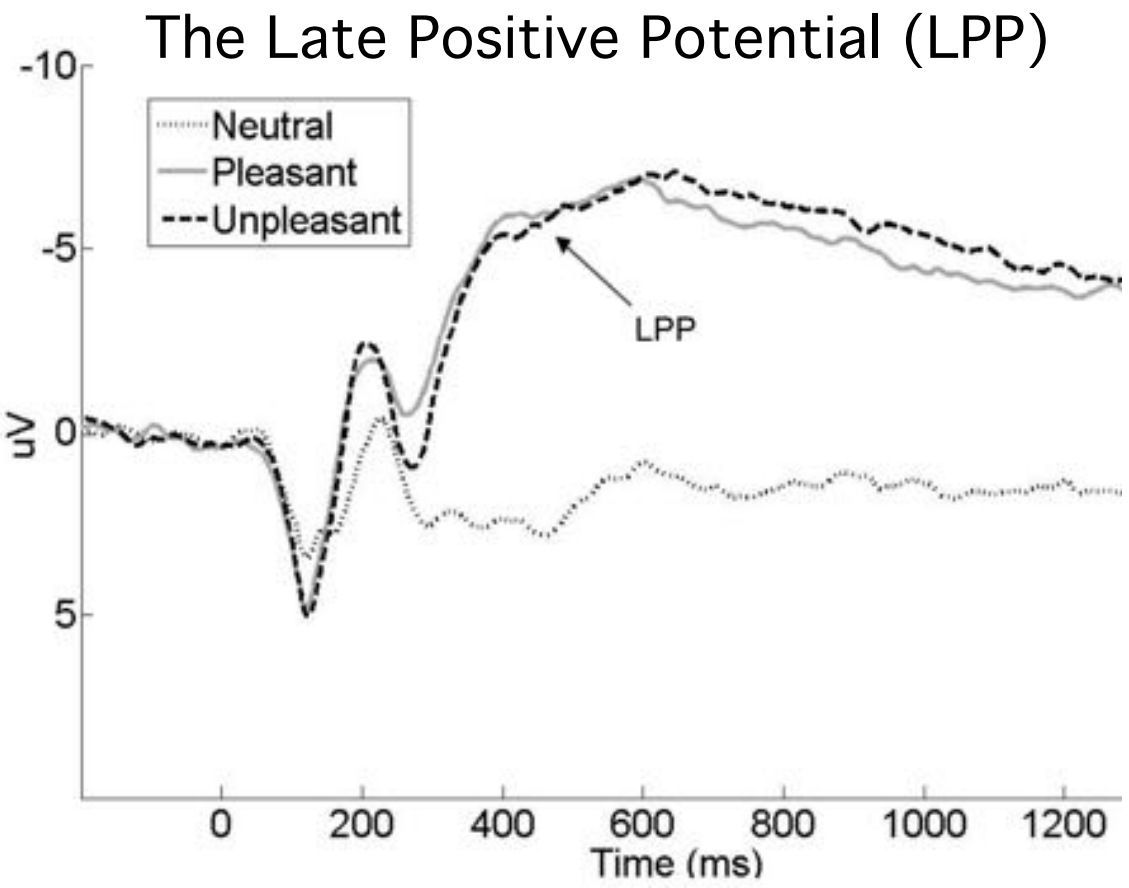
ERP Recording & Analysis

Summary of EEG/ERP Processing Steps

https://erpinfo.org/order-of-steps



Prediction: the CS+ will elicit a large late positive potential (which reflects emotional arousal)

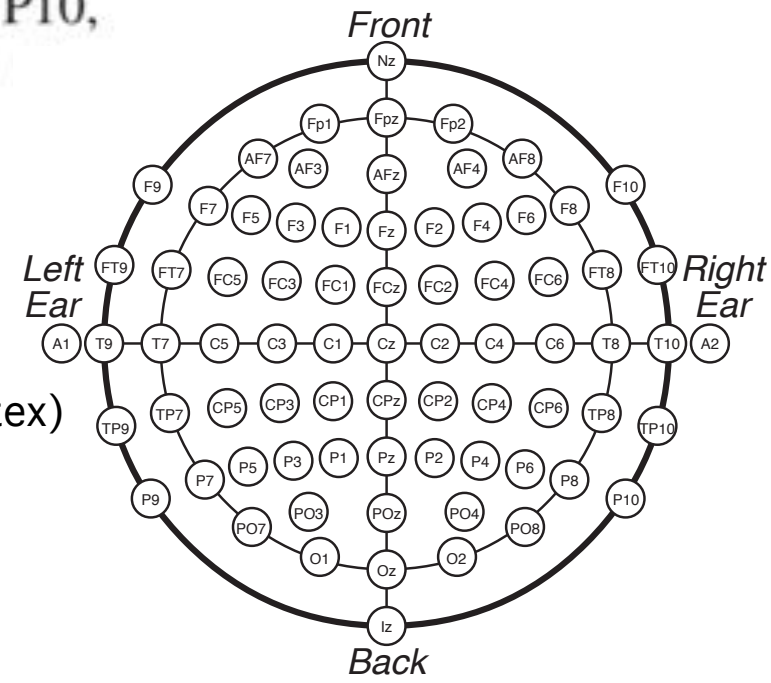


Hajcak et al. (2012, Oxford Handbook of ERP Components)

2.3 | Psychophysiological recording and analysis

The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz).

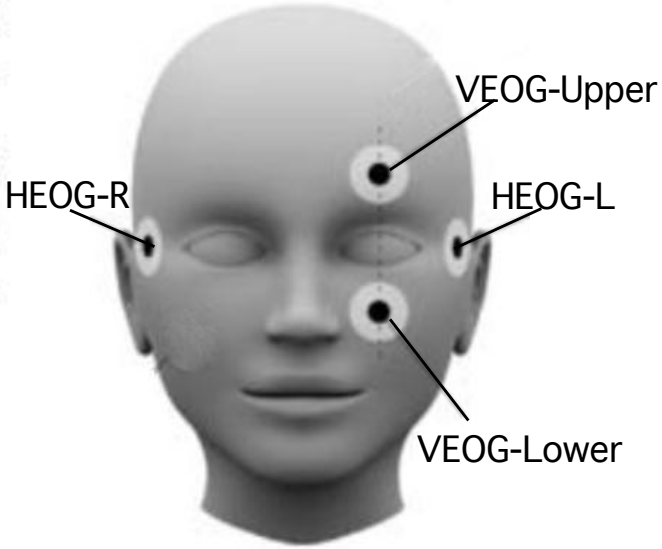
The International 10/20 System



Fp: Frontal Pole
F: Frontal
C: Central (Vertex)
P: Parietal
O: Occipital
T: Temporal

2.3 | Psychophysiological recording and analysis

The EEG was recorded using a Brain Products ActiCHamp system with electrodes located above the left and right mastoid processes and at 27 standard scalp locations (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P5, P6, P7, P8, P9, P10, PO3, PO4, PO7, PO8, O1, O2, Fz, Cz, Pz, Poz, Oz). The horizontal and vertical electrooculogram (EOG) was measured from electrodes located approximately 1 cm lateral to the outer canthus of each eye and from an electrode placed below the right eye.



Rogalska et al. (2019, Open Physics)

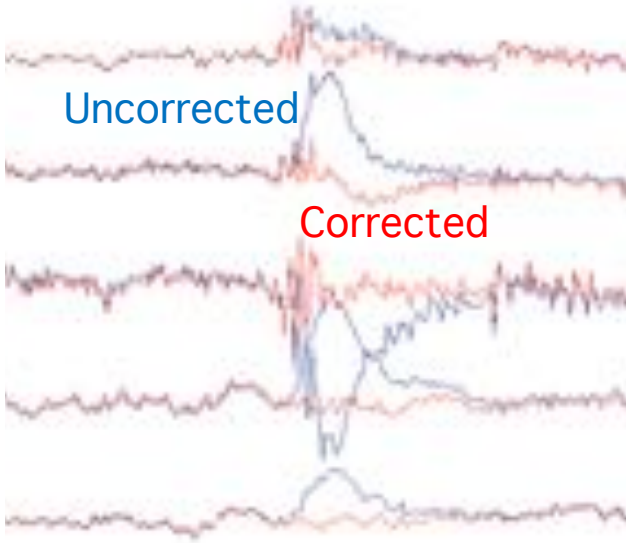
All signals were recorded in single-ended mode and digitized at 1000 Hz with a cascaded integrator-comb anti-aliasing filter with a half-power cutoff at 260 Hz. The electrode impedances were kept below 80 KΩ. All data analyses were performed using EEGLAB Toolbox (Delorme & Makeig, 2004) and ERPLAB Toolbox (Lopez-Calderon & Luck, 2014), which are open-source MATLAB packages for EEG/ERP analysis. The signals were resampled offline to 250 Hz (after application of an antialiasing filter). The EEG signals were referenced to the average of the two mastoid electrodes and high-pass filtered using a noncausal Butterworth filter (half-amplitude cutoff = 0.1 Hz, slope = 12 dB/octave).

