

*Deception Detection (continued)*  
*and*  
*Cardiovascular Psychophysiology*

# Announcements 2/22/21

- Electricity test – See me about retake if needed
- If you have ideas about research paper/proposal please share
- Announcement from Admin:  
If a student is enrolled in an In-Person or Flex In-Person course for Spring 2021, but now plans to participate 100% remotely, please ask the student to complete the [100% Remote Learning Declaration](#) to verify that they will not be returning to campus at any point during the semester. The Office of the Registrar may contact the instructors to verify that they have approved the student's request to learn remotely.

# Questions and Feedback

This weeks lecture honestly really upset me with the injustice of it all. I took forensic psych last semester and we talked about varying 'lie detector' tests, so I knew, but it still it just so horrible in my opinion. Do you think they should ever be used, or be admissible in court, or just allowed at all? I know we said police like them, even though they don't work, because they can scare people into confessing, but a lot of things scare people into confessing, and a lot of innocent people give false confessions.

Returning to last time

# The Polygraph

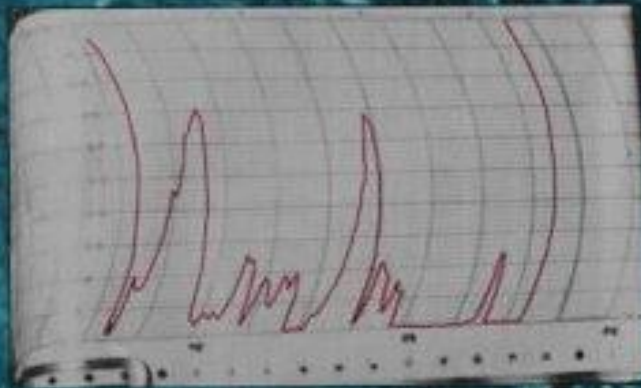
- Does not assess lying
- Assesses emotion/arousal
- Has an unacceptable high false positive rate
- Shows evidence of racial bias
- Especially problematic for low base-rates of deception (e.g. screening)
- Appears to remain in use because it is useful for eliciting confessions

# Roadmap

- Abbreviated History and Overview of the Conventional Polygraph
- Limitations to Conventional Polygraphy
  - The Polygraph Test is especially likely to falsely incriminate the innocent
- Why polygraphers over-estimate the accuracy of the test
- No credible scientific exists to support using the Polygraph Test
- Overview of alternatives: Assessing recognition



A  
**TREMOR**  
IN THE  
**BLOOD**



USES AND ABUSES OF THE  
**LIE DETECTOR**

DAVID T. LYKKEN

**COMMITTEE TO REVIEW THE SCIENTIFIC  
EVIDENCE ON THE POLYGRAPH**

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- JAMES J. BLASCOVICH, Department of Psychology, University of California, Santa Barbara
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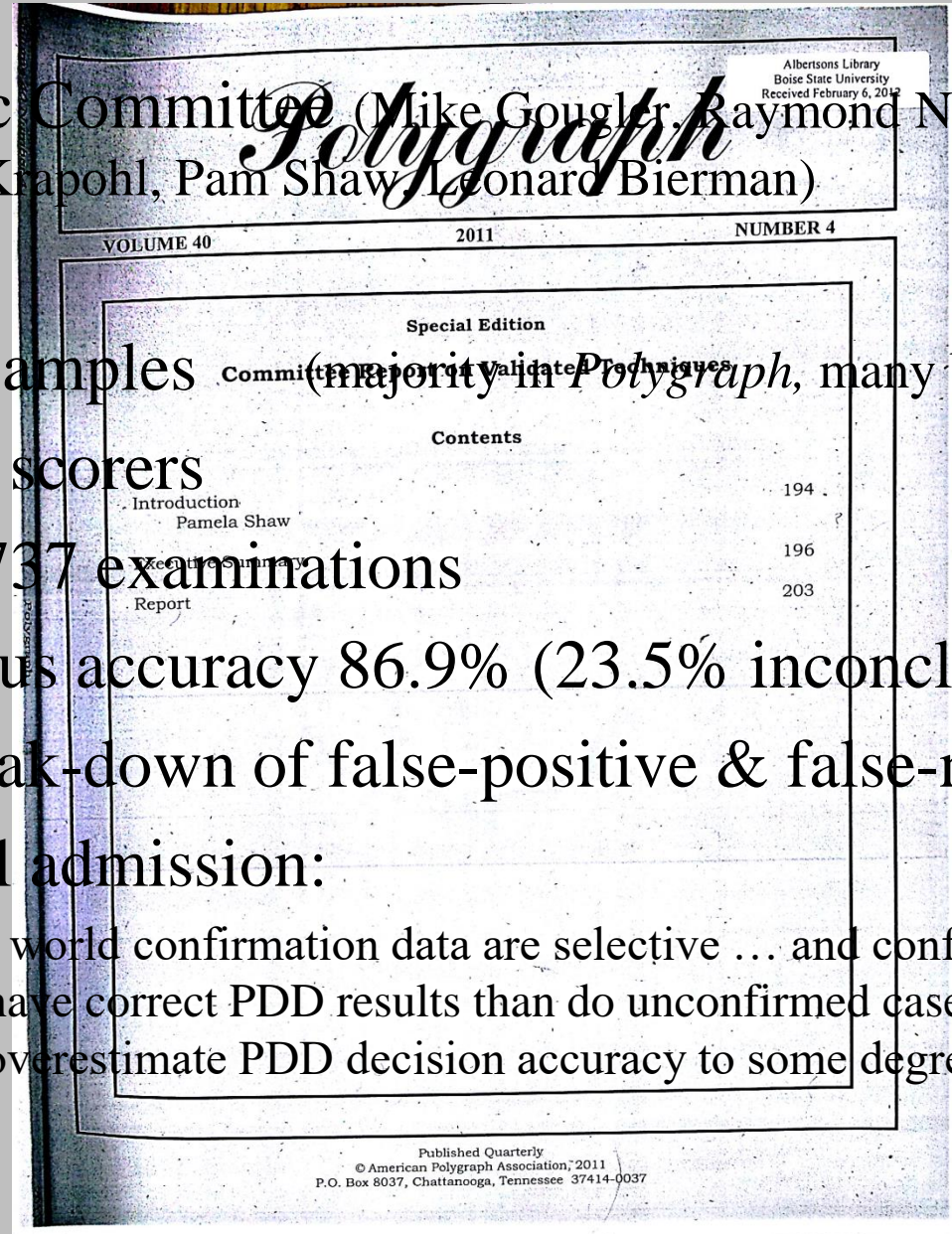
# NRC (2003) Key Conclusions

- “What is remarkable, given the large body of relevant research, is that claims about the accuracy of the polygraph made today parallel those made throughout the history of the polygraph: practitioners have always claimed extremely high levels of accuracy, and these claims have rarely been reflected in empirical research.”
- “Almost a century of research in scientific psychology and physiology provides little basis for the expectation that a polygraph test could have extremely high accuracy.”



# “Meta-Analytic Survey” by APA

- Ad-hoc Committee (Mike Gouglar, Raymond Nelson, Mark Handler, Donald Krapohl, Pam Shaw, Leonard Bierman)
- Scope:
  - 45 samples (majority in *Polygraph*, many by Raymond Nelson)
  - 295 scorers
  - 11,737 examinations
- Omnibus accuracy 86.9% (23.5% inconclusive)
- No break-down of false-positive & false-negative
- Critical admission:
  - “Real world confirmation data are selective ... and confirmed cases more often may have correct PDD results than do unconfirmed cases. As a result, field studies may overestimate PDD decision accuracy to some degree.”



Albersons Library  
Boise State University  
Received February 6, 2012

# Polygraph

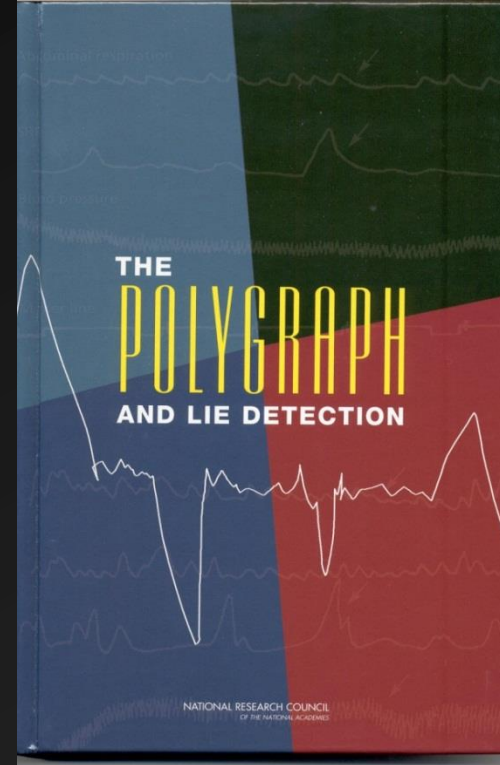
VOLUME 40 2011 NUMBER 4

Special Edition  
**Committee Report on Validated Techniques**

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Published Quarterly  
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P.O. Box 8037, Chattanooga, Tennessee 37414-0037



[jallen.faculty.arizona.edu/polygraph](http://jallen.faculty.arizona.edu/polygraph)



# Detour

➤ How I got involved in expert testimony



# Syllabus addendum

## **Notification of Objectionable Materials:**

This course will contain material of a mature nature, which may include explicit language or discussion of sexual situations, and/or violence. The instructor will provide advance notice when such materials will be used. Students are not automatically excused from interacting with such materials, but they are encouraged to speak with the instructor to voice concerns and to provide feedback.



# Cases involving Sexual Misconduct

- ◆ Allegations of sexual misconduct in domestic relations cases
  - ◆ Typically custody cases
  - ◆ One parent accuses other of sexual misconduct with a child
  - ◆ Psychological evaluation ensues

Clinical interview

Review of collateral information

Polygraph test

Personality Assessment Inventory

Millon Clinical Multi-Axial Inv. III

Multiphasic Sex Inventory II

Abel & Becker Sexual Interest Card Sort

Shipley Inst. Of Living Scale

# Cases involving Sexual Misconduct

- ◆ Allegations of sexual misconduct in domestic relations cases
  - ◆ If a parent is deemed to be a risk - correctly or incorrectly - two statutes may impose limits
    - ◆ ARS25 403.05 would prohibit awarding that parent sole or joint physical or legal custody
    - ◆ ARS25 408 (H1) may further limit the extent and nature of parenting time allowed
  - ◆ Thus the evaluation has a pivotal role

# Cases involving Sexual Misconduct

- ◆ Sex offender monitoring
  - ◆ Maintenance Polygraphs



# Never Trust the Polygraph

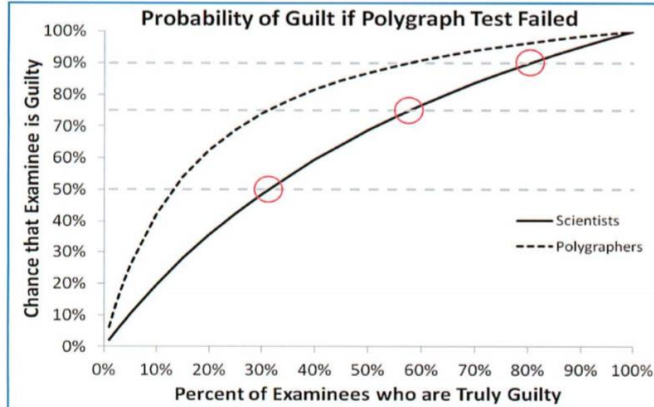
By John J.B. Allen, Ph.D., Distinguished Professor of Psychology, University of Arizona

Editor's Note: This article is abridged with author's permission.

Although polygraph tests are seldom admitted in court, their use influences cases when the results are part of the evaluation process in domains such as child custody, dependency and sexual misconduct. In such cases, the polygraph test may be part of a larger assessment to identify whether a parent poses a significant risk to a child. It is important that these assessments be accurate, as failure to identify a risk endangers children but false identification needlessly damages fundamental relationships. In cases where a parent is deemed to be a risk – correctly or incorrectly – ARS25-403.05 would prohibit awarding that parent legal decision-making, and ARS25-408 (H) (1) can limit the extent and nature of parenting time.

The idea of detecting lies with technology is appealing, perhaps because humans are notoriously poor at detecting deception. (1). Unfortunately, anyone who promises to accurately detect lying ... is lying. Why? There is no unique physiological response(s) associated with lying (2). The polygraph cannot assess lying per se, but instead assesses emotion that can arise when specific questions are asked. As such, a verdict of "guilty" or "lying" from a polygraph is best interpreted as "emotionally aroused" or "anxious." Many innocent individuals are nervous or fearful when a polygrapher asks about sexual misconduct or other behavior that can restrict their parenting time. It is no surprise that the test is highly likely to misidentify innocent people as deceptive, misidentifying 40-50% of innocent individuals as culpable (2, 3) (false positives). Likewise, information about countermeasures is easily obtained (e.g., antipolygraph.org) and can create false negatives among dangerous individuals.

The test referred to as "The Polygraph" uses some variant of the Control Question Technique (CQT). A CQT involves about 10 questions, which fall into two categories. Relevant questions inquire about specific details (e.g., "Did you touch the child between the legs?"). Control questions inquire about questionable behavior but they do not directly accuse (e.g., "Do you find teenage girls attractive?"). Although examinees are not told the distinction between the questions, they are led to believe (falsely) that there are two ways to



**The probability that an examinee is in fact guilty after failing a polygraph test, which depends on what percentage of polygraph examinees are in actually guilty.** The probabilities are shown using the accuracy rates provided by scientific research (solid line) as well as those provided by polygraphers (which are higher due to the inherent selection bias in field studies; dashed line). As shown by the red circles in the figure, the probability that an examinee is in fact guilty after failing the polygraph test is: only 50% when about 31% of examinees are truly guilty; 75% when 58% of examinees are guilty; and 90% when 80% of examinees are guilty. These data illustrate & underscore the key conclusion of the scientific review of the National Research Council that "Almost a century of research in scientific psychology and physiology provides little basis for the expectation that a polygraph test could have extremely high accuracy." (2, p. 2)

fail the test: 1) they can fail the relevant questions, in which case they are guilty; or 2) they can fail the control questions, in which case they appear capable of committing the crime. Thus, it is assumed they will deny both questions, and it is further assumed that for the guilty, relevant questions will be of greater concern and elicit larger physiological responses (a reasonable assumption). It is further assumed (unreasonably) that for innocent, control questions will be of greater concern and thus elicit a larger response than the relevant questions. Examinees that have sufficiently larger responses to relevant questions are deemed deceptive; examinees with larger responses to control questions are deemed innocent. For cases where relevant and control responses are similar, an "indeterminate" outcome is reported, which occurs in 5-20% of examinations.

A comprehensive scientific review by the National Research Council (NRC) of the National Academy of Sciences (2) found that the polygraph test suffers from unacceptably low accuracy. The NRC committee

held public hearings, visited government polygraph facilities, accessed unpublished government reports, including classified material, and produced a comprehensive volume that is available for free at: [www.nap.edu/catalog.php?record\\_id=10420](http://www.nap.edu/catalog.php?record_id=10420). More recently, an ad-hoc committee of the American Polygraph Association published a survey of field polygraph results (4), including more than 45 published samples and 11,000 examinations, and reported overall accuracy of 86.9%, but only after excluding 23.5% of cases with indeterminate verdicts. Unfortunately, more than half the samples came from articles of the lead investigator, and all suffered from the inherent selection bias: to wit, cases selected for inclusion in a field study are biased in favor of demonstrating accuracy because the associated confessions are not independent but a consequence of the polygraph exam. This problem is widely known, and referenced in the executive summary written by this ad-hoc committee of the American Polygraph Association (4).

Continued on Page 18 ...



# The Case

- ◆ Child Custody Case

- ◆ Psychological Evaluation: 39 page report

- ◆ Highlights

- ◆ Ex-wife accuses defendant of touching daughter, first time at age 2
- ◆ History of domestic disputes with police dispatch (but no arrests)
- ◆ History of calls to CPS (but no action taken)
- ◆ History of parental drug abuse
- ◆ Court found “serious credibility issues with both parents”

# The Case

- ◆ Child Custody Case

- ◆ Psychological Evaluation: 39 page report

- ◆ Highlights

- ◆ As daughter becomes capable of verbal reporting, she reports inconsistent information concerning

- ◆ Who touched her

- ◆ Where she was touched

- ◆ Comprehensive risk assessment could not determine whether nor by whom she was touched

- ◆ Defendant took three polygraphs over 1 year span

# The Case

## ◆ Child Custody Case

## ◆ Polygraph #1

- ◆ “Have you ever put your fingers into Susie’s bare vagina, even a little other (sic) cleaning her as a small child?”
- ◆ “Did you lie to me when you said you never put any of your fingers into Susie’s vagina, even a little, other than cleaning her as a small child?”

## ◆ Verdict: Not Deceptive

# The Case

◆ Child Custody Case

◆ Polygraph #2

◆ Verdict: Not Deceptive



# The Case

◆ Child Custody Case

◆ Polygraph #3

◆ Verdict: **Deceptive**

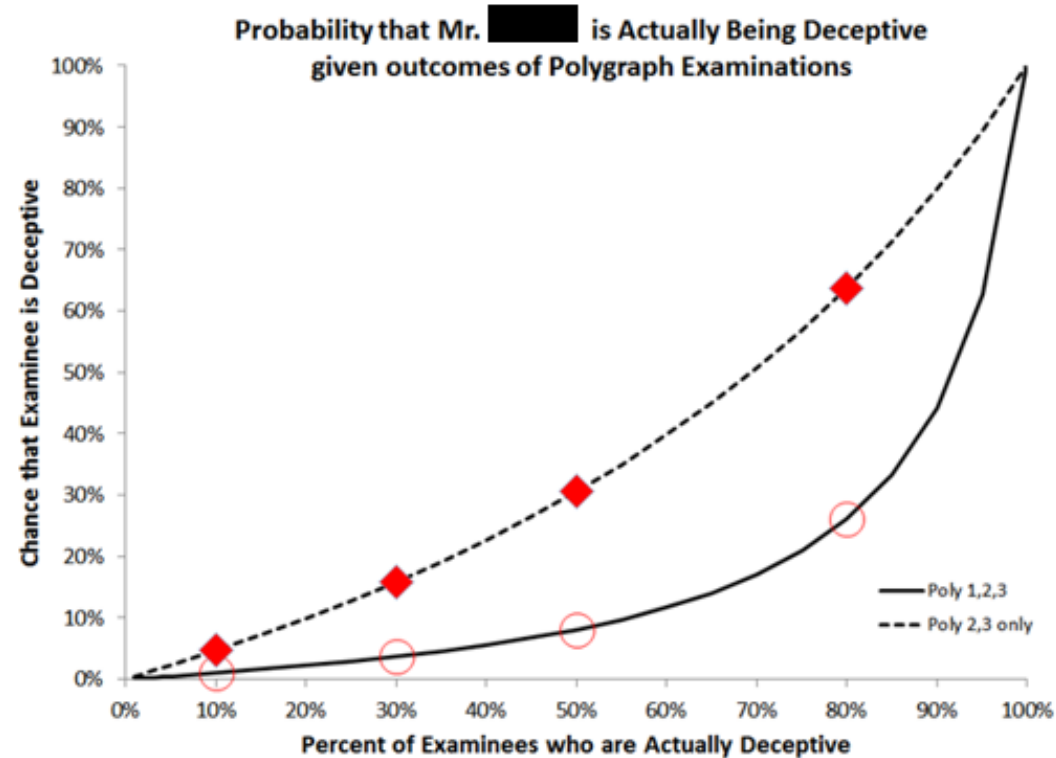
# The Case

## ◆ Child Custody Case

## ◆ My report

- ◆ Overview of Polygraph CIT procedure and logic
- ◆ Scientific opinion of the Polygraph
- ◆ Scientific research on the polygraph
- ◆ NRC Report (and comment on APA report)
- ◆ Specific comment on false positive and true positive rates

Source	Outcome	p for formula	q for formula
Poly 1: [REDACTED] *	Nondeceptive	0.12	0.6
Poly 2: [REDACTED]	Nondeceptive	0.12	0.6
Poly 3: [REDACTED]	Deceptive	0.88	0.4
*Polygraph quality review questioned this test		Sensitivity	Specificity
		0.88	0.60



# The Case

## ◆ Child Custody Case

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- ◆ Specific comment on false positive and true positive rates
- ◆ Specific comment about relevant items



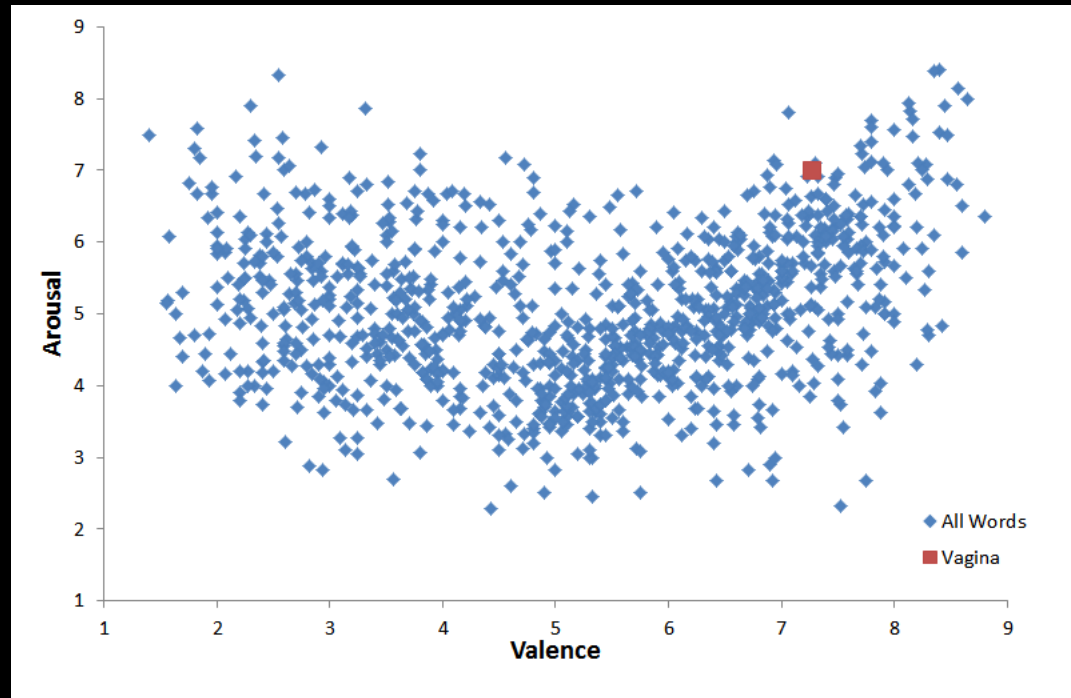
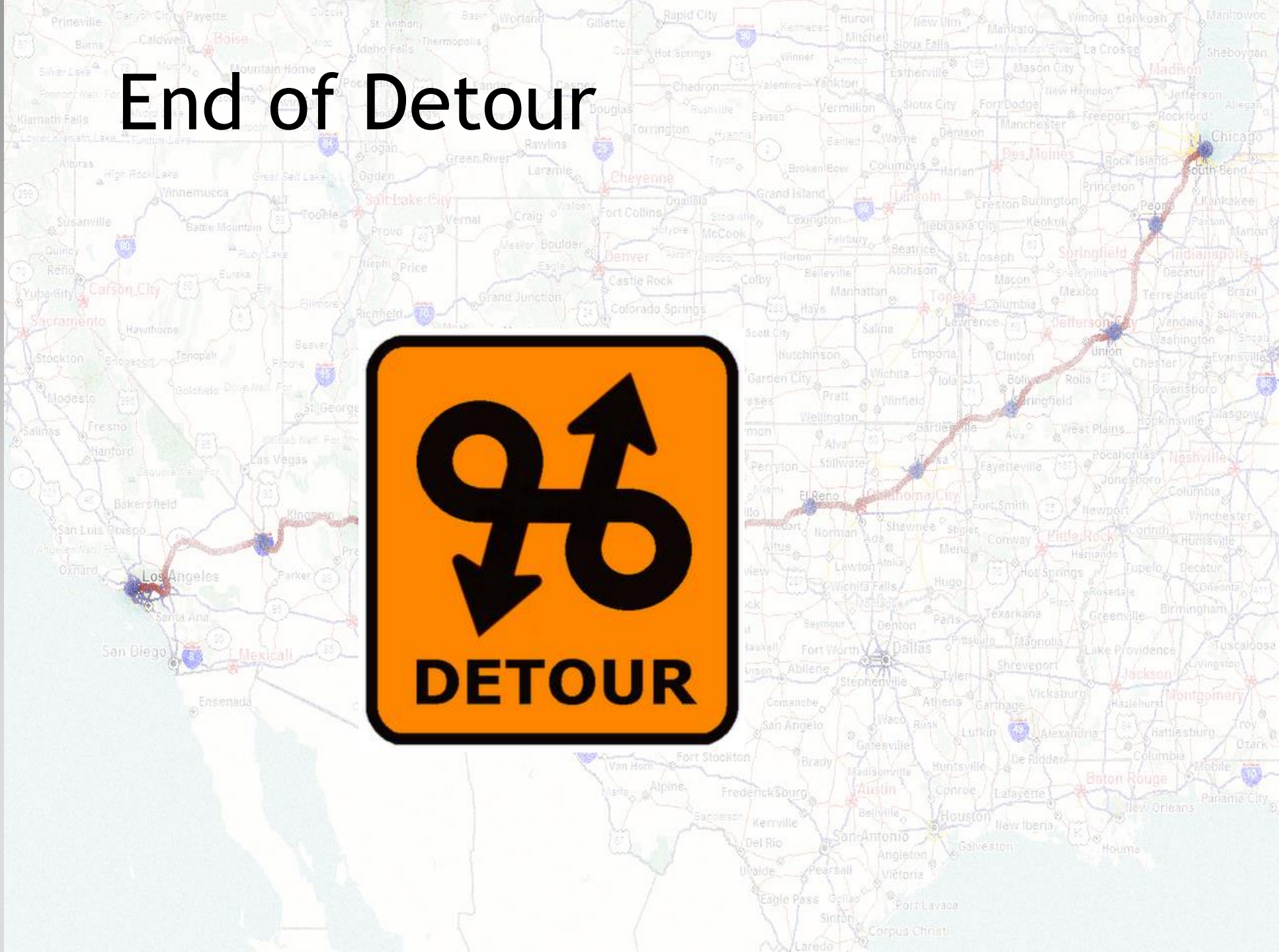


Figure 1. Valence and arousal ratings for 1032 emotional words, with the ratings for “Vagina” shown in red. Ratings are from male research participants (Affective Norms for English Words [ANEW]; Bradley and Lang, 1999, Technical Report C-1, University of Florida). Valence is rated from 1 to 9 (unpleasant to pleasant) and arousal is rated from 1 to 9 (calm to arousing).

