

# PSYC401A/501A: Principles of Psychophysiology

**Spring, 2025, Mondays, 2:00-4:45 p.m.  
Room 321 Psychology**

**Course Resources Online:  
[psychophyslab.arizona.edu/courses](https://psychophyslab.arizona.edu/courses)**

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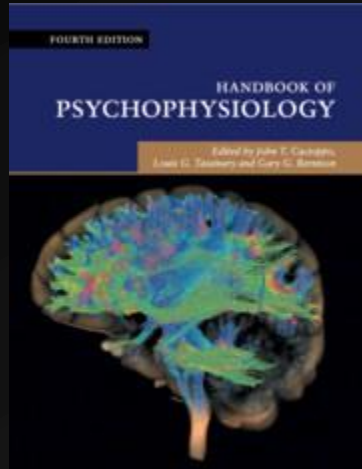
# Administrivia

- Introductions
- REC** ➤ Overview of [Syllabus](#)
- Class Format

# Substantive Topics

- General Definition and Interpretive Issues
- Review of studies that highlight the utility of a psychophysiological approach

# Main Text



Cacioppo, J.T., Tassinary, L.G. , & Berntson, G.G (2016). *Handbook of Psychophysiology* (4<sup>th</sup> edition). Cambridge, UK: Cambridge University Press.



John T. Cacioppo  
1951-2018



Gary G Berntson



Louis G Tassinary

[Washington Post Memorial Article on John Cacioppo](#)

[University of Chicago Tribute](#)

# General Issues

- Definition
- Scope
- Problems of inference
- Problems and Prospects for the field



Definition

Psychophysiology

# Definition



- Darrow (1964) Presidential Address:
  - the science which concerns physiological activities which underlie or relate to psychic events
- Ax (1964) Opening Editorial, *Psychophysiology*

Psychophysiology is a research area which extends observation of behavior to those covert proceedings of the organism relevant to a psychic state or process under investigation and which can be measured with minimal disturbance to the natural functions involved. Modern psychophysiology is a response to the challenge inherent in the full realization of the complex nature of the human organism.

Psychophysiology provides a method for bringing both physiological and psychological aspects of behavior into a single field of discourse by which truly organismic constructs may be created.

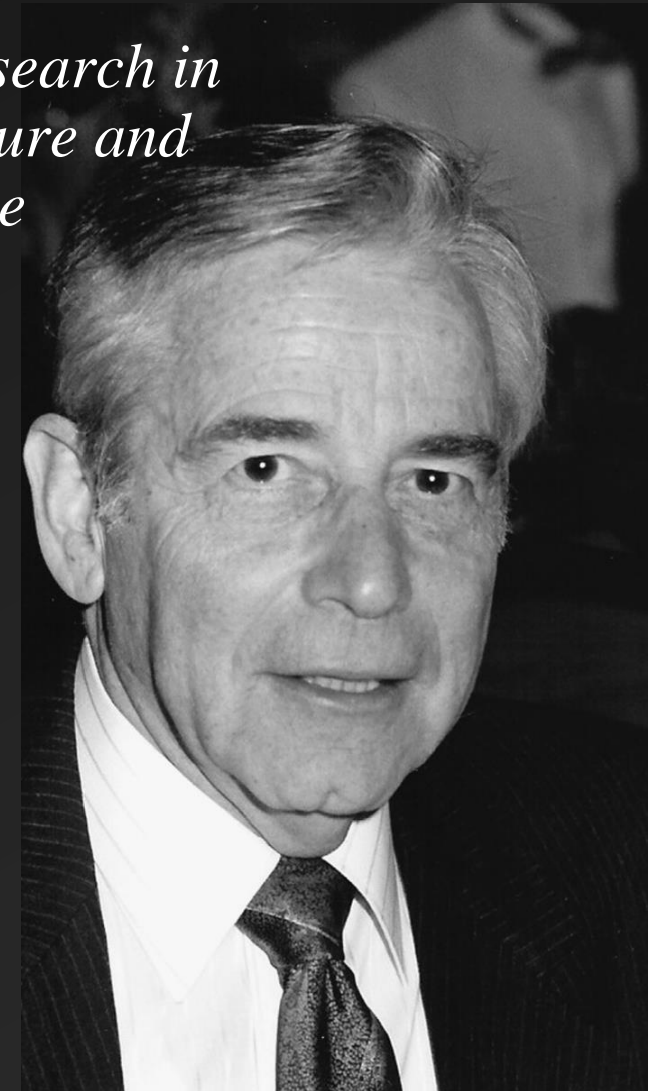
# Definition

- Stern (1964), also in the 1<sup>st</sup> issue of *Psychophysiology*  
*I would like to offer as a working suggestion that any research in which the dependent variable is a physiological measure and the independent variable a "behavioral" one should be considered psychophysiological research*

July, 1964      TOWARD A DEFINITION OF PSYCHOPHYSIOLOGY      91

TABLE 1

	Independent variable	Dependent variable
Physiological psychology	Brain lesion	Learning—behavioral
	Brain stimulation	Performance
	Drug administration	Conditioning
	Diet manipulation	Food selection
Psychophysiol- ogy	Auditory stimulation	Habituation of orienting re- sponse
	Vigilance experiment	EEG evoked response
	Sleep deprivation	Background EEG
	Psychologic or psychiatric state (fear, anxiety, depression, etc.)	Conditionability of physiologi- cal system
	Dreaming	Physiological correlates



Yet he concludes... *“I wish our editor the best of luck in defining the scope of articles acceptable for our journal.”*





[“Emotion-Controlled” Cat Ears by Necomimi](#)



# Definition

- Cacioppo Tassinary & Berntson (2016):
  - the scientific study of social, psychological, and behavioral phenomena as related to and revealed through physiological principles and events in functional organisms
- Allen (2025, this very moment):
  - The use of a particular set of physiologically-based dependent or independent variables to gain insights into psychological questions; when done well, psychophysiological methods
    - provide an independent method (to behavior and self report)
    - provide information that is not accessible through other psychological methods
    - link behavior and experience to underlying systems, by using paradigms with solid theoretical foundations
- Distinguished from: Physiological psychology, Behavioral Neuroscience

# Scope

## “Classic Measures”

- Skin Conductance (level and response)
- Cardiac measures (heart rate, variability, contractility, both SNS and PNS measures, blood pressure, plethysmography)
- Oculomotor and pupilometric measures
- Electromyographic activity
- Respiration
- Gastrointestinal activity
- Penile and vaginal plethysmography
- Electroencephalographic oscillatory measures (frequency domain EEG and sleep psychophysiology)
- Event-related brain potentials
- Event-related frequency changes

## “Newer Measures”

- Hormonal and Endocrinological measures
- Immune function
- Functional neuroimaging
  - PET
  - fMRI
  - Optical Imaging
- MEG

## Manipulations

- Classical Biofeedback
- Transcranial Magnetic Stimulation
- Transcranial Direct Current Stimulation
- Transcranial Alternating Current Stimulation
- Transcranial Electrical Interference Stimulation
- Transcranial Ultrasound

# Thematic x Systemic Psychophysiology

	Cognitive psychophysiology	Developmental psychophysiology	Clinical psychophysiology	Social psychophysiology	Applied psychophysiology
Electrodermal psychophysiology	fMRI during emotion				Lie Detection
Cardiovascular psychophysiology			Cardio effects prejudice		
Electroencephalographic psychophysiology		EEG Asym Inhibited kids			Neurowear!
Electromyographic psychophysiology					
Hemodynamic psychophysiology	fMRI during emotion				
Etc...					

# More Applied Psychophysiology



[Chaotic Moon's mind-controlled skateboard](#)

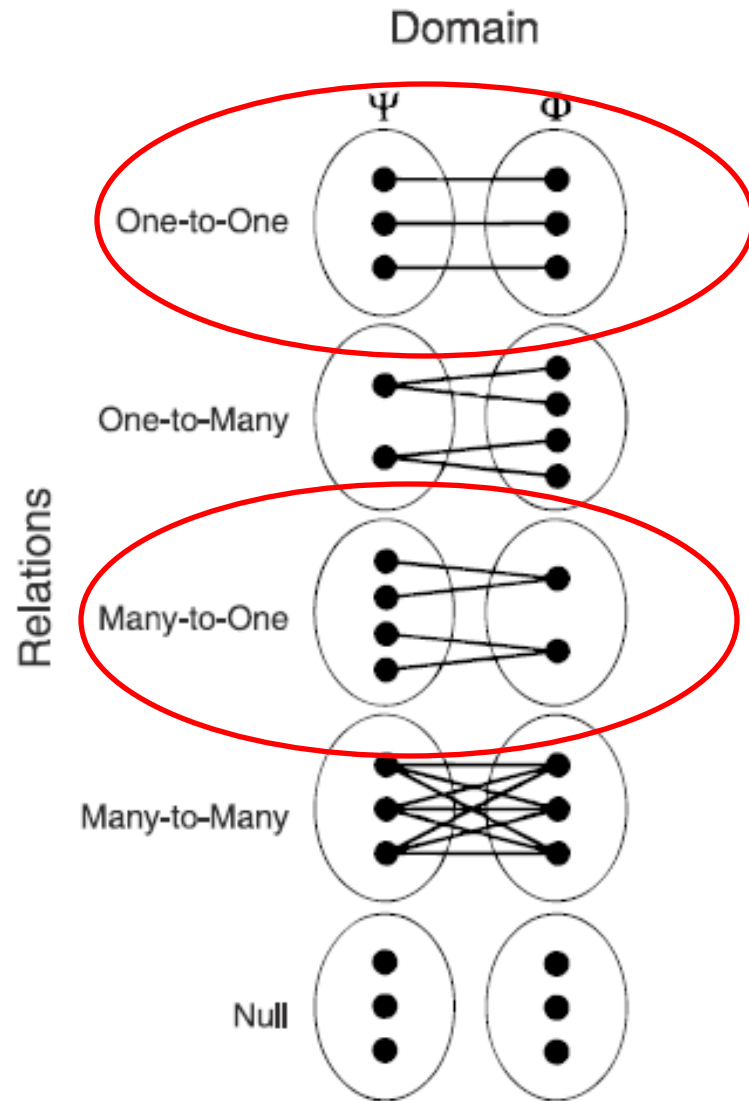
# Problems of Inference: Correlate Vs Substrate

- Is observed physiological activity a substrate of observed behavior? BEWARE
- Helpful Criteria
  - Is  $\Phi$  necessary for behavior?
  - If  $\Phi$  removed, would behavior be altered?
- But ultimately, not easily resolved

A scientific theory is a description of causal interrelations. Psychophysiological correlations are not causal. Thus in scientific theories, psychophysiological correlations are monstrosities. This does not mean that such correlations have no part in science. They are the instruments by which the psychologist may test his theories. (Gardiner, Metcalf, & Beebe-Center, 1937, p. 385)

or her

# Problems of Inference



From Cacioppo, Tassinary, & Berntson, 2000, 2007

Only these types of relationships would allow a formal specification that psychological elements are a function of specific physiological elements

Figure 2. Possible relationships between elements in the psychological ( $\Psi$ ) and physiological ( $\Phi$ ) domains.

# Reducing the Complexity

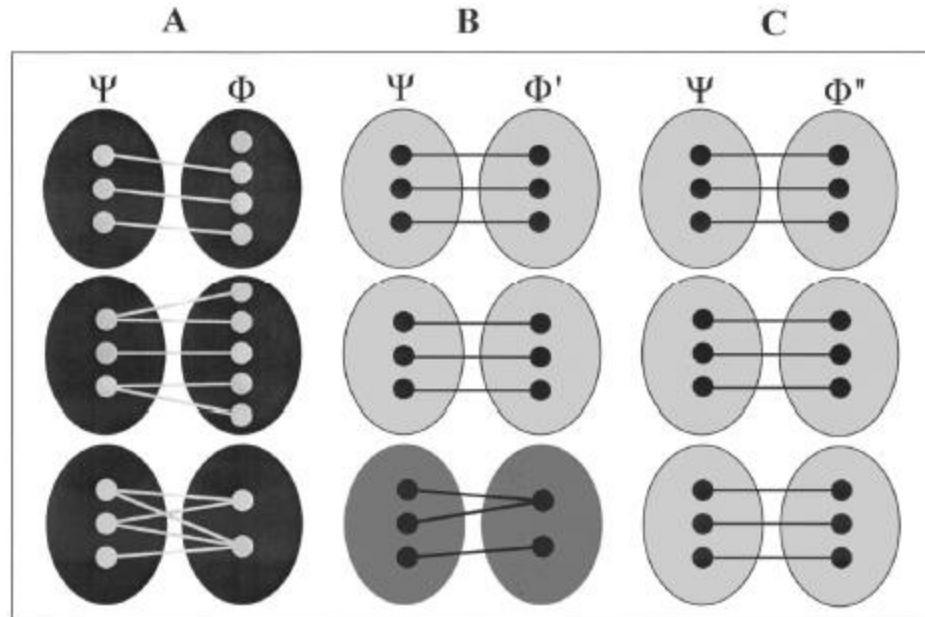


Figure 1. Depiction of logical relations between elements in the psychological ( $\Psi$ ) and physiological ( $\Phi$ ) domains. Left panel: Links between the psychological elements and individual physiological responses. Middle panel: Links between the psychological elements and the physiological response pattern. Right panel: Links between the psychological elements and the profile of physiological responses across time.