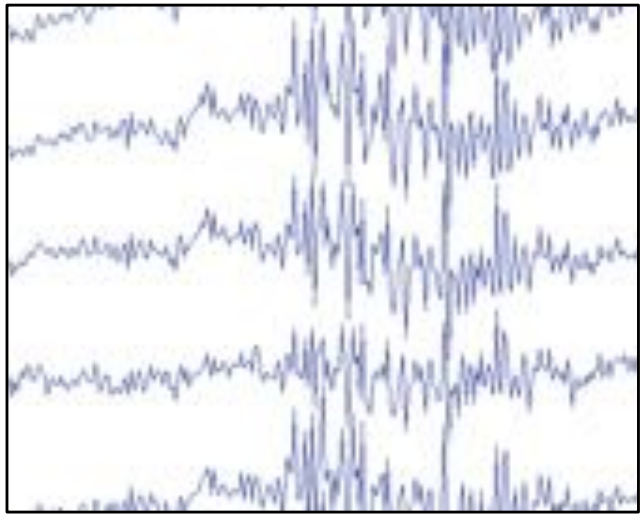
Sampling period = 1 ms
Sampling rate = 1000 Hz

New Sampling period = 4 ms
New Sampling rate = 250 Hz

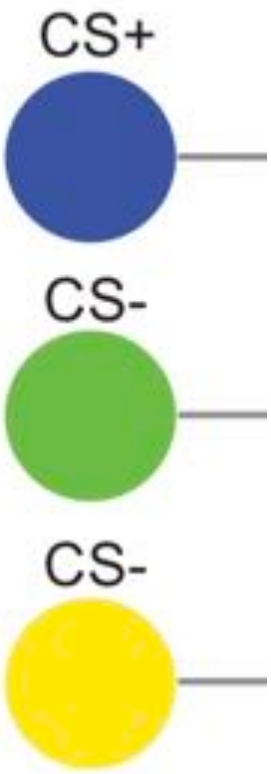
To correct the EEG for eyeblinks and horizontal eye movements, ICA was conducted using EEGLAB's BIN-ICA routine. The criterion for component rejection was the consistency between the shape, timing, and spatial location of a given component compared to the single-trial EOG data. For eyeblinks, one or two components were identified per participant, whereas for horizontal eye movements, one component was selected for correction in each participant.

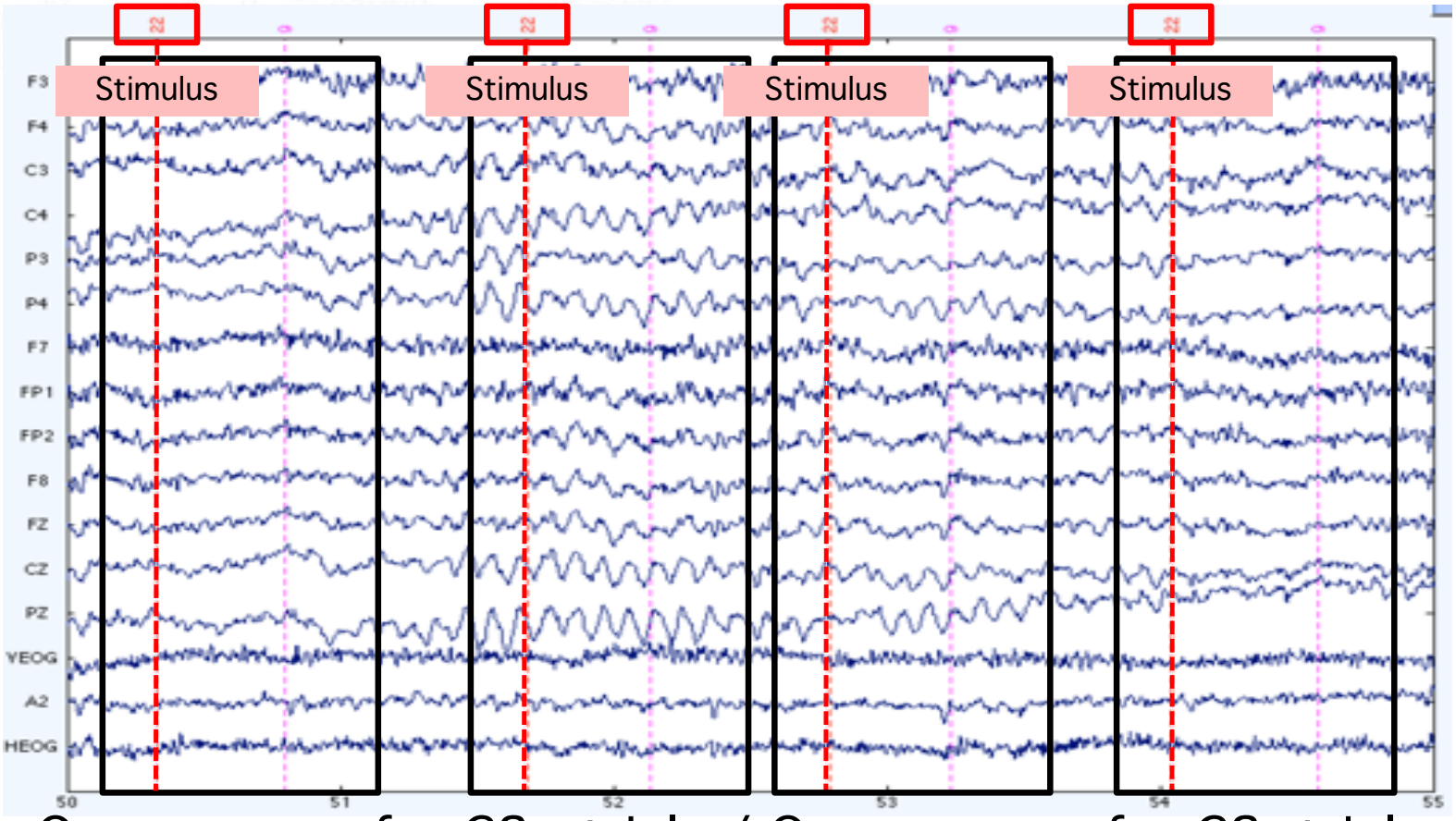
The artifact correction process was supplemented with artifact rejection to eliminate trials with clearly artifactual voltage deflections. Specifically, trials were excluded if the peak-to-peak voltage within the EEG epoch was greater than 300 μV in any 200-ms window in any channel. An average of 0.69% of trials was rejected in the participants (range = 0–



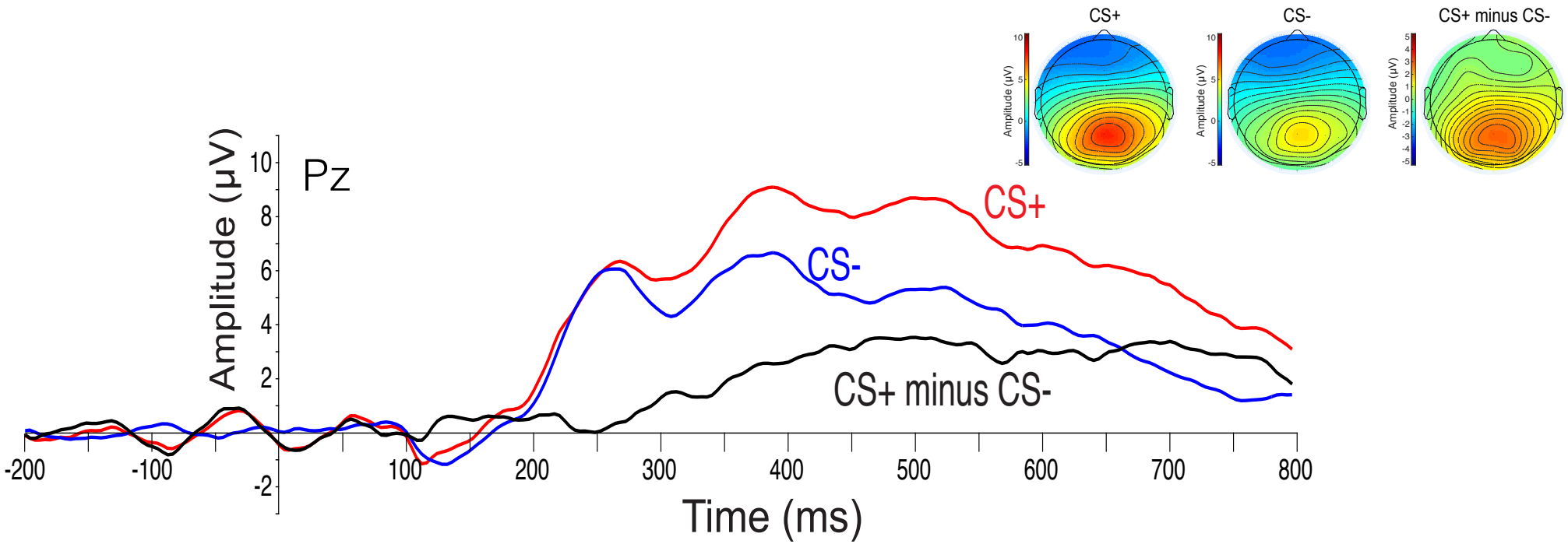


For the LPP analysis, averaged ERP waveforms were computed with a 1,000-ms epoch, starting 200 ms before stimulus onset,