# End of Detour





# Roadmap

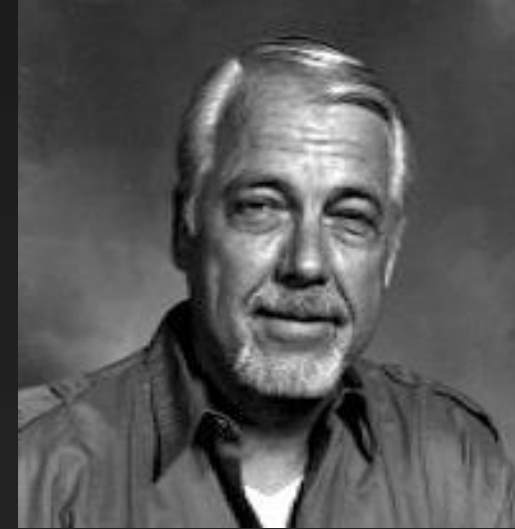
- Abbreviated History and Overview of the Conventional Polygraph
- Limitations to Conventional Polygraphy
  - The Polygraph Test is especially likely to falsely incriminate the innocent
- Why polygraphers over-estimate the accuracy of the test
- No credible scientific exists to support using the Polygraph Test
- Overview of alternatives: Assessing recognition

# The GKT as an alternative to Traditional Polygraph Procedures

## ➤ **Guilty Knowledge Test (GKT)**

➤ **Devised by Lykken(1959)**

➤ **Can utilize Skin Conductance or other measures (e.g. Event-Related Brain Potentials)**

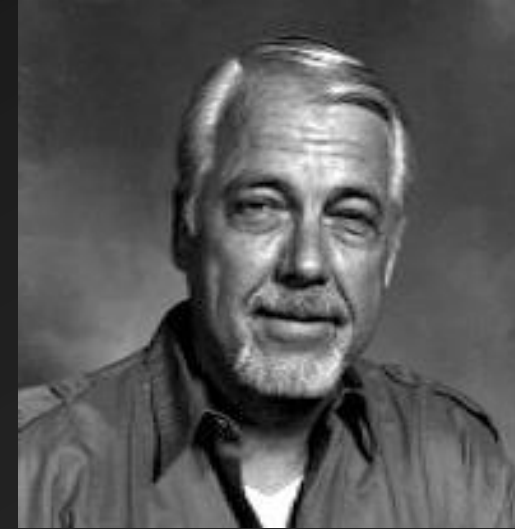


➤ **Sometimes termed “Concealed Information Test” (CIT)**

# The GKT as an alternative to Traditional Polygraph Procedures

David T. Lykken 1928-2006

“In my junior year I signed up for Professor Heron’s two-quarter course in learning theory where, in the second quarter, our assignment was to invent a theory of our own that circumvented the inadequacies of the theories of Hull, Tolman, or Skinner. It dawned on me that, while in chemistry I was just about up to Lavoisier, in psychology I was already at the cutting edge! Psychology seemed right up my alley, an exciting new endeavor where lots of obvious ideas had not yet been exploited, a field demanding rough carpentry rather than meticulous cabinet-making. Because I was, in effect, paying my own way, I had only to get the approval of the counselor who advised us veterans and he agreed that psychology was more interesting. Neither of us considered what sort of job I might aspire to with a BA in psychology.”



**“nation Test”**



# Guilty Knowledge Test (GKT)

- The GKT does not assess lying as indexed by fear of being detected, but probes for guilt as indexed by recognition
- A series of questions is devised, each having several alternatives, only one of which is true about the crime in question
- Chances of an innocent person looking guilty on a 10-item GKT are  $1/5^{10}$ .

# Assessing Recognition: For Specific Incidents Investigations

- Used when information about a crime or event is available that only a real culprit would know
- Series of questions constructed, only one of which has correct critical detail

Regarding the abduction location, do you know for sure it was...

1. ... at a Toy Store?
2. ... at a Shopping Mall?
3. ... at a City Park?
4. ... at a Friend's House?
5. ... at School?
6. ... at a Restaurant?

Other questions about

- Time abductee taken
- Clothing worn
- etc. for 6-10 questions

- Subject instructed to answer "no" to each item, so that if guilty, subject would be lying to the critical item.
- Critical item never positioned at beginning.
- A consistent peak of physiological response on one critical alternative suggests guilt.

# GKT Accuracy: Lab Studies

Study (1 <sup>st</sup> Author, Yr)	N	Percent Correct	
		Guilty	Innocent
Lykken '59	98	88	100
Davidson '68	48	92	100
Podlesney '78	18	90	100
Balloun '79	34	61	88
Giesen '80	40	92	100
Bradley '81	192	59	89
Bradley '84	16	100	100
Iacono '84	55	91	100
Steller '87	87	85	100
Iacono '92	71	87	71
O'Toole '94	45	77	94
<b>Study Median</b>	<b>48</b>	<b>88</b>	<b>100</b>

# GKT – Box Score, and Concerns

- Superior to CQT, especially in protecting the innocent
- Resistance to use among those in the polygraph community
  - Concern about applicability, especially in high profile cases
  - The GKT for OJ
- Despite limitations of CQT, may have utility for eliciting confessions
- Over 5,000 GKT tests given in Japan each year, for example



# The current and future status of the concealed information test for field use

**Izumi Matsuda<sup>1\*</sup>, Hiroshi Nittono<sup>2</sup> and John J. B. Allen<sup>3</sup>**

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The Concealed Information Test (CIT) is a psychophysiological technique for examining whether a person has knowledge of crime-relevant information. Many laboratory studies have shown that the CIT has good scientific validity. However, the CIT has seldom been used for actual criminal investigations. One successful exception is its use by the Japanese police. In Japan, the CIT has been widely used for criminal investigations, although its probative force in court is not strong. In this paper, we first review the current use of the field CIT in Japan. Then, we discuss two possible approaches to increase its probative force: sophisticated statistical judgment methods and combining new psychophysiological measures with classic autonomic measures. On the basis of these considerations, we propose several suggestions for future practice and research involving the field CIT.

**Keywords:** concealed information test, field application, probative force, statistical judgment, combination of measures

# Countermeasures to GKT?

- Iacono et al. (1984, 1987) increased incentives and found no effects (relative to placebo) for:
  - Diazepam (widely prescribed tranquilizer)
  - Methylphenidate (stimulant)
  - Meprobamate (tranquilizer)
  - Propranolol (widely prescribed cardiac med.  $\beta$ -blocker that inhibits SNS activity)
- Overall hit-rate for the guilty was >90%



# Physical Countermeasures and the CQT

- Honts et al. (1983, 1984)
  - 78% of highly motivated subjects could be trained to "beat" the CQT by biting their tongues or pressing their toes to the floor during control questions
  - Although it took training, motivated suspects could easily obtain it or it could be provided (e.g., [antipolygraph.org](http://antipolygraph.org))
- The polygraphers were unable to detect these subtle maneuvers
- "Counter-countermeasures" worked to detect those using countermeasures: 80% could be detected by a blind analysis of EMG recordings
  - Such counter-countermeasures rarely used in field polygraphy

# Physical Countermeasures and the GKT

- The rectangularity score of the GKT should -- in theory -- be much less susceptible to these techniques
  - GKT and rectangularity scores rarely used in field polygraphy

# Synopsis

- There is no unequivocal lie response
- Polygraphy:
  - assesses emotional reactions
  - has an unacceptably high false-positive rate
  - shows racial bias
  - is vulnerable to countermeasures that can reduce true-positive rate
- Polygraphers overestimate accuracy due to how cases are selected for inclusion in studies
- Assessing recognition may prove more accurate, but potentially less widely applicable
- Polygraphs are useful for eliciting admissions and confessions; i.e. “scare the hell out of people”

# Science and Pseudo-Science, Debate and Diatribes, Validity versus Vitriol

*If I announce to my scientific colleagues that I have invented a new test that can identify schizophrenia with 90% or 95% accuracy, my colleagues will be interested -- but skeptical. I would be expected to support my assertion with experimental evidence and that evidence would be very critically examined. Even if my proofs withstood such scrutiny, many would reserve judgment until an independent investigator had confirmed my findings. All this skepticism about a claim that I can distinguish "crazy people" from normal ones! The tools of the psychologist are not precision instruments; really high accuracy is seldom achieved. Skepticism is appropriate. Nevertheless, when the polygrapher announces that his psychological test can separate liars from the truthful with a validity of 90%, or 95%, or even 99%, the typical reaction is a kind of marveling acceptance. The critic who questions these claims is greeted with surprise and skepticism. Nearly every American has heard of the lie detector; without really knowing what is involved, many assume that it is nearly infallible. So deeply ingrained is this mystique that, gradually over the last 50 years, the burden of proof has somehow shifted to the critic.*

Lykken, in *A Tremor in the Blood*, 1981

# Science and Pseudo-Science, Debate and Diatribe, Validity versus Vitriol

*Unfortunately, the minute a small handful of psychologists -- one or two pseudo-knowledgeable and one or two completely ignorant of what they were even trying to do -- got into the picture, two expressions, "false positive" and "false negative", came to light. It appears that some people turn out to be weird ducks. Sadly, when that type of inquirer doesn't understand something, he is usually prone to attach strange names to it under the guise of professionalism or scientific exploration on both sides of the same coin. By confusing other people more so than himself he feels he can still call himself an "expert." Those two phrases appeared in a tumor in the brain [sic]. Before then, they had never existed in polygraph language. In all sincerity, however, foul ball psychologists are few and far between.*

Ferguson, in *Preemployment Polygraphy*, 1984

# Approaches to Detecting Deception

Emotion/Arousal	Memory/ Recognition	Other Cognitive Correlates
<ul style="list-style-type: none"><li>➤ “The” Polygraph</li><li>➤ Facial Expression</li><li>➤ Voice Stress</li><li>➤ Facial Blood Flow</li><li>➤ Thermography</li><li>➤ Demeanor</li></ul>	<ul style="list-style-type: none"><li>➤ Guilty Knowledge Test<ul style="list-style-type: none"><li>➤ Autonomic (SCR)</li><li>➤ Central (ERP, fMRI?)</li></ul></li></ul>	<ul style="list-style-type: none"><li>➤ Response Conflict</li><li>➤ Attention and Memory Load</li><li>➤ Both ERP and fMRI</li><li>➤ Linguistic Analysis</li></ul>

Note that none detect lying *per se*



# Should the Polygraph Test be used, and if so under what circumstances?

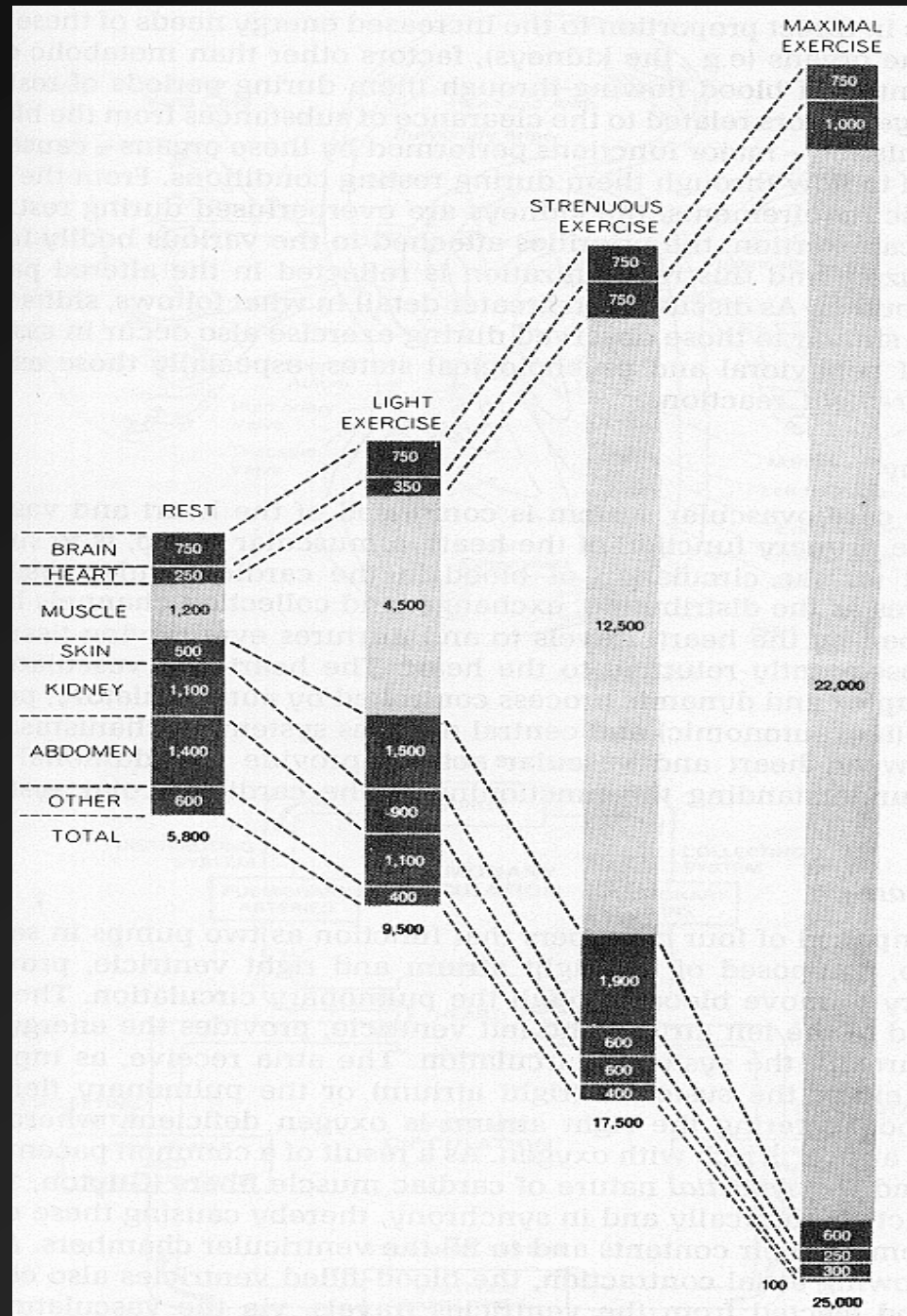


# *Cardiovascular Psychophysiology*

# Facts and Functions

- The busy heart
  - Six quarts of blood pumped per minute
  - 100,000 beats per day
  - Try it!
- Functions
  - Transport oxygen from lungs and nutrients from gut
  - Transport waste products
  - Transport regulatory substances (e.g. endocrines)
  - Thermal exchange between core and periphery

# Metabolic Demands



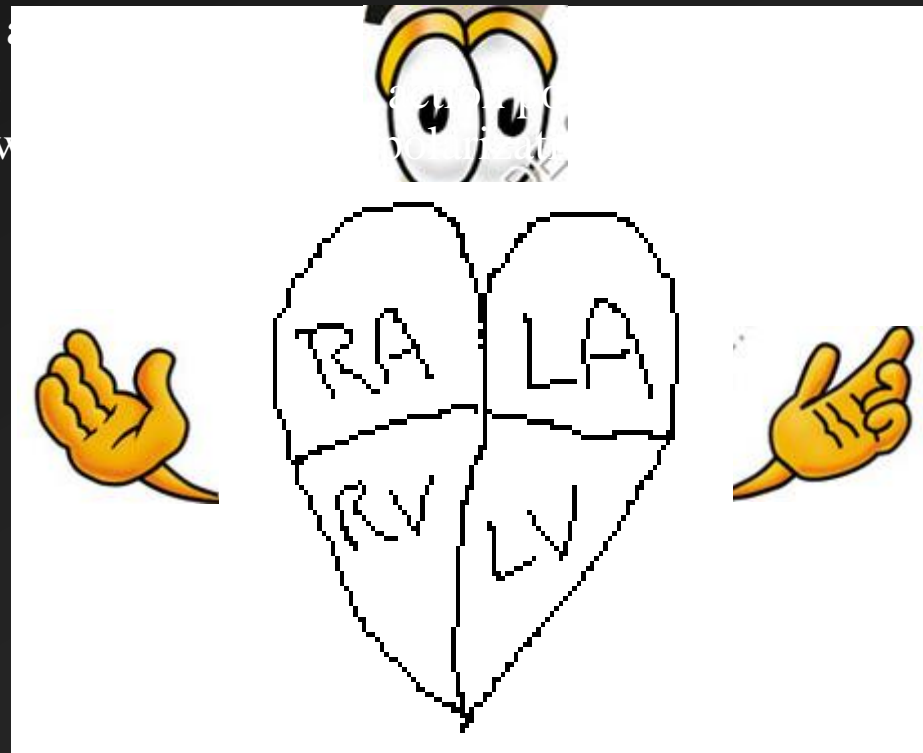
# Anatomy of the Heart

## ➤ Cardiac Muscle (myocardium)

- not striated, not smooth
- four features distinguish from smooth or striate
  - Muscle has unstable resting potential – basis for intrinsic and rhythmic contraction
  - Action potential freely conducted from one cell to another (lattice-like syncytial) network of cardiac fibers
  - Repolarization lasts 400 ms
  - Contraction phase = depolarization followed by repolarization (0.1-0.2 secs)

## ➤ Four chambers

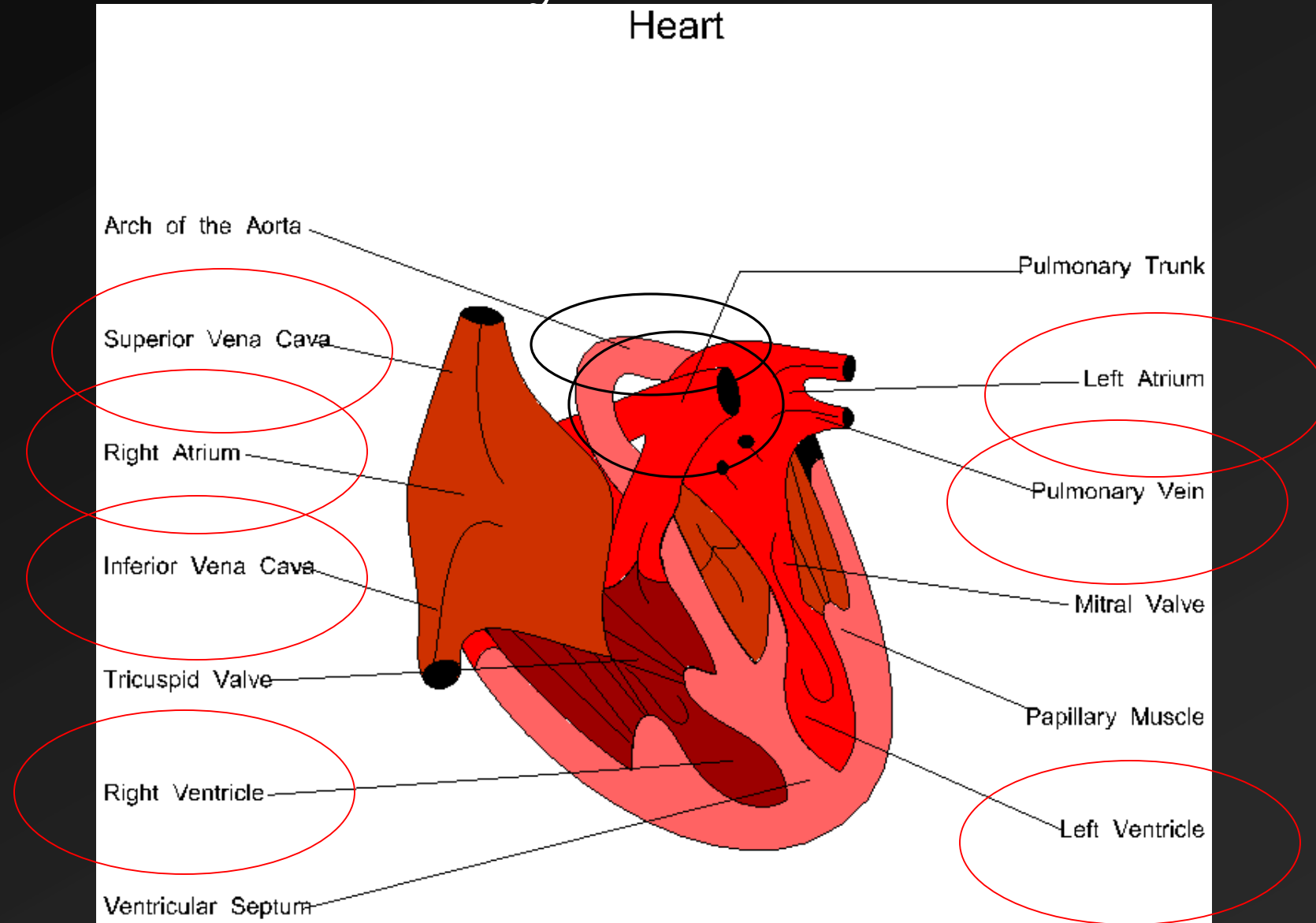
- Right Atrium
- Right Ventricle
- Left Atrium
- Left Ventricle



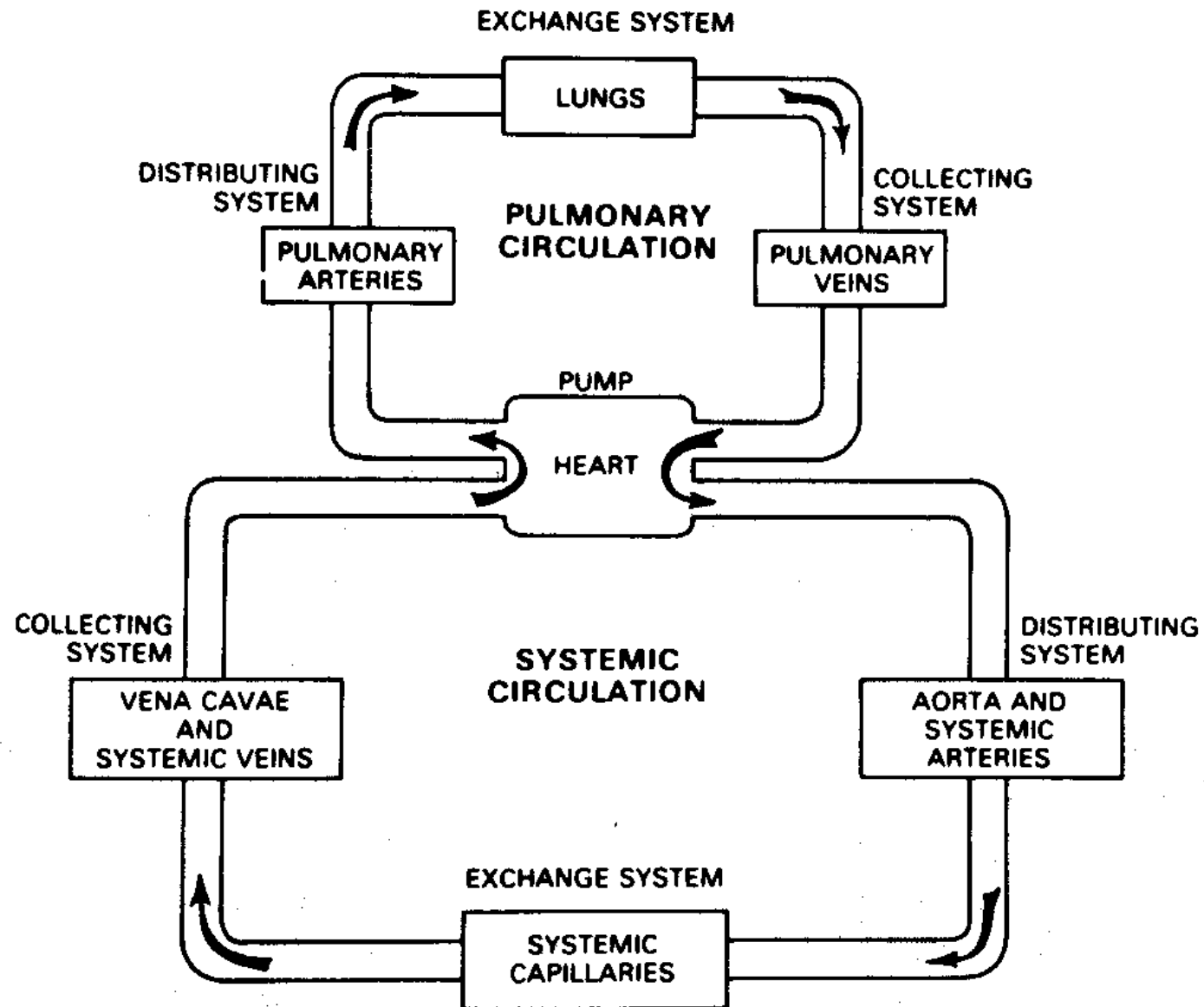


# Anatomy of the Heart

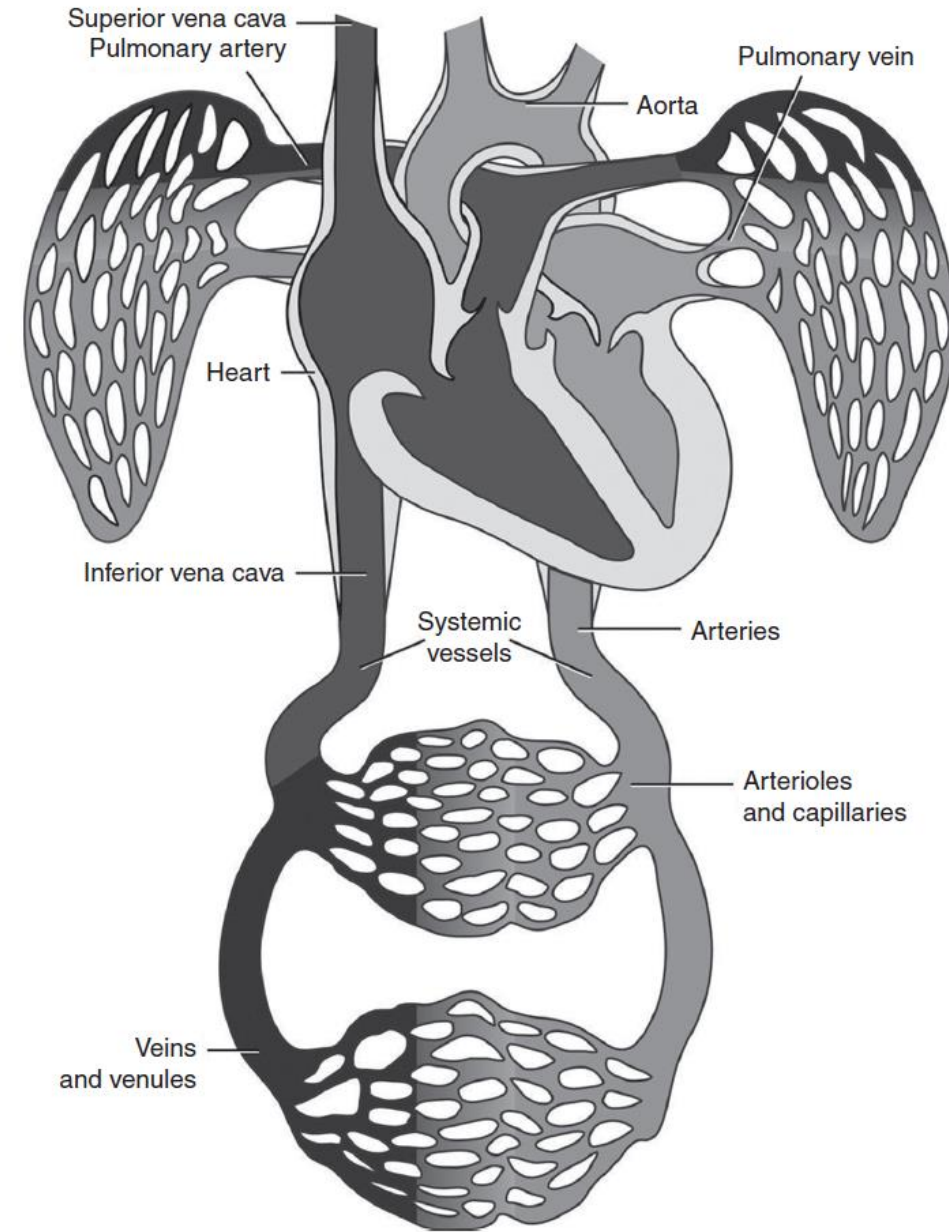
## Heart



# Human Circulatory System

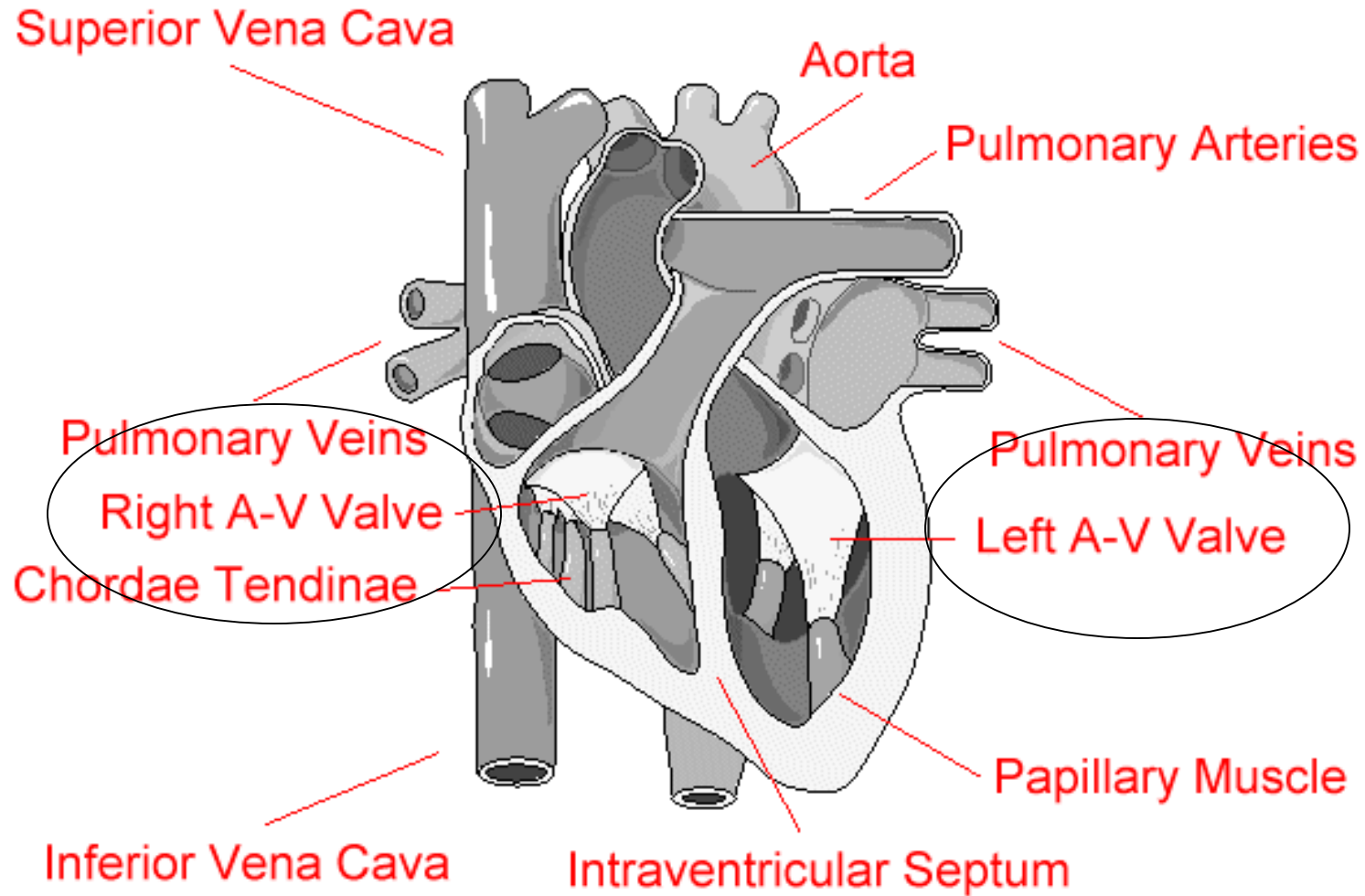


# Circulation in a bit more realistic detail



**Figure 9.1** Systemic and pulmonary circulation. In keeping with usual depictions of the heart, the right side of the heart is on the left side of the picture. Lighter gray areas indicate oxygenated blood and darker gray areas indicate deoxygenated blood.