From Cacioppo, Tassinary, & Berntson, 2000



# Typical Scenarios

- Typical structure/assumption of psychophysiological or imaging study:
  - $P(\Phi | \Psi) > 0$
- Typical structure/assumption of biofeedback study:
  - $P(\Psi | \Phi) > 0$
- Typical hunt for “markers” or biological substrate
  - Study begins  $P(\Phi | \Psi) > 0$
  - Desirable (but often invalid) inference (*reverse inference*)
    - $P(\Psi | \Phi) > 0$
    - Only valid given 1:1 relationship of  $\Psi$  and  $\Phi$
  - Use complementary approaches; e.g.,
    - fMRI =  $P(\Phi | \Psi)$
    - Lesion =  $P(\Psi | \Phi)$
    - Stimulation =  $P(\Psi | \Phi)$

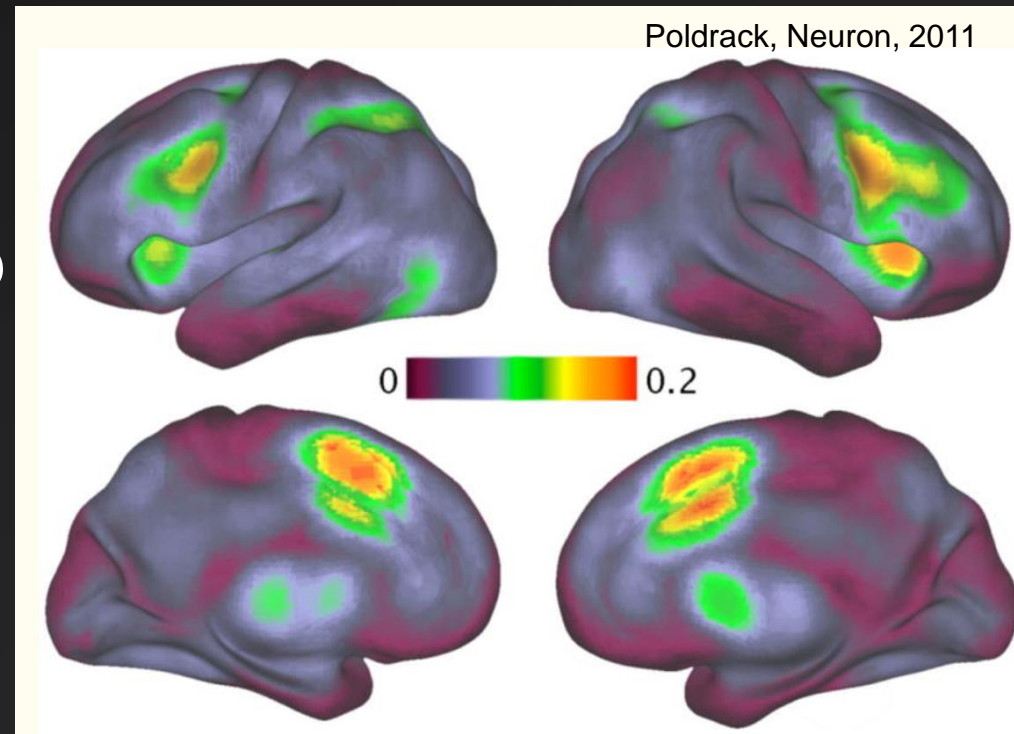


Figure 1

A rendering of base rates of activation across 3,489 studies in the literature; increasingly bright yellow/red colors reflect more frequent activation across all studies, with the reddest regions active in more than 20% of all studies. Regions of most frequent activation included the anterior cingulate cortex, anterior insula, and dorsolateral prefrontal cortex. Reprinted with permission from [Yarkoni et al., 2011](#).

# The Taxonomy of $\Phi$ and $\Psi$

**One-to-one, Context Dependent**

**Example:** medical tests (fasting glucose)

**Inference** given  $\Phi$ : yes, if conditions were met

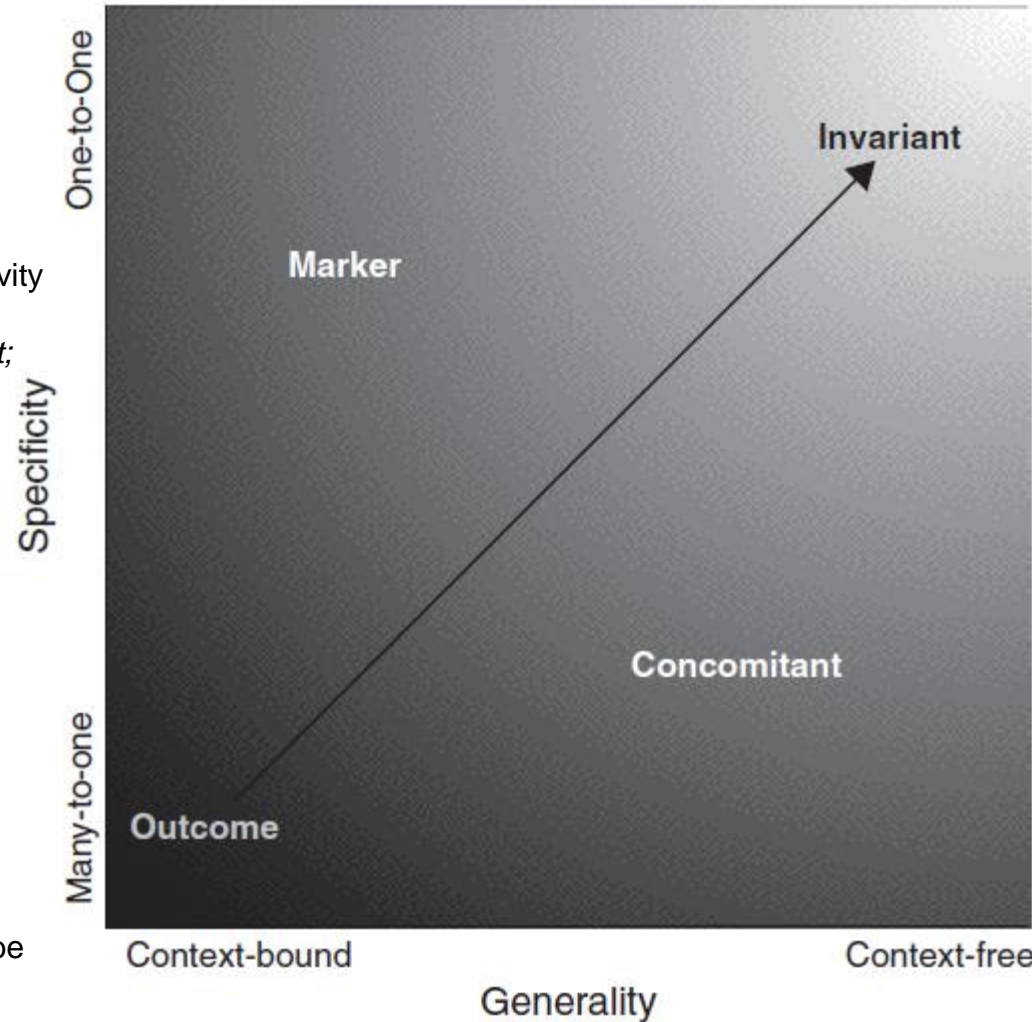
**Utility:** with sufficient sensitivity and specificity can indicate presence of  $\Psi$  *in this context*; RDoC?

**Many-to-one, Context Dependent**

**Example:** affect and HR in IAPS paradigm

**Inference** given  $\Phi$ : none

**Utility:** Informs and tests theories; absence of  $\Phi$  can be informative



**One-to-one, Context independent**

**Example:** IT15 near end of short arm chromosome 4 and Huntington's

**Inference** given  $\Phi$ : definitely  $\psi$

**Utility:** This is the Holy Grail that gets you the Nobel prize!

**Many-to-one, Context Independent**

**Example:** arousal and skin conductance (SC); orienting and SC; familiarity and SC

**Inference** given  $\Phi$ : none  
**Utility:** Limited: control the context! Might absence of  $\Phi$  be informative?

Figure 1.1 Taxonomy of psychophysiological relationships.

# The Inference Problem Illustrated

Azari et al. (2001). Neural correlates of religious experience. *European Journal of Neuroscience*, 13, 1649-1652.

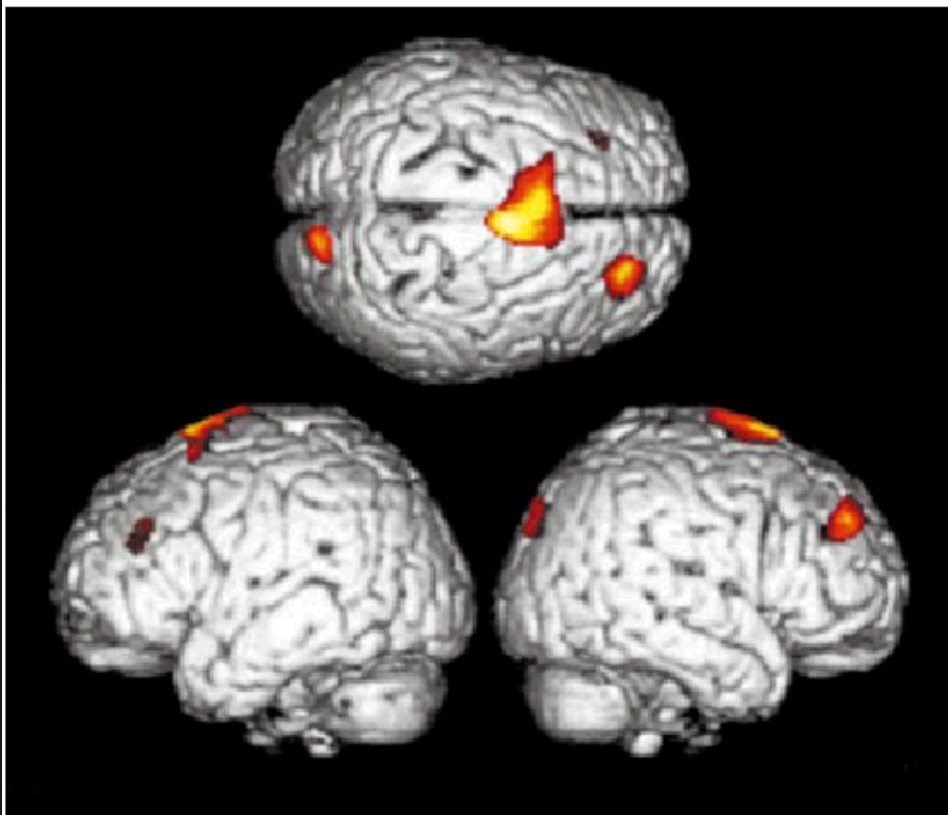


FIG. 1. Significant activations for the contrast 'religious-recite' vs. 'rest' in religious subjects, rendered onto canonical T1-weighted image of SPM97d ( $P < 0.001$ , uncorrected for multiple comparisons) (see also Table 2). Shown are the left, dorsal and right view of the brain. Scans for each subject were realigned and spatially normalized onto the PET template, and smoothed using an isotropic Gaussian kernel with FWHM set at 20 mm. The SPM grey matter threshold was set to its default value. For task comparisons, an ANCOVA (analysis of covariance) model was fitted to the data for each voxel.

During religious recitation, self-identified religious subjects activated a frontal-parietal circuit, composed of the dorsolateral prefrontal, dorsomedial frontal and medial parietal cortex. Prior studies indicate that these areas play a profound role in sustaining reflexive evaluation of thought. Thus, religious experience may be a cognitive process which, nonetheless, feels immediate.

# Love your iPhone?

Earlier this year, I carried out an fMRI experiment to find out whether iPhones were really, truly addictive, no less so than alcohol, cocaine, shopping or video games. In conjunction with the San Diego-based firm MindSign Neuromarketing, I enlisted eight men and eight women between the ages of 18 and 25. Our 16 subjects were exposed separately to audio and to video of a ringing and vibrating iPhone.

In each instance, the results showed activation in both the audio and visual cortices of the subjects' brains. In other words, when they were exposed to the video, our subjects' brains didn't just see the vibrating iPhone, they "heard" it, too; and when they were exposed to the audio, they also "saw" it. This powerful cross-sensory phenomenon is known as synesthesia.

But most striking of all was the flurry of activation in the insular cortex of the brain, which is associated with feelings of love and compassion. The subjects' brains responded to the sound of their phones as they would respond to the presence or proximity of a girlfriend, boyfriend or family member.