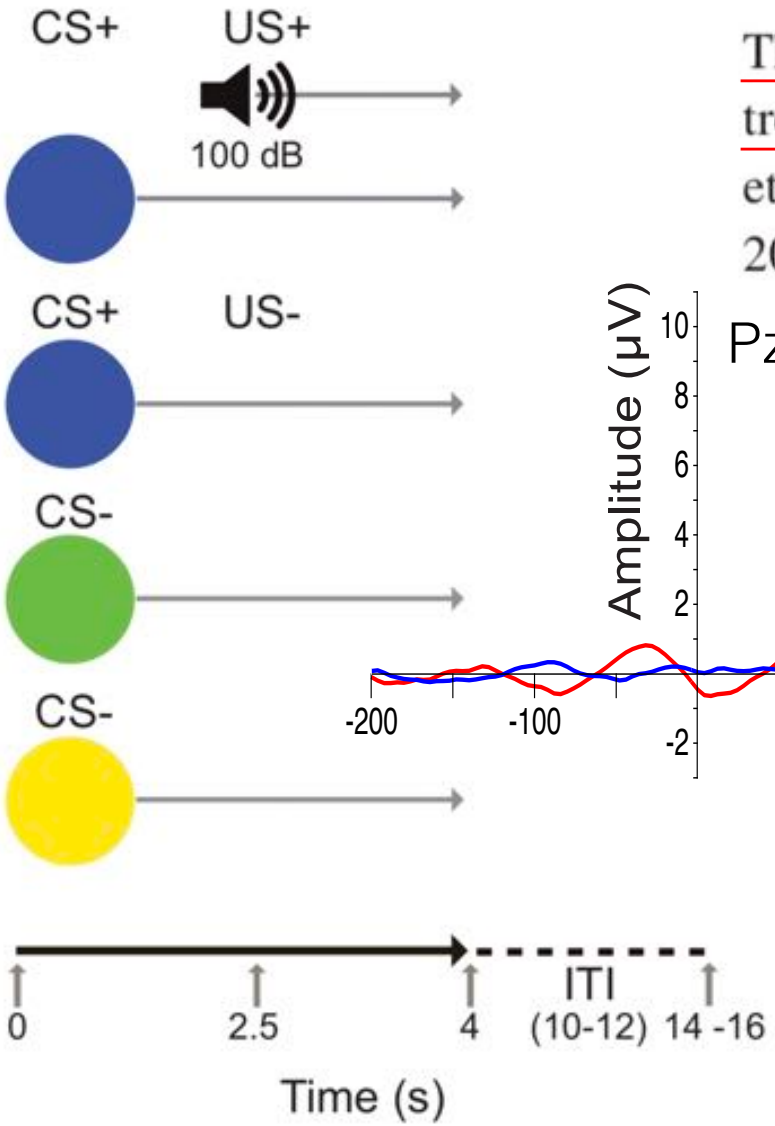
One average for CS+ trials / One average for CS- trials



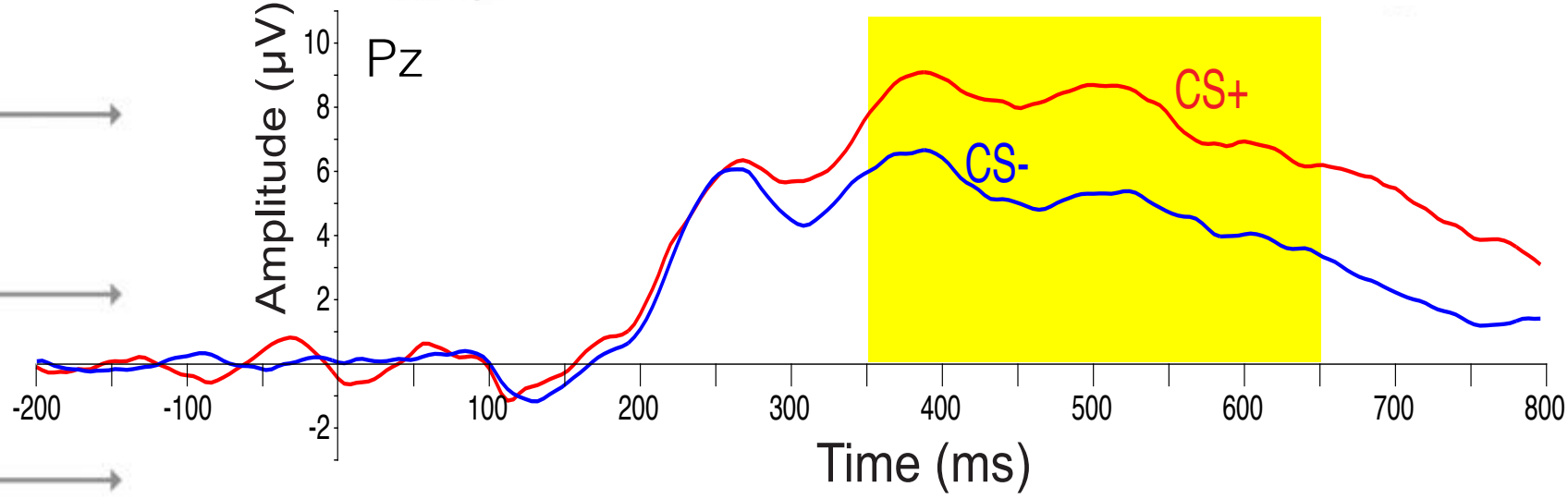
The LPP was larger for the CS+ color than for the CS- colors.

There was also a larger skin conductance response for the CS+, but the response of the skin was delayed for several seconds.

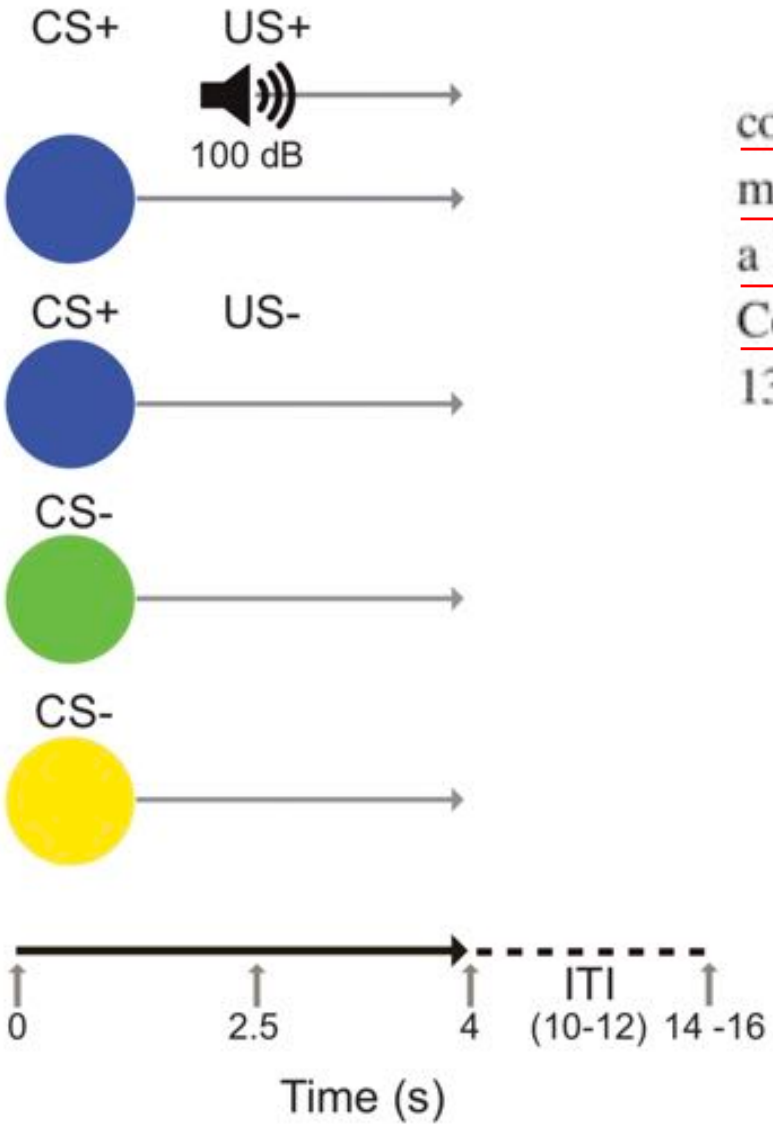
The difference wave shows the time course of the brain's differential response to CS+ and CS-. It cannot exceed zero until the brain has determined whether or not a given stimulus is associated with the noise burst.



The LPP was measured as the mean amplitude at the Pz electrode site in the time window between 350–650 ms (Liu et al., 2012; Weinberg, Hilgard, Bartholow, & Hajcak, 2012).