# Anatomy of the Heart



# More Valves

## ➤ Aortic and Pulmonary Valves

- Respond to relative pressure difference between ventricles and aorta or pulmonary artery
- As ventricles contract, pressure builds, and forces valves open when pressure exceeds arterial pressure
- “Dub” in the Lub-Dub sound (sounds are valves closing or “slamming” shut)



# Neural Conduction of the Heart

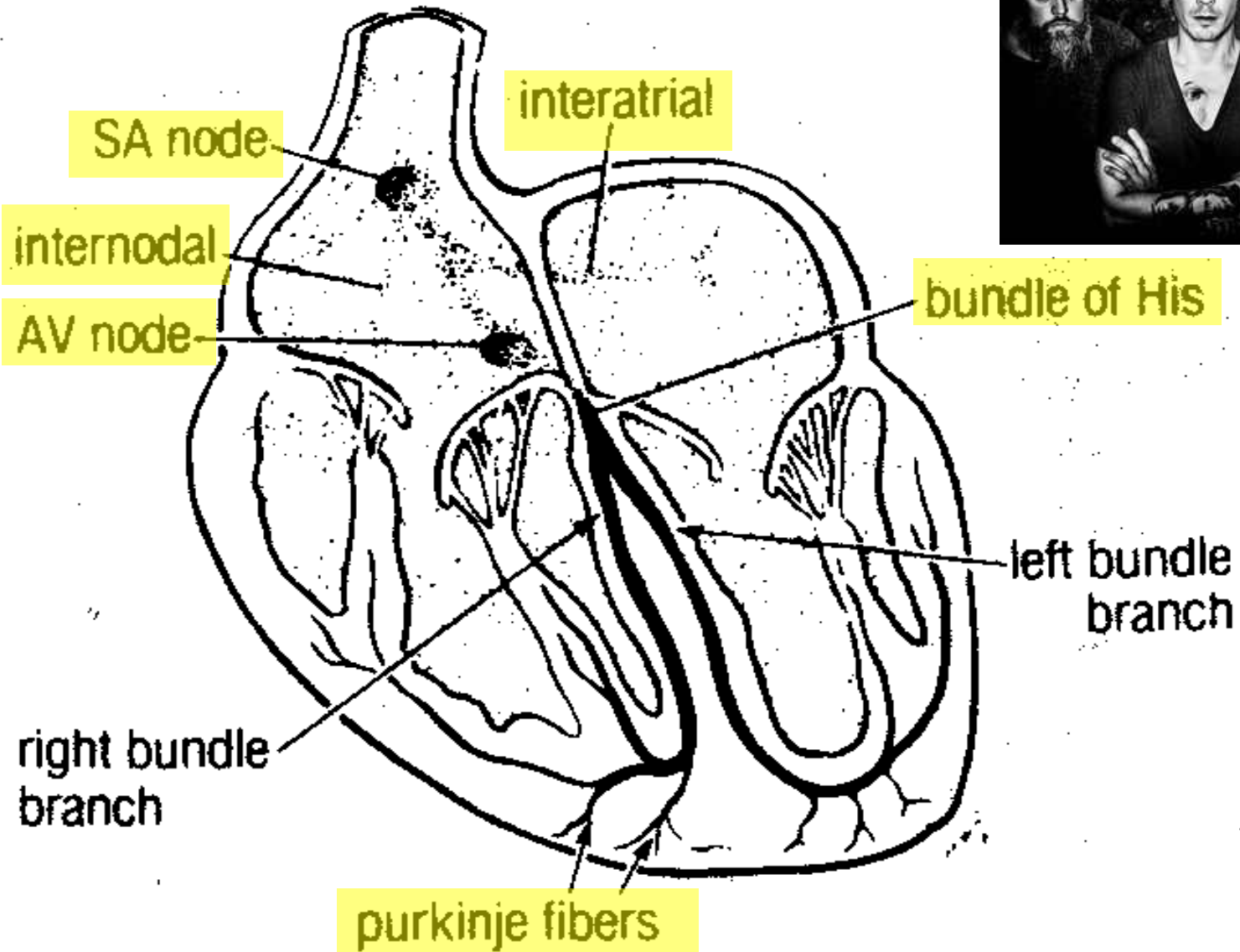
- Two Nodes
  - Sino-Atrial (SA) node – “Primary Pacemaker”
  - Atrial-Ventricular (AV) node – “Yoked”
- Nodes have intrinsic rhythmicity
  - SA node: 105 bpm
  - AV node: 40-60 bpm
- Denervated heart would still beat at over 100 bpm
  - Must be extrinsic influences to slow or speed heart



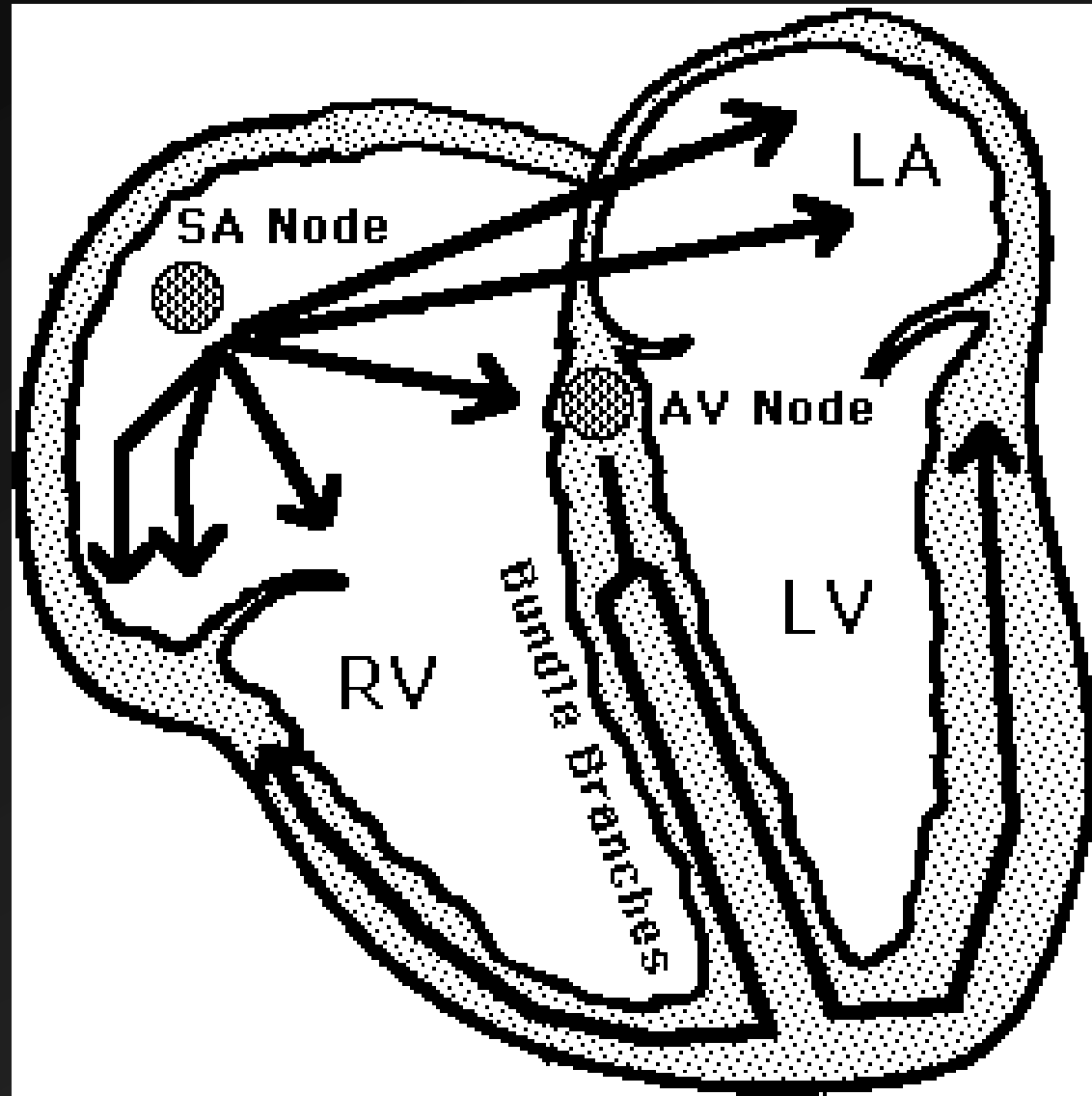
# Neural Conduction of the Heart

- Hierarchy ensures that normally the SA node “drives” the system
  - AV nodes provide a critical delay (allows atria to fully contract before ventricles do)
  - AV nodes have important refractory period to prevent rapid successive ventricular contractions
- A coordinated wave of depolarization
  - Contraction of 4 chambers of heart must be precisely choreographed

# Nodes and Fibers

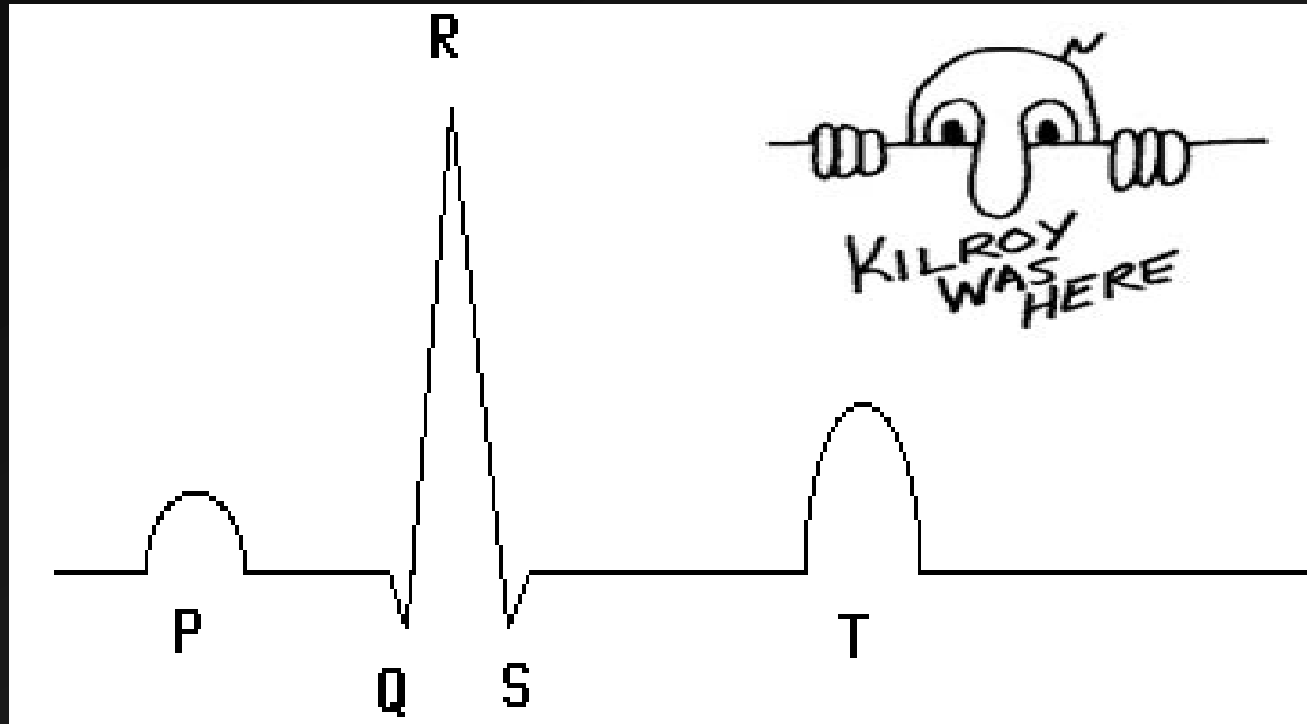


# The SA and AV Nodes in Action



Important: refractory period of the AV node is longer than the time it takes the ventricles to contract

# The Schematized EKG waveform



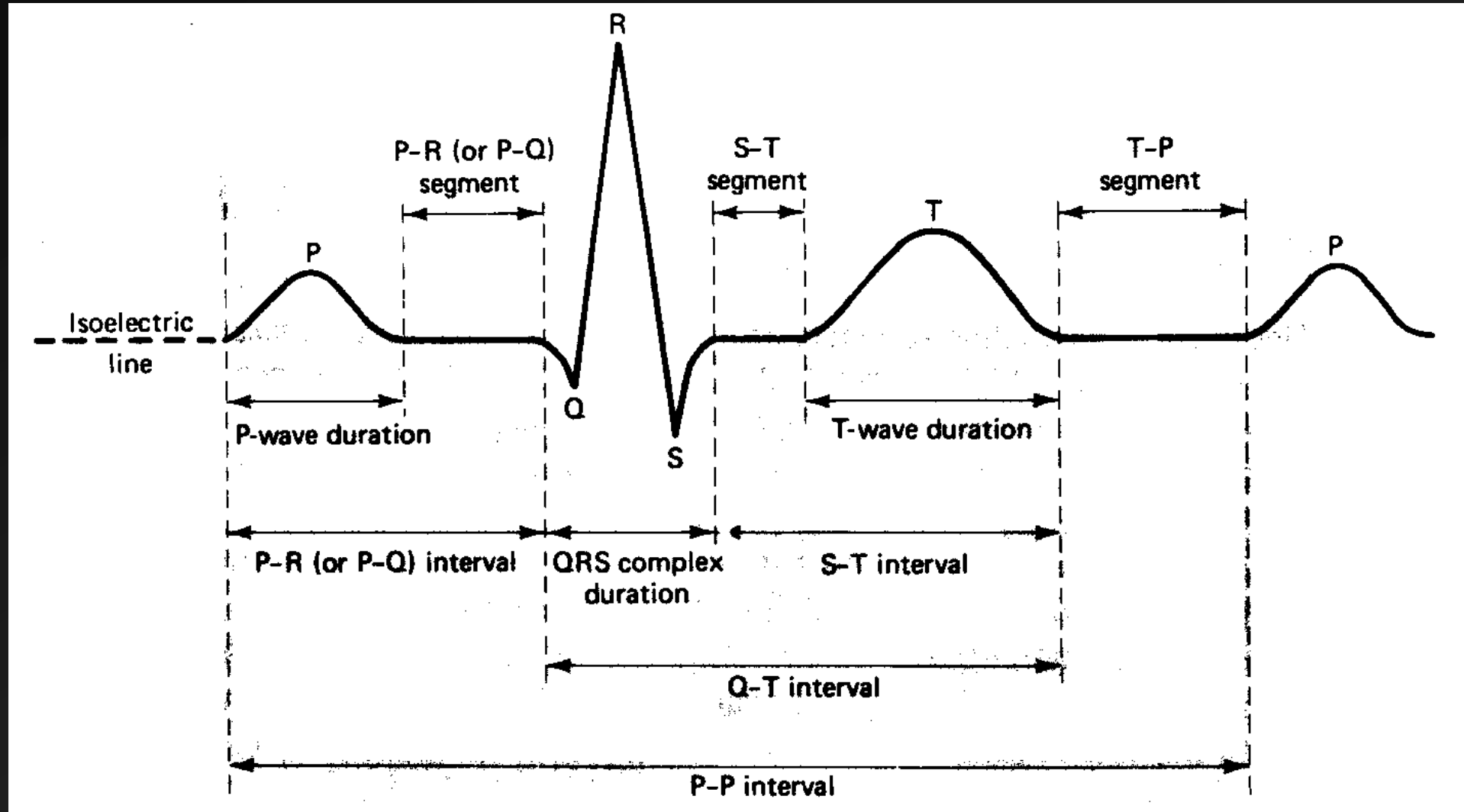
P = Atrial depolarization

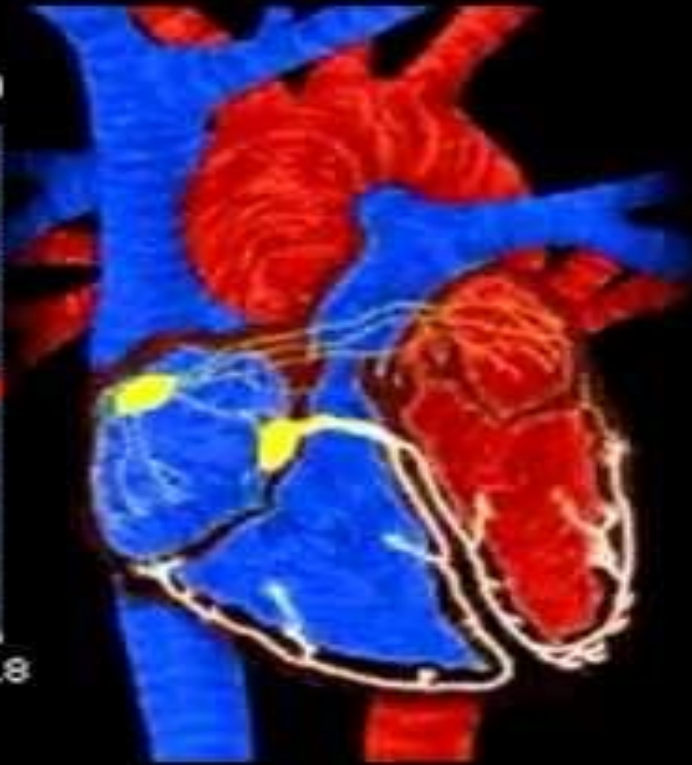
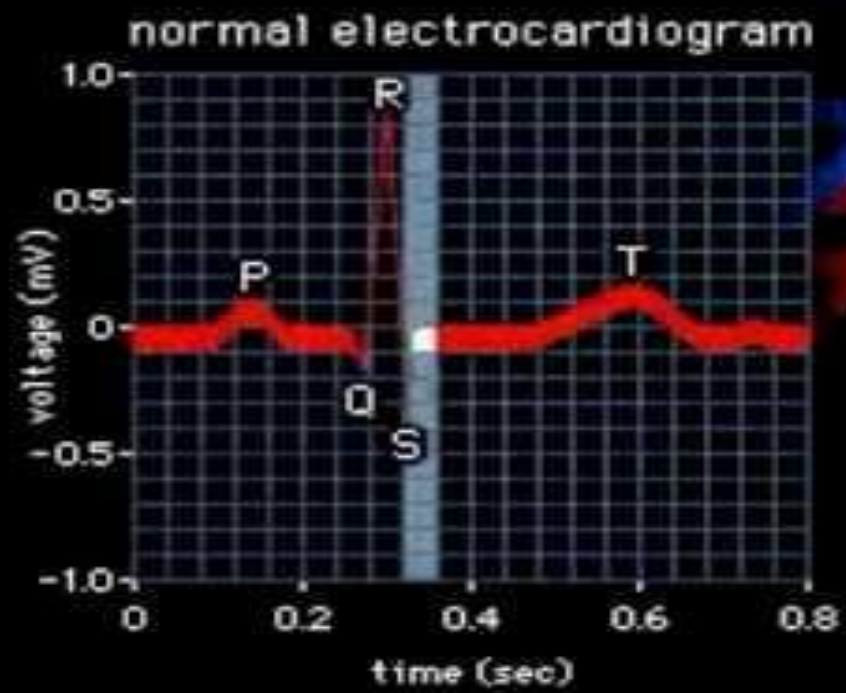
QRS = Ventricular depolarization

T = Ventricular repolarization

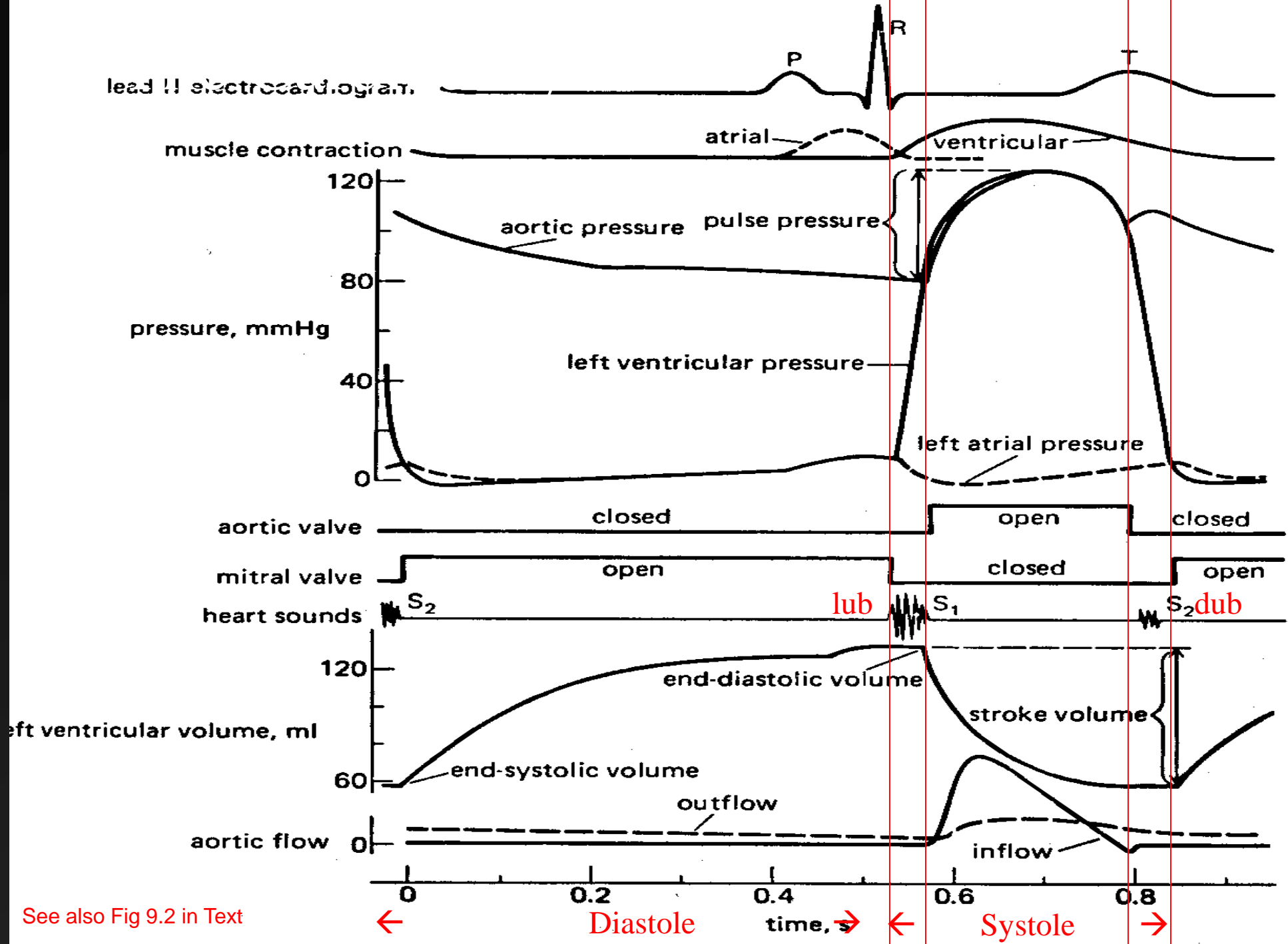
Note that Atrial repolarization is not visible