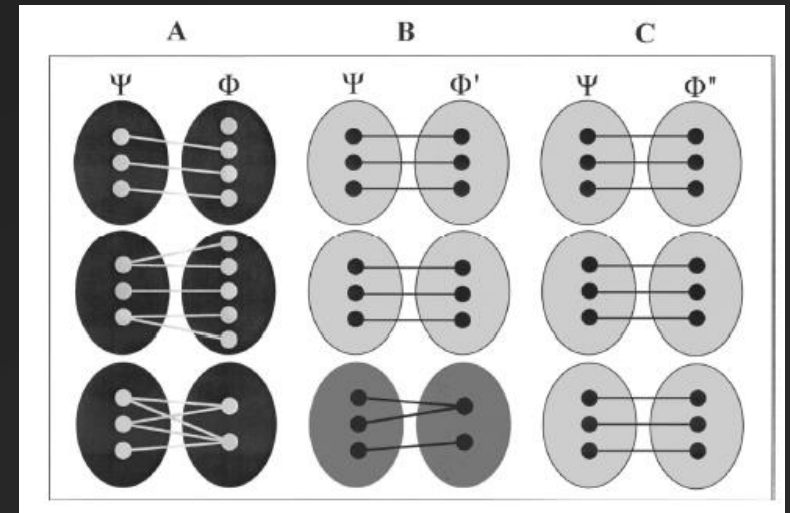
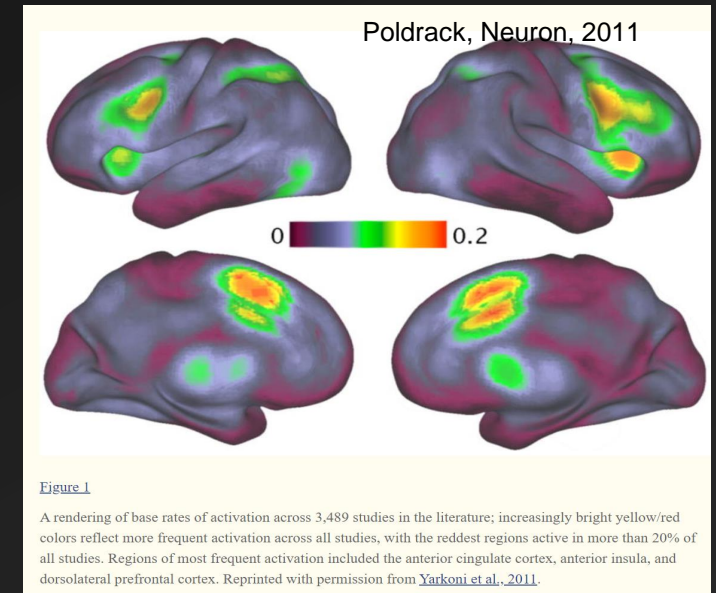
In short, the subjects didn't demonstrate the classic brain-based signs of addiction. Instead, they loved their iPhones

"NYT Op-Ed + fMRI = complete crap"  
-- Russ Poldrack



# The Reverse Inference Problem

- Just because region  $X$  is active during state/process  $Y$ ...
- It does not follow that activity in region  $X$  implies the existence of state/process  $Y$
- Single region approaches unlikely to yield informative inference
- Machine-learning approaches (MVPA: multi-voxel pattern analysis) more promising



# Compounding the Problem: Spurious findings



## Neural correlates of interspecies perspective taking in the post-mortem Atlantic Salmon: An argument for multiple comparisons correction

Craig M. Bennett<sup>1</sup>, Abigail A. Baird<sup>2</sup>, Michael B. Miller<sup>1</sup>, and George L. Wolford<sup>3</sup>

<sup>1</sup> Psychology Department, University of California Santa Barbara, Santa Barbara, CA; <sup>2</sup> Department of Psychology, Vassar College, Poughkeepsie, NY;

<sup>3</sup> Department of Psychological & Brain Sciences, Dartmouth College, Hanover, NH

### INTRODUCTION

With the extreme dimensionality of functional neuroimaging data comes extreme risk for false positives. Across the 130,000 voxels in a typical fMRI volume the probability of a false positive is almost certain. Correction for multiple comparisons should be completed with these datasets, but is often ignored by investigators. To illustrate the magnitude of the problem we carried out a real experiment that demonstrates the danger of not correcting for chance properly.

### METHODS

**Subject.** One mature Atlantic Salmon (*Salmo salar*) participated in the fMRI study. The salmon was approximately 18 inches long, weighed 3.8 lbs, and was not alive at the time of scanning.

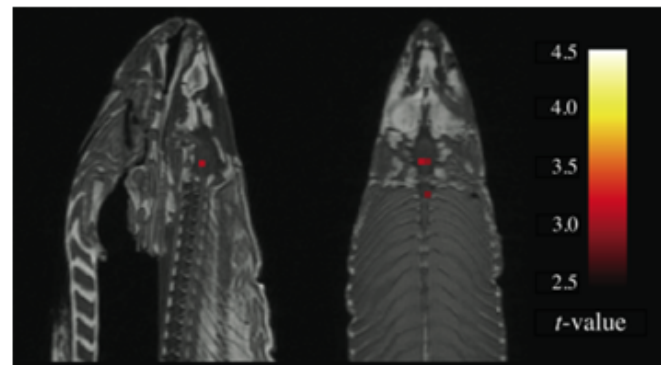
**Task.** The task administered to the salmon involved completing an open-ended mentalizing task. The salmon was shown a series of photographs depicting human individuals in social situations with a specified emotional valence. The salmon was asked to determine what emotion the individual in the photo must have been experiencing.

**Design.** Stimuli were presented in a block design with each photo presented for 10 seconds followed by 12 seconds of rest. A total of 15 photos were displayed. Total scan time was 5.5 minutes.

**Preprocessing.** Image processing was completed using SPM2. Preprocessing steps for the functional imaging data included a 6-parameter rigid-body affine realignment of the fMRI timeseries, coregistration of the data to a T<sub>1</sub>-weighted anatomical image, and 8 mm full-width at half-maximum (FWHM) Gaussian smoothing.

**Analysis.** Voxelwise statistics on the salmon data were calculated through an ordinary least-squares estimation of the general linear model (GLM). Predictors of

### GLM RESULTS



A  $t$ -contrast was used to test for regions with significant BOLD signal change during the photo condition compared to rest. The parameters for this comparison were  $t(131) > 3.15$ ,  $p(\text{uncorrected}) < 0.001$ , 3 voxel extent threshold.

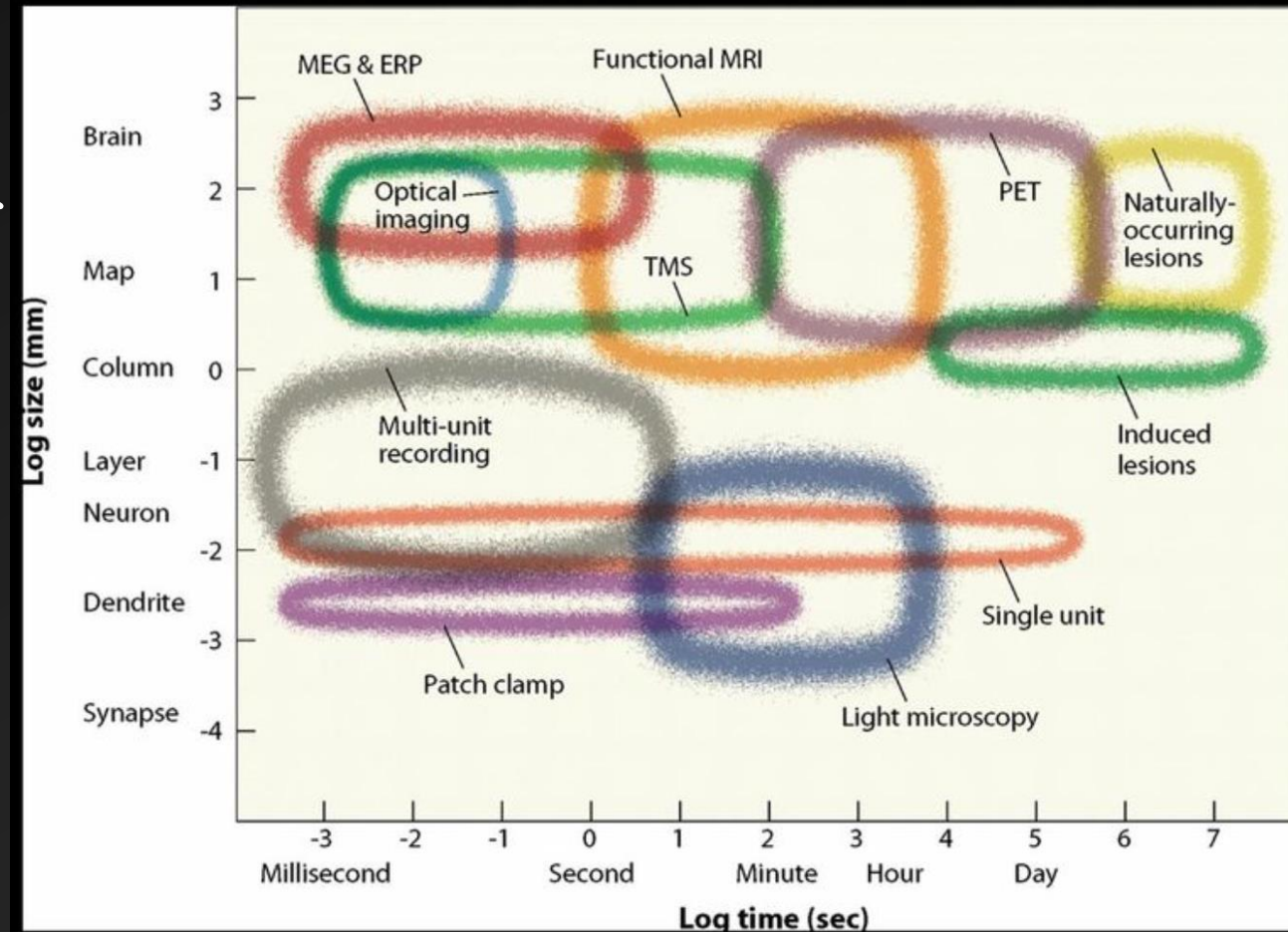
Several active voxels were discovered in a cluster located within the salmon's brain cavity (Figure 1, see above). The size of this cluster was  $81 \text{ mm}^3$  with a cluster-level significance of  $p = 0.001$ . Due to the coarse resolution of the echo-planar image acquisition and the relatively small size of the salmon brain further discrimination between brain regions could not be completed. Out of a search volume of 8064 voxels a total of 16 voxels were significant.

Identical  $t$ -contrasts controlling the false discovery rate (FDR) and familywise error rate (FWER) were completed. These contrasts indicated no active voxels, even at relaxed statistical thresholds ( $p = 0.25$ ).

# Problems and Prospects for Psychophysiology

## Problems/Challenges

- Interpretive ambiguity, reverse inference
- Time resolution and time courses of various systems/measures differ substantially
- Spatial resolution
- What is the functional significance of the observed physiological measure?





# Problems and Prospects for Psychophysiology

## Prospects

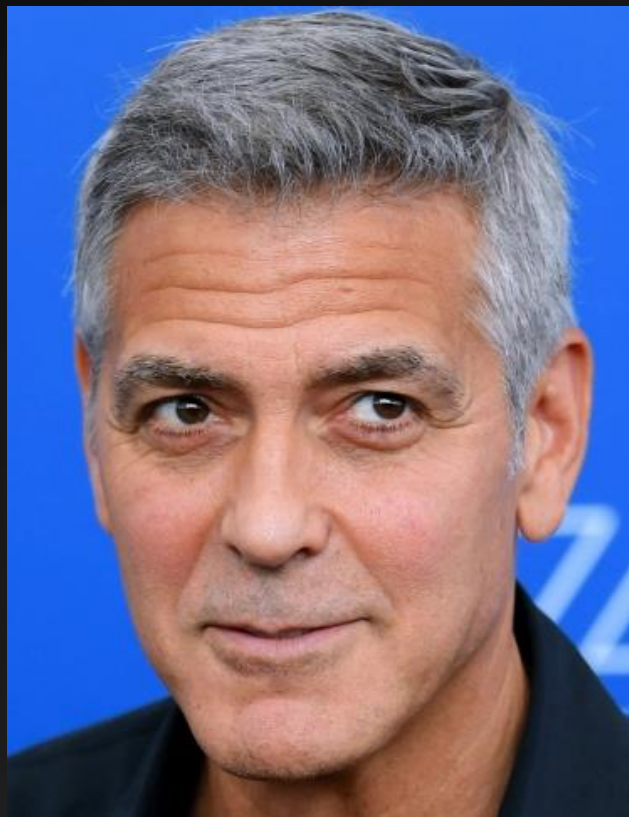
- Non-invasive
- Measures of real-time information
- May be sensitive to things that we ourselves cannot be
- Ideally suited for populations that have limited verbal/cognitive capacity
- May tap function at roughly the proper level of the nervous system to be useful to psychological investigators
- Psychophysiology is now more integrated into psychology as a whole -- you will see it in "nonspecialty" journals
- More and more "canned" packages make it accessible to the novice, but novices need advice and consultation!
- Even though there will always be newer technologies (e.g., PET, SPECT, MEG/SQUID, MRI, Functional MRI, etc.), traditional psychophysiology
  - Has generally excellent real-time resolution
  - Is flexible
  - Is cost-effective
  - Can be integrated with many of the newer technologies
  - Principles generalize across many measures
  - Newer technologies nonetheless based on fundamental principles of psychophysiology, and are in fact, psychophysiological measures
- When you tell folks at a party that you are a psychophysicologist rather than a psychologist, you are spared hearing the history of peoples' family pathology

# A few selected studies to highlight the utility of a psychophysiological approach

- Bauer (1984): Prosopagnosia
- Öhman & Soares (1993): Phobias
- Spiegel (1985): Hypnosis
- Deception Detection studies
- Investigation of Persistent Vegetative State
- Brain-Computer Interfaces for assisted communication

# Bauer (1984): Neuropsychologia

- Prosopagnosia
- Administered a version of the Guilty Knowledge Test (GKT)
  - As administered to the prosopagnosic patient
    - Set A consisted of 10 photographs of very famous folks; Set B consisted of 8 family members
    - During the display, five choices for the correct name were presented auditorially



L'Espresso  
L'Espresso  
L'Espresso

# Bauer (1984): Neuropsychologia

## ➤ Results

- Patient naming: 0/10 famous faces, 0/8 family members
- Controls naming = 9/10 famous, 0/8 of patient's family members
- Electrodermally, patient produced largest SCR to correct alternative
  - for 60% of famous faces (controls 80%, *ns* difference),
  - for 62.5% of family members (controls 37.5%)

## ➤ Conclusions

- Dissociation between psychophysiological and behavioral measures -  
- psychophysiology told us something that the patient could not
- Patient can, at an autonomic level, properly identify faces
  - *viz.* that "prosopagnosia involves a functional defect not at the perceptual level itself, but at a stage of processing where adequate perceptual information is utilized in complex decisions about the stimulus identity" (p.463)

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# Öhman & Soares (1993)