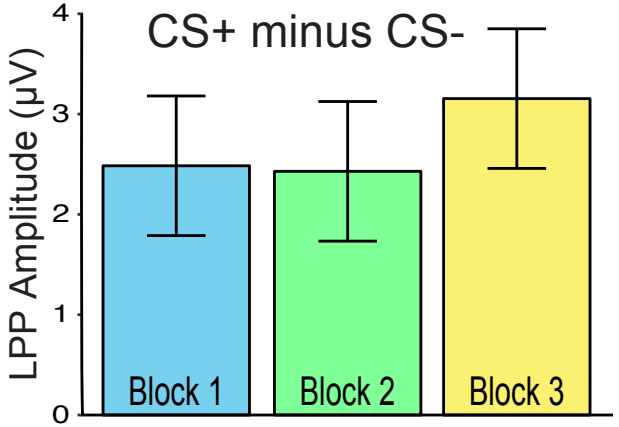


	Block 1	Block 2	Block 3
CS+			
CS-			



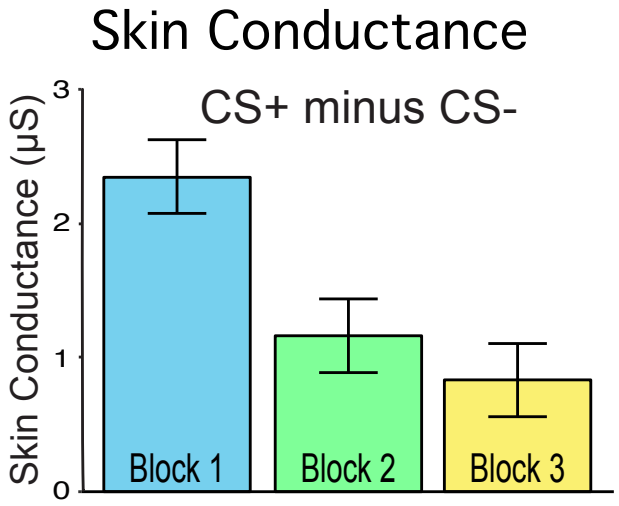
A two-way repeated measures ANOVA with factors of condition (CS+US−/CS−) and block yielded a significant main effect for condition, $F(1, 68) = 25.29$, $p < .001$, but not a significant effect for block, $F(2, 136) = 1.13$, $p = .32$. The Condition × Block interaction was not significant, $F(2, 136) = 0.5$, $p = .6$.

Late Positive Potential



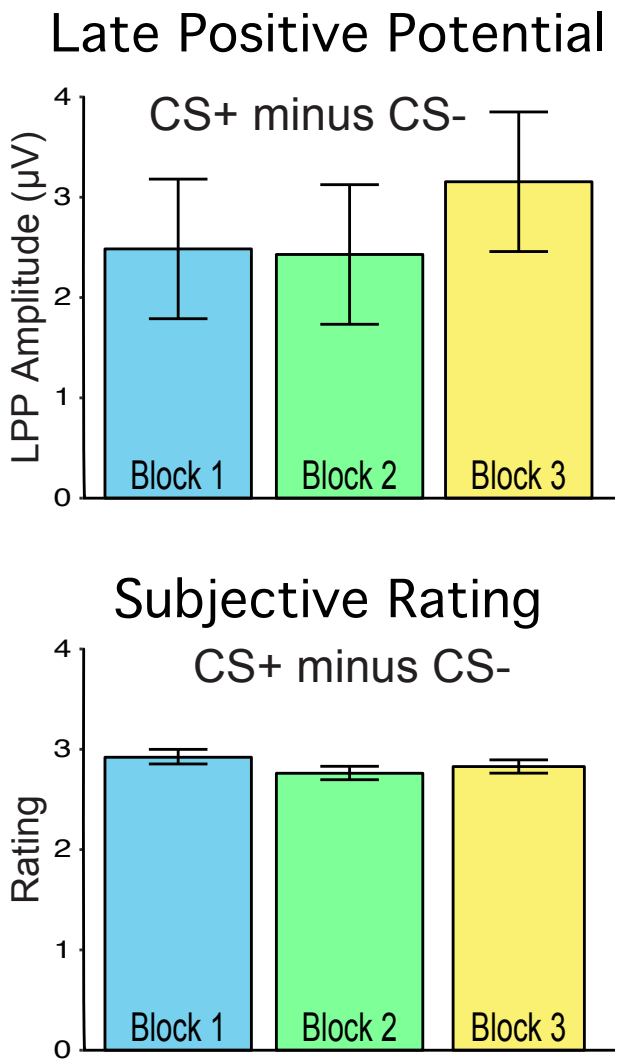
4 | DISCUSSION

Replicating prior research, we found that the SCR was significantly larger on CS+US− trials than on CS− trials. However, this effect habituated very rapidly and was quite small after the first aversive conditioning block. We also found that the LPP was larger on CS+US− trials than on CS− trials, thus showing that it can be used as an index of aversive learning (see also Nelson et al., 2015). Unlike the SCR, however, the LPP conditioning effect was stable over blocks, as was the subjective self-report measure. This provides preliminary evidence that the LPP may be more closely related to conscious awareness of threat than is the SCR. When combined with the fact that the LPP is a direct and immediate measure of neural activity in the brain, the present findings indicate that the LPP is a useful complement to the SCR for assessing aversive conditioning.



4 | DISCUSSION

Replicating prior research, we found that the SCR was significantly larger on CS+US− trials than on CS− trials. However, this effect habituated very rapidly and was quite small after the first aversive conditioning block. We also found that the LPP was larger on CS+US− trials than on CS− trials, thus showing that it can be used as an index of aversive learning (see also Nelson et al., 2015). Unlike the SCR, however, the LPP conditioning effect was stable over blocks, as was the subjective self-report measure. This provides preliminary evidence that the LPP may be more closely related to conscious awareness of threat than is the SCR. When combined with the fact that the LPP is a direct and immediate measure of neural activity in the brain, the present findings indicate that the LPP is a useful complement to the SCR for assessing aversive conditioning.



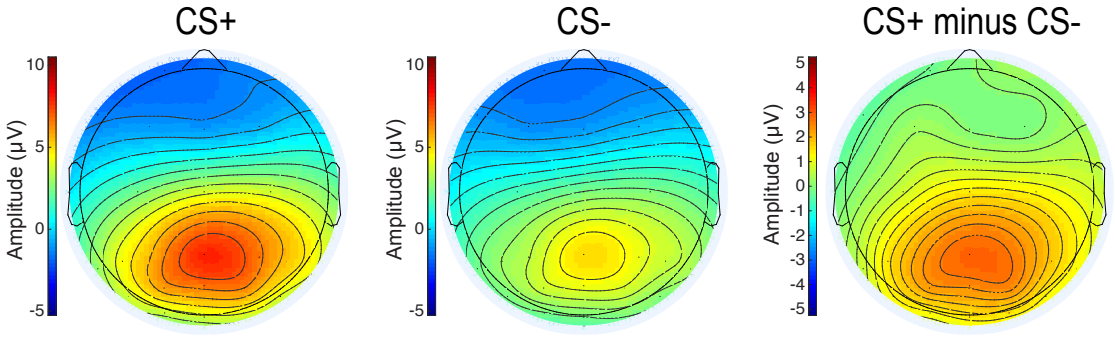
This video was made possible by NIH grant R25MH080794 and is shared under the terms of a Creative Commons license (CC BY-SA 4.0)