# The EKG waveform

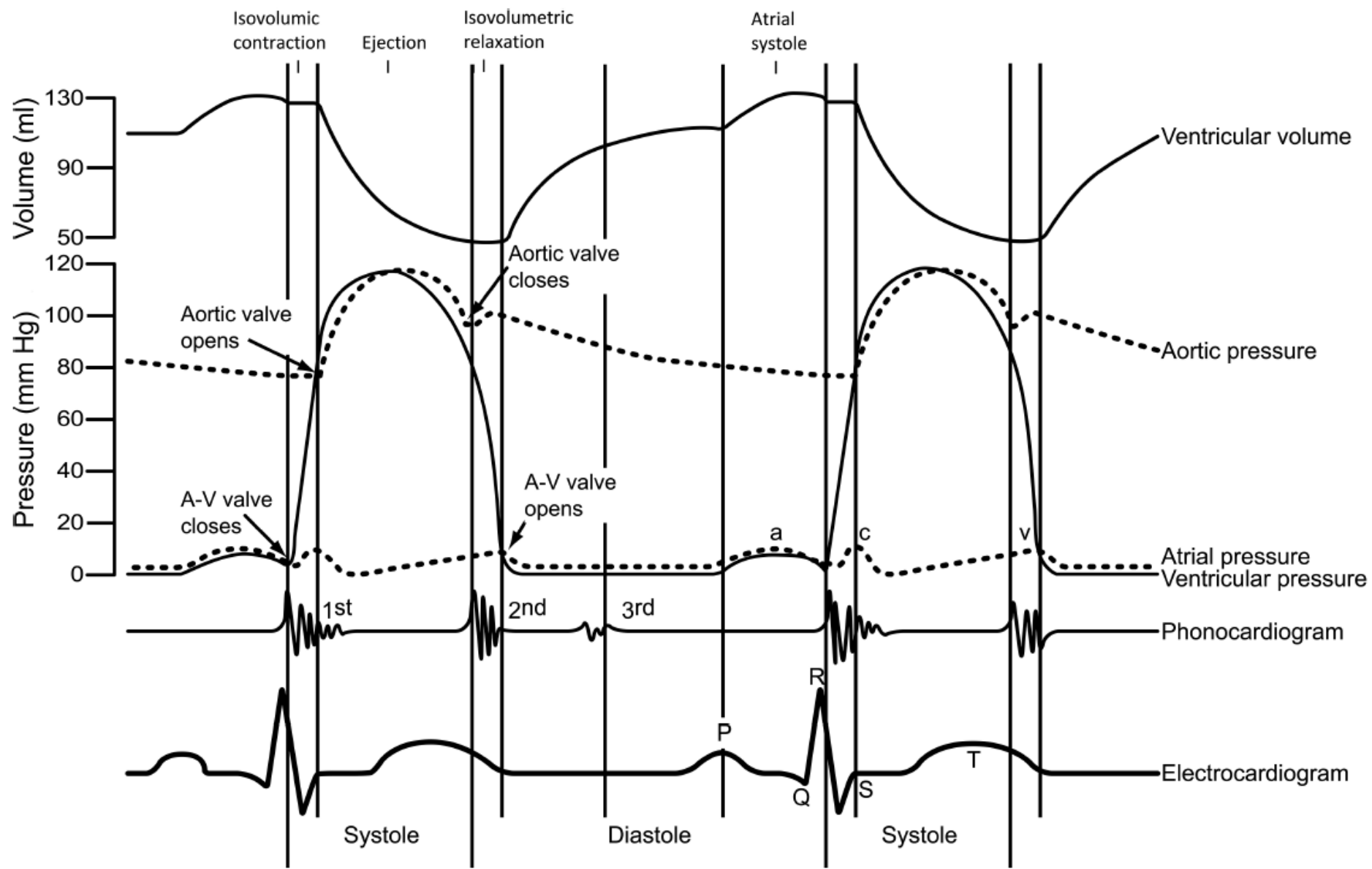




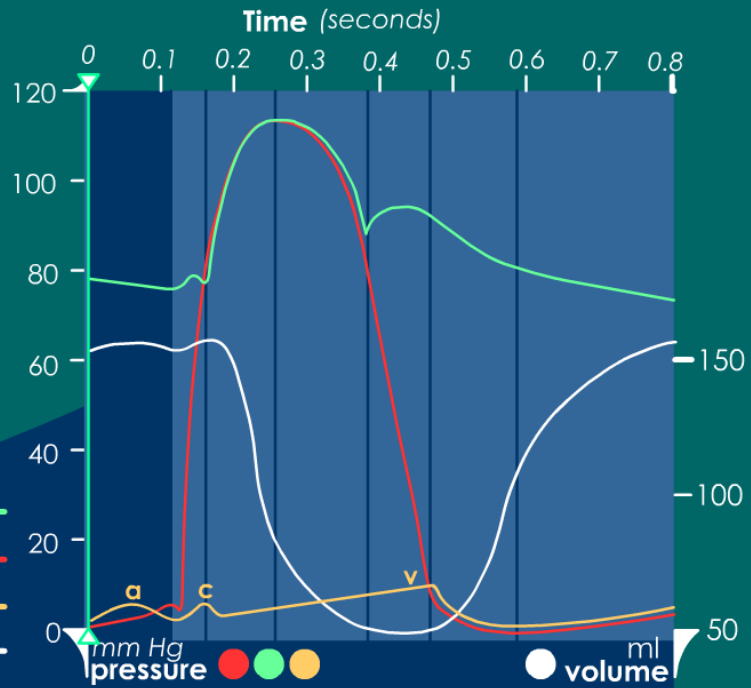
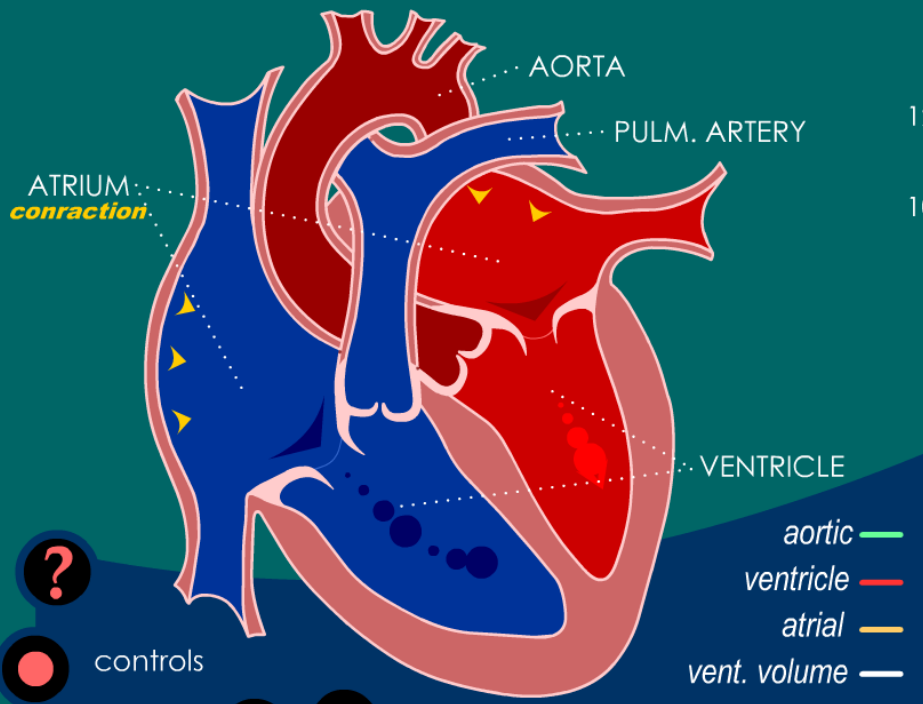




See also Fig 9.2 in Text



**Figure 9.2** The cardiac cycle. Two cardiac cycles are shown for ventricular volume, aortic pressure, atrial pressure, ventricular pressure, the phonocardiogram, and the electrocardiogram (ECG). Phases of the cycle are indicated at the top of the figure above the brackets.



?

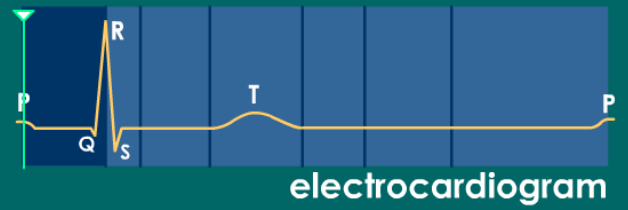
controls

▶ ◻ ◀ ◂ ◃

**SYSTOLE** **DIASTOLE**

- atrial systole
- isovolumetric contraction
- rapid ejection
- reduced ejection
- isovolumetric relaxation
- rapid ventricular filling
- diastasis

**Tutorials** ▼

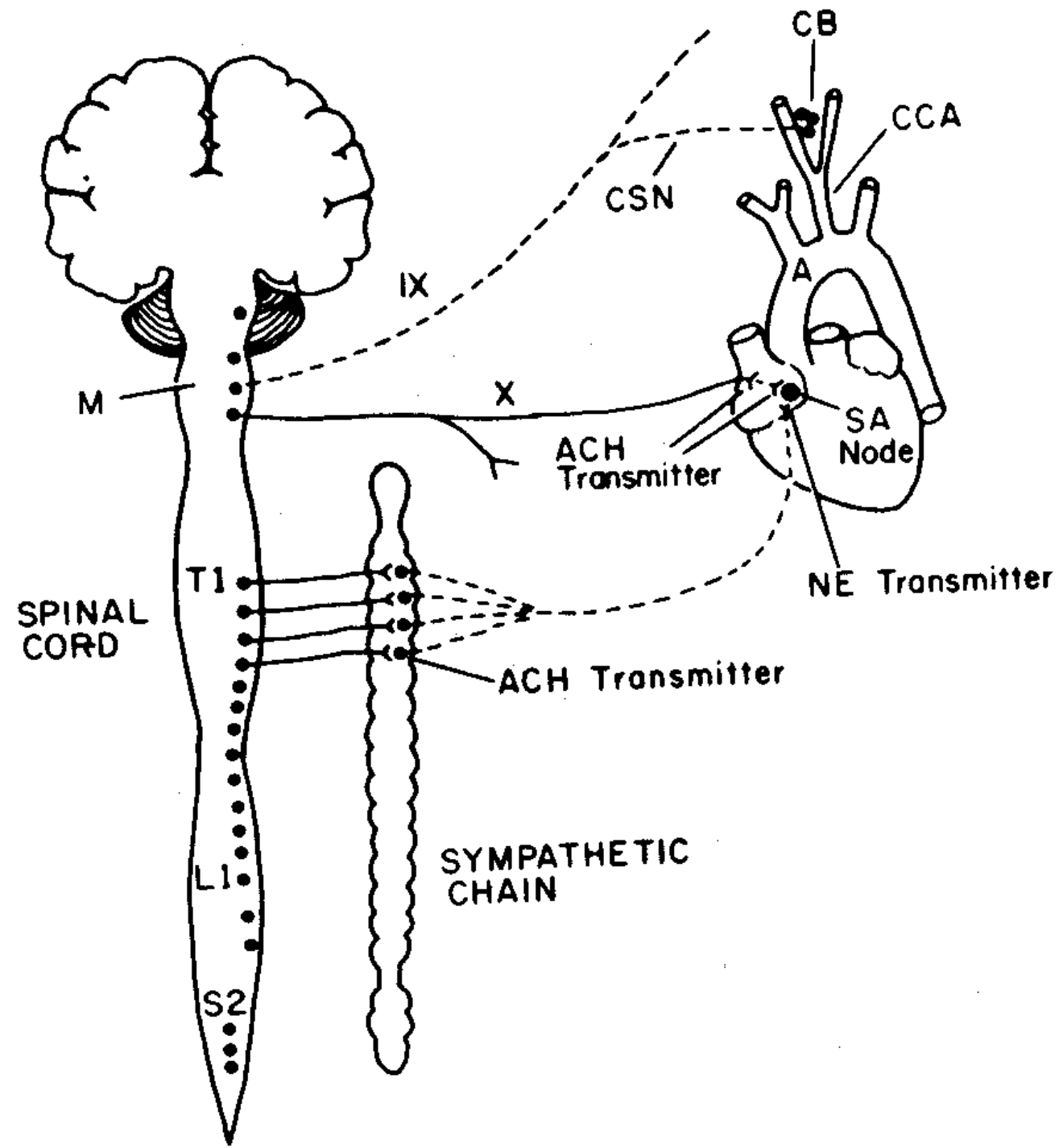


# Cardiac Output

$$CO = HR \times SV$$

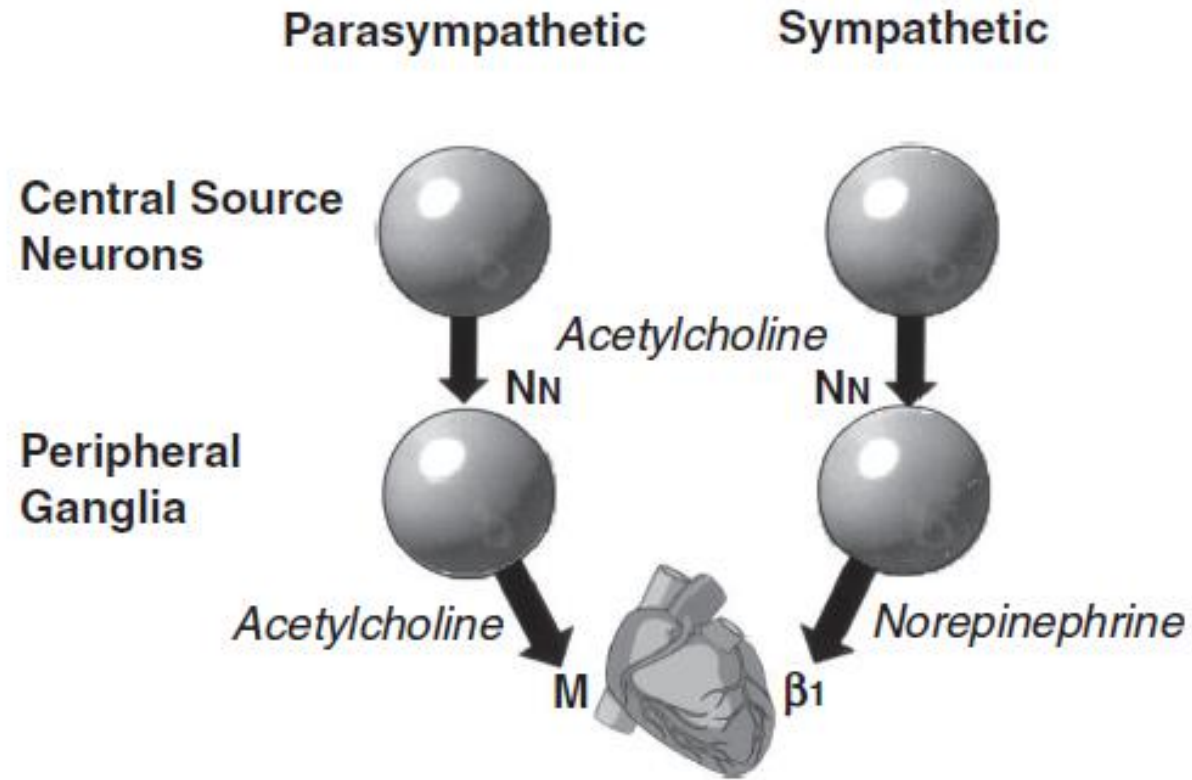
# Cardiac Chronoptropy

- Heart rate regulated extrinsically
- Vagal (PNS) influence
  - Slows HR
  - So too will dripping ACH on SA node
  - Likely that all changes below 100 bpm are predominately vagally induced
- SNS influence
  - Speeds HR, but impact not as strong as PNS
  - Main effect is to increase contractility



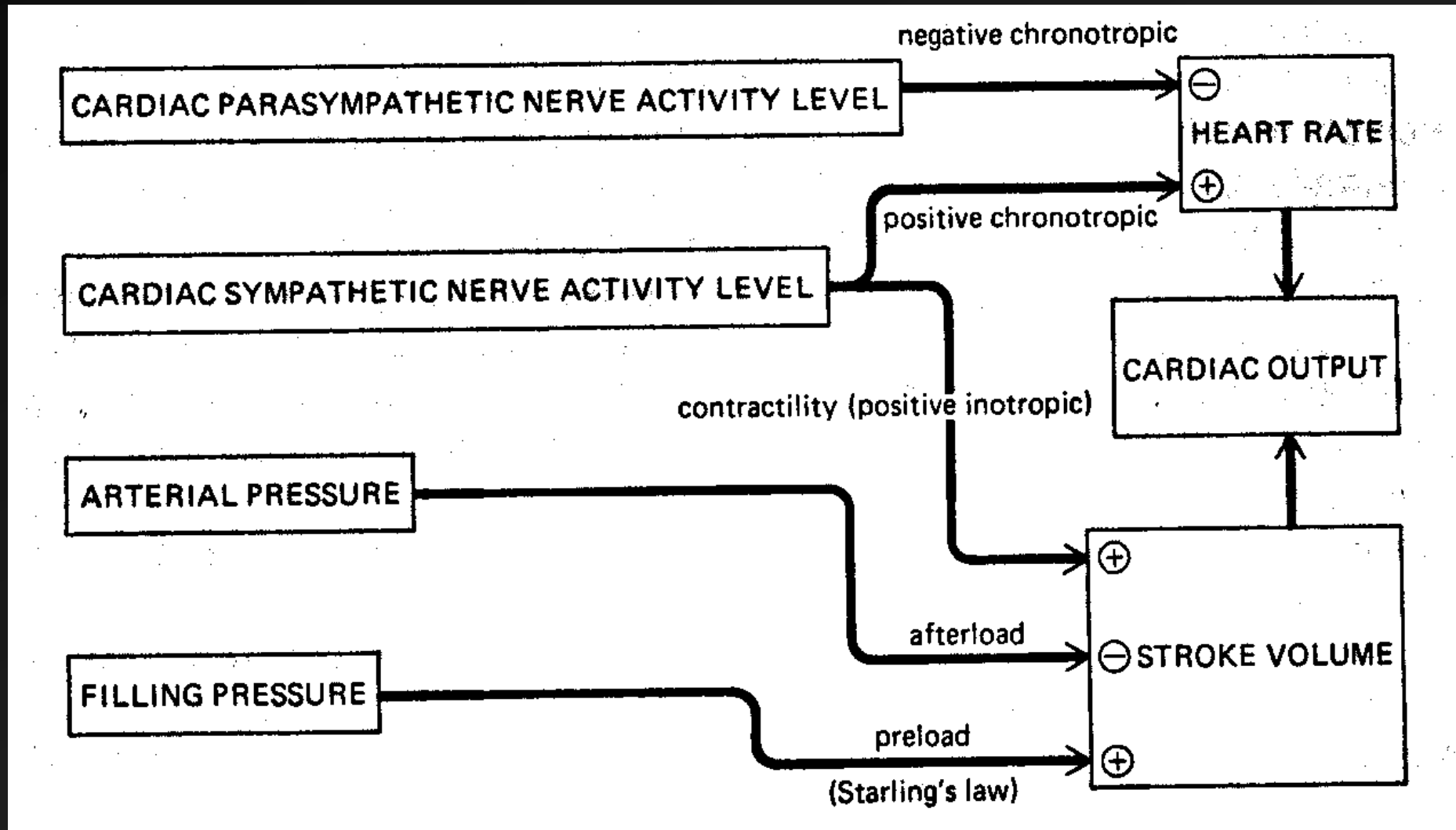


## *Autonomic Innervation*

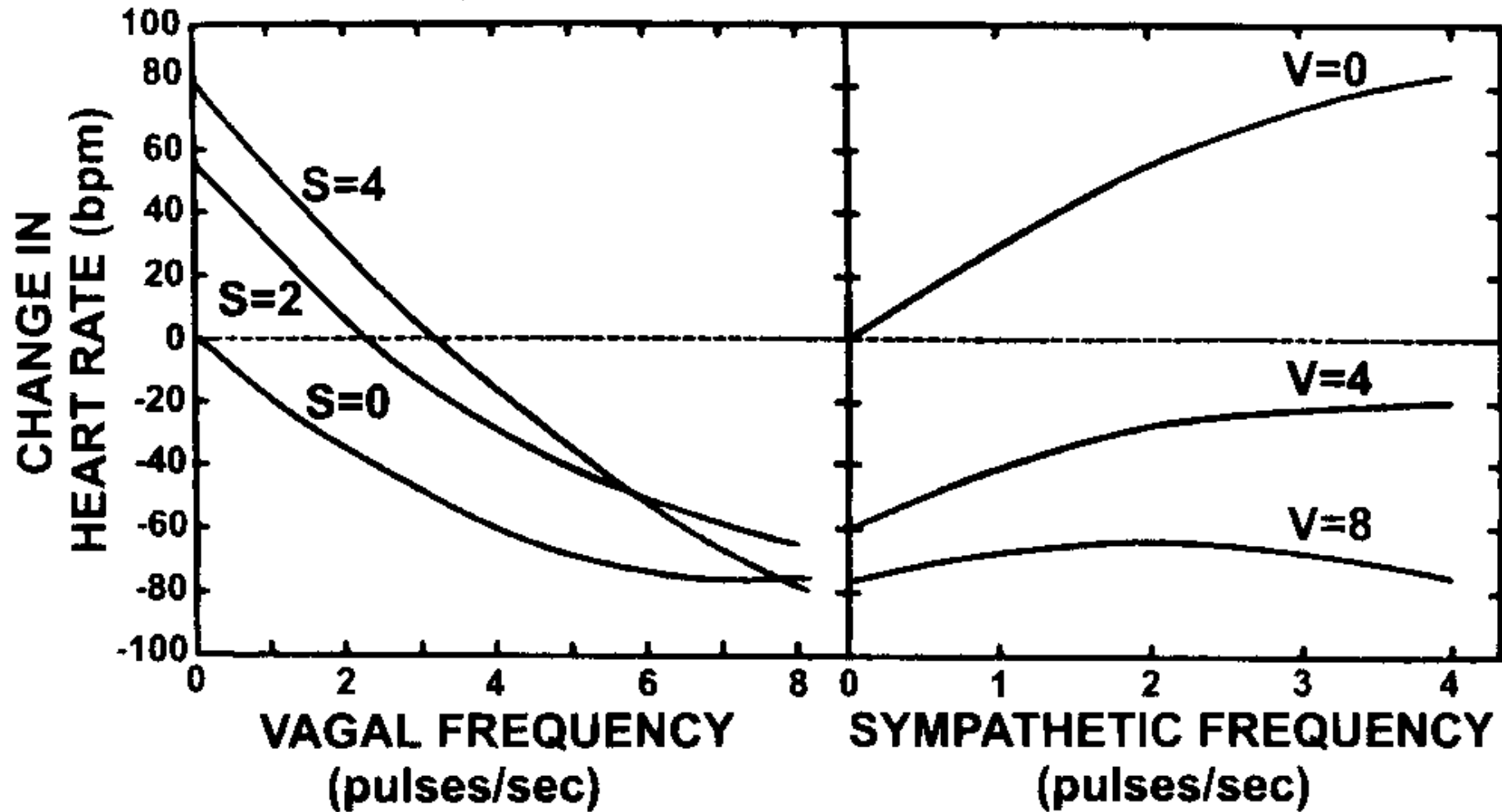


**Figure 9.6** General pattern of pharmacology of the autonomic innervations. Abbreviations refer to the relevant postsynaptic receptor populations:  $N_N$  – nicotinic cholinergic; M – muscarinic cholinergic;  $\beta_1$  – beta1 adrenergic.

# SNS and PNS influences

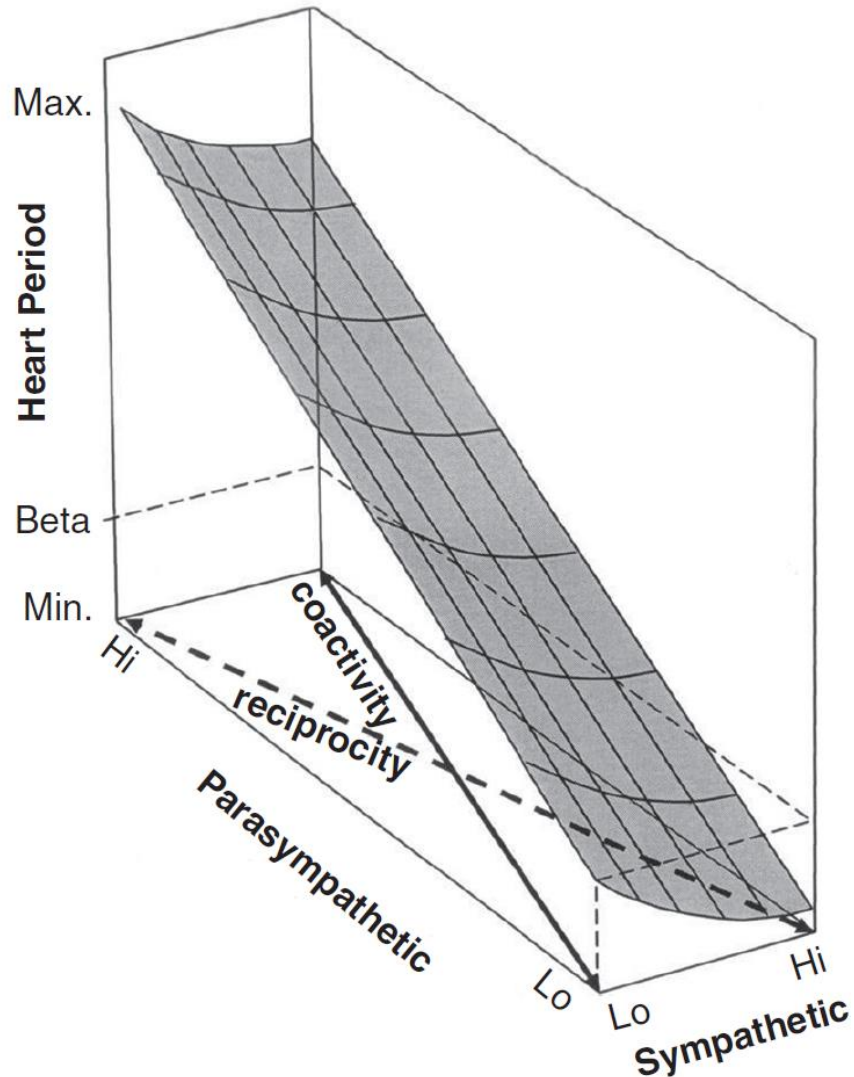


# HR change to simultaneous vagal and sympathetic stimulation



(A) **Autonomic Continuum**  
Parasympathetic ← Sympathetic.

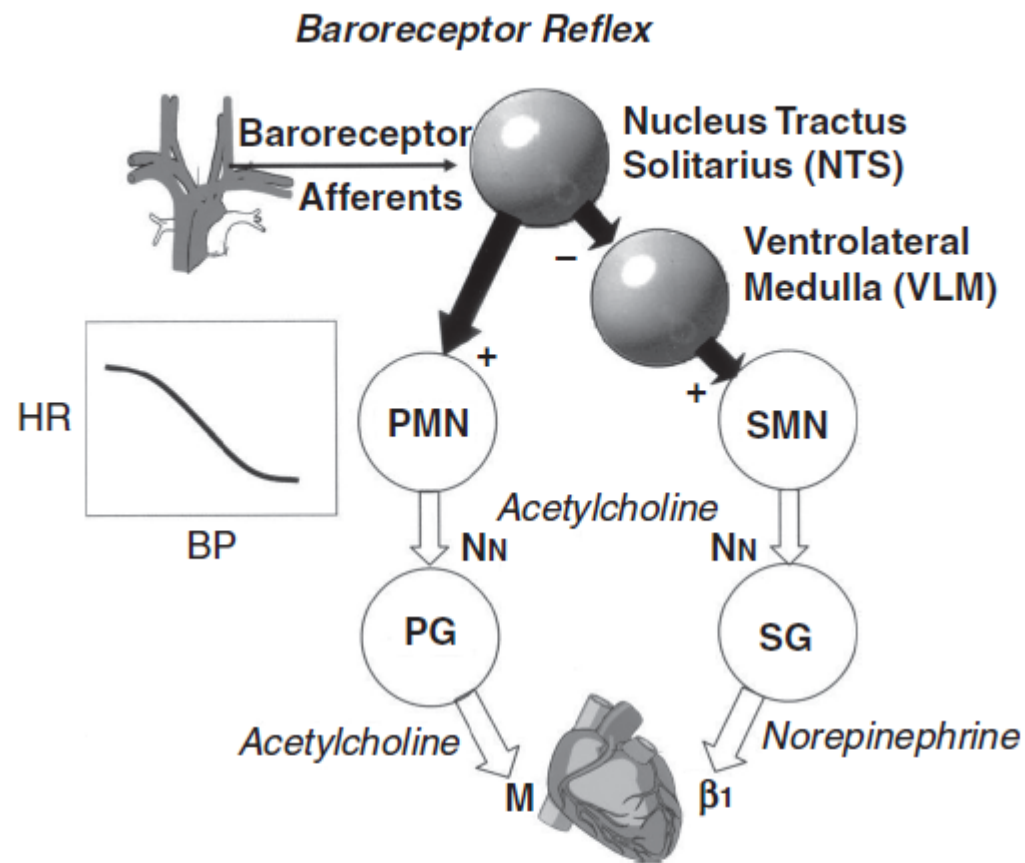
(B) **Cardiac Autonomic Space**



**Figure 9.9** Autonomic space. (A) Continuum model of autonomic control, wherein the status of the system can be depicted along a single continuum extending from parasympathetic dominance to sympathetic dominance. (B) A more comprehensive model of autonomic control, characterized by an autonomic plane (representing the fact that parasympathetic and sympathetic systems can change reciprocally, coactively, or independently) and an overlying effector surface which illustrates the end organ state (heart period) for any location on the underlying autonomic plane. Beta illustrates the intrinsic heart period in the absence of autonomic control.