## Journal of Abnormal Psychology



Arne Öhman  
1943-2020

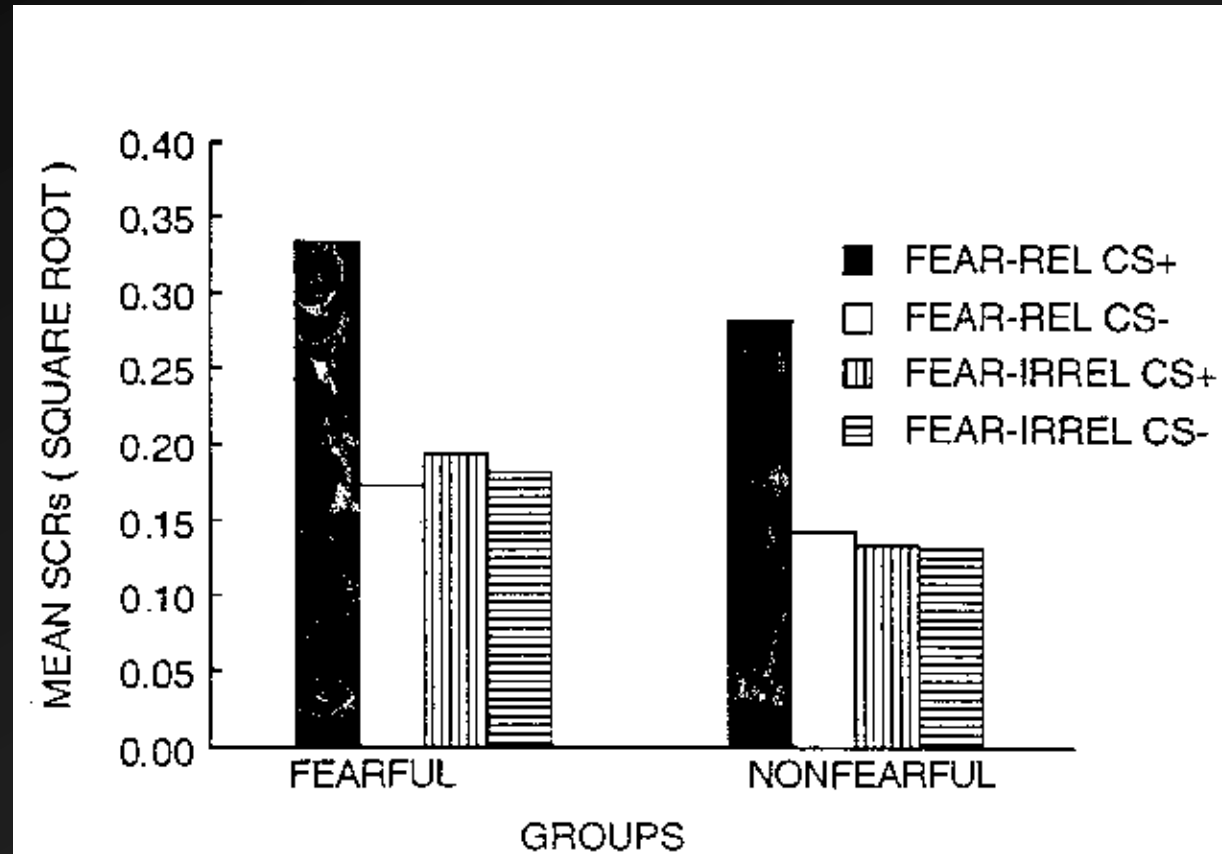
- Hypothesize that information processing of the phobic stimulus is rooted in archaic information processing mechanisms outside of the control of conscious intentions
- Use a CS+/CS- paradigm for fear-relevant and fear-irrelevant stimuli
  - Fear relevant is snake/spider; irrelevant is a flower or mushroom
  - During acquisition trials, CS+ is shocked, CS- is not
  - This leads to larger SCR to CS+ than CS- , and when stimuli are presented above threshold (with awareness), no difference between fear-relevant and fear-irrelevant
  - After acquisition, masked presentations (30 msec, followed by 100 msec mask)
  - Electrodermally, masking effectively eliminates the difference between CS+ and CS- for fear-irrelevant stimuli, but the difference between CS+/CS- is preserved for fear-relevant stimuli





# Öhman & Soares (1993)

## Journal of Abnormal Psychology



**Figure 1.** Mean skin conductance responses (SCRs) (square-root transformed) to fear-relevant (snakes, spiders, and rats) or fear-irrelevant (flowers and mushrooms) stimuli previously followed (CS+) or not followed (CS-) by an electric shock unconditioned stimulus among the fearful and nonfearful groups of subjects during extinction.

# Öhman & Soares' Conclusions

- Fear conditioning to nonprepared stimuli may involve conscious mechanisms
- Fear conditioning to prepared stimuli may be possible through mechanisms outside of conscious/controlled information processing
- Latter system may be fast and sensitive to danger cues
- May also explain why exposure therapy is critical to decrease the autonomic responses

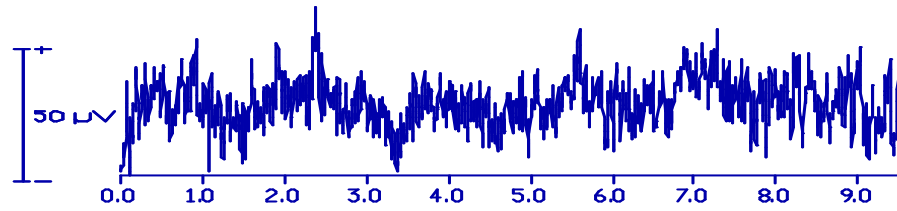
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# Speigel, Cutcomb, Ren, & Pribram. (1985) Journal of Abnormal Psychology

- Hypnosis
  - individual difference variable,
  - assessed via responsiveness to suggestions
- Two issues recurrently arise in hypnosis:
  - (1) Do the effects have veracity?
  - (2) If so, how are they accomplished?
- ERPs 101: Signal averaging

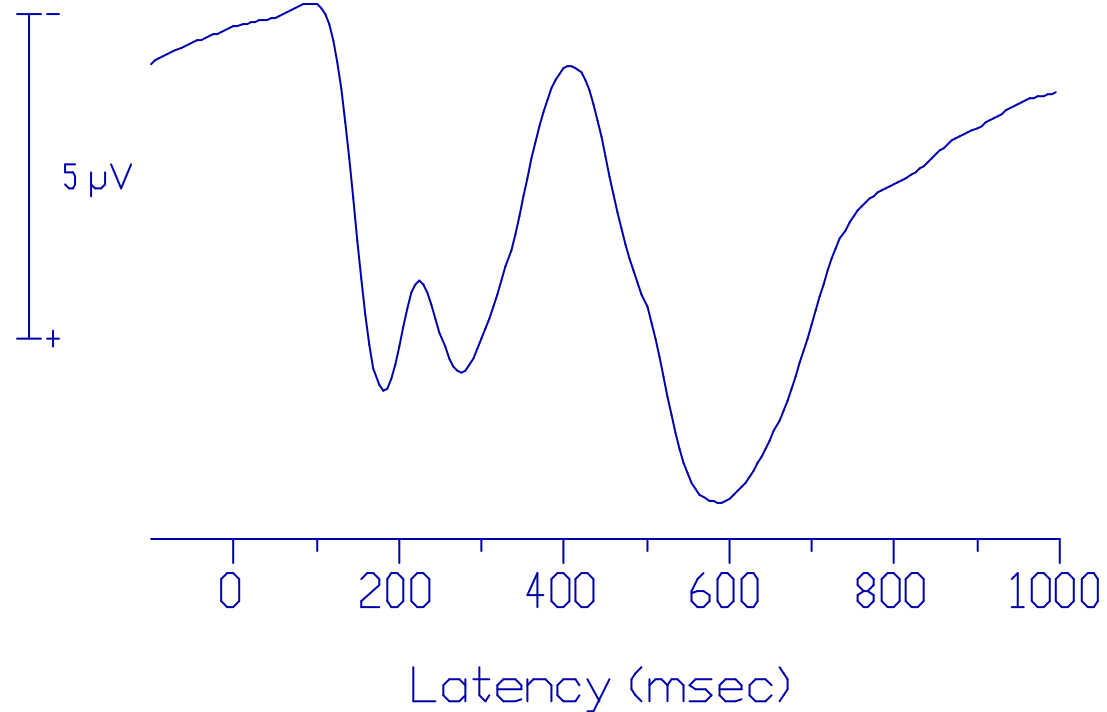
# Ongoing EEG



Stimuli



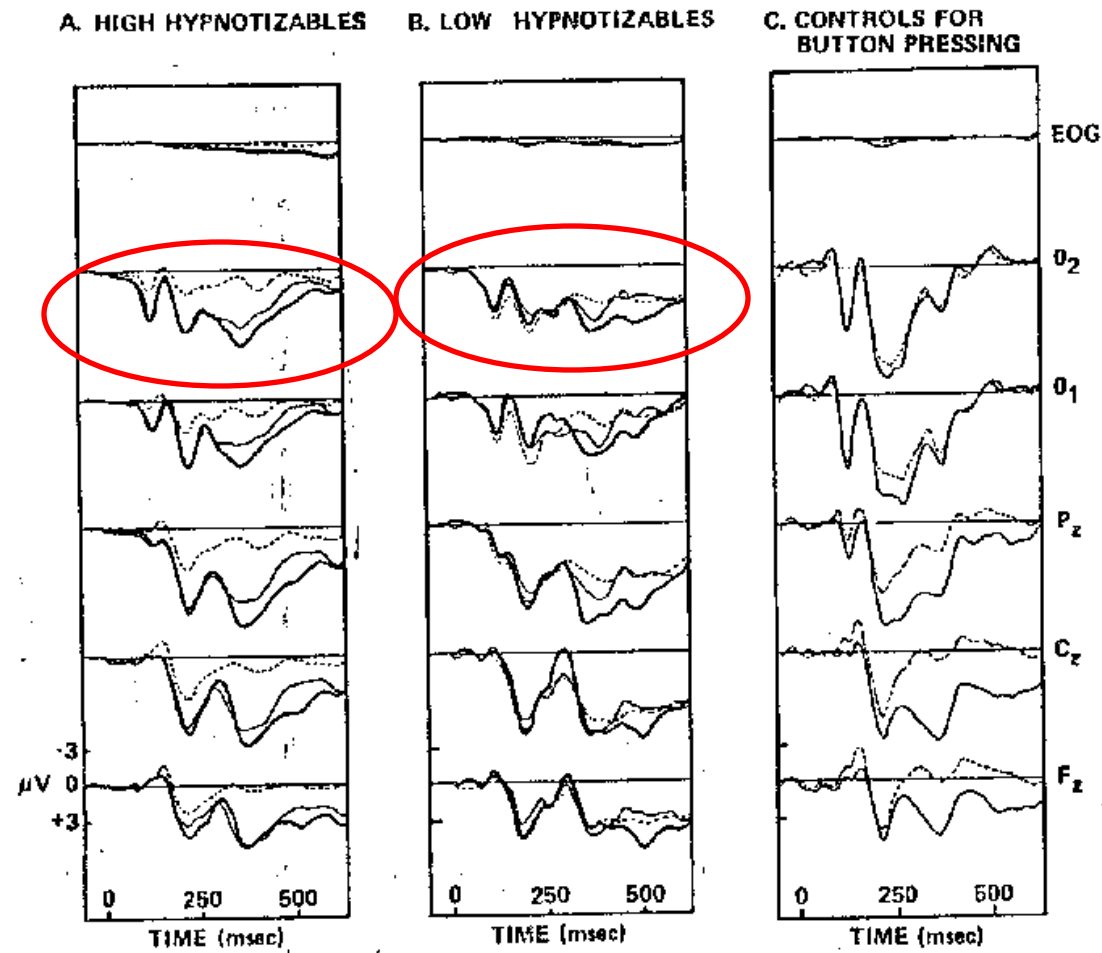
# Visual Event-related Potential



# Speigel, Cutcomb, Ren, & Pribram. (1985) Journal of Abnormal Psychology

- The study design
  - Very high or very low hypnotizable subjects selected
  - Given three suggestions:
    - Hypnotic enhancement
    - Hypnotic diminution
    - Hypnotic obstruction
  - An additional button-pressing control group

# HYPNOTIC HALLUCINATION ALTERS EVOKED POTENTIALS



*Figure 1.* Effect of hypnotic obstructive hallucination on visual evoked potentials. (Visual evoked potentials [VEPs] recorded at leads Fz, Cz, Pz, O<sub>1</sub>, and O<sub>2</sub> are expressed as the mean of recordings in each condition from 6 individuals per group yielding approximately 1,800 VEPs per waveform. In A and B, high hypnotizable and low hypnotizable group data shown are VEPs to stimuli observed in the hypnotic enhancement condition [thick solid lines], the hypnotic diminution condition [thin solid lines], and the hypnotic obstructive hallucination condition [dotted lines]. In C, control subjects for button pressing, solid lines are VEPs to stimuli that were all treated as button-pressing targets. Dotted lines are VEPs in a passive attention condition in which all stimuli were treated as standards and required no button pressing.)