ERP Recording & Analysis

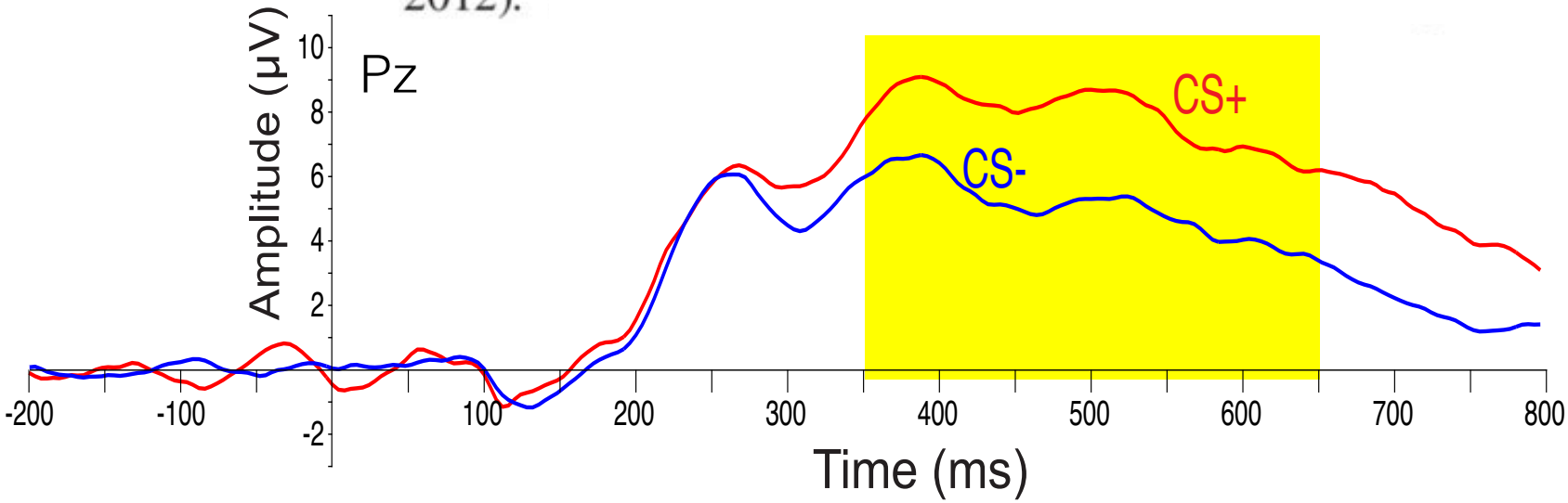
Choosing Time Windows & Electrodes

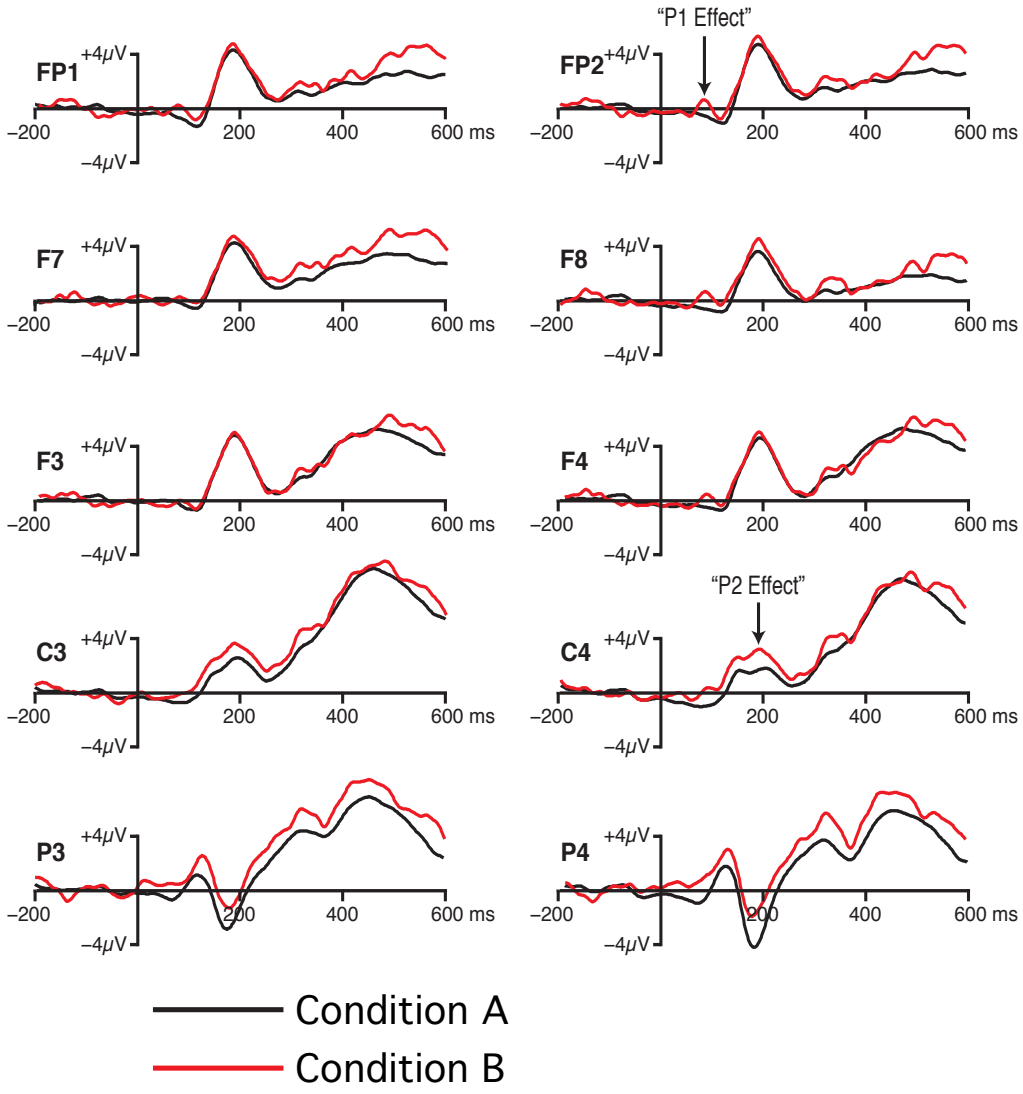
You might think you could just look at the waveforms and scalp distributions and see that this is where the effect is.

But it can be dangerous to use what you see in the data to determine how you analyze the data.



The LPP was measured as the mean amplitude at the Pz electrode site in the time window between 350–650 ms (Liu et al., 2012; Weinberg, Hilgard, Bartholow, & Hajcak, 2012).



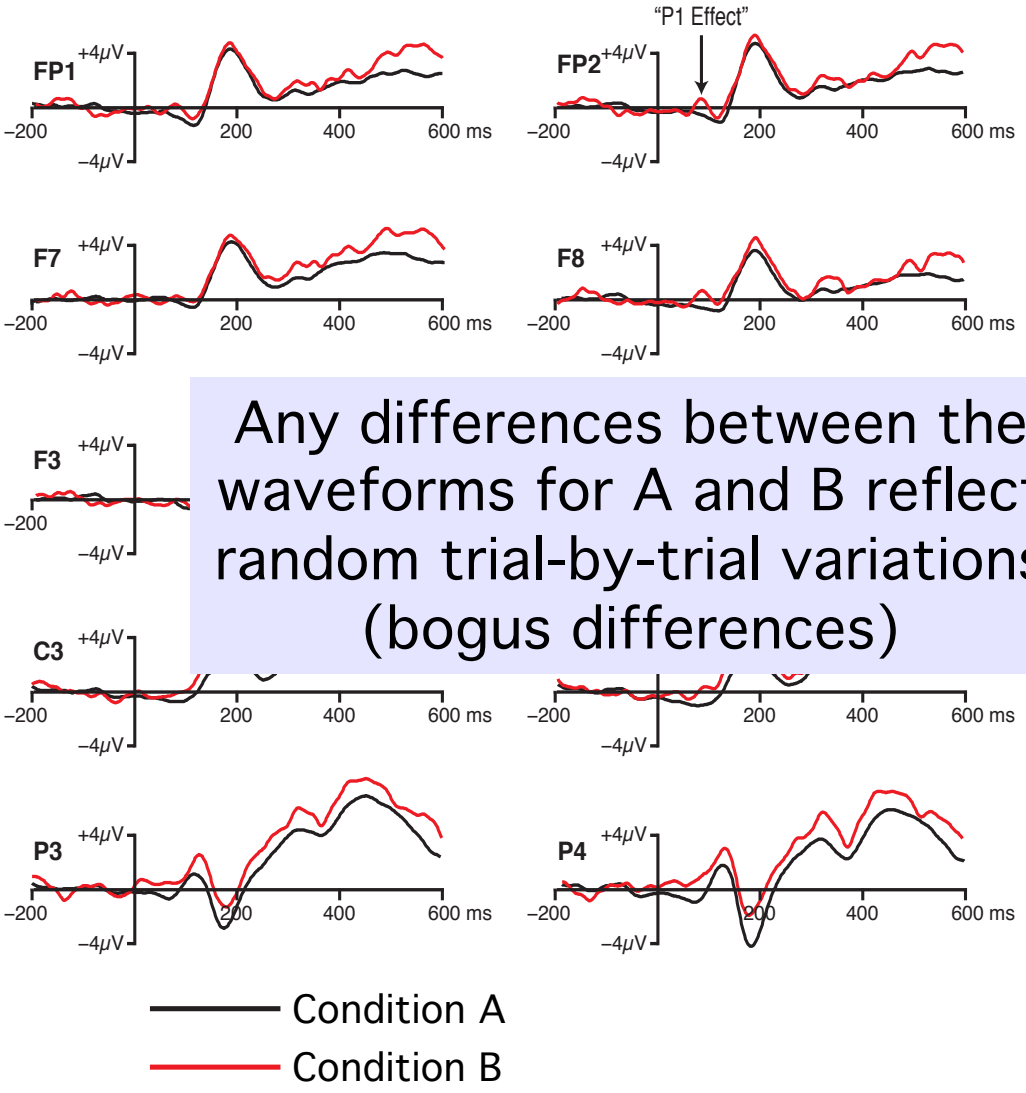


Conditions A and B were created by randomly sampling EEG epochs from a single condition of a real experiment

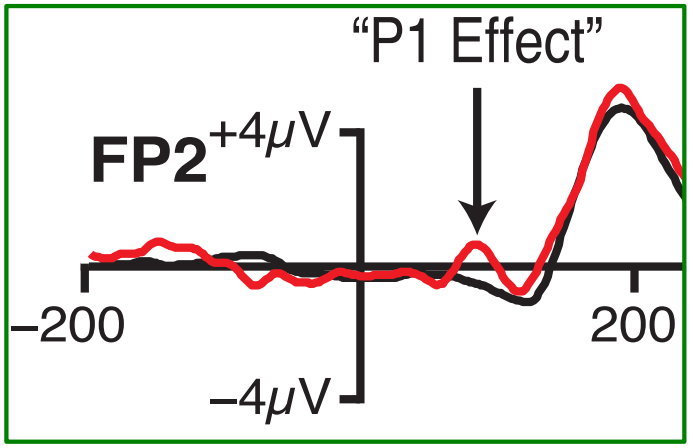
Any differences between the waveforms for A and B reflect random trial-to-trial variations in the EEG ("bogus" differences)

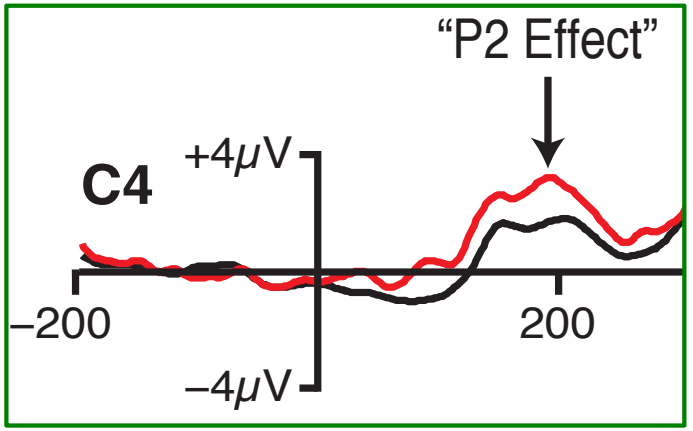
"Bogus But Significant" = Due Solely to Noise = Type I error