# Integrated Control Mechanisms

- Baroreceptor Reflex
  - Pressure sensitive receptors
  - located in the arch of the aorta and carotid sinus nerves
  - Join Vagal and Glossopharangeal nerves
  - Terminate in regulatory centers in medulla
  - With increase in BP, causes compensatory decrease in HR, contractility, and SV
  - Quickly adjusts to maintain BP
- Valsalva Maneuver

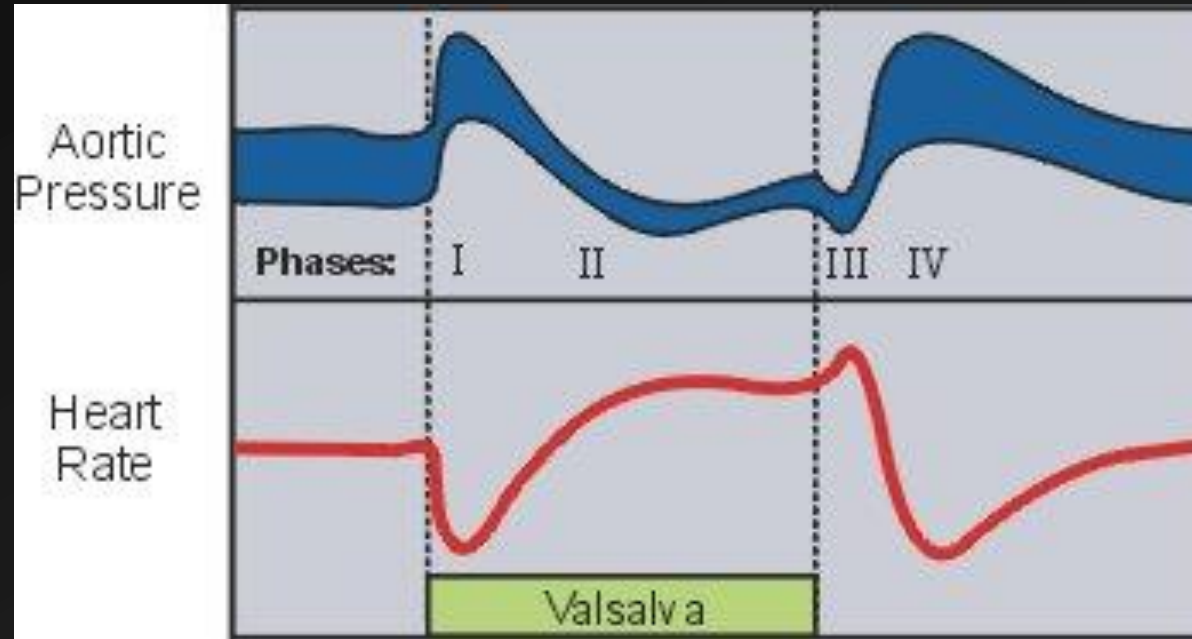


**Figure 9.7** General organization of the baroreceptor heart rate reflex. Reflex originates in mechanoreceptors in the heart and the carotid and other great arteries. The NTS excites (+ symbol) the parasympathetic motor neurons (PMN) and inhibits (- symbol) relay neurons to the sympathetic motor neuron pool (SMN). Insert illustrates the relationship between blood pressure (BP) and heart rate (HR). PG and SG depict parasympathetic and sympathetic ganglia, respectively. Other abbreviations are as in Figure 9.6.



# Valsalva Maneuver:

conduct a maximal, forced expiration against a closed glottis and holding this for at least 10 seconds



- Phase I: Increase Aortic Pressure, Reflex Bradycardia (baroreceptors)
- Phase II: Since Vena Cava compressed, decreased venous return, CO plummets, leads to increase HR
- Phase III: End of compression, dip in aortic pressure, compensatory increase in HR
- Phase IV: End of compression, sudden venous return, increase CO and aortic pressure, compensatory decrease in HR

# Integrated Control Mechanisms

- Respiratory Effects
  - Respiratory Sinus Arrhythmia (RSA)
    - This arrhythmia is not a bad thing!
  - HR acceleration linked to inspiration
  - HR deceleration linked to expiration
- RSA
  - Indexes strength of Vagal influence
  - More later...

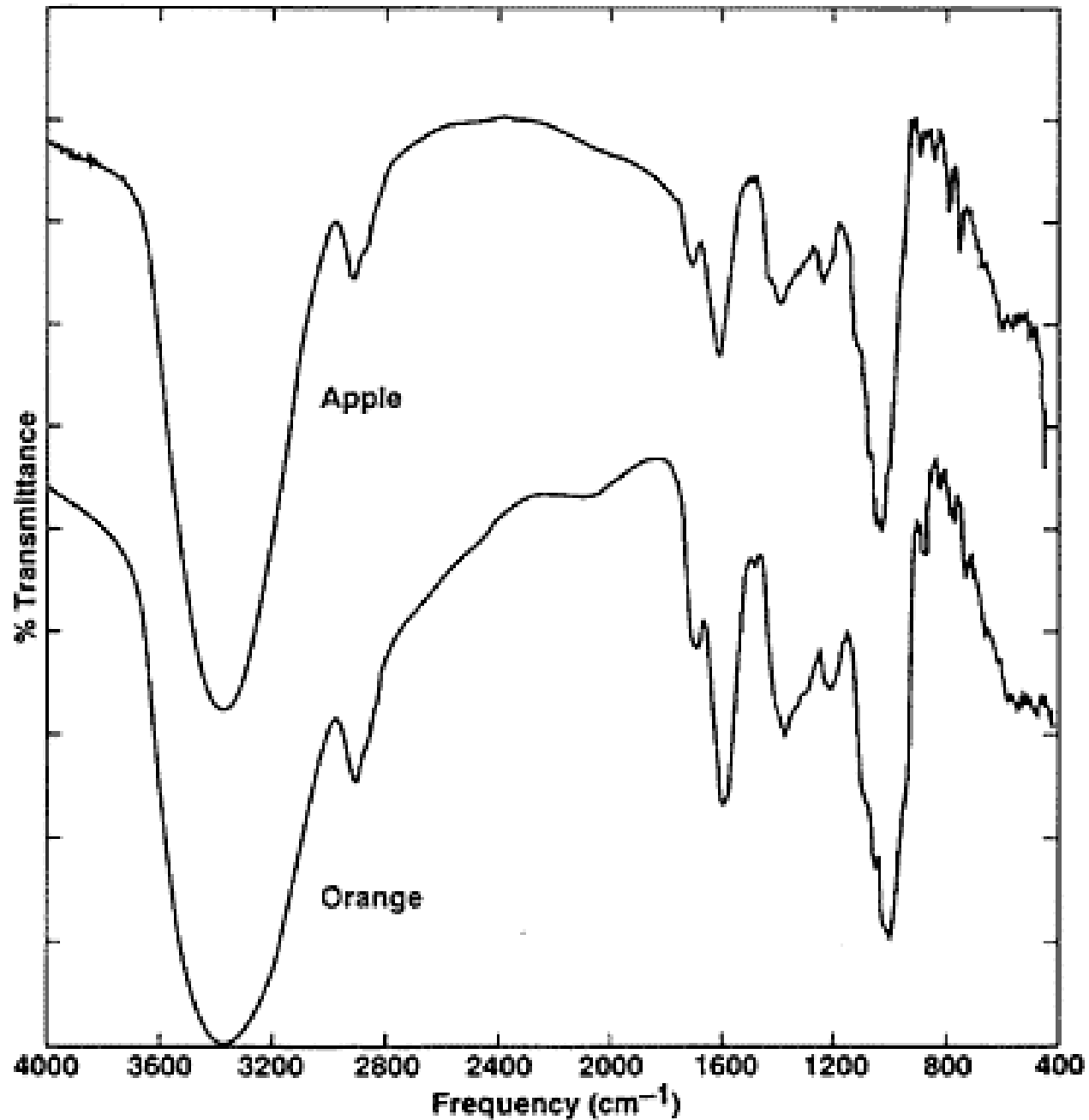
# Cardiac Inotropy

- Contractility is predominately Sympathetically mediated
- Often measured invasively, but can be measured noninvasively
  - EKG plus phonocardiogram
  - Impedance cardiography

# SNS and PNS Integration: A Caveat

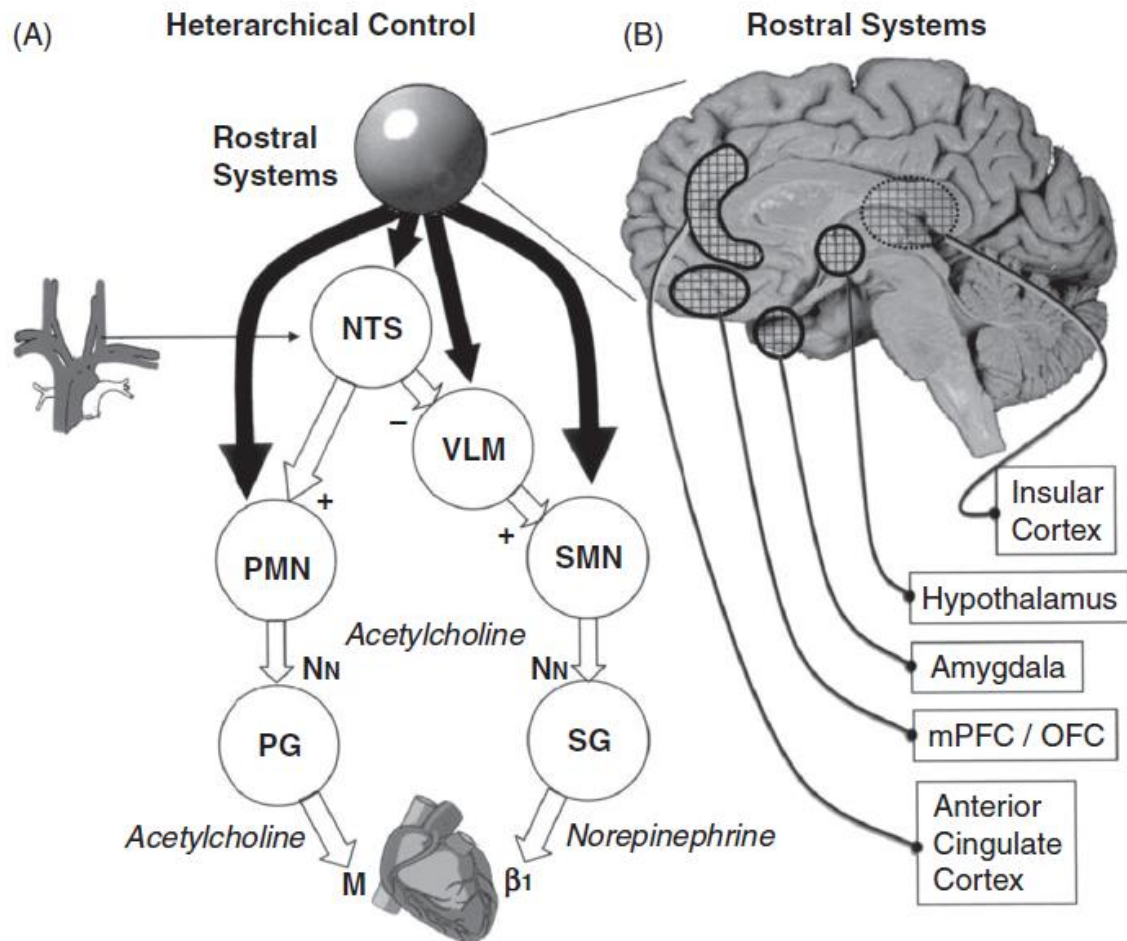
- Relatively easy to measure PNS: RSA or other metrics of HRV
- Relatively easy to measure SNS: Contractility via PEP
- BUT... one is measure of chronotropy, other is measure of inotropy
  - Changes in contractility can occur independently of changes in rate
  - SNS inputs for inotropy primarily controlled by left-sided inputs to AV node
  - SNS inputs of chronotropy primarily controlled by right-sided inputs to SA node
- Thus, like “mixing apples and oranges”

# APPLES VS ORANGES



Comparison of the 2.5-25 mm infrared transmission spectra of a Granny Smith apple and a Sunkist Navel orange.

Source: *Biomednet.com*



**Figure 9.8** Rostral neural systems and heterarchical control. (A) Schematic representation of higher neural control of the autonomic nervous system. The figure illustrates the two general features of heterarchical control: a hierarchical structure together with long ascending (and descending) connections which bypass intermediate levels of organization. (B) Higher neural systems and areas that have been implicated in autonomic control. mPFC – medial prefrontal cortex; OFC – orbitofrontal cortex; other abbreviations are as in Figure 9.7.

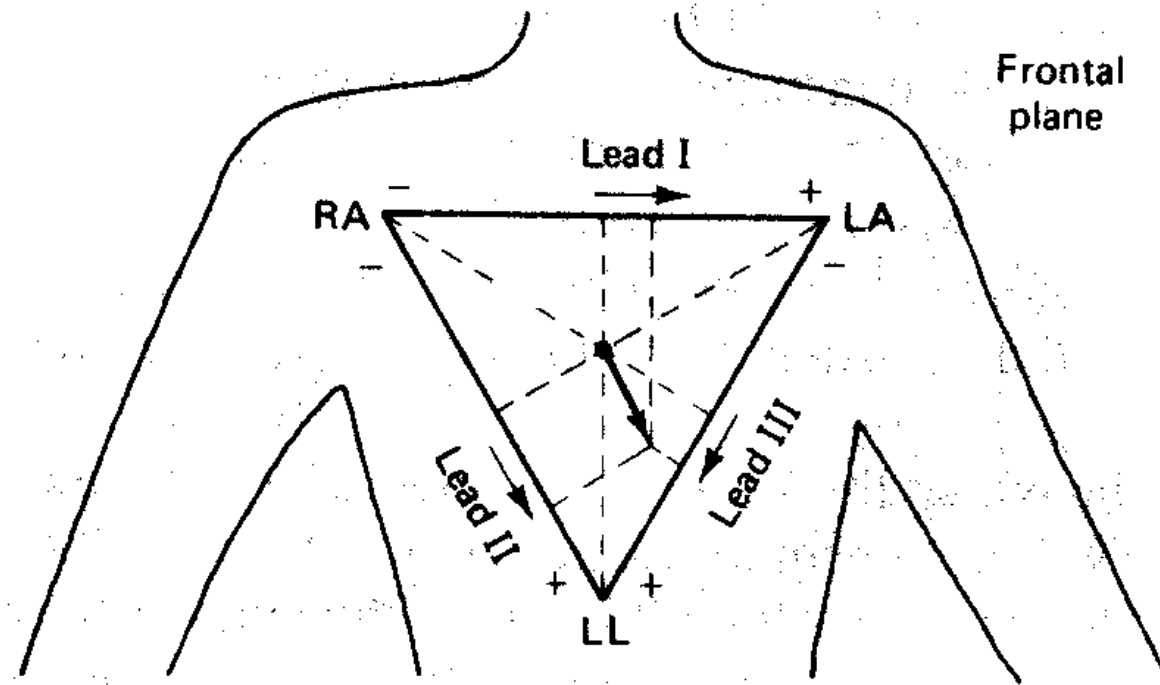


# Cardiovascular Measures

- Electrocardiogram (EKG)
- Phonocardiogram (PCG)
- Impedance cardiography
- Photoplethysmography
- Ballistocardiography
- Blood Pressure
- Impedance cardiography

# EKG

AC signal  
Sample 200-500 Hz



## Bipolar

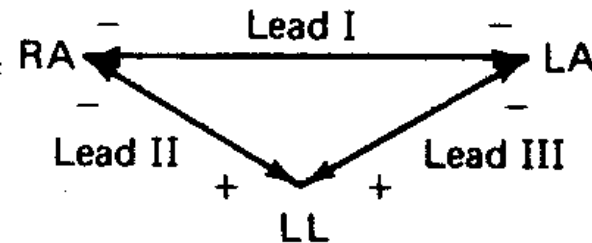
Bipolar limb leads: ECG voltage measurements between pairs of limbs:

Lead I: between RA and LA

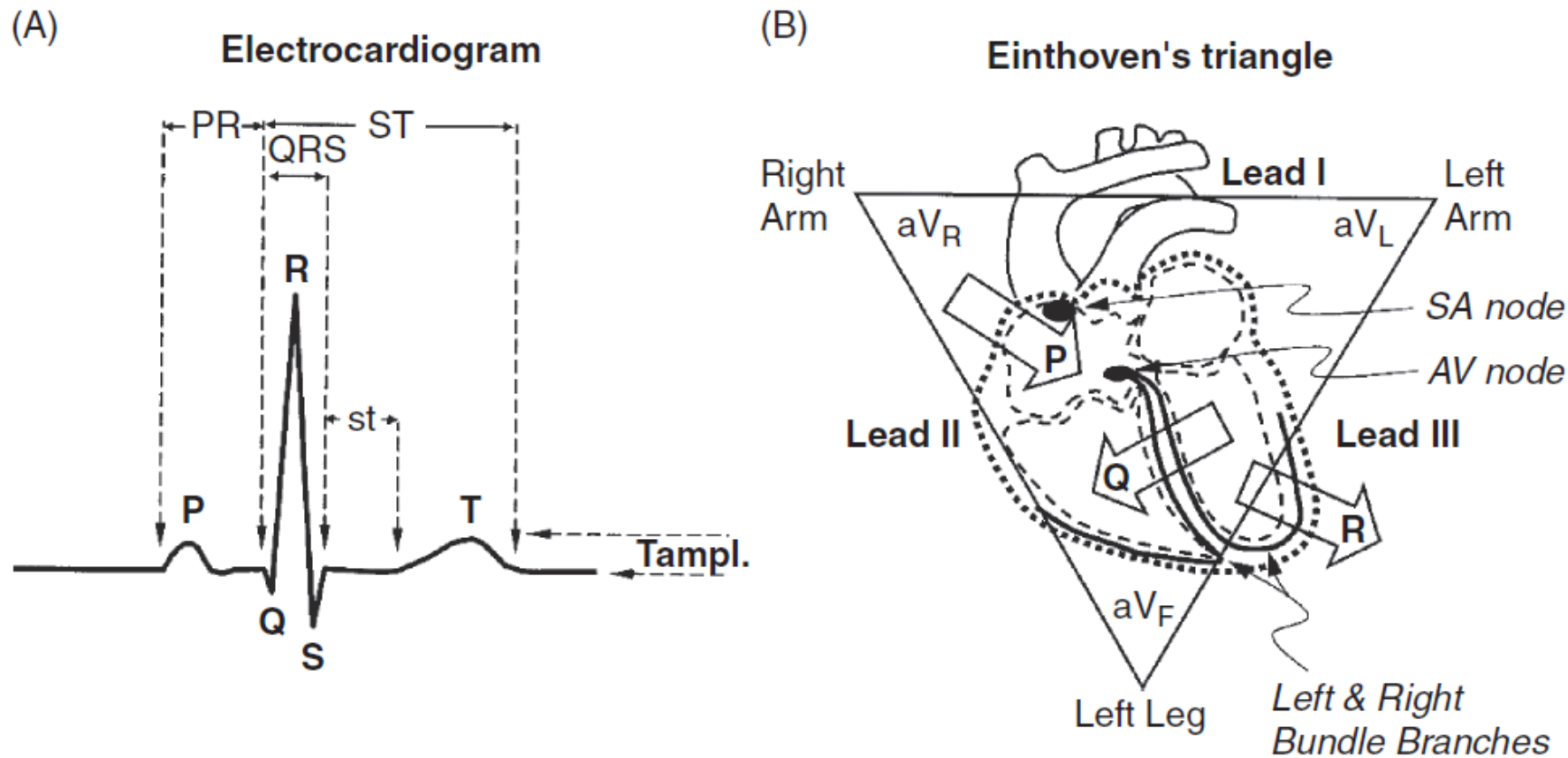
Lead II: between RA and LL

Lead III: between LA and LL

Einthoven triangle, showing relation of the bipolar limb leads



# EKG



**Figure 9.3** The heart and the electrocardiogram. (A) General morphology of the electrocardiographic (ECG) signal showing the P, Q, R, S, & T components, the PR, ST, and QRS intervals, the *st* segment, and the T wave amplitude. (B) The heart, conduction system, and Einthoven's triangle. Open arrows indicate typical electrical vectors associated with the propagation of electrical activation during the P, Q, and R waves of the ECG.

# Which Time?

- Real time
  - Heart Rate
    - Expressed as beats per time (usually bpm)
- Cardiac time
  - Heart Period; interbeat interval (IBI)
  - Expressed in msec
- Converting

$$HR = \frac{1}{HP} \times 60,000$$

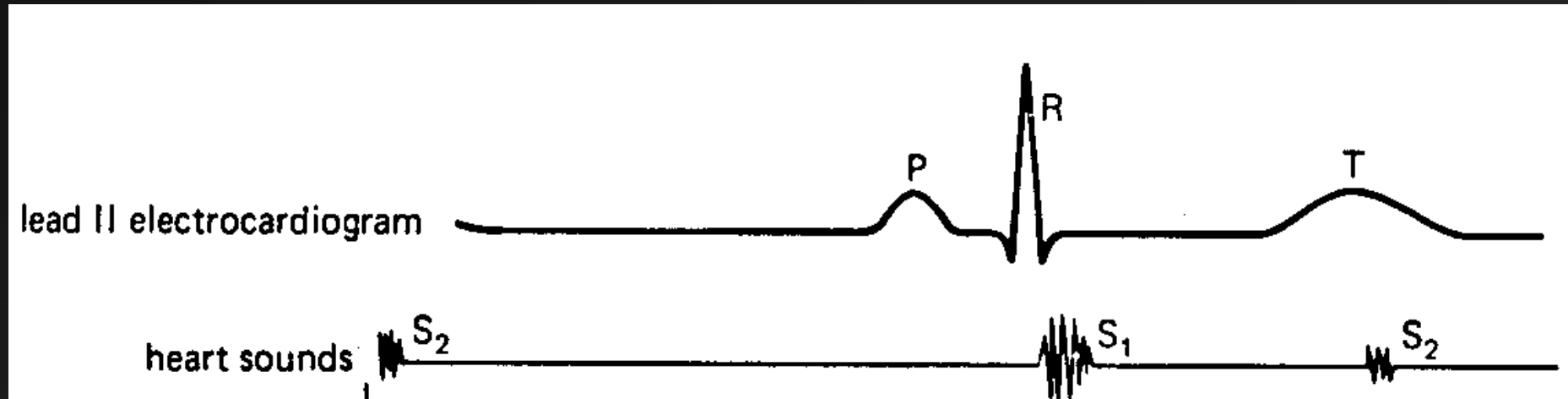
$$HR = \frac{1}{1000} \times 60,000 = 60bpm$$

# Which Time?

- HR more intuitive
- HP better behaved for statistical analysis
  - More closely and linearly related to changes in SNS and PNS
- Other considerations for measuring change: time vs cycles
  - If examining fixed time, slower HR provides fewer cycles than fast HR
  - If examining fixed number of cycles, those with fast rate provide shorter time segment for data analysis

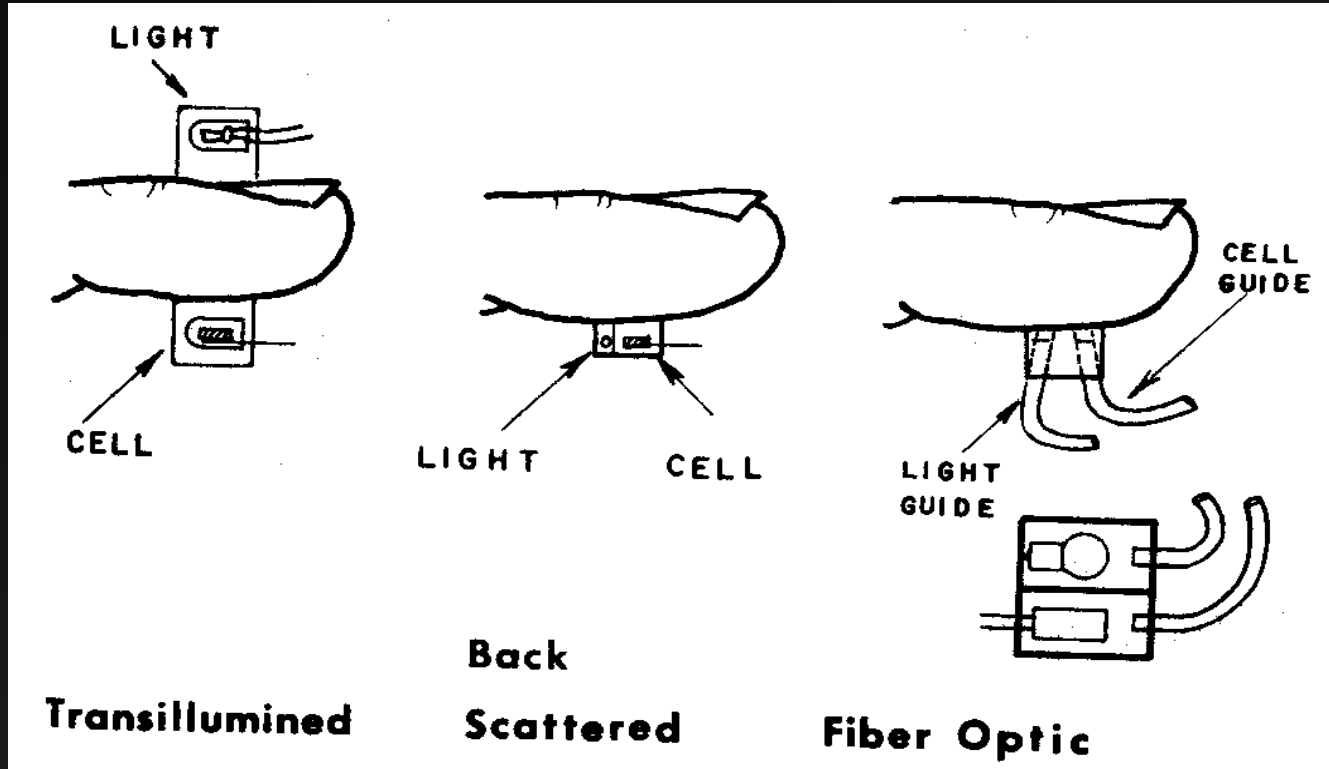
# Phonocardiography

- Position microphone over heart
- Lub-Dub is transduced to electrical signal





# Photoplethysmography

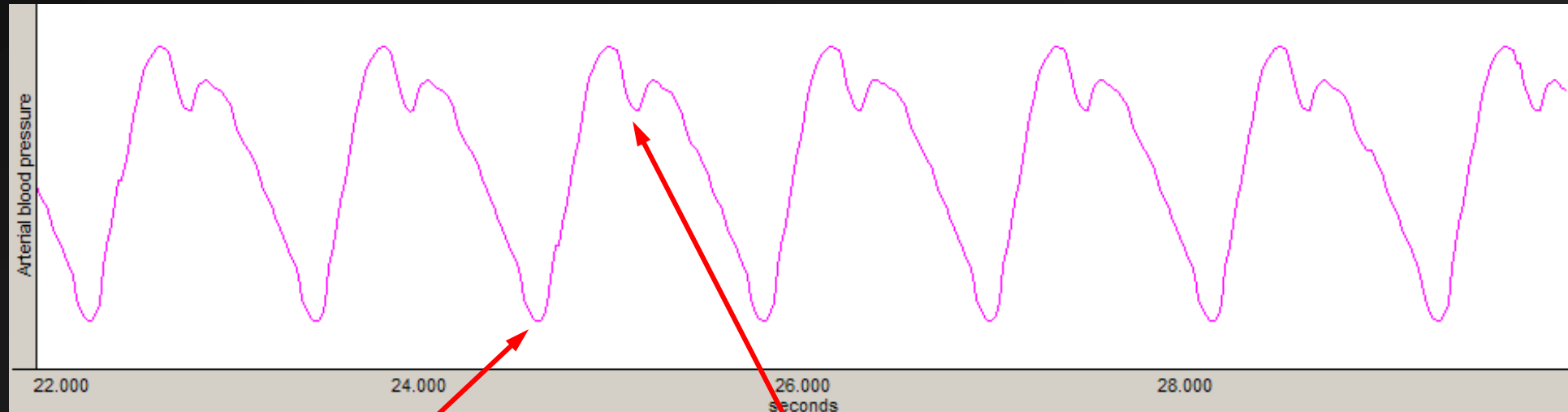


Three methods, all involve measuring light absorbed by peripheral vasculature

- Living tissue relatively transparent to IR light
- Blood relatively opaque to IR light
- Photocell transduces light received to electrical signal