# Hypnosis and Spiegel continued

- Subsequent study using somatosensory ERPs found that suggestion to block mildly painful stimulus reduce P1 and P3 amplitudes in high- but not low-hypnotizable subjects.
- Also found that suggestions to increase intensity resulted in increase in P1 amplitude, but again, only in the high hypnotizable subjects
- Collectively these studies may suggest alterations at the level of signal detection, not simply interpretation of the signal

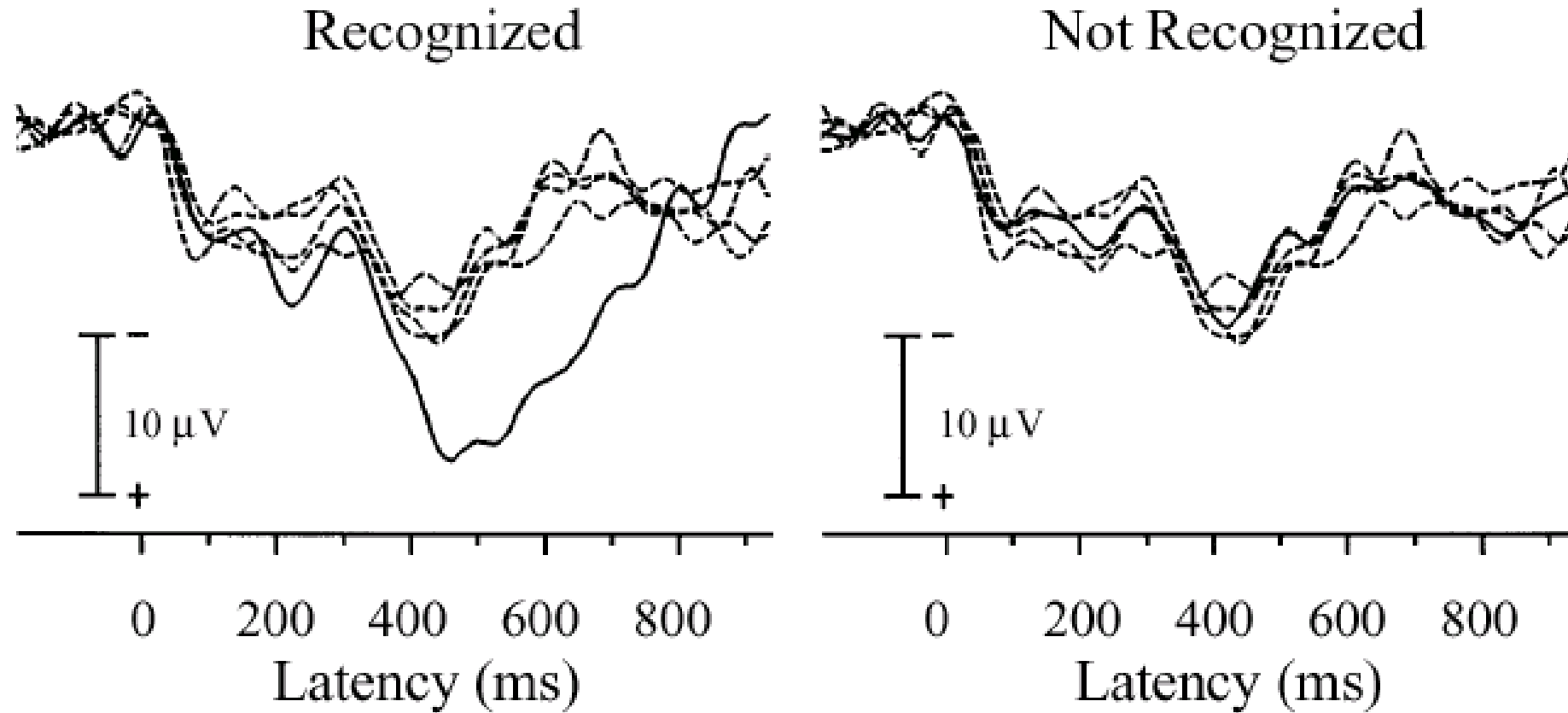
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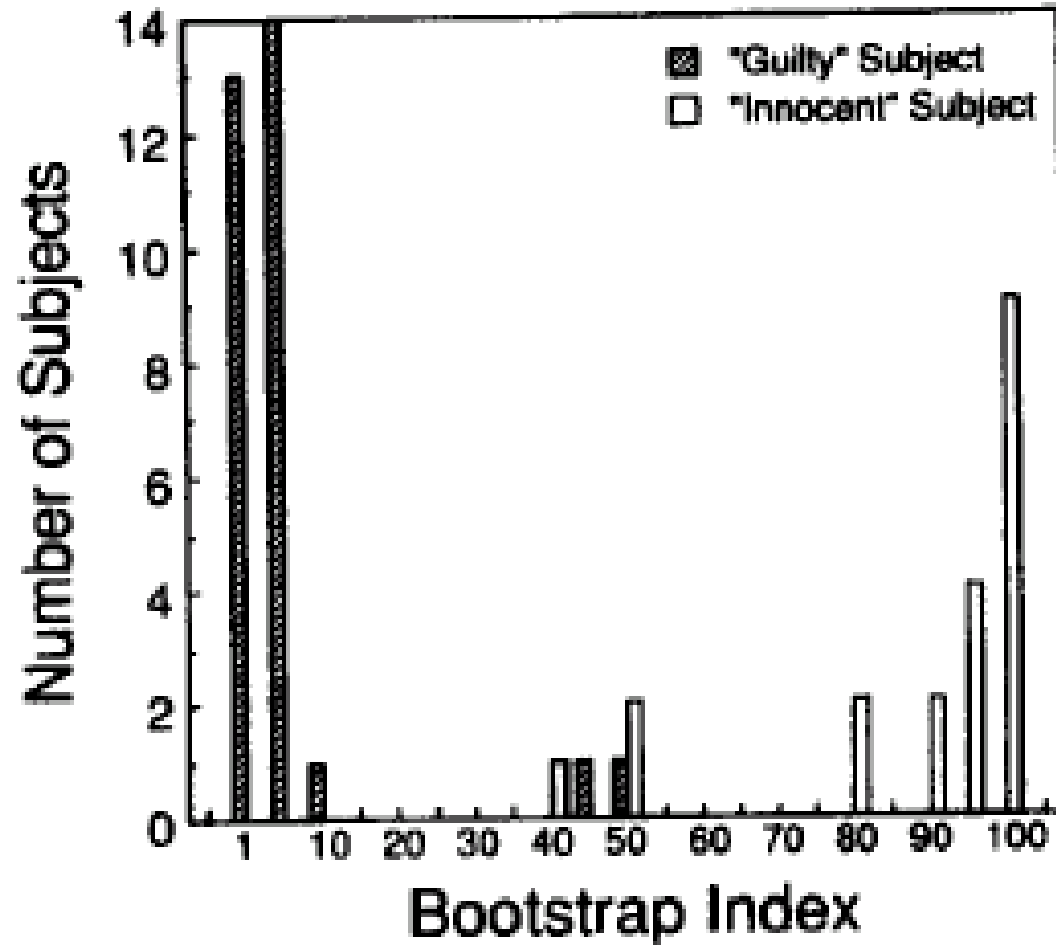
# Farwell & Donchin (1991) Psychophysiology

- Conventional Polygraphy unacceptably inaccurate
- Rather than rely on autonomic arousal, could rely on a cognitive response of recognition
- Mock Crime Scenario, multiple choice (variant of Guilty Knowledge Test)
  - Clothing of contact (“Green Hat”)
  - Name (“Tim Howe”)
  - Operation codename (“Op Pig”)
  - Location (“Shark Street”)
  - ...

# Rationale



## Bootstrap Index for "Guilty" and "Innocent" Conditions



**Figure 2.** The distribution of the bootstrap statistic for all 40 tests conducted in Experiment 1. Dark bars indicate the number of subjects who were "guilty" and were assigned a given bootstrap value. Light bars show the same data for the "innocent" subjects.

**Table 2**

**2A: ACCURACY OF DETERMINATIONS**

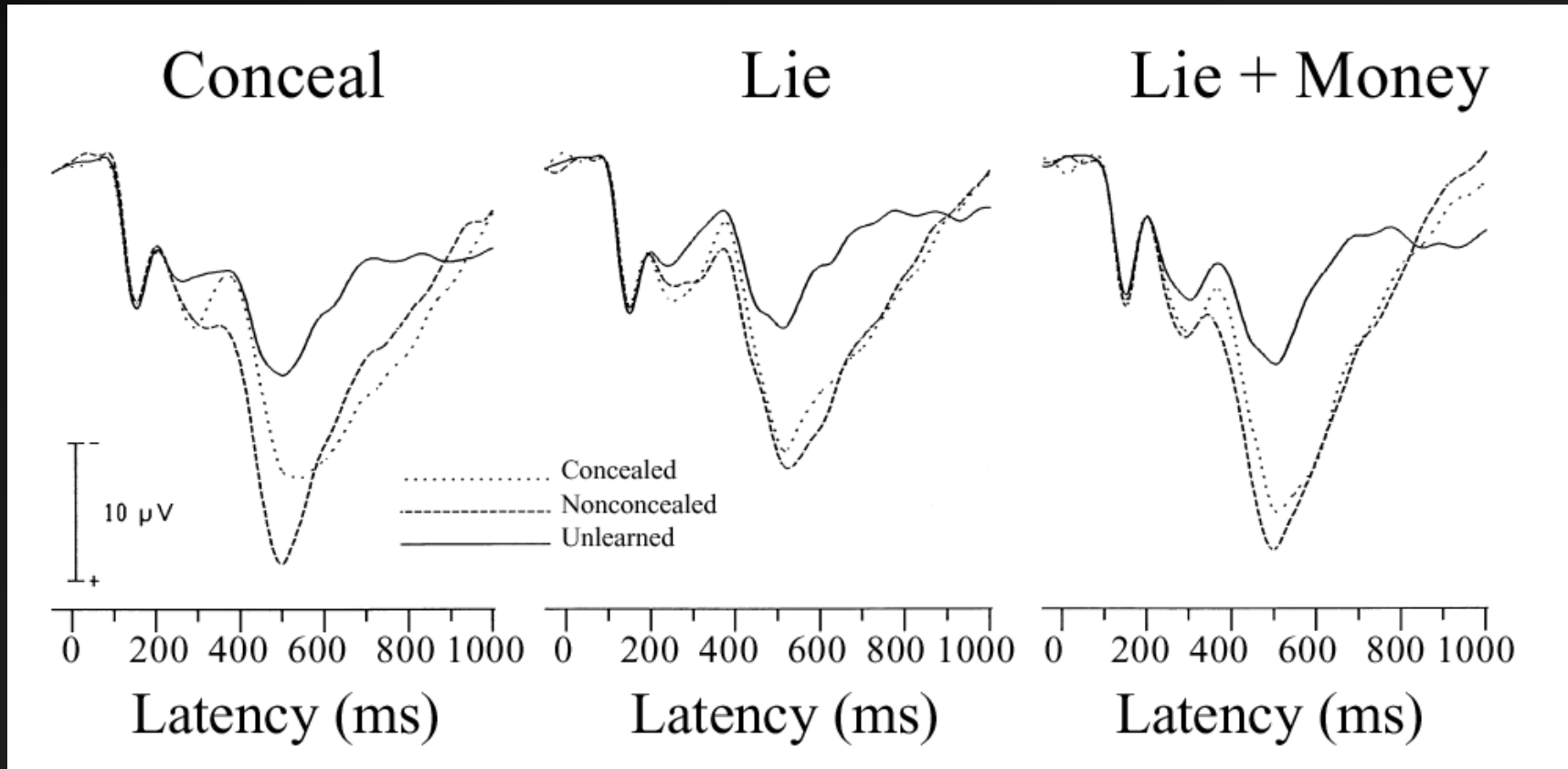
Decision	Subject State		Total
	Guilty	Innocent	
Guilty	18	0	18
Innocent	0	17	17
Indeterminate	2	3	5
Total	20	20	40

# Allen, Iacono, & Danielson (1992)

## Psychophysiology

- Participants learned two lists of words to criterion
- In key task
  - Participants only acknowledge recognizing words from the second list
  - Words from both lists and 5 other unseen lists appear in randomized orders
- Three instruction sets (n=20 per)
  - Conceal
  - Lie
  - Lie + \$\$

# Allen, Iacono, & Danielson (1992) Psychophysiology



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# Persistent Vegetative State

- PVS patients typically are not non-responsive
  - But responses to varied stimuli lack:
    - voluntary components
    - cognitive aspects
    - evidence of awareness of self
    - evidence of awareness of surroundings.
  - No meaningful communication
- MCS (Minimally Conscious State) by contrast:
  - Minimal, if even highly inconsistent, signs of conscious behavior can be observed

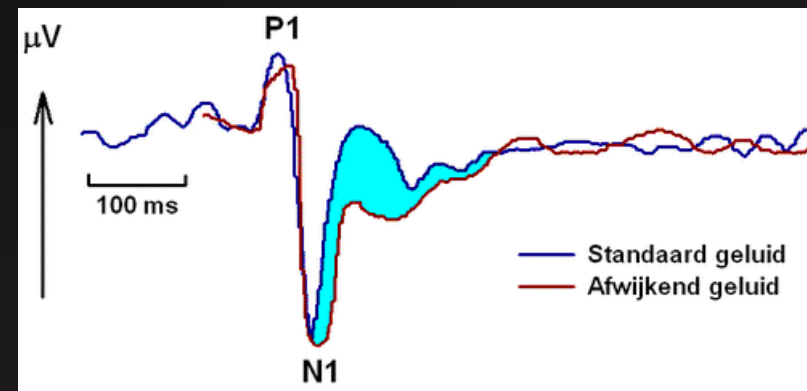
# Persistent Vegetative State


- Diagnostic errors in PVS up to 40% (Andrews et al., 1996)
- Might psychophysiological assessment help?
  - How best to validate such new measures against some gold standard when diagnostic errors are so common?
  - Create continuous measure and link to physiology (Wijnen, van Boxtel, Eilander, & de Gelder (2007) *Clinical Neurophysiology*)
  - Range from complete non-response to normal consciousness

Levels of Consciousness (LoCs)

Global level	Score	Description of the levels
Coma		<i>Eyes are closed all the time. No sleep-wake cycles present.</i>
	1	All major body functions such as breathing, temperature control, or blood pressure can be disturbed. Generally, no reactions are noticed after stimulation. Sometimes reflexes (stretching or flexing) can be observed as a reaction when strong pain stimuli have been applied. No other reactions present.
Vegetative State (VS)		<i>Patient has some sleep-wake cycles, but no proper day-night rhythm. Most of the body functions are normal. No further ventilation is required for respiration.</i>
	2	<b>Very little response (hyporesponsive)</b> Generally no response after stimulation. Sometimes delayed presentation of reflexes is observed.
	3	<b>Reflexive state</b> Often stimuli result in massive stretching or startle reactions, without proper habituation. Sometimes these reactions evaluate into massive flexing responses. Roving eye movements can be seen, without tracking. Sometimes grimacing occurs after stimulation.
	4	<b>High active level and/or reactions in stimulated body parts</b> Generally spontaneous undirected movements. Retracting a limb following stimulation. Orienting towards a stimulus, without fixating. Following moving persons or objects, without fixating.
Minimally Conscious State (MCS)		<i>Patient remains awake most of the day.</i>
	5	<b>Transitional state</b> Following and fixating of persons and objects. Generally more directed reactions to stimuli. Behaviour is automatic, i.e. opening of the mouth when food is presented, or reaching towards persons or objects. Sometimes emotional reactions are seen such as crying or smiling towards family or to specific (known) stimuli.
	6	<b>Inconsistent reactions</b> Sometimes, but not always, obeying simple commands. Totally dependent. Patient has profound cognitive limitations; neuropsychological testing is impossible. Level of alertness is fluctuating, but in general low.
	7	<b>Consistent reactions</b> Patient obeys simple commands. The level of alertness is high and stable. Many cognitive disturbances remain. Patient is totally dependent.
Consciousness	8	Patient is alert and reacts to his/her environment spontaneously. Functional understandable mutual communication is possible, sometimes with technical support. As yet, cognitive and behavioural disturbances can be present.