Luck & Gaspelin (2017)



Any differences between the waveforms for A and B reflect random trial-by-trial variations (bogus differences)



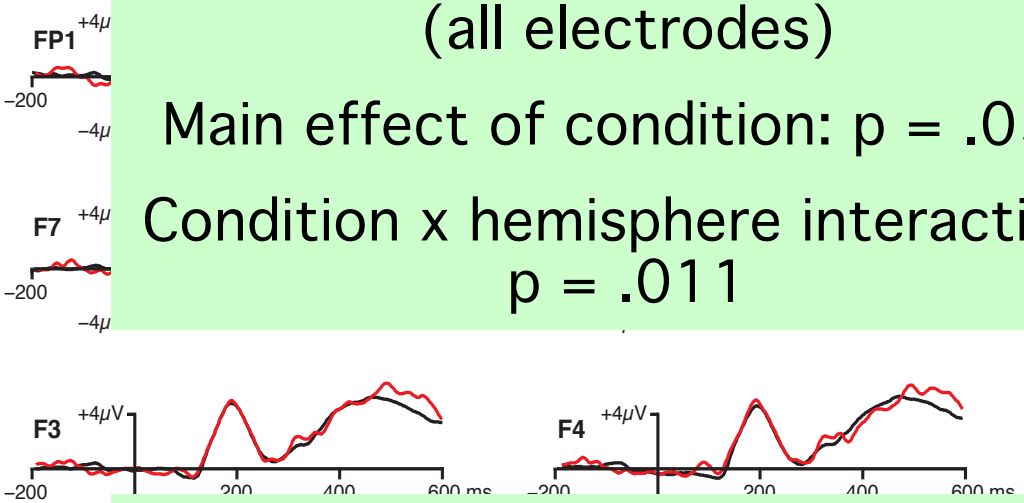


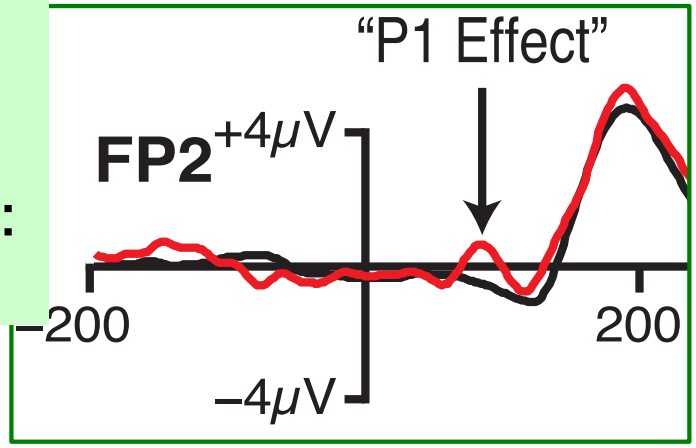
Luck & Gaspelin (2017)

Mean amplitude from 50-150 ms (all electrodes)

Main effect of condition: p = .051

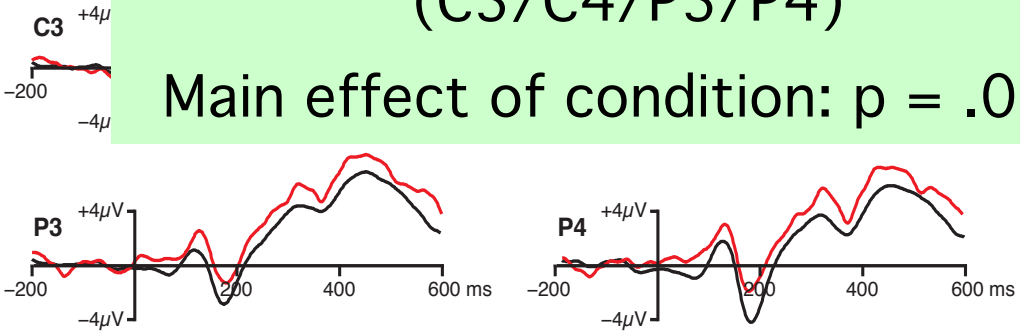
Condition x hemisphere interaction: p = .011

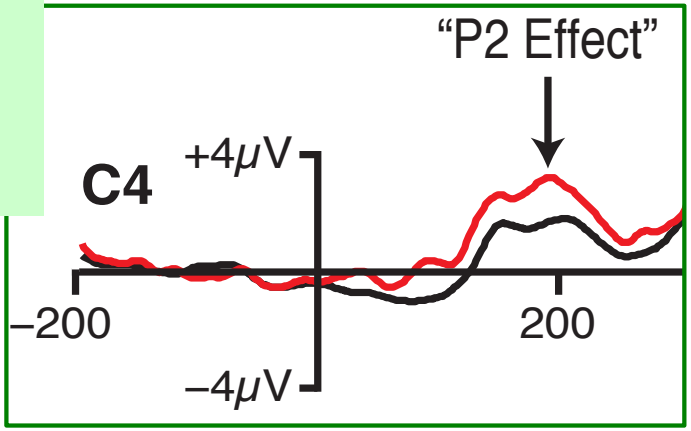




Mean amplitude from 150-250 ms (C3/C4/P3/P4)

Main effect of condition: p = .026



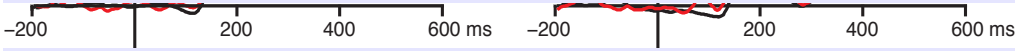


Condition A

Condition B

Luck & Gaspelin (2017)

Conditions A and B were created by randomly sampling EEG epochs from a single condition of a real experiment

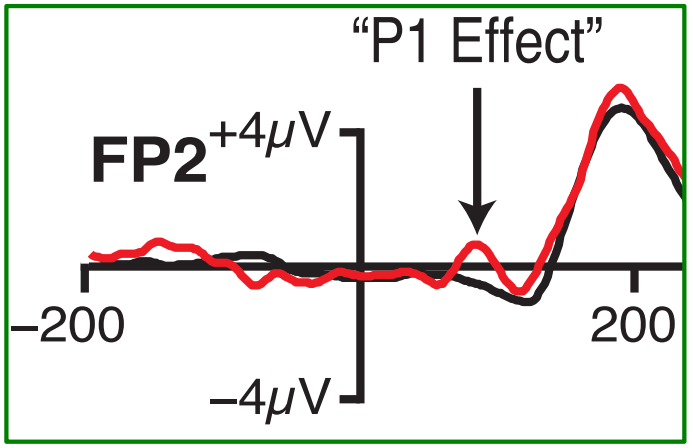


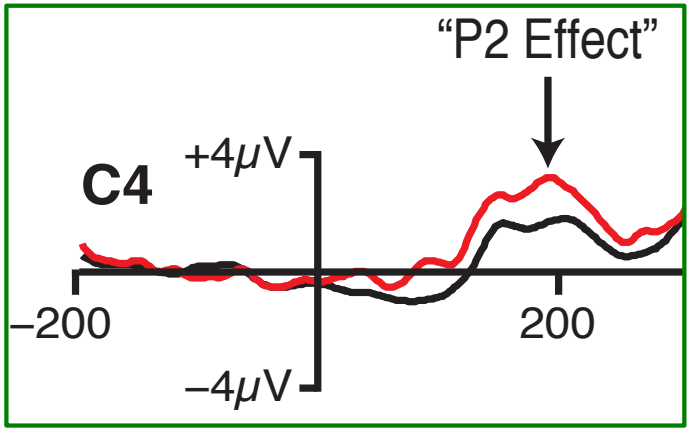
Any differences between the waveforms for A and B reflect random trial-by-trial variations (bogus differences)

There are so many time points and electrode sites that you will almost always be able to find a bogus-but-significant effect somewhere