# The Photoplethysmographic Output

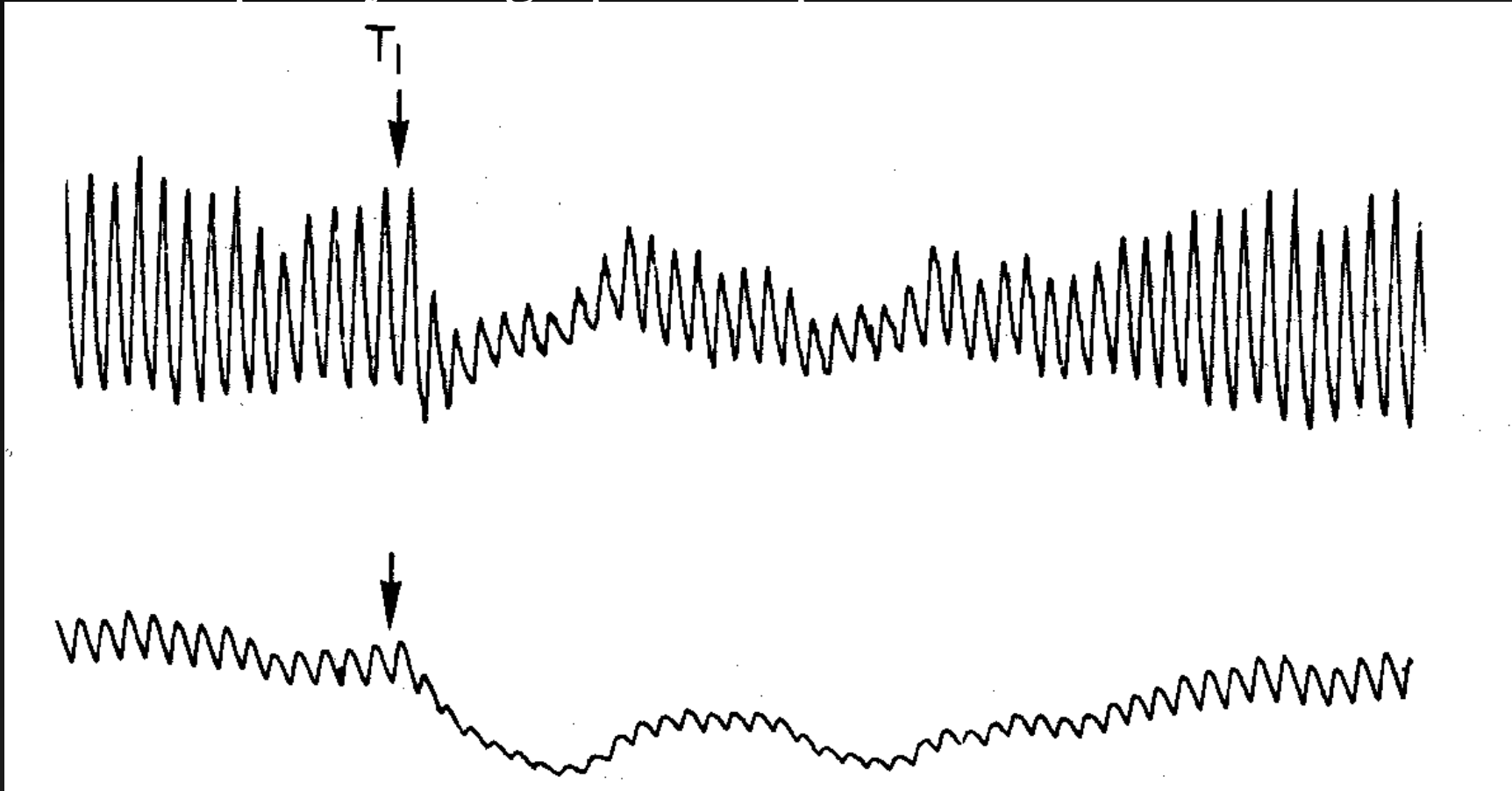


Increase in Pressure due to opening of Aortic Valve

~LVET

Dichrotic Notch; closing of valve, end of ejection

# Photoplethysmograph: Peripheral Vasoconstriction



$T_1$  is onset of constriction

Top Panel: Pulse Volume (recorded with 1 sec time constant)

Lower Panel: Blood Volume (no filter)

## Measuring contractility with EKG, PCG, and Photoplethysmography

PEP = Pre-ejection period

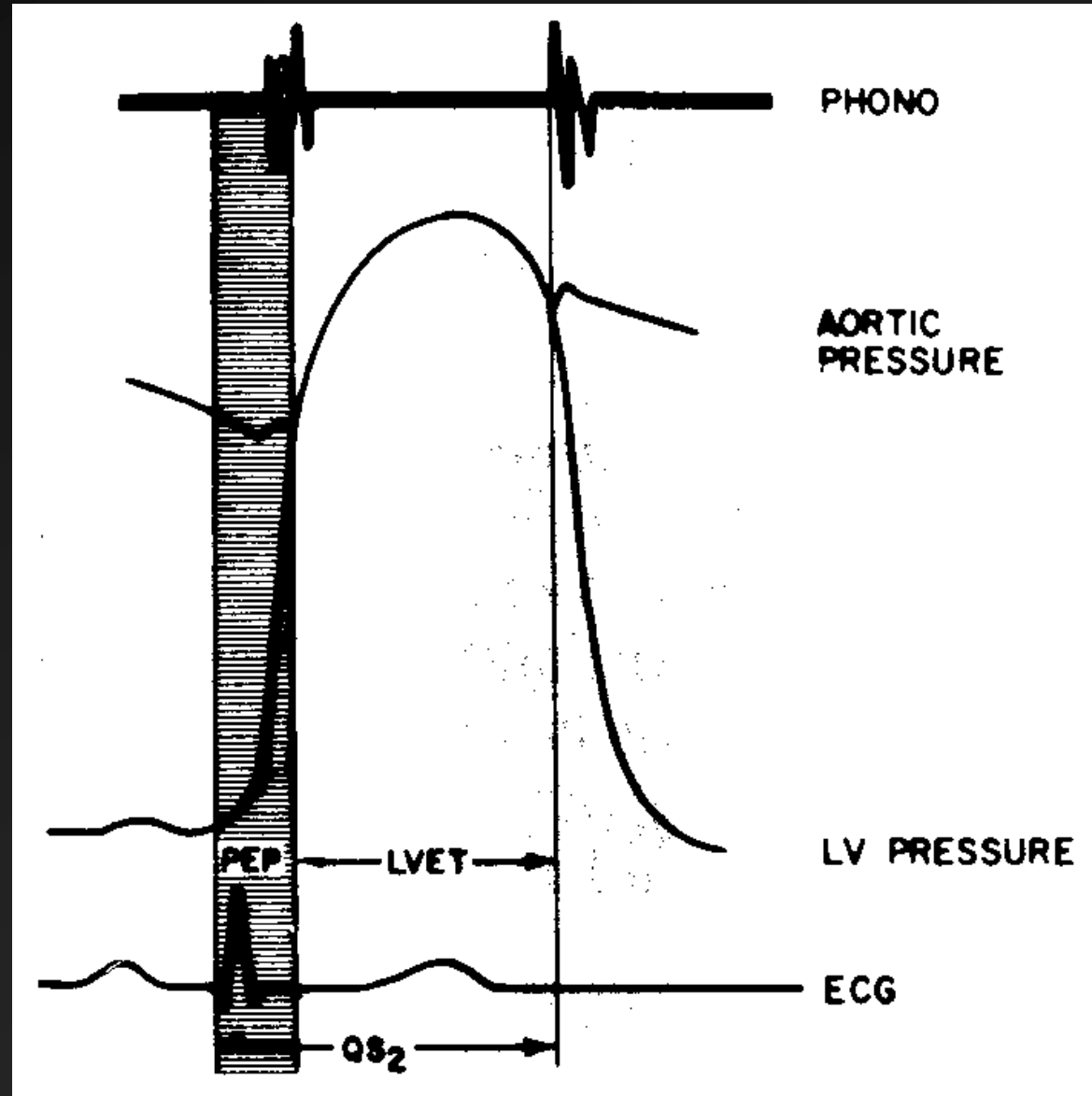
LVET = Left Ventricular Ejection  
Time

= Upswing of pressure  
wave to S<sub>2</sub>

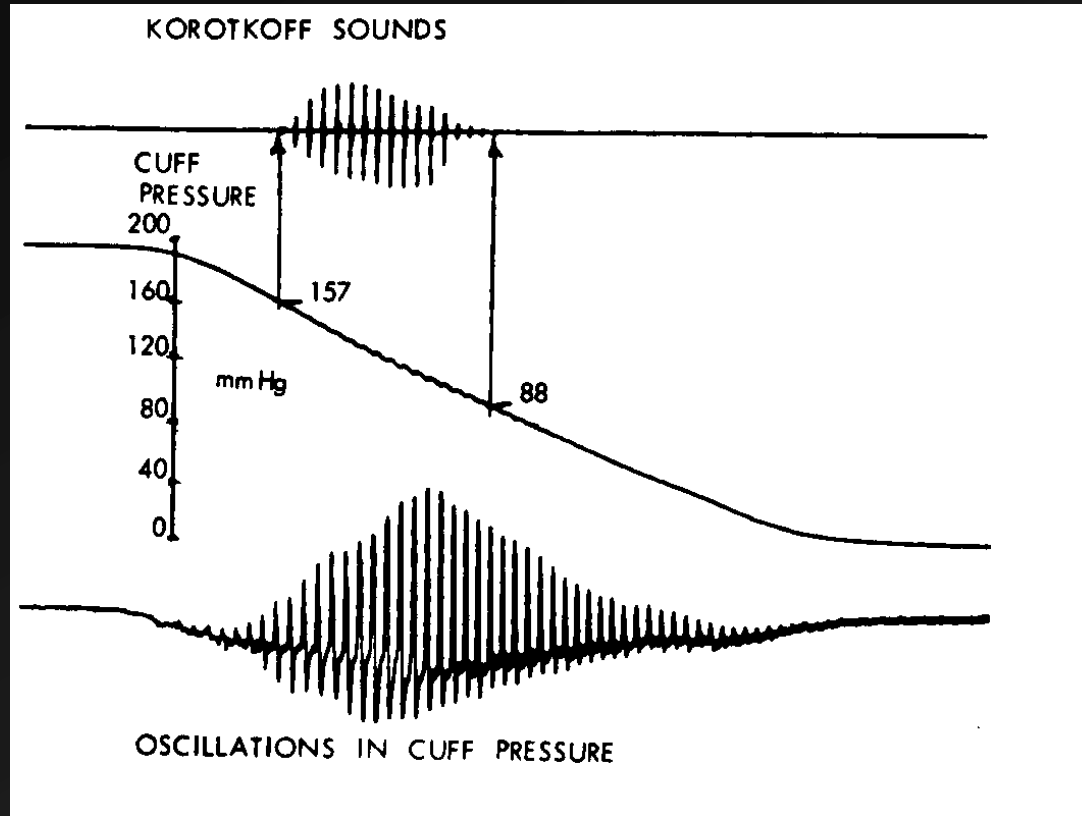
Electromechanical Systole =  
Q to S<sub>2</sub>

PEP = EMS – LVET

PEP reflects sympathetic  
influence on cardiac  
contractility



# Measuring Blood Pressure



Inflate cuff and then slowly deflate

As cuff pressure decreases below SBP, K-sounds will appear and slowly increase in volume

They will then decrease and finally disappear when cuff pressure reaches DBP

Auscultatory Technique

- Not good for instantaneous readings
- Not good for repeated readings



# BP and Stress?

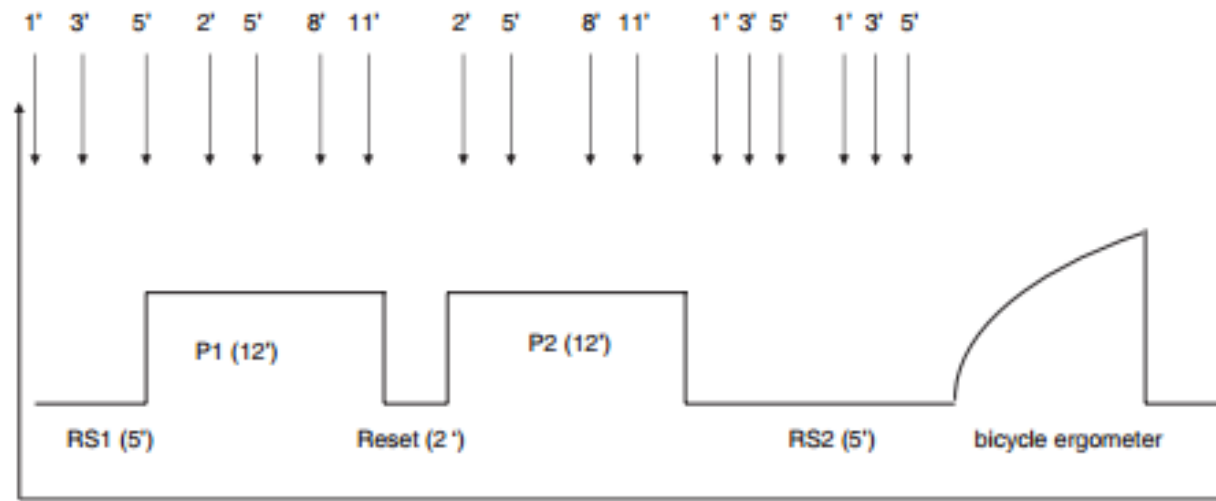
*Psychophysiology*, 45 (2008), 327–332. Blackwell Publishing Inc. Printed in the USA.  
Copyright © 2007 Society for Psychophysiological Research  
DOI: 10.1111/j.1469-8986.2007.00622.x

## Cardiovascular effects in adolescents while they are playing video games: A potential health risk factor?

PETER BORUSIAK,<sup>a</sup> ANASTASIOS BOUIKIDIS,<sup>b</sup> RÜDIGER LIERSCH,<sup>a</sup> AND JARROD B. RUSSELL<sup>a</sup>

<sup>a</sup>Zentrum für Kinder- und Jugendmedizin, Helios Klinikum Wuppertal, Wuppertal, Germany

<sup>b</sup>Zentrum für Kinder- und Jugendmedizin, Evangelisches Krankenhaus Oberhausen, Oberhausen, Germany



**Fig 1.** Study design (RS1, RS2 = resting phase 1 and 2; P1, P2 = video game phase 1 and 2; arrows indicating blood pressure measuring)

# BP and Stress?

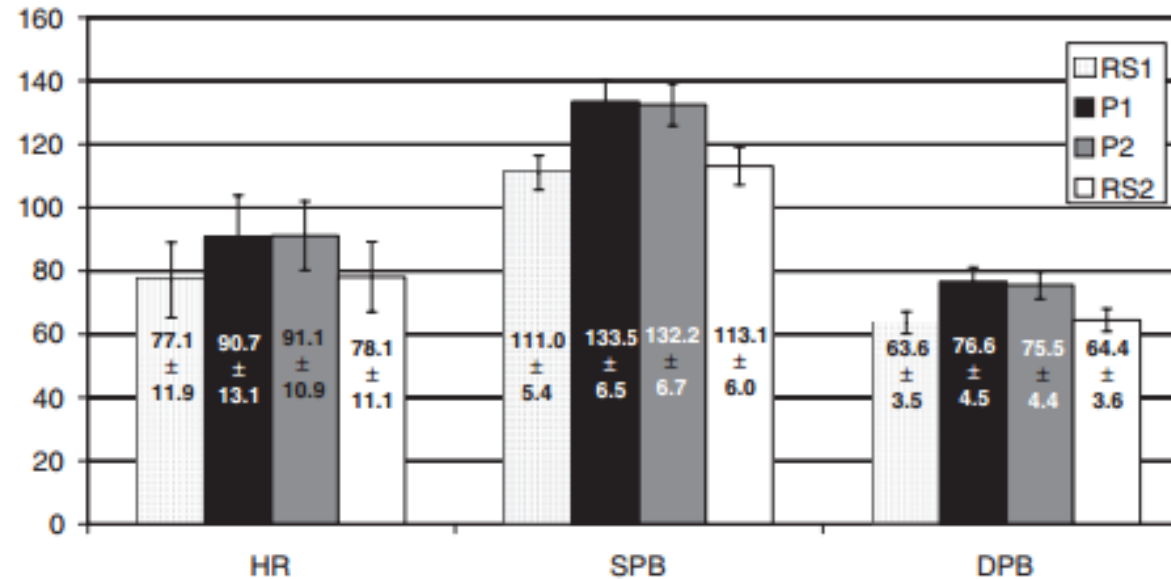


Fig 2. Mean values and SD of cardiovascular parameters during resting state and video game

Differences were significant for heart rate (HR), systolic (SBP) and diastolic blood pressure (DBP) comparing resting phases and game phases. No significant differences could be found comparing RS1 vs. RS2 and P1 vs. P2 (RS1, RS2 = resting phase 1 and 2; P1, P2 = video game phase 1 and 2).

- Significantly elevate BP during Video Game (VG)
- Energy consumption during Video Game unaltered compared to Rest, and significantly lower compared to Exercise!
- “Comparing all measured parameters it can be said that the relation of blood pressure and energy consumption during VG might not be favorable.”

# Stress, Exertion, or both?

<https://www.youtube.com/watch?v=rMqVmiOwU4>

# Ballistocardiography

- Imagine
  - On a chair on a platform on an air hockey table
  - Cardiac events cause movement of platform
- Applications:
  - Finding individuals hiding in vehicles
  - Finding individuals stuck in rubble

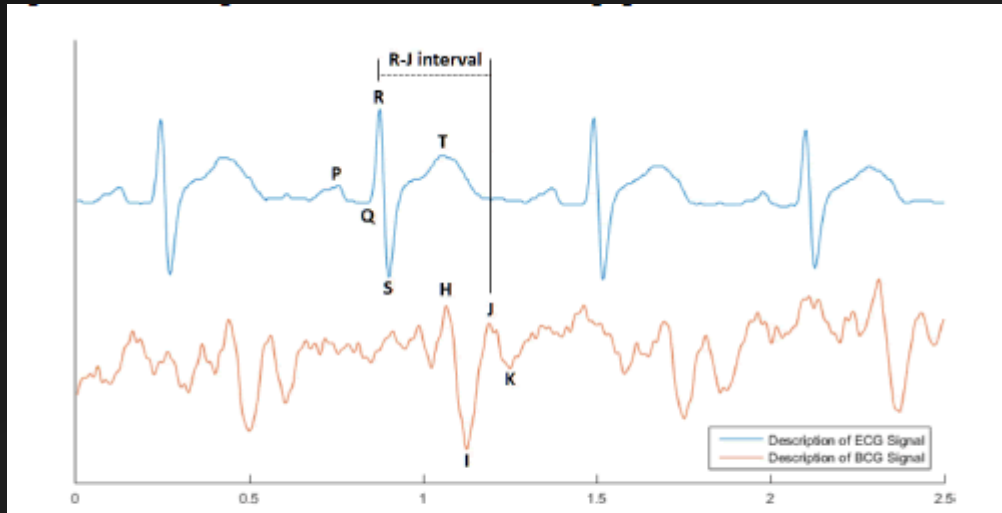
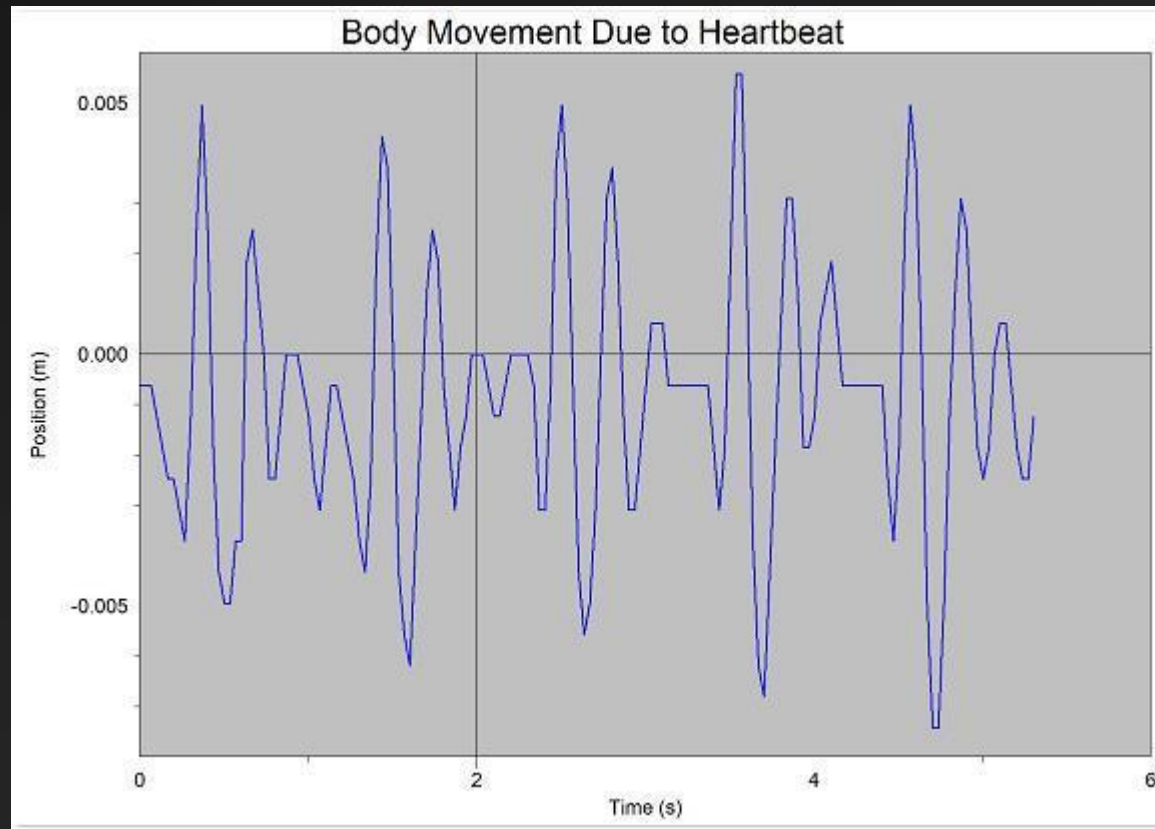


Figure 1. Location of P, Q, R, S, and T peaks in ECG and H, I, J, and K peak in BCG signal. The x-axis represents time [sec], and the y-axis is expressed in arbitrary units.

ring of older patients

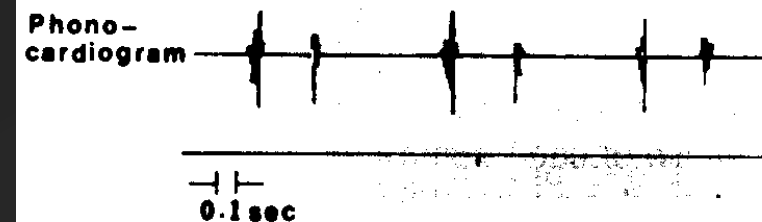
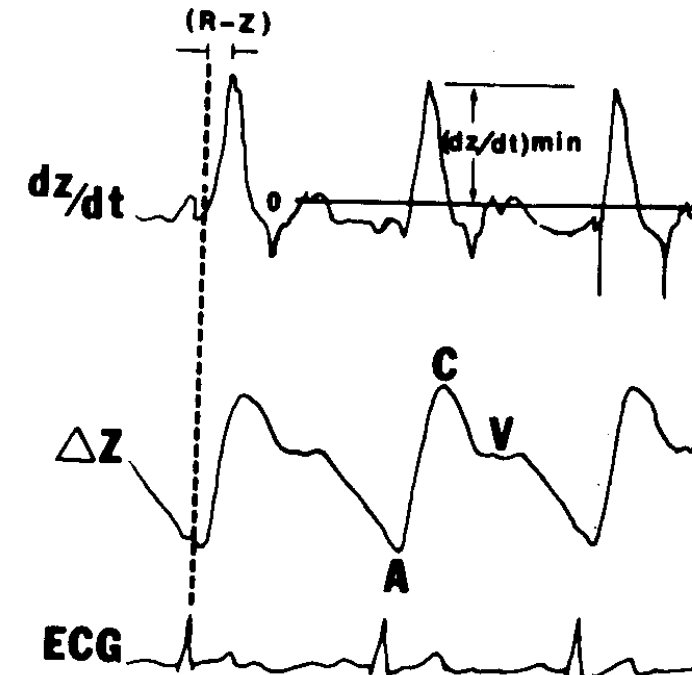
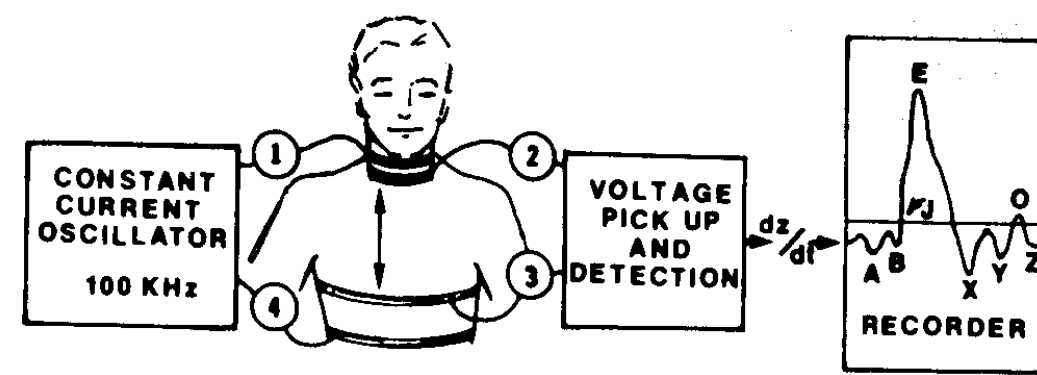


# Ballistocardiography



# Impedance Cardiography

- Low energy high-frequency AC passed through thoracic region (1-4 mA, 100 KHz)
- Changes in impedance to signal created by mechanical events of cardiac cycle, especially changes in thoracic blood volume
- $\Delta Z$  is change in impedance
- $Dz/dt$  is 1st derivative of impedance signal  $Z$
- R-Z is time from r-wave to peak ventricular contraction indicated in  $Z$  signal
- The “Heather” index – divide  $dz/dt$  by R-Z interval; putative measure of heart’s ability to respond to stress



# Measuring Vagal Influence

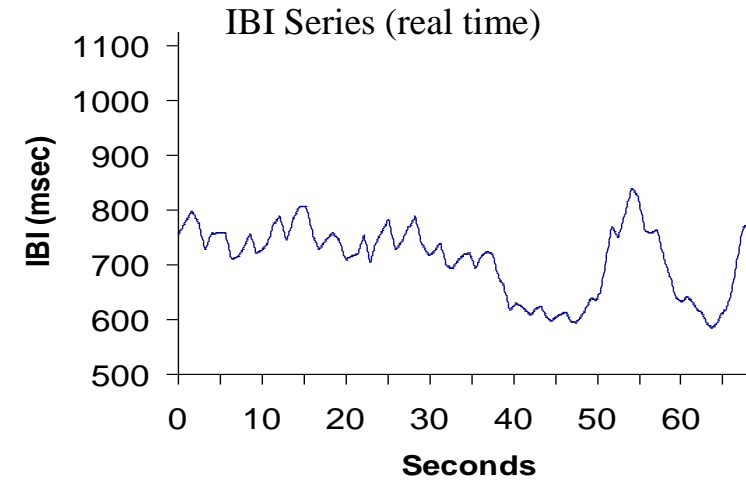
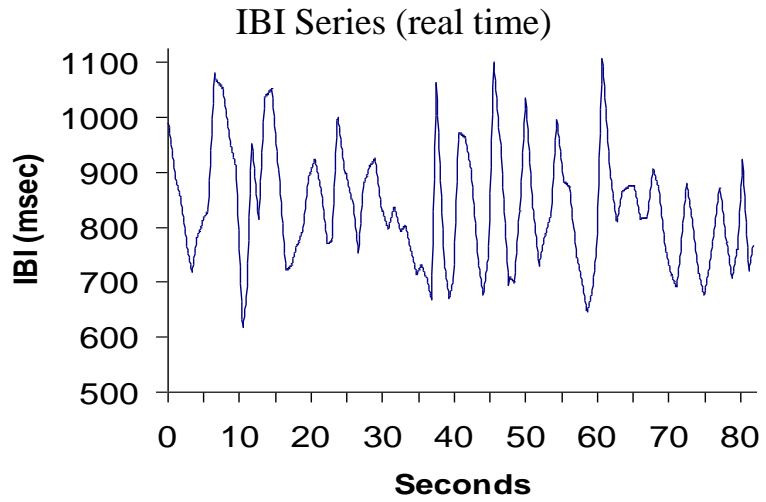
- Descending Vagal Influence slows HR
- Respiration interrupts this vagal influence
- The size of periodic oscillations due to respiration can therefore index the strength of the Vagal influence
  - Note, however, that under some circumstances, there can be dissociation between RSA and presumed central cardiac vagal efferent activity (cf., Grossman & Taylor, 2007)
  - Concerns over changes in rate, and to lesser extent depth
  - See special issue of *Biological Psychology*, 2007 for more in depth treatment of these issues and more!
- [Demo](#) with QRSTool