# Mismatch Negativity



- Discovered by Näätänen, Gaillard, & Mäntysalo, 1978
- Rare deviant (“Afwijkend geluid”) elicits sustained negative voltage at scalp, maximal at fronto-central sites 
- Regardless of whether the stimuli are attended
- Can vary in pitch, loudness, duration



# Longitudinal Study

- Create continuous measure and link to physiology (Wijnen, van Boxtel, Eilander, & de Gelder (2007) *Clinical Neurophysiology*)
- Ten severely brain-injured patients (age 8-25)
- Longitudinal assessment starting 9 days after admission (and then every 2 weeks)

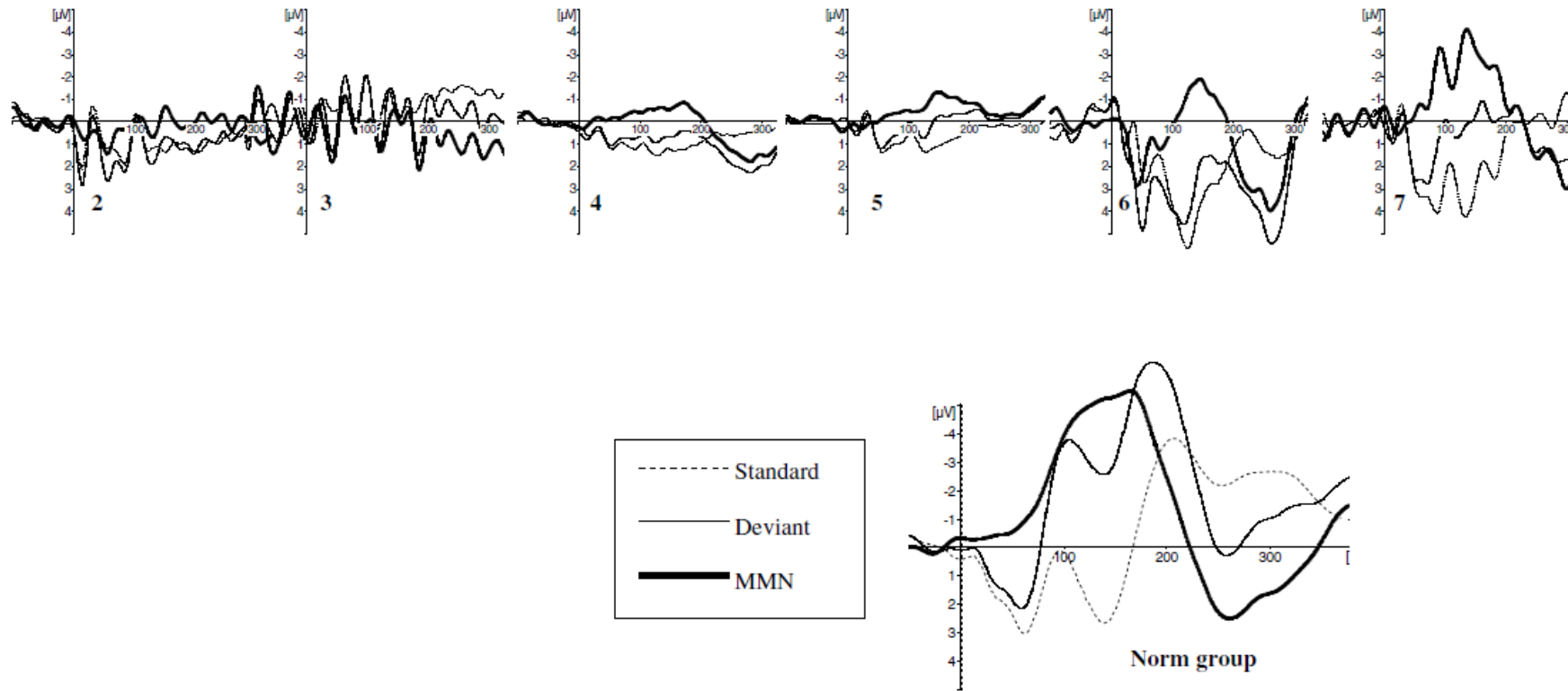


Fig. 2. Grand averages of MMN (Fz-linked Mastoids, 0.15–30 Hz, 48 dB/octave) for each Level of Consciousness according to the levels in Table 2 versus the norm group. Potentials related to the standard stimuli, potentials related to the deviant stimuli, and the MMN (difference between the deviant and standard).

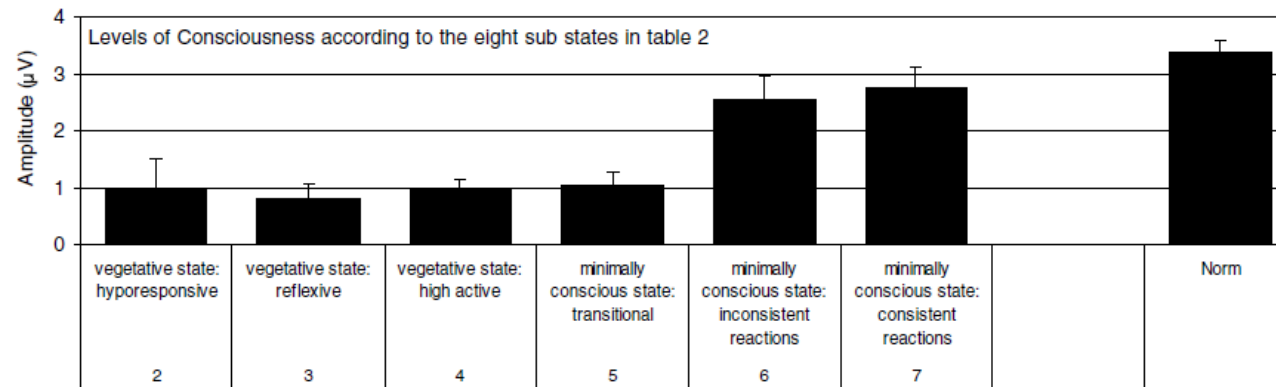
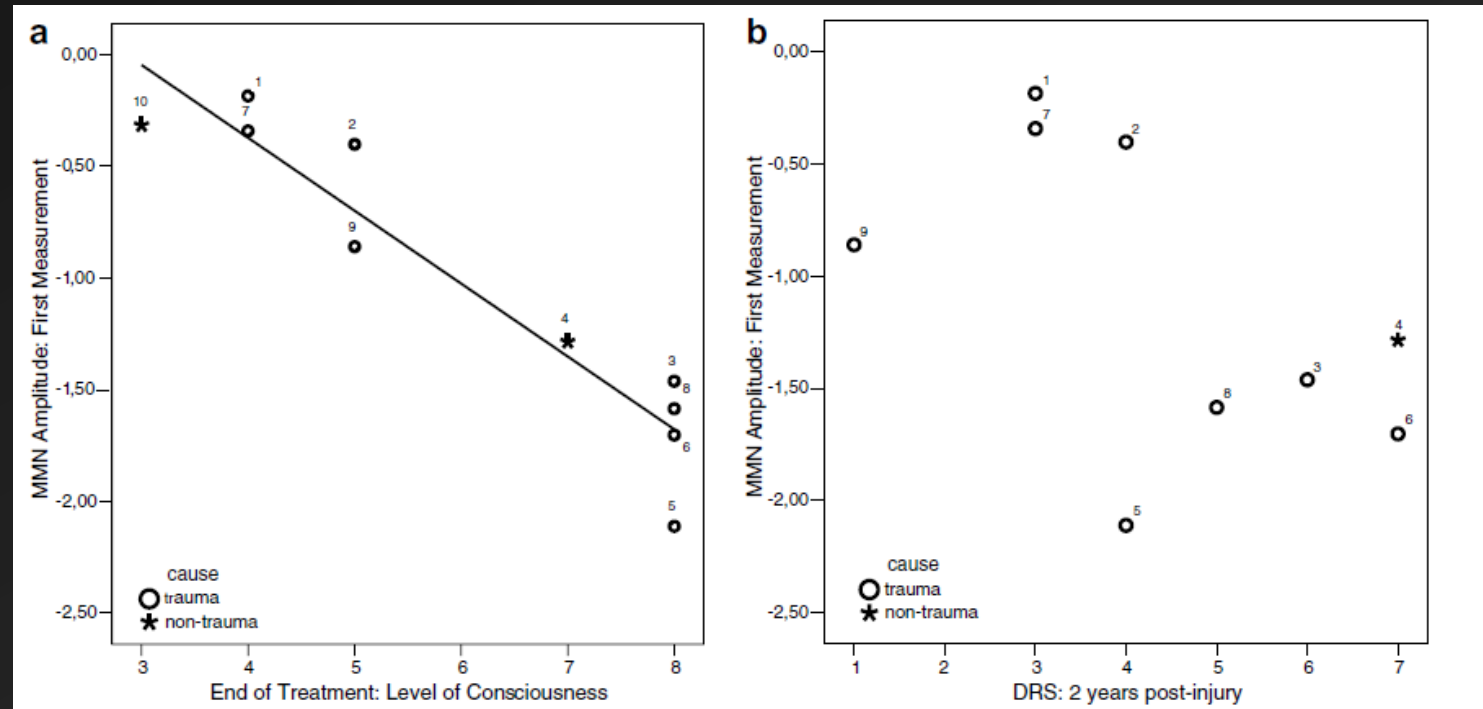


Fig. 1. Longitudinal measurements: mean MMN-amplitude (Fz) and standard error for each Level of Consciousness according to the levels in Table 2 versus the norm group. For number of measurements see Table 3.

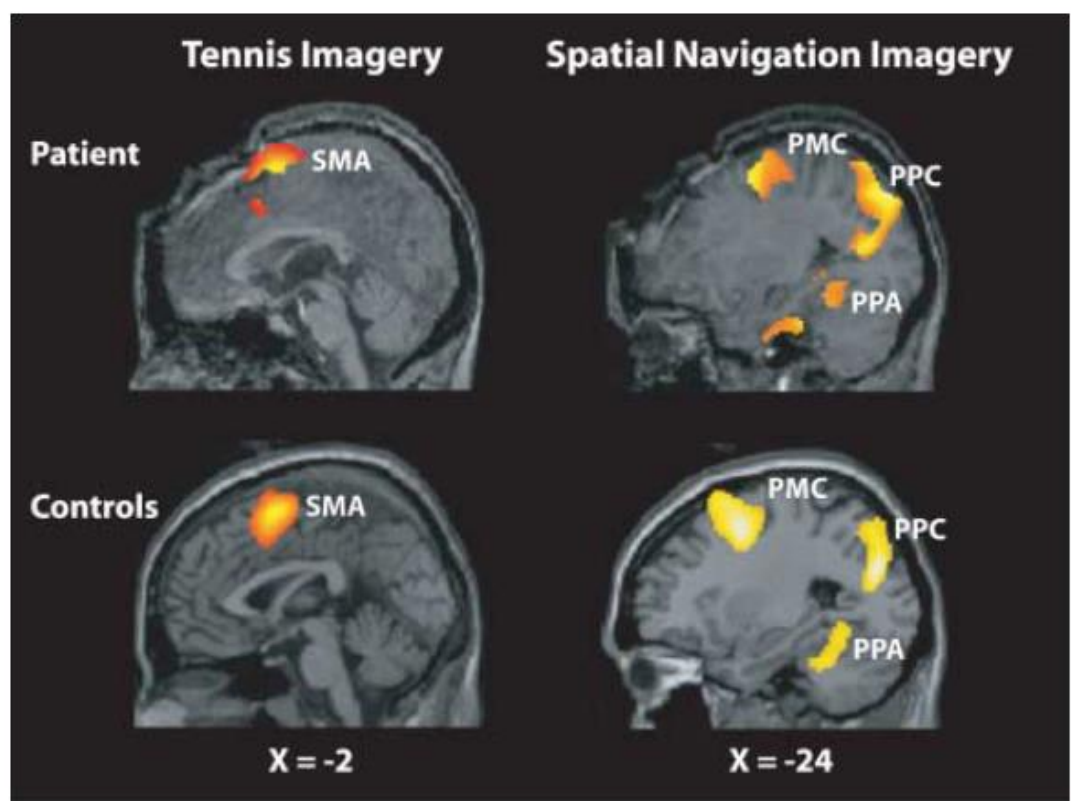
# Longitudinal Study

- Predictive value?
  - MMN during first assessment strongly predicted level of consciousness at discharge ( $\beta = -.94, p < .00001$ )
  - Also predicted functional outcome two years later





# Another approach



**Fig. 1.** We observed supplementary motor area (SMA) activity during tennis imagery in the patient and a group of 12 healthy volunteers (controls). We detected parahippocampal gyrus (PPA), posterior parietal-lobe (PPC), and lateral premotor cortex (PMC) activity while the patient and the same group of volunteers imagined moving around a house. All results are thresholded at  $P < 0.05$  corrected for multiple comparisons.  $X$  values refer to distance in mm from the midline in stereotaxic space (SOM text).