Condition A

Condition B

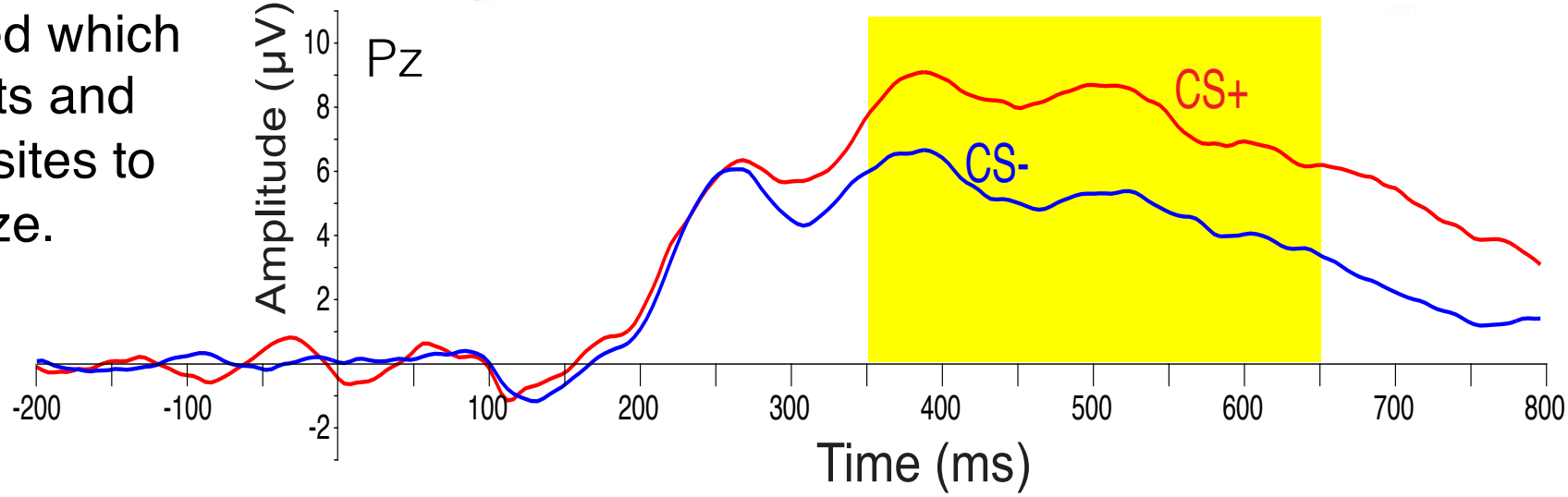




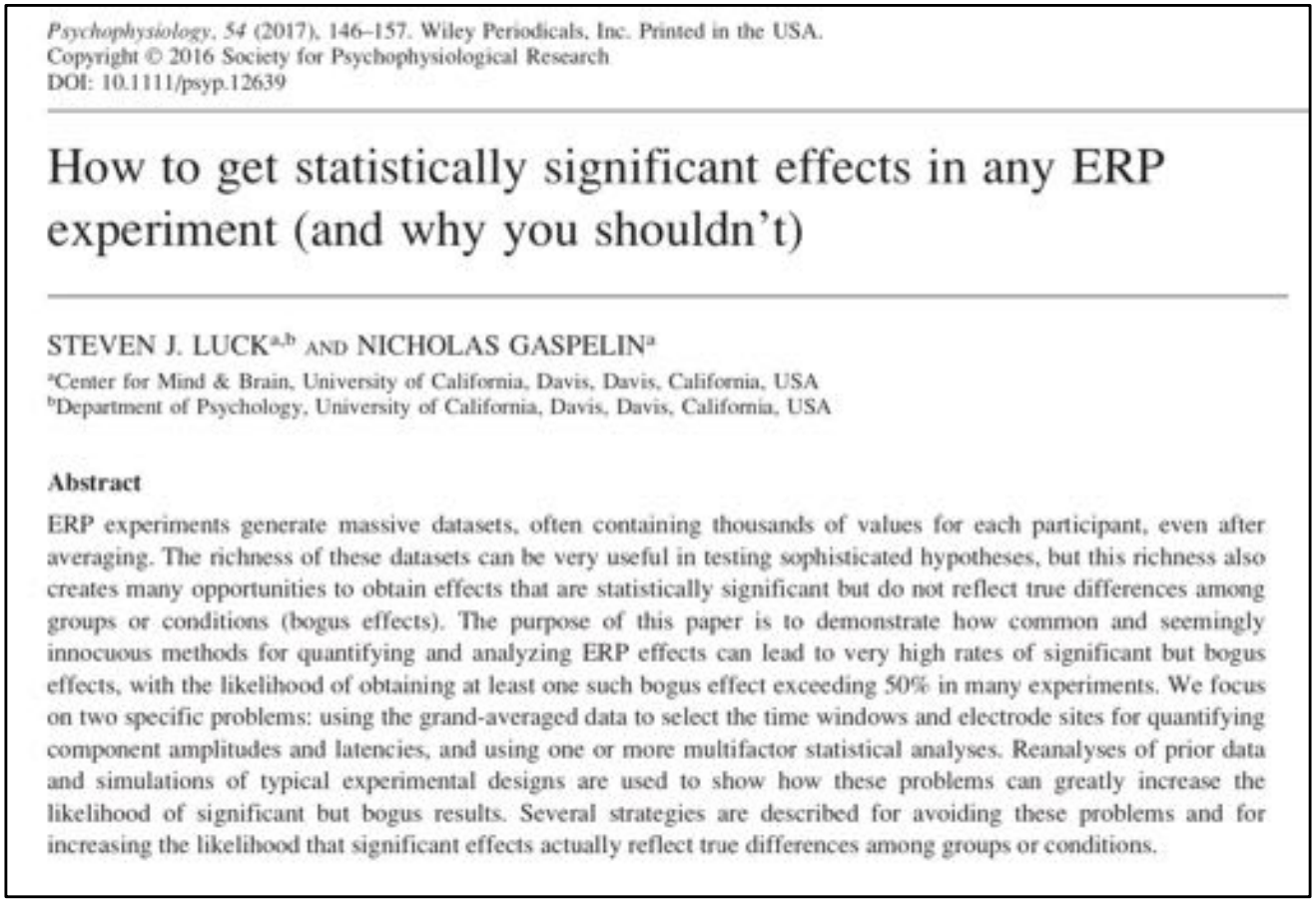
Luck & Gaspelin (2017)

When you're reading an ERP paper, you should look at how they decided which time points and electrode sites to analyze.

The LPP was measured as the mean amplitude at the Pz electrode site in the time window between 350–650 ms (Liu et al., 2012; Weinberg, Hilgard, Bartholow, & Hajcak, 2012).



Ideally, the researchers will have chosen their time windows and electrode sites before seeing the data, on the basis of prior research. Felix chose to measure the LPP from 350 to 650 milliseconds at the Pz electrode site because that's where other studies have found similar LPP effects.



Psychophysiology, *54* (2017), 146–157. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/psyp.12639

How to get statistically significant effects in any ERP experiment (and why you shouldn't)

STEVEN J. LUCK[a,b] AND NICHOLAS GASPELIN[a]

[a]Center for Mind & Brain, University of California, Davis, Davis, California, USA
[b]Department of Psychology, University of California, Davis, Davis, California, USA

Abstract

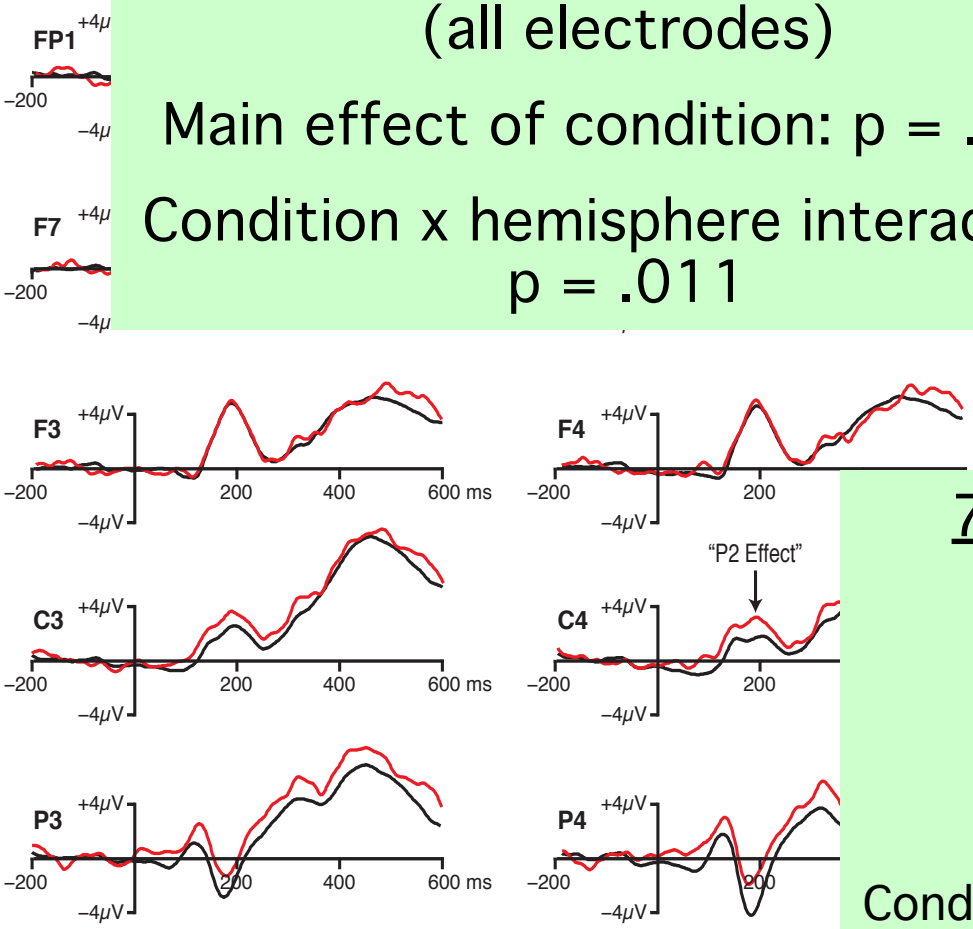
ERP experiments generate massive datasets, often containing thousands of values for each participant, even after averaging. The richness of these datasets can be very useful in testing sophisticated hypotheses, but this richness also creates many opportunities to obtain effects that are statistically significant but do not reflect true differences among groups or conditions (bogus effects). The purpose of this paper is to demonstrate how common and seemingly innocuous methods for quantifying and analyzing ERP effects can lead to very high rates of significant but bogus effects, with the likelihood of obtaining at least one such bogus effect exceeding 50% in many experiments. We focus on two specific problems: using the grand-averaged data to select the time windows and electrode sites for quantifying component amplitudes and latencies, and using one or more multifactor statistical analyses. Reanalyses of prior data and simulations of typical experimental designs are used to show how these problems can greatly increase the likelihood of significant but bogus results. Several strategies are described for avoiding these problems and for increasing the likelihood that significant effects actually reflect true differences among groups or conditions.