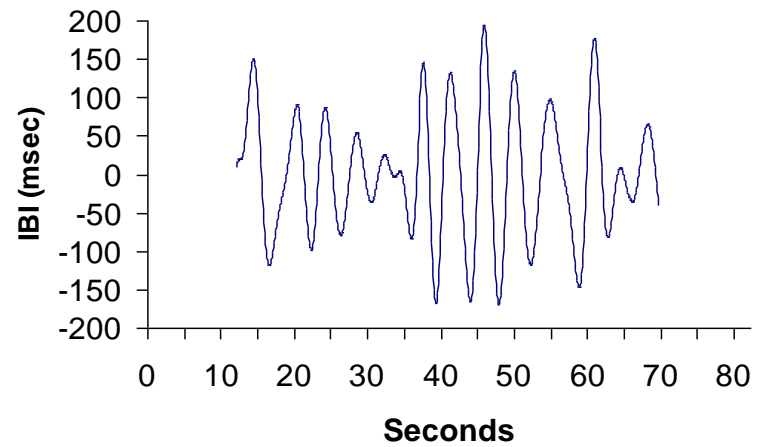
# Abbreviated History of HR Variability

(with thanks to Porges, 2007)

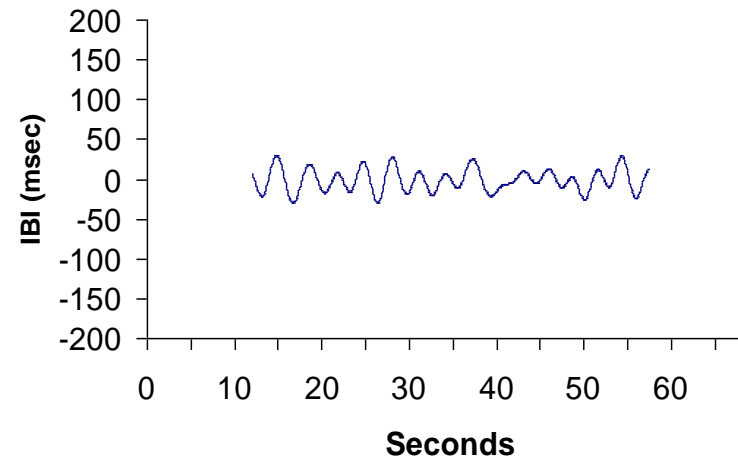
- Physiology treated HR as DV, similar to behavior
- Dominance of behaviorism emphasized control over the DV (behavior)
- Changes in HR unrelated to the manipulation considered noise
  - Lacey (1967) and Obrist (1981) had models related to attention, and metabolic demand, but HR *variability* did not fit in either model
  - Via appropriate experimental design, HR should be entirely under the control of experimental or environmental demands
- Nonetheless, history of quantifying HR variability dates to the 1950's with case report long before that:
  - 1958: Lacey and Lacey, greater HRV associated with greater impulsivity
  - 1915: Eppinger and Hess, described a vagotonic syndrome with clinical features that included an exaggerated RSA
  - Interest in HRV as an *individual difference* variable, however, really starts with the work of Steve Porges



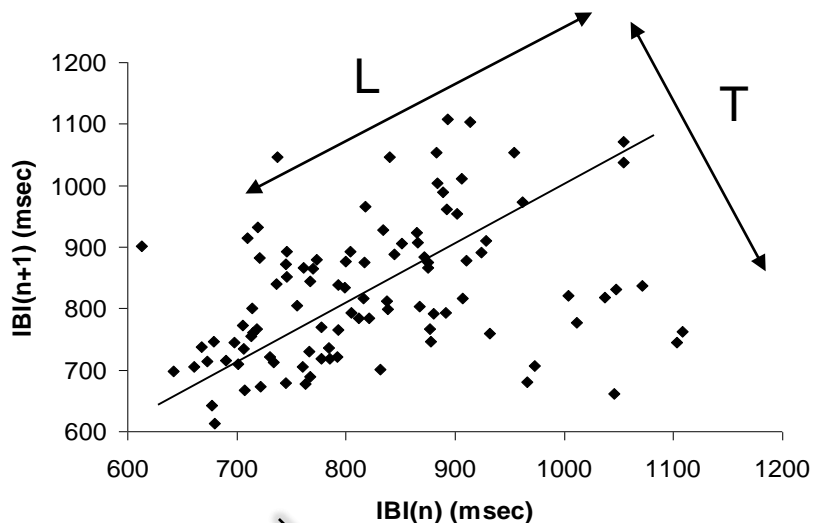
.12-.40 Hz filtered IBI Time Series



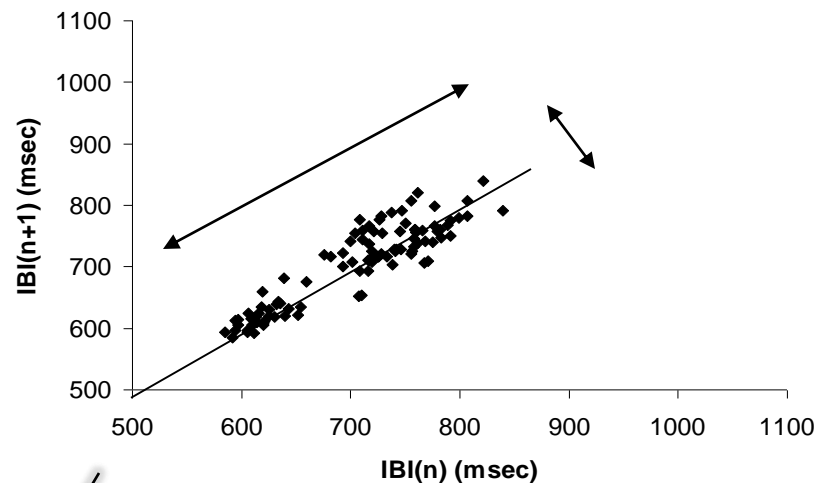
.12-.40 Hz filtered IBI Time Series



### High Variability Subject



### Low Variability Subject



Rate		
73.3	HR	85.7
832.3	IBI	707.7
Total Variability		
9.2	HRV	8.3
112.4	SDNN	66.3
132.8	RMSSD	27.7
"Sympathetic"		
1.4	CSI	4.7
"Parasympathetic"		
57.1	PNN50	10.8
97.6	MCD	22.0
5.3	CVI	4.5
8.8	RSA	5.3

Metrics output by CMetX, with notes concerning computation

**Metrics of rate, which are influenced by both parasympathetic (PNS) and sympathetic (SNS) influences**

Mean interbeat interval (IBI), calculated as simple average of IBIs

Mean heart rate (HR), calculated as the average of the rate-transformed IBIs, not as the rate-transformation of the average IBI

**Metrics summarizing total heart rate variability, which are influenced by both SNS and PNS**

Heart rate variability (HRV), operationalized as the natural log of the variance of the IBI time series

Standard deviation of IBI series (SDNN); NN in the acronym SDNN is the abbreviation for "normal-to-normal intervals," which is the artifact-free IBI series

Root mean square of successive differences between IBIs (RMSSD)

**Putative sympathetic metric**

A cardiac sympathetic index (CSI; Toichi et al. (1997), see Fig. 1)<sup>a</sup>

**Putative parasympathetic metrics**

Mean absolute successive IBI difference (MSD)

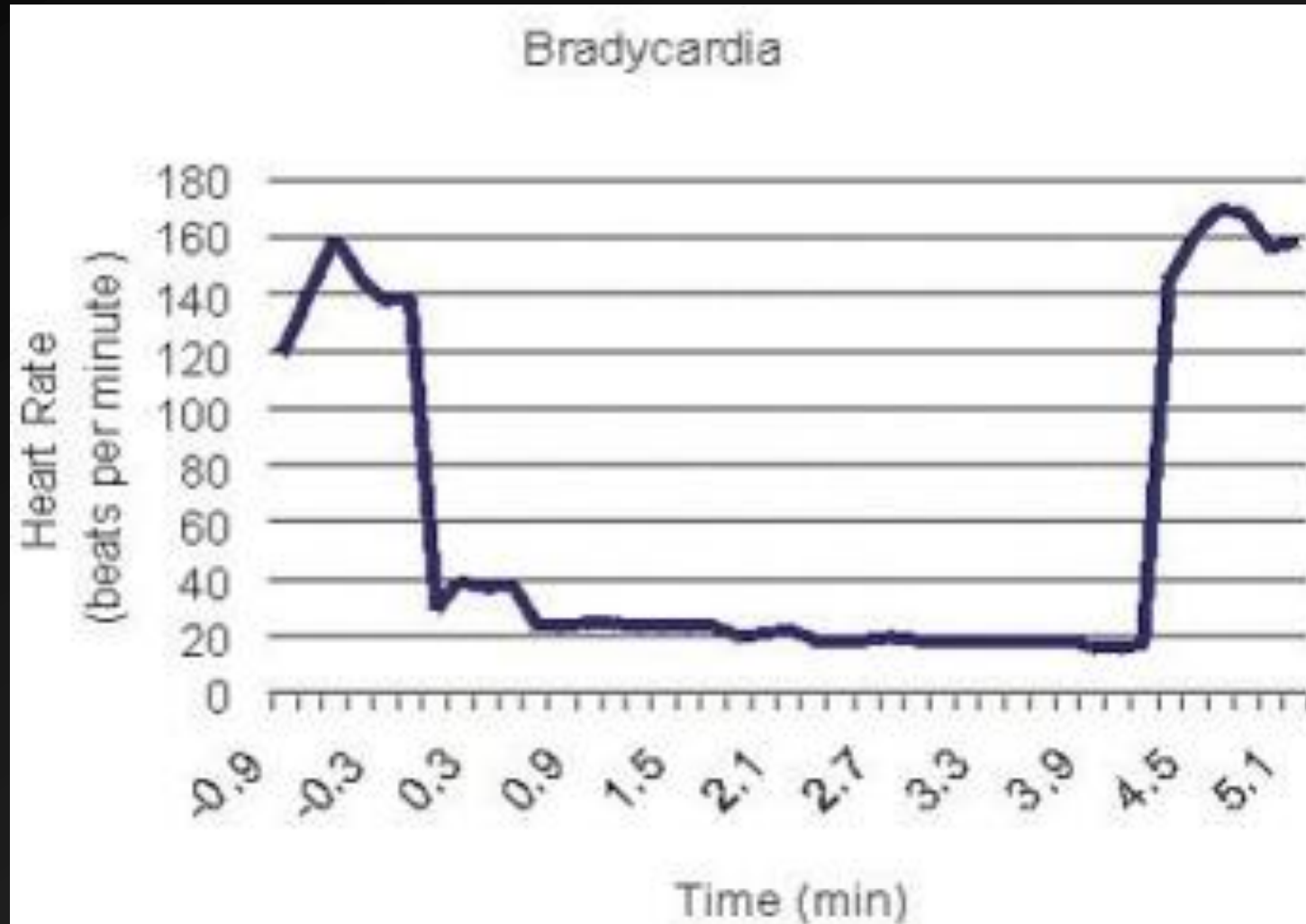
Proportion of consecutive IBI differences >50 ms (pnn50)

Respiratory sinus arrhythmia (RSA), defined as natural log of band-limited (.12-.40 Hz) variance of IBI time series

A cardiac vagal index (CVI; Toichi et al. (1997), see Fig. 1)<sup>a</sup>

# Cardiac Vagal Control and Modulation

- Two Vagal Efferent Branches which terminate on SA Node (Porges 1995, 2003, 2007)
  - Reptilian “Dumb”: Dorsal Motor Nucleus
    - Massive reduction in HR & conservation of oxygen.
    - [Dive reflex](#) -- cold water on the face during breath hold
  - Phylogenetically newer “smart” Vagus
    - Originates from Nucleus Ambiguus
    - Modulates influence to:
      - Promote attentional engagement, emotional expression, and communication.
    - Mobilizes organism to respond to environmental demands
      - Phasically withdraws inhibitory influence, increasing HR
      - Upon removal of the environmental stressor, resumes its efferent signal
        - Slowing heart rate
        - Allows the organism to self-soothe
- This polyvagal theory is not without its critics (e.g., Grossman & Taylor, 2007).



Bradycardia observed in a diving seal. Data adapted from R.S. Elsner (1998), courtesy of <http://www.deeperblue.net/article.php/225>

	ANS Component	Behavioral Function	Lower motor neurons
	<b>Myelinated vagus</b> <i>(ventral vagal complex)</i>	<b>Social communication, self-soothing and calming, inhibit "arousal"</b>	<b>Nucleus ambiguus</b>
	<b>Sympathetic-adrenal system</b>	<b>Mobilization (active avoidance)</b>	<b>Spinal cord</b>
	<b>Unmyelinated vagus</b> <i>(dorsal vagal complex)</i>	<b>Immobilization (death feigning, passive avoidance)</b>	<b>Dorsal motor nucleus of the vagus</b>

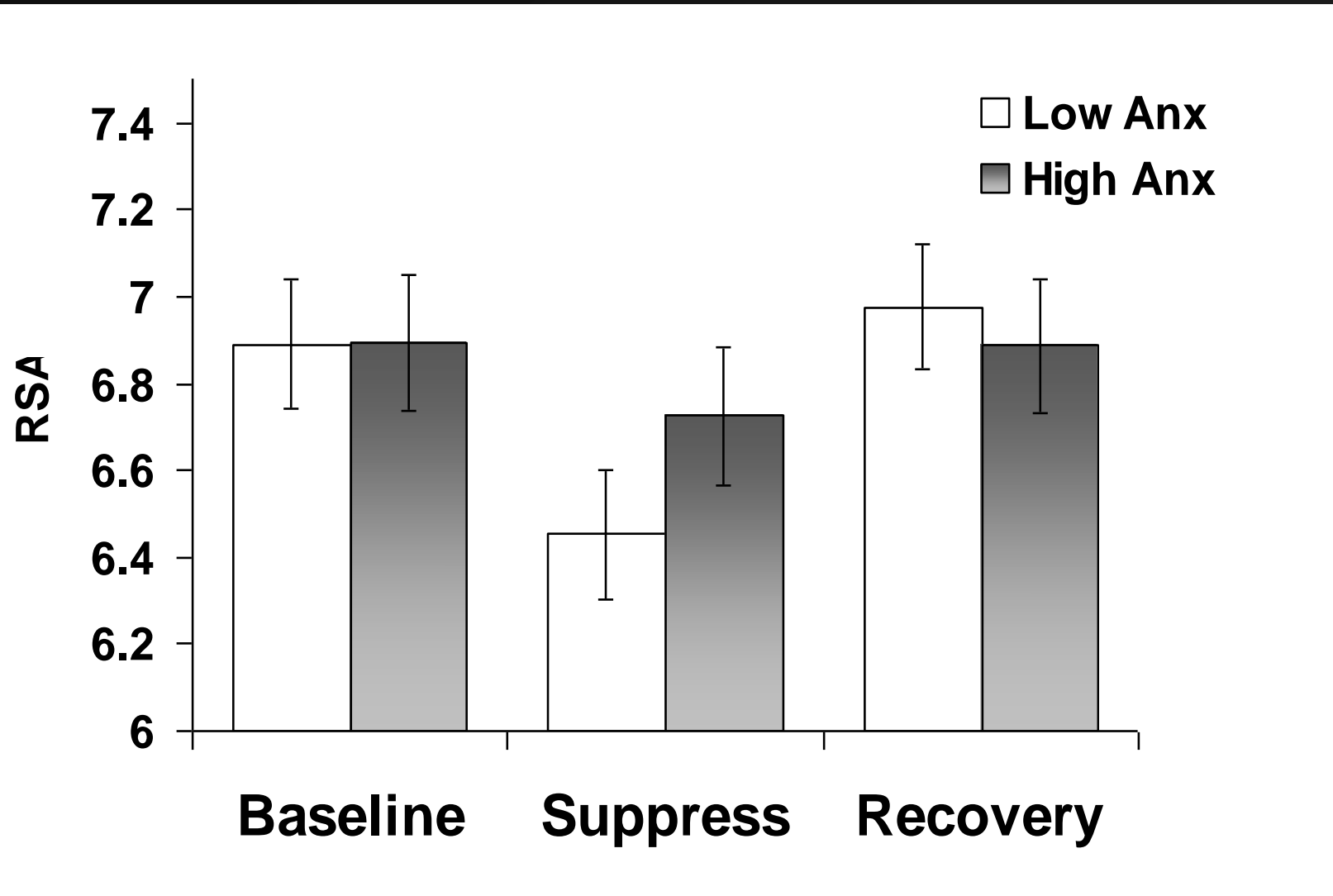
Fig. 1. Phylogenetic stages of the polyvagal theory.

# Tonic Vs Phasic

- Tonic Level indexes capacity
- Phasic change indexes actualization of that capacity
- Attention
  - higher vagal “tone” was associated with faster reaction time to a task requiring sustained attention
  - Hyperactive kids treated with Ritalin (Porges, Walter, Korb, & Sprague, 1975).
    - attentional skills improved
    - appropriate task-related suppression of heart rate variability was observed while performing the task requiring sustained attention
- Emotion
  - Beauchaine (2001):
    - low baseline vagal “tone” is related to negative emotional traits
    - high vagal withdrawal is related to negative emotional states



# Task-related and Emotion-related modulation



# Individual Differences in Cardiac Vagal Control (aka “Trait Vagal Tone”)

- Infants
  - Various sick infants have lower vagal tone (Respiratory Distress Syndrome, Hydrocephalic)
  - Infants with higher vagal tone (Porges, various years)
    - More emotionally reactive (both + & -)
    - More responsive to environmental stimuli (behaviorally and physiologically)
- Anxiety Disorders
  - Lower Vagal Tone in GAD ([Thayer et al., 1996](#))
  - Lower Vagal Tone in Panic Disorder ([Friedman & Thayer, 1998](#))
- Depression
  - Depression characterized by lower Vagal tone?
  - State dependent? ([Chambers & Allen, 2002](#))

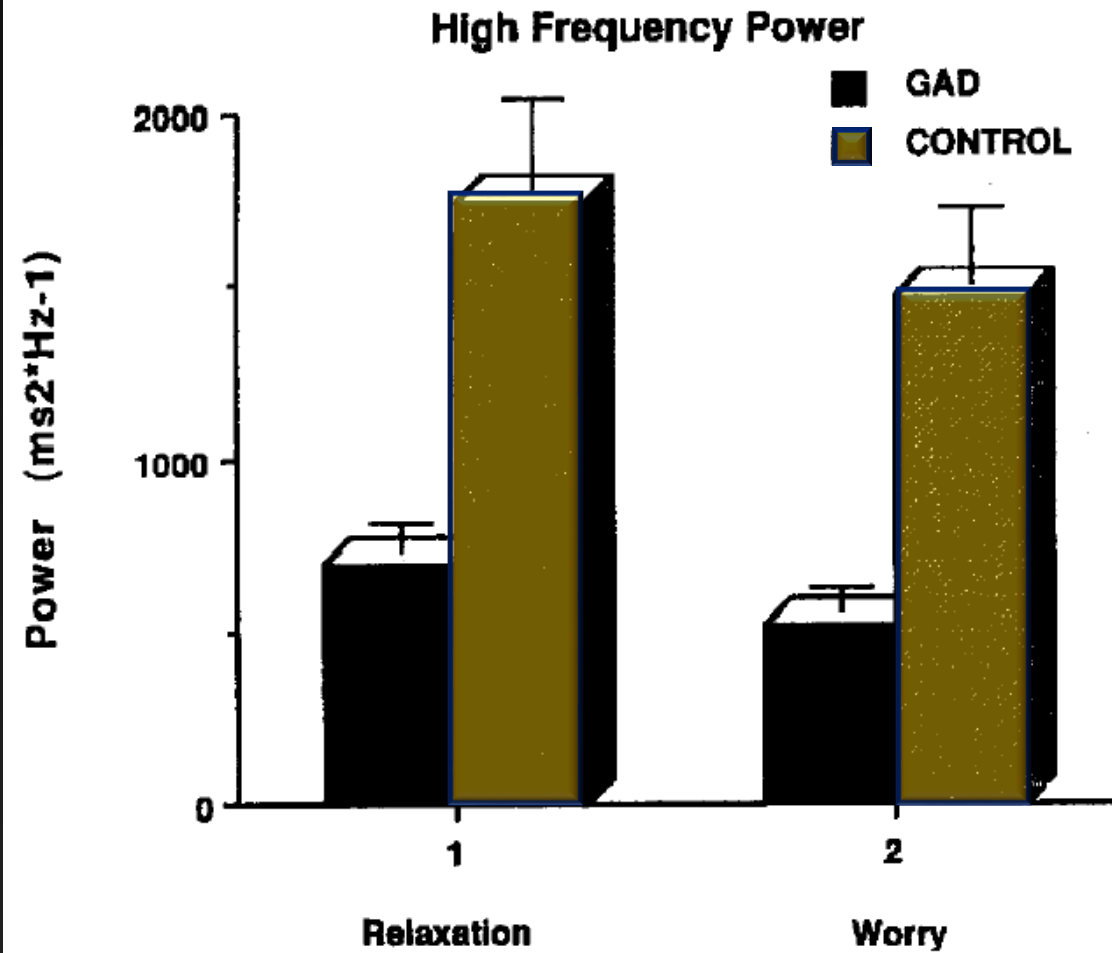
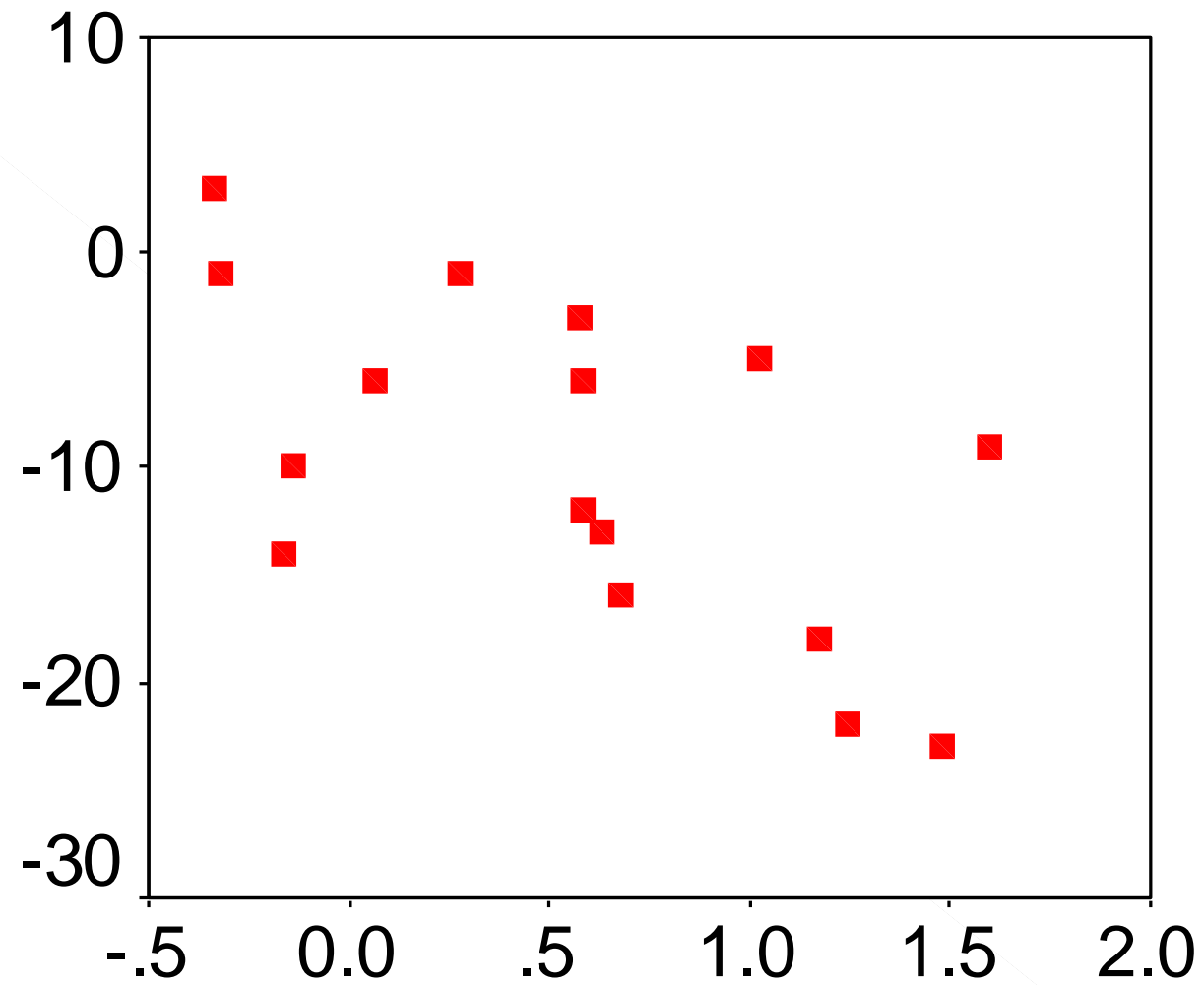


Figure 1. Power in the high frequency (respiratory) component of heart period variability in GAD patients and controls during relaxation and worry.

Table 1  
Significant contrasts among panickers, blood phobics, and controls

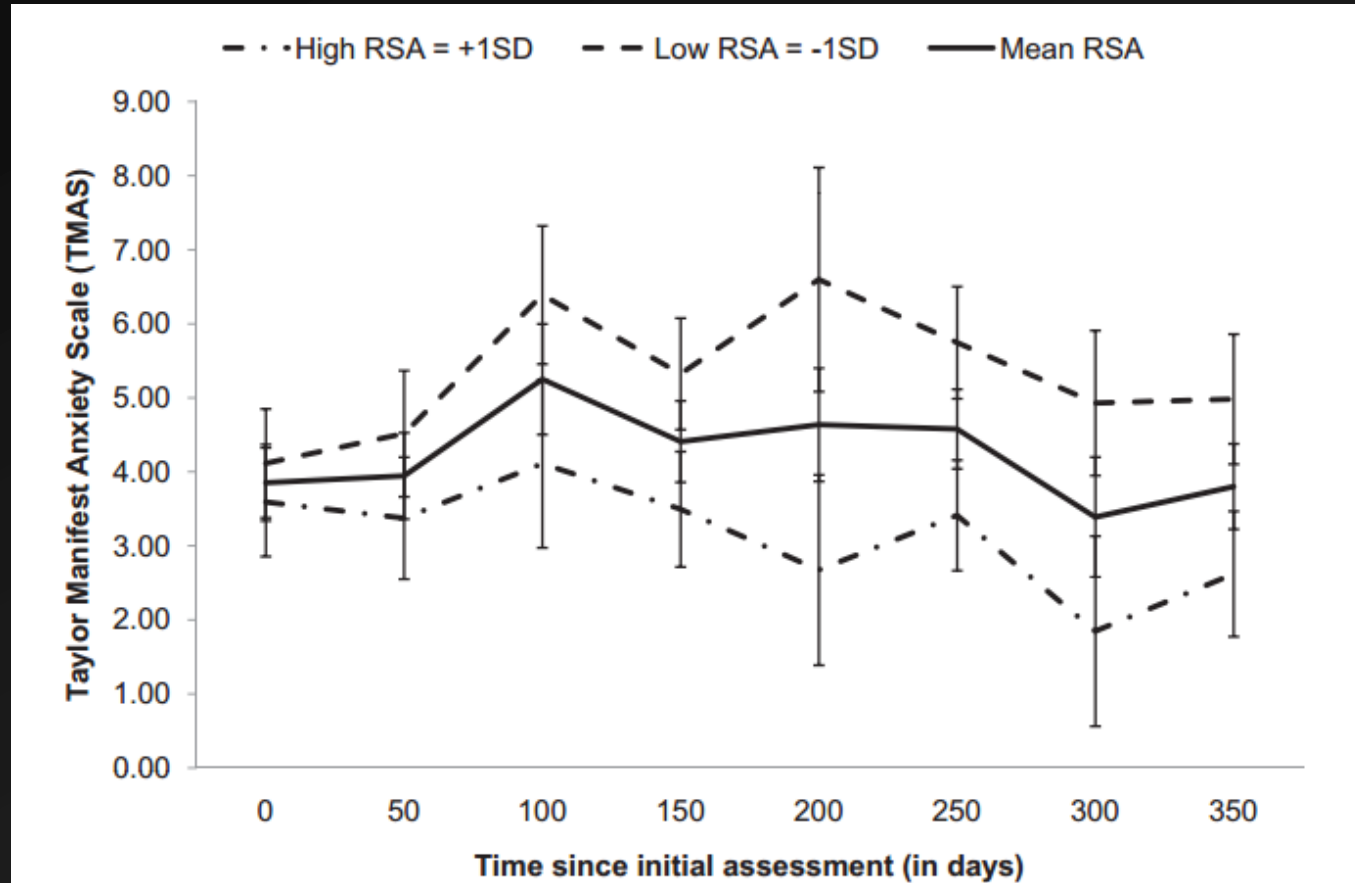
Variable	Panic (mean, S.D.)	Blood phobic (mean, S.D.)	Control (mean, S.D.)	T ratio, df, p value
IBI (ms)	761.8 (141.0)	837.1 (92.4)	905.2 (132.5)	P < B 4.59 (215) $p < 0.001$ P < C 7.65 (214) $p < 0.001$ B < C 4.30 (207) $p < 0.001$
VAR (ms <sup>2</sup> )	3942 (4009)	4334 (2663)	6112 (4563)	P < C 3.70 (214) $p < 0.001$ B < C 3.44 (207) $p < 0.001$ P = B N.S.
MSD (ms)	44.4 (31.2)	55.6 (22.7)	71.4 (32.1)	P < B 3.05 (215) $p < 0.001$ P < C 6.34 (214) $p < 0.001$ B < C 4.11 (207) $p < 0.001$
HF power (ms <sup>2</sup> Hz <sup>-1</sup> )	991 (1225)	1385 (1073)	2239 (1911)	P < B 2.49 (212) $p < 0.01$ P < C 5.67 (212) $p < 0.001$ B < C 3.90 (203) $p < 0.001$
LF/HF	2.1(2.5)	1.3 (1.8)	1.0 (1.5)	P < B 2.41 (209) $p < 0.005$ P < C 3.64 (203) $p < 0.001$ B = C N.S.