“These results confirm that, despite fulfilling the clinical criteria for a diagnosis of vegetative state, this patient retained the ability to understand spoken commands and to respond to them through her brain activity, rather than through speech or movement.”

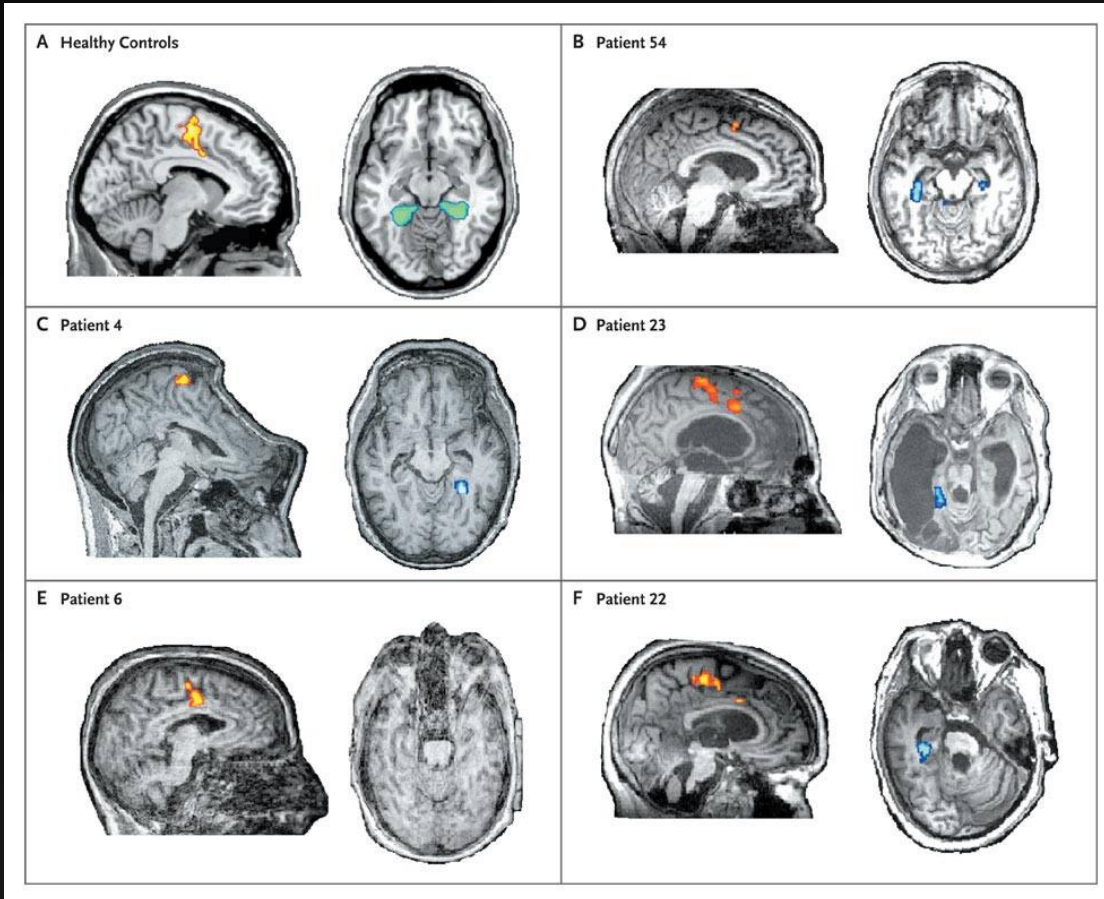
“... suggests a method by which some noncommunicative patients, including those diagnosed as vegetative, minimally conscious, or locked in, may be able to use their residual cognitive capabilities to communicate their thoughts to those around them by modulating their own neural activity.”

See also:

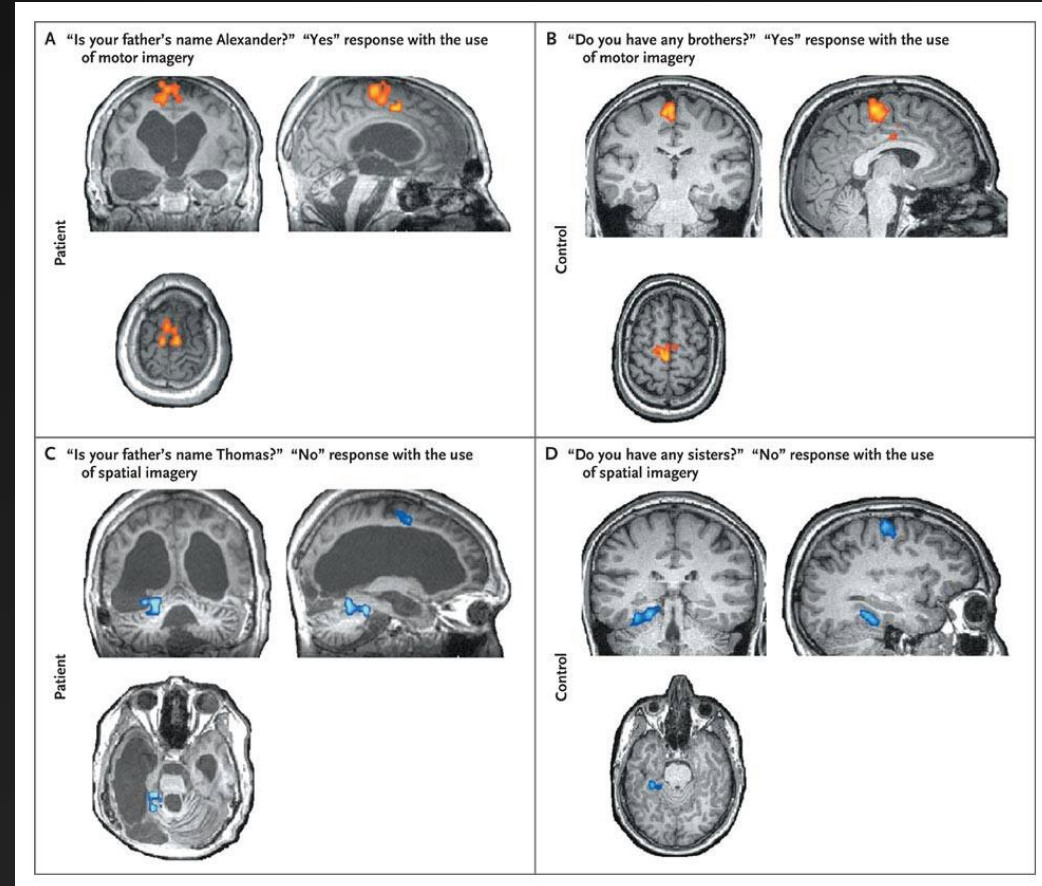
Naci L, Owen AM. Making Every Word Count for Nonresponsive Patients. [JAMA Neurol. 2013 Aug 12.](https://doi.org/10.1001/jamaneurol.2013.3686) doi: 10.1001/jamaneurol.2013.3686.



# Extension



Functional MRI scans show activations associated with the motor imagery as compared with spatial imagery tasks (yellow and red) and the spatial imagery as compared with motor imagery tasks (blue and green). These scans were obtained from a group of healthy control subjects and five patients with traumatic brain injury.



Results of two sample communication scans obtained from Patient 23 (Panels A and C) and a healthy control subject (Panels B and D) during functional MRI are shown. In Panels A and B, the observed activity pattern (orange) was very similar to that observed in the motor-imagery localizer scan (i.e., activity in the supplementary motor area alone), indicating a "yes" response. In Panels C and D, the observed activity pattern (blue) was very similar to that observed in the spatial-imagery localizer scan (i.e., activity in both the parahippocampal gyrus and the supplementary motor area), indicating a "no" response.

# A few selected studies to highlight the utility of a psychophysiological approach

- Bauer (1984): Prosopagnosia
- Öhman & Soares (1993): Phobias
- Spiegel (1985): Hypnosis
- Deception Detection studies
- Investigation of Persistent Vegetative State
- Brain-Computer Interfaces for assisted communication

# Syndromes where interaction with environment difficult or impossible

- Amyotrophic lateral sclerosis (ALS)
- Vegetative States

Farwell & Donchin (1988) *Electroencephalography and clinical Neurophysiology*

- Attempted to develop an applied ERP system for communication without motor system involvement
- For “locked in” patients

## CRT Display Used in the Mental Prosthesis

MESSAGE

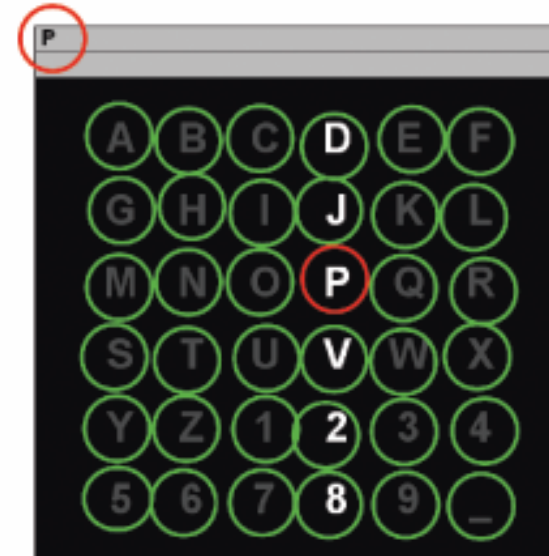
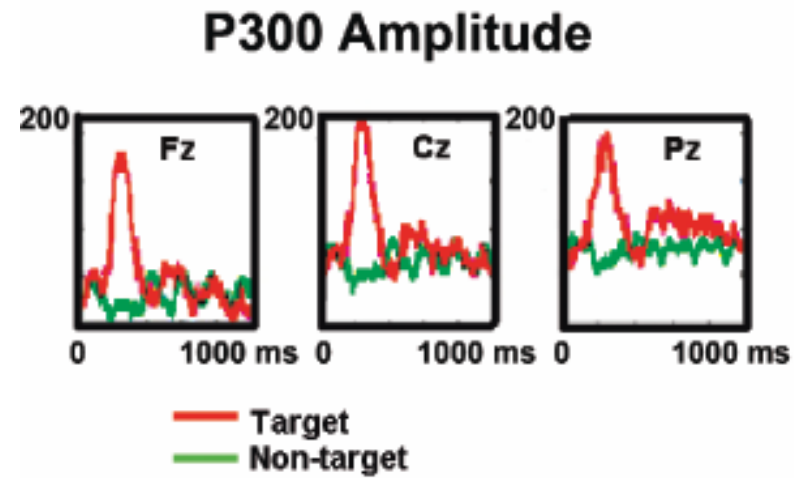
BRAIN

Choose one letter or command

A	G	M	S	Y	*
B	H	N	T	Z	*
C	I	O	U	*	TALK
D	J	P	V	FLN	SPAC
E	K	Q	W	*	BKSP
F	L	R	X	SPL	QUIT

Fig. 1. CRT display used in the mental prosthesis. The rows and columns of the matrix were flashed alternately. The letters selected by the subject ('B-R-A-I-N') were displayed at the top of the screen in the pilot study.

### c P300 –Brain-Computer-Interface (BCI)



P300-BCI. Rows and columns of letter strings are lighted in rapid succession. Whenever the desired letter (P) is among the lighted string, a P300 appears in the EEG (after Sellers & Donchin 2006; Piccione et al.2006).

