Heart Rate
Variability Biofeedback

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Heart Rate Variability

- Heart rate variability (HRV) is the study of the various component rhythms and influences contributing to the overall phenomenon of heart rate
- Higher HRV is a marker of health and adaptive capacity in a biological organism

Heart Rate Variability

- The *interbeat interval* (IBI) is the time between one R wave (or heart beat) and the next, in milliseconds
- IBI is highly variable within any given time period
- Multiple biological rhythms overlay one another to produce the resultant pattern of variability
- Interbeat interval variation, or heart rate variability, has relevance for physical, emotional, and mental function

Measurement of R-Wave

- The time between R-wave peaks is interbeat interval or heart period. It is also called "NN" (normal to normal) interval.

Heart Rate Variability

- The rate at which the heart beats is constantly changing
- HR increases with exertion, decreases with rest
- HR increases with anxiety, decreases with relaxation
- HR increases with inhalation, and decreases with exhalation

Heart Rate Variability

- HRV concerns constant variations in HR, even within rest period or exercise period
- Mechanisms affecting heart rhythms operate at various frequencies
- Spectral analysis, using the Fast Fourier Transform, identifies the variation as waveforms elapsing within each time frame

Frequency Ranges

- The primary frequency ranges utilized in research and practice are:
  - High Frequency -- .15 - .4 Hz
  - Low Frequency -- .04 - .15 Hz
  - Very Low Frequency -- .0033 - .04 Hz
  - Ultra Low Frequency -- < .0033, beyond biofeedback measurement technology
    - **Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996)**

Cardiac Rhythms: Do the Arithmetic

- High Frequency
  - .4 Hz: .4 cycles/second X 60 sec./min. = 24 cycles/min.
- Low Frequency
  - .1 Hz translates into 6 cycles/min.
- Very Low Frequency
  - .04 translates into 2.4 cycles/minute
  - .004 translates into 14.4 cycles in one hour
- Ultra Low Frequency
  - .001 Hz translates into 3.6 cycles in one hour

Cardiac Rhythms:Two

- High Frequency – parasympathetic pathways, influences of respiration in normal frequencies on vagal tone
- Low Frequency – influence of BP rhythms (baroreceptors) on heart rhythms (meditative/slow breathing augments this range)
- Very Low Frequency – sympathetic pathways, influences of visceral and thermal regulation (rumination and worry augment this range)
- Ultra Low Frequency

HRV: Developmental I

- HRV increases fivefold in infancy and early childhood
  - Some report RSA peaking at 4-6, others at 10-14
  - The proportionate variability in individuals (relative to age peers) is stable through childhood
    - Salomon (2005)

HRV is Relatively Stable

- A recent pediatric study found that HRV during a stress trial predicted resting HRV in the same child 3 years later
  - Kristen Salomon (2005). RSA during stress predicts resting RSA 3 years later in a pediatric sample. *Health Psychology, 24* (1), 68-76/

HRV: Developmental II

- HRV reduces over adult lifespan
  - Twenty year olds may show coherent swings of twenty beats per minute or more during breathing exercises
  - Individuals over fifty often show changes of ten *bpm* or less
  - This loss of variability correlates with loss of resilience in health

HRV in Health

- Changes in the amount of HRV are related to change in autonomic activity in:
  - Aging: Decreases "vagal tone," decreases variability
  - Exercise: <u>Improves</u> HRV
  - Stress: HRV decreases with SNS arousal
  - Circadian rhythms: HRV changes with time of day

HRV: What Difference Does it Make?

- IBI changes precede incidents of fetal distress
- Reduced heart rate variability
  - Correlates with higher risk of post-infarction mortality
  - Predictor of mortality (all causes)
  - Especially sudden death

SDNN: Medical Index of Heart Rate Variability

- N to N interval is the "normalized" beat to beat interval

- SDNN is the standard deviation of those interbeat intervals, a measure of how variable are those intervals
- The SDNN is a measure in milliseconds (ms)

SDNN: Medical Index (cont).

- SDNN allows for classification into health status, with corresponding morbidity and mortality:
  - "Unhealthy" (< 50 ms)
  - "Compromised health" (> 50 ms and < 100 ms)
  - "Healthy" (>100 ms)
- Moving from a lower range to a higher range is typically clinically significant for patient survival

Depression, HRV, and Mortality

- Depression in patients who have an MI increases mortality
- Recent research shows depressed patients twice as likely as non-depressed to have lower HRV (16 % vs. 7 %)
- Lower HRV is strong independent predictor of post-MI death
  - Carney et al (2001). *Circulation, 104* (17), 2024-2038.