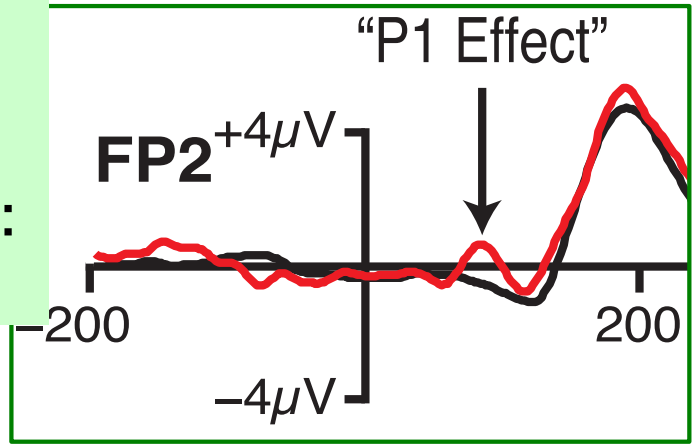
Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, *54*, 146–157.

Mean amplitude from 50-150 ms (all electrodes)

Main effect of condition: p = .051

Condition x hemisphere interaction: p = .011



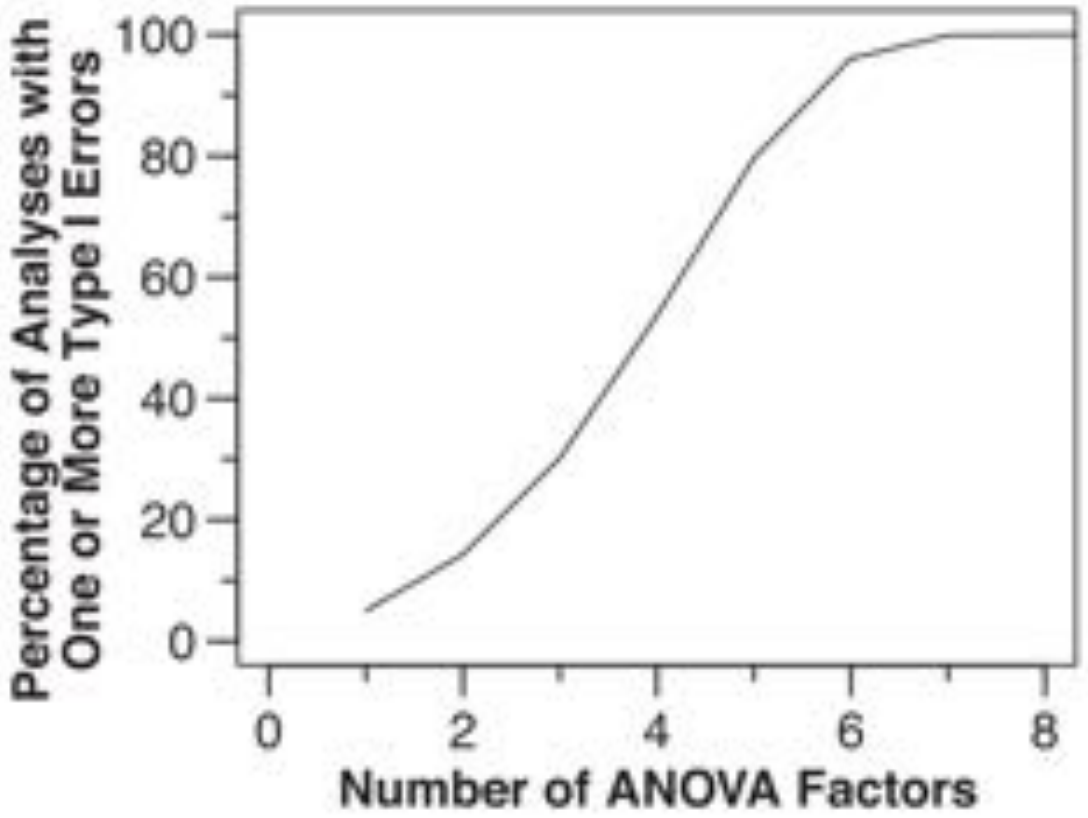


7 Main Effects and Interactions

Condition main effect
Hemisphere main effect
Anterior-to-Posterior main effect
Condition x Hemisphere
Condition x Anterior-to-Posterior
Hemisphere x Anterior-to-Posterior
Condition x Hemisphere x Anterior-to-Posterior

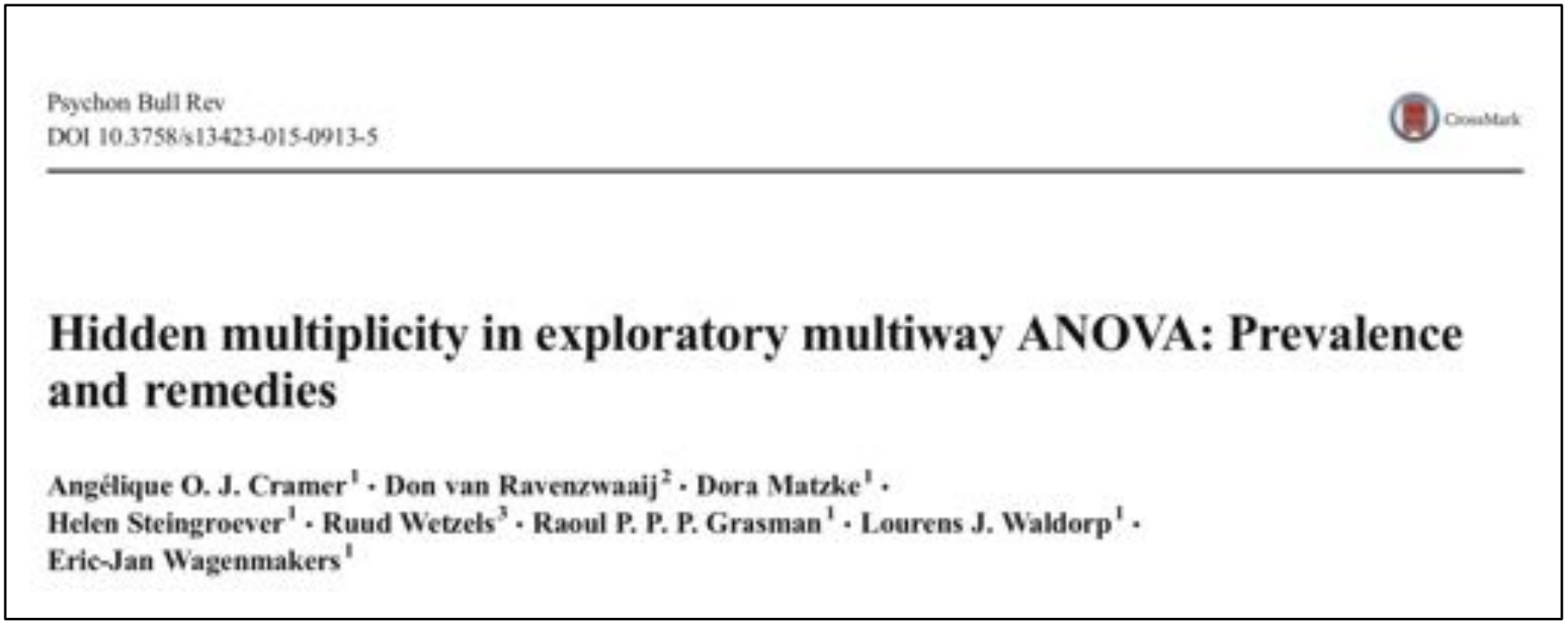
30% false positive rate if all effects are actually null!

Luck & Gaspelin (2017)



If you have an ANOVA with F factors, the number of p values is F^2-1
and the probability that at least one will be significant by chance $\cong 1 - .95^{F^2-1}$

Luck & Gaspelin (2017)



Psychon Bull Rev
DOI 10.3758/s13423-015-0913-5

Hidden multiplicity in exploratory multiway ANOVA: Prevalence and remedies

Angélique O. J. Cramer[1] · Don van Ravenzwaaij[2] · Dora Matzke[1] · Helen Steingroever[1] · Ruud Wetzels[3] · Raoul P. P. P. Grasman[1] · Lourens J. Waldorp[1] · Eric-Jan Wagenmakers[1]

Cramer, A. O. J., van Ravenzwaaij, D., Matzke, D., Steingroever, H., Wetzels, R., Grasman, R. P. P. P., Waldorp, L. J., & Wagenmakers, E.-J. (2015). Hidden multiplicity in exploratory multiway ANOVA: Prevalence and remedies. *Psychonomic Bulletin & Review, 23*, 640–647.