# Can't we speed things up?



<http://www.youtube.com/watch?v=2KtMCX7FfZ0>

<https://www.youtube.com/watch?v=zqYJQGk5I4M>



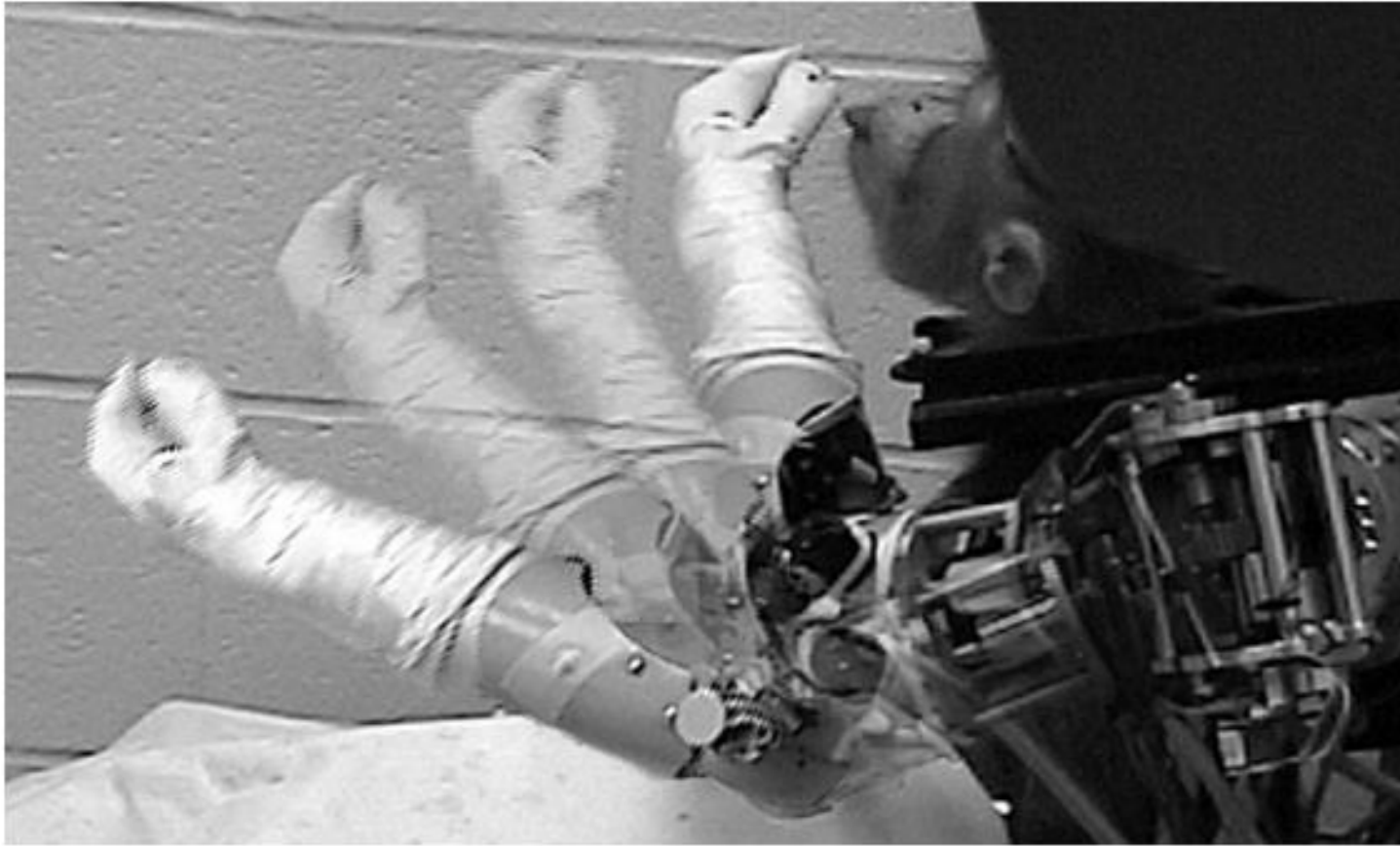


Fig. 4. A monkey is feeding himself with the aids of a robotic arm by producing the same pattern of neural activity in the motor cortex as would be required to move his own limb. The trajectory of the robot arm is depicted sequentially. In expectancy of the piece of an apple, the monkey protrudes his tongue. From the monkey only the head is visible. (We thank Dr. Andrew Schwartz, from the School of Medicine, University of Pittsburgh, Pittsburgh, USA, for this picture and for the permission of reproduction.)



# Operant methods (Birbaumer et al.)

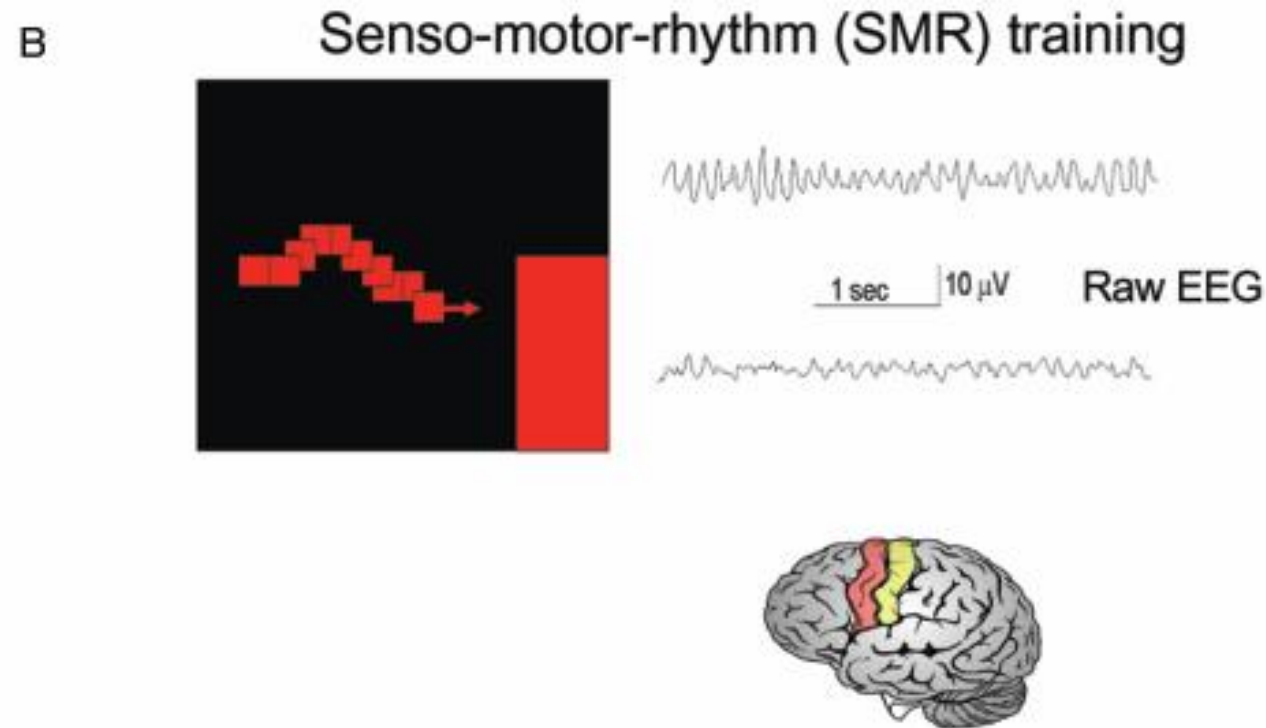
IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 51, NO. 6, JUNE 2004

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## Brain-Computer Communication and Slow Cortical Potentials

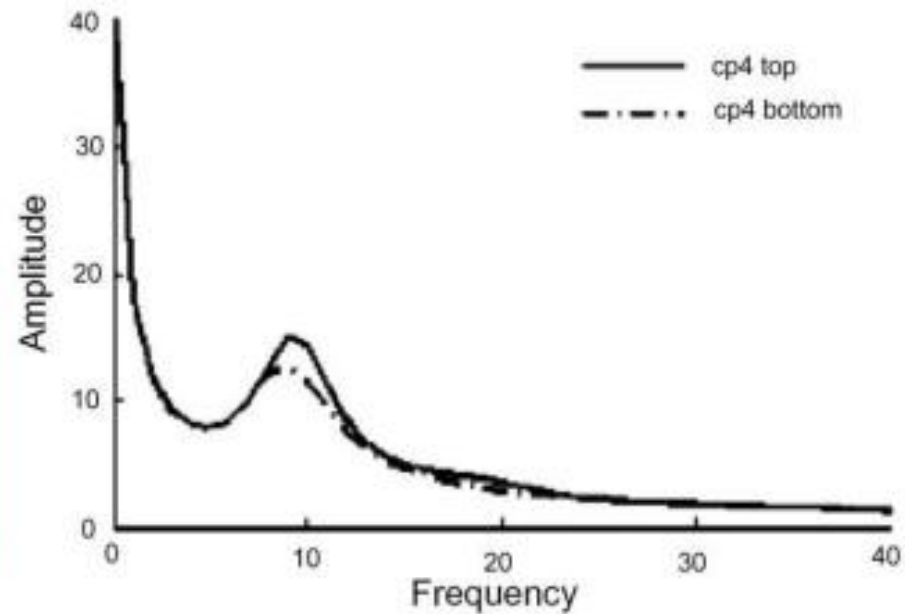
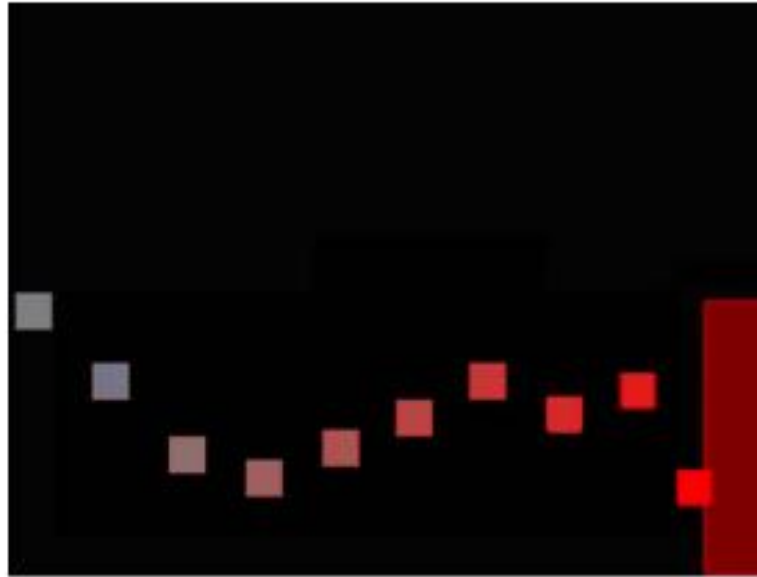
Thilo Hinterberger\*, Stefan Schmidt, Nicola Neumann, Jürgen Mellinger, Benjamin Blankertz, Gabriel Curio,  
and Niels Birbaumer

# Senso-motor Rhythm Training



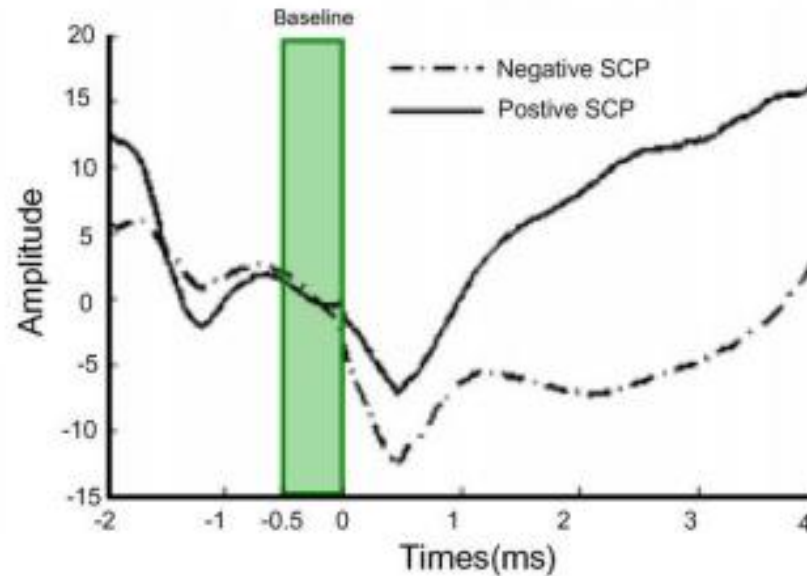
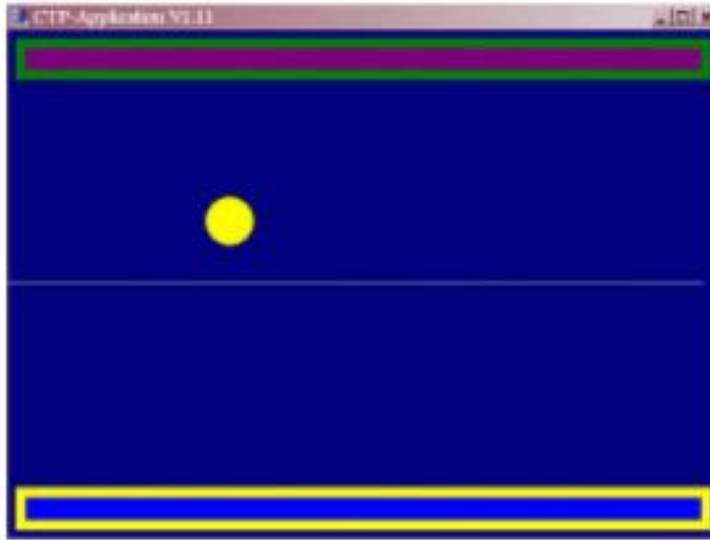
Top right: Senso-motor-rhythm (SMR) oscillations from sensorimotor cortex during inhibition of movement and imagery or execution of movement (EEG trace below). On the left part of the picture is the feedback display with the target goal on the right side of the screen indicating the required SMR increase (target at bottom) or SMR decrease (target at top). The cursor reflecting the actual SMR is depicted in red moving from the right side of the screen toward the target goal.

# Senso-motor Rhythm Training



- Patients' task is to move the cursor into the target.
- Cursor movement is indicated by the squares (only one square is visible).
- The cursor moves steadily from left to right, vertical deflections correspond to the SMR amplitude.
- EEG frequency power:
  - Bold line: frequency power spectrum when the cursor had to be moved toward the top target
  - Dashed line: cursor had to be moved toward the bottom target.

# Slow Cortical Potentials (SCP)



- Targets are presented at the top or bottom of the screen.
- Patients' task is to move the cursor (yellow dot) toward the target
- Cursor moves steadily from left to right and its vertical deflection corresponds to the SCP amplitude.
- A negative SCP amplitude (dashed line) moves the cursor toward the top, positive SCP amplitude (bold line) toward the bottom target.
- Before each trial, a baseline is recorded indicated by the green bar.
- At time point -2 s the task is presented, at -500 ms the baseline is recorded and at zero cursor movement starts.

A



BCI using slow cortical potentials (SCP depicted at the top). Patient selects one letter from the letter string on screen (right below) with positive SCPs, the spelled letters appear on top of the screen

# Many Methods

- Many EEG DVs
- Many features to extract
- Many classification algorithms
- Meta-analysis of main methods

(Lotte, Bourgrain, Cichocki, Congedo, Rakotomamonjy, Yger (2018) *J Neural Engineering*)

- Commercial implementation
- The future?

# Coming Up:

- Next session ... Reviews of:
  - Basic Electricity
  - Basic Neurophysiology and Neuroanatomy
- Don't forget to turn in your comment/questions on class webpage  
<https://psychophyslab.arizona.edu/psy401a501a>