HRV is sensitive marker of changes in depression

- Nahshoni et al (2001). *American Journal of Geriatric Psychiatry, 255-60*
  - Cardiac vagal activity increased after ECT in 11 elderly depressed patients compared to controls.
  - Results similar to many medication studies

Medical Applications of HRV

- Outcome studies supporting several applications
  - Asthma
    - Paul Lehrer, Lehrer, P., Evgeny Vaschillo, Bronya Vaschillo, Shou-En Lu, Anthony Scardella, Mahmood Siddique, & Robert Habib (2004). Biofeedback treatment for asthma. *Chest, 126,* 352-361.
  - Chronic Obstructive Pulmonary Disorder
    - Nicholas Giardini, Leighton Chan, Soo Borson, University of Washington "Combined HRV and Heart Oxymetry Biofeedback for COPD," APB, *29* (2), 121-133.

Medical Applications of HRV

- Outcome studies supporting several applications
  - Cardiovascular Rehabilitation
    - Jessica Del Pozo, Richard Gevirtz, Bret Scher, & Erminia Guarneri (2004). Biofeedback

treatment increases heart rate variability in patients with known coronary artery disease. *American Heart Journal*, *147*, E11.

– Hypertension
  – Herbs, D. , Gevirtz, R. N., & Jacobs, D. (1994). The effect of heart rate pattern biofeedback for the treatment of essential hypertension. *Biofeedback and Self-Regulation, 19* (3), 281 Abstract.

Medical Applications of HRV

- Gevirtz , Lehrer, Bhat and others report using HRV for several additional disorders:
  - Irritable Bowel Syndrome
  - Chronobiological disorders such as Fibromyalgia and Chronic Fatigue syndrome
  - Myofascial Pain Disorder
  - Anxiety Disorders
  - Anger Management

HRV Biofeedback: What Do We Train?

- I. Training for Optimal Breathing
  - Practitioners teach diaphragmatic breathing
  - Biofeedback displays the process of breathing, the rate of breathing, and the amplitude of breathing
  - *Trainee pursues smooth, even breathing, with large amplitude and low rate*

HRV Biofeedback: What Do We Train?

- II. Training for HRV Coherence
  - Trainees produce familiar phasic relationship of heart rate variations with respiration
  - Heart rate variations become more orderly or *coherent*
  - *Trainee pursues smooth, curvilinear, sinusoidal variation*

HRV Biofeedback: What Do We Train?

- III. Training for Magnitude of Variation
  - Biofeedback can reward for increases in the HR Max – HR Min
  - Biofeedback can reward for increases in the SDNN
  - *Trainees pursue increased magnitude of variability*

HR Max-HR Min: Common Index in Biofeedback Training

- HR Max-HR Min: What is the difference in Beats per Minute (BPMs) from the highest HR and lowest HR in one EKG cycle
- HRV biofeedback can signal each time this Index increases above a threshold
- Training can produce HR Max-HR Min amplitudes of 20-50 BPMs

Increased SDNN as Training Criteria

- SDNN is the standard deviation of the interbeat intervals, a measure of how variable are these intervals
- SDNN is a measure in milliseconds (ms)
- Rewards can be programmed to condition increases in the SDNN

HRV Biofeedback: What Do We Train?

- IV. Training for Spectral Distribution
  - Using the FFT, various forms of spectral feedback can be given
  - Biofeedback rewards for shifts into the Low Frequency range of HRV via direct observation of 2D or 3D spectral displays
  - *Trainees pursue spectral shifts*

Spectral Training Criteria

- IV. Spectral Feedback (cont.)
  - Rewards for increasing Per Cent Power (or Per Cent Amplitude in LF range)
  - Rewards for creating unimodal spike of HRV activity at about 0.1 Hz (Peak Frequency and Amplitude of Peak Frequency)

Value of Multiple Training Strategies

- Two trainees produced apparently identical smooth sinusoidal respiratory curves, with sharply different heart rate variability
  - HR Max - HR Min
    - Subject 1 – 3 beats per minute
    - Subject 2 – 17 beats per minute

HRV Biofeedback: What Do We Train?

- V. Training for Relaxation
  - Some subjects find explicit training to change physiology distracting
  - During hypnotic induction, autogenic training, or imagery exercises, many of the subjects show increased coherence, increased magnitude of variation, and spectral shifts
  - *Trainees pursue subjective relaxation*

HRV Biofeedback: What Do We Train?

- VI. Training for Positive Emotion
  - Heart Math emphasis on cultivating positive emotion, and decreasing negative emotion
  - Operationally the biofeedback displays show the same parameters
  - *The trainees pursue warm appreciation, "loving kindness," and generally positive feelings*

Hostility and the Pumping Heart
Anger Sends Clogged Arteries into Spasm

- Dr. Boltwood (Stanford University, 1993)
- Remembering anger produces spasm in arteries with atherosclerosis

Anger and Negative Emotion Disrupts Orderly Rhythms in the Heart

- The human heart rate varies constantly
  - Healthy biological systems show large oscillations/variation
- Depression reduces heart rate variability
- Negative emotions such as anger create disorganized heart rate variation
- Positive emotions—"heart felt emotions" create coherent and harmonic variations in heart rhythms

HRV in