P, panic; B, blood phobic; C, control.



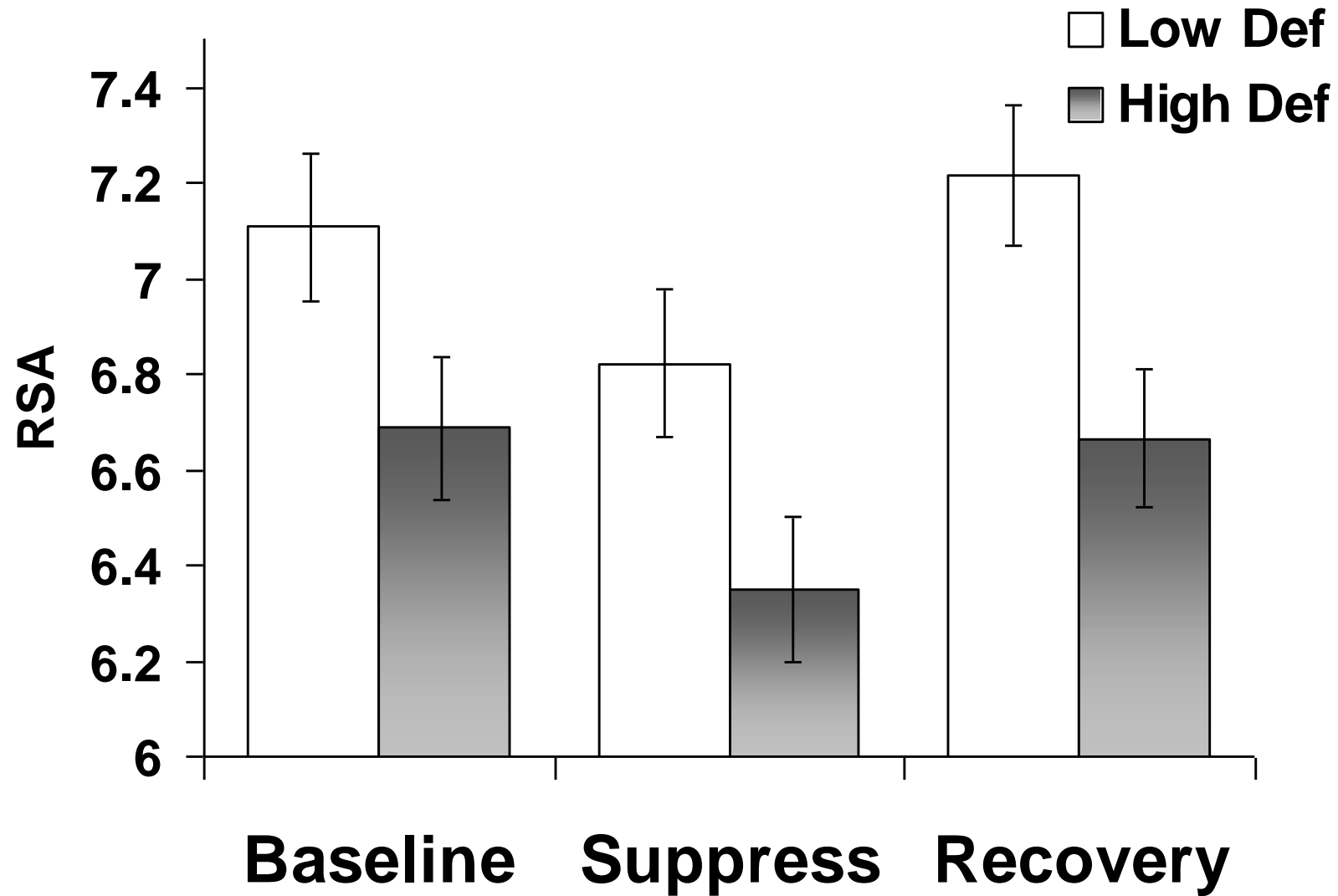
Change in Vagal Tone

# Can Vagal Control predict development of anxiety following stressors?



**Fig. 1.** Effect of the interaction between RSA adjusted for age and Time since initial assessment on TMAS over a 1-year period. Although RSA is a continuous variable, for illustrative purposes, its effect on TMAS is plotted at  $\pm 1$  SD from the mean. Error bars represent standard errors. RSA: respiratory sinus arrhythmia; SD: standard deviation; TMAS: Taylor Manifest Anxiety Scale.

# Vagal Control and Defensive Coping

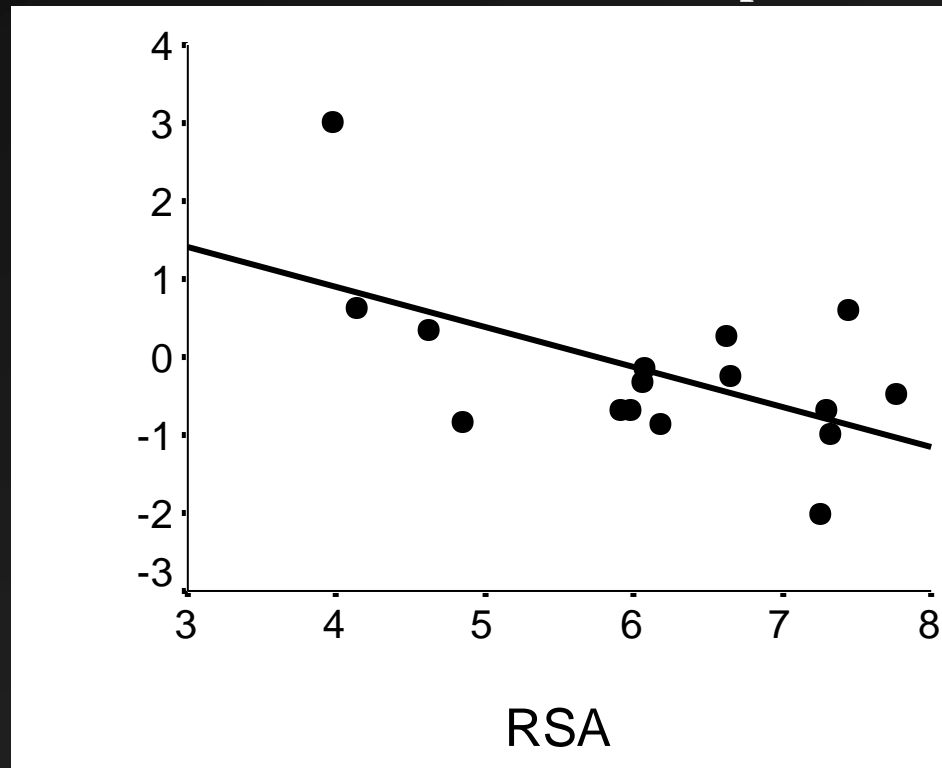




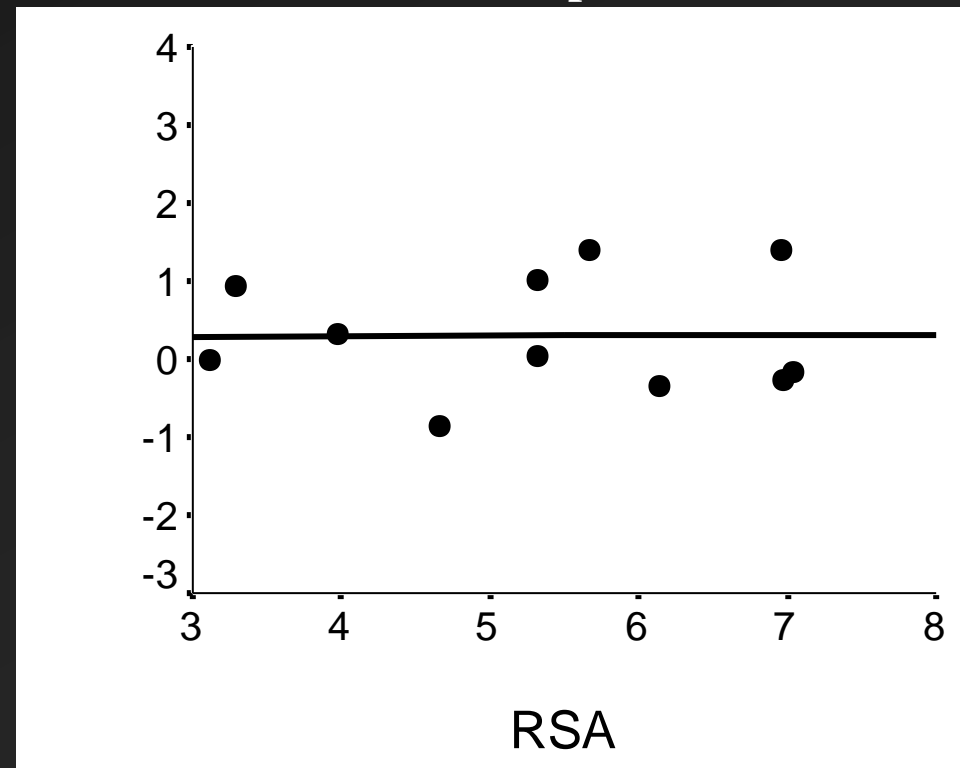
# Trait Vagal Tone as Moderator of Response following Bereavement

- ❑ Bereavement as a period of cardiovascular risk
- ❑ Disclosure as an intervention for Bereavement (O'Connor, Allen, Kaszniak, 2005)
- ❑ Overall, all folks get better, but no differential impact of intervention
- ❑ BUT... Vagal Tone as moderator

Intervention Group



Control Group



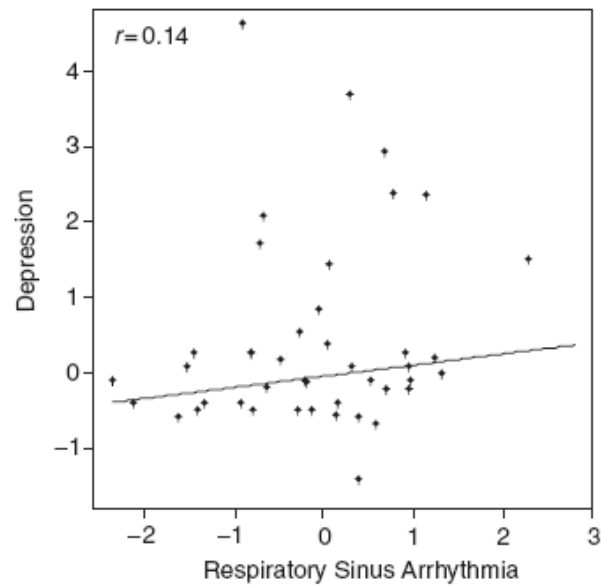
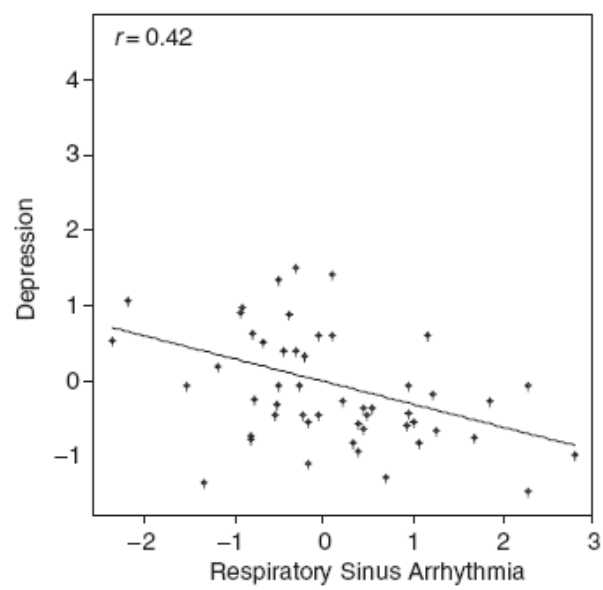


Figure 1. Scatterplot, prediction line, and prediction equation for the relationship between respiratory sinus arrhythmia (log of the variance of the band-limited [12–40 Hz] IBI series) and depression score (residualized on baseline depression score), for the disclosure group (top panel) and the control group (bottom panel). Negative depression score represents improvement from baseline to follow-up.

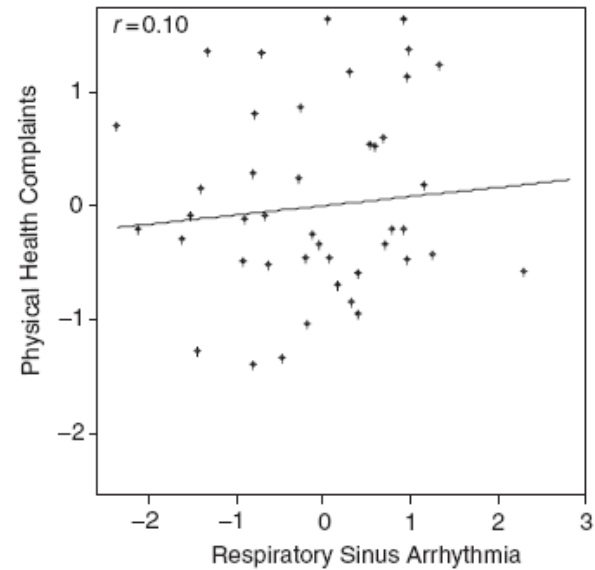
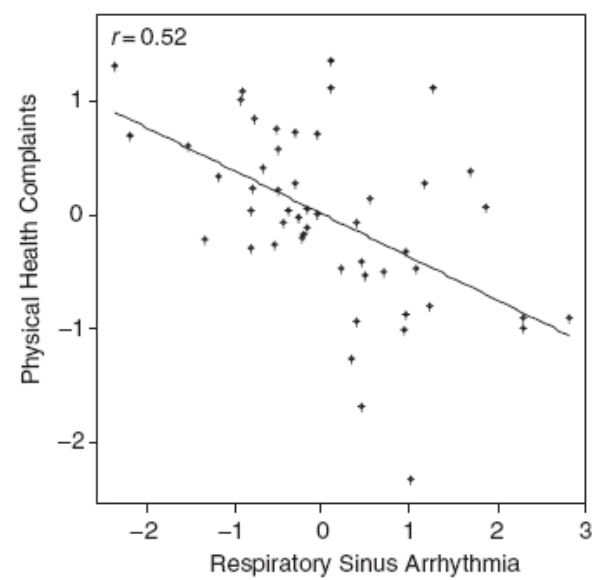
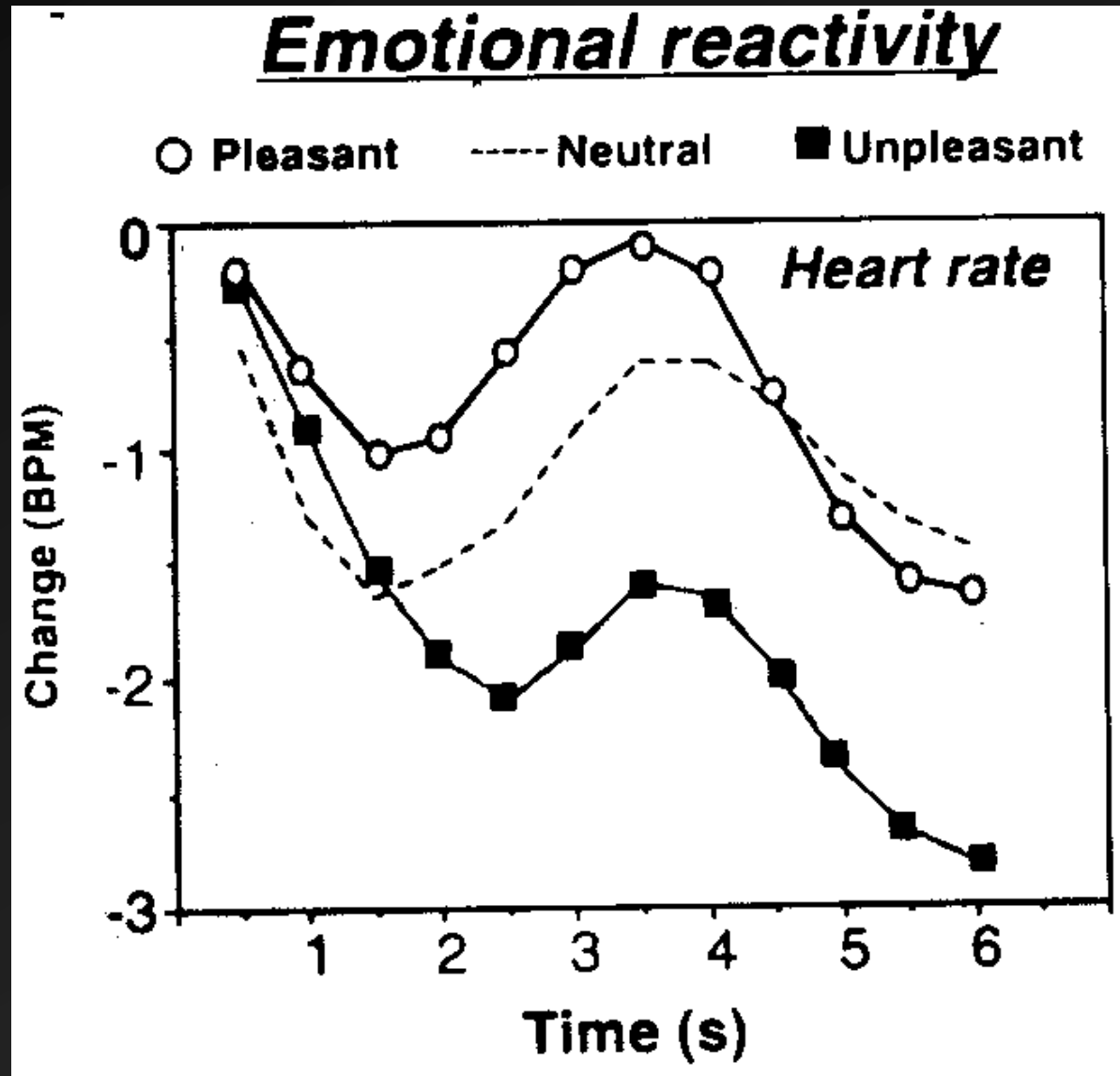


Figure 2. Scatterplot, prediction line, and prediction equation for the relationship between respiratory sinus arrhythmia (log of the variance of the band-limited [12–40 Hz] IBI series) and physical health complaint score (residualized on baseline physical health complaints score) for the disclosure group (top panel) and the control group (bottom panel). Negative physical health complaint score represents improvement from baseline to follow-up.

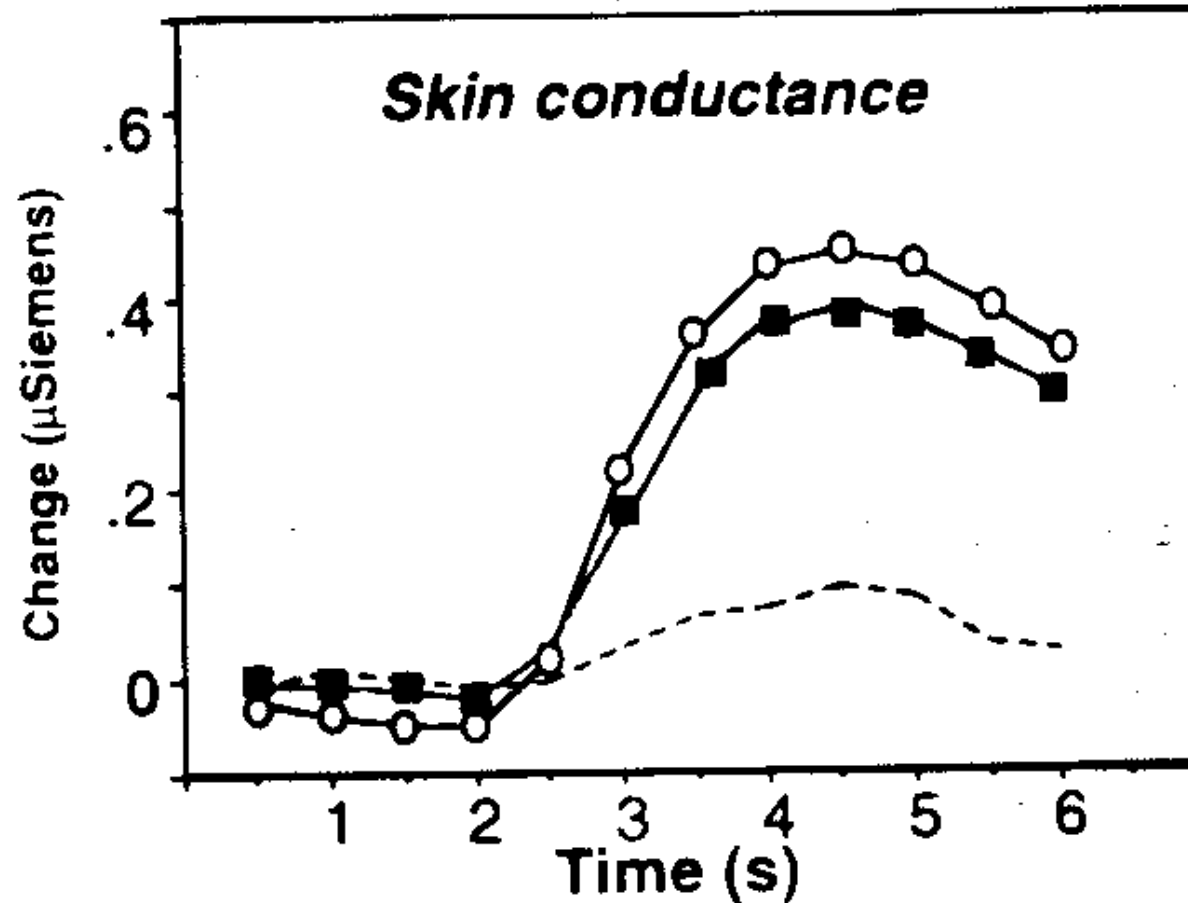
# Orienting, Attention, and Defense

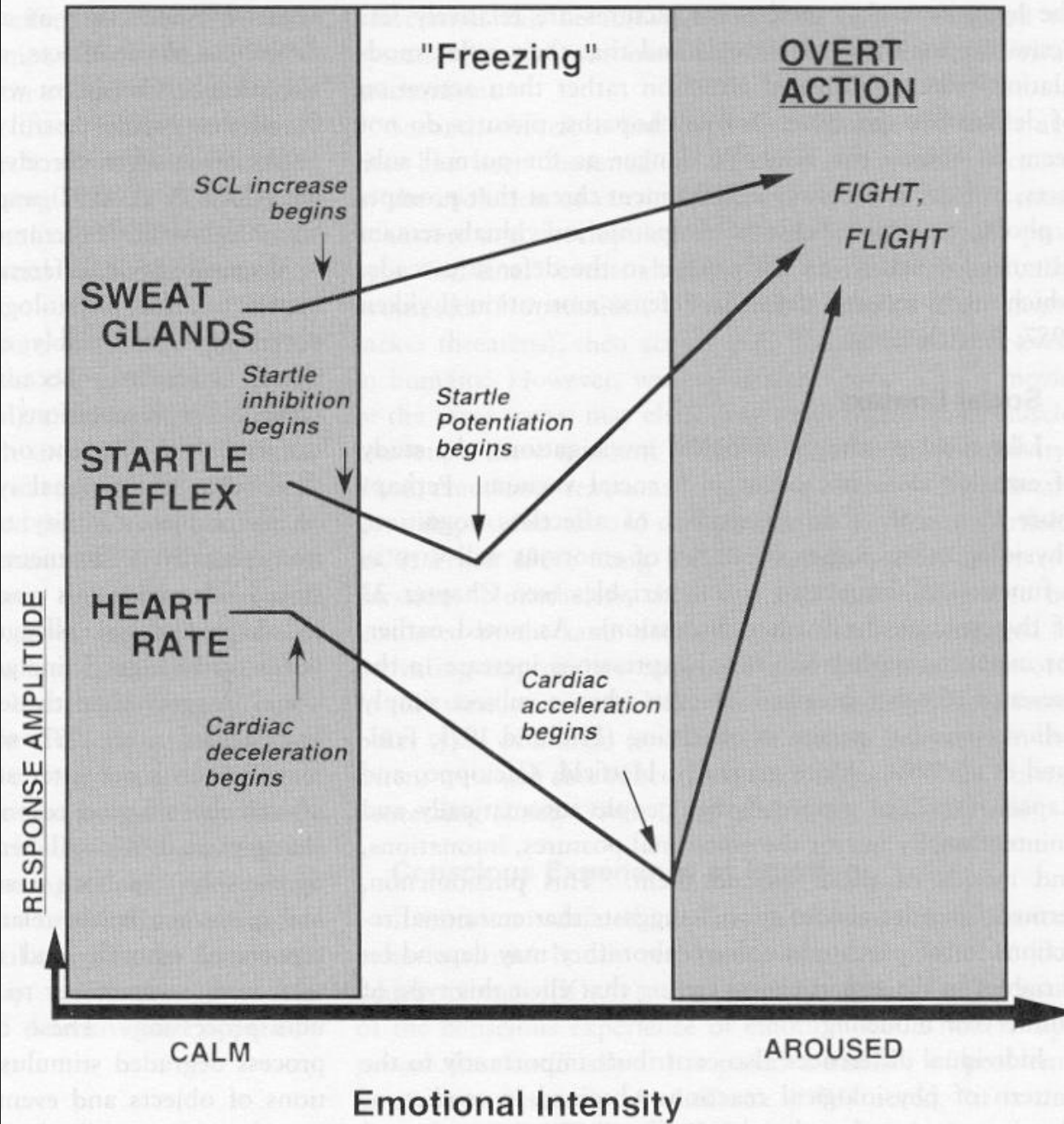


# SCR (by contrast)

## Emotional reactivity

○ Pleasant    ----- Neutral    ■ Unpleasant





OR  $V_s$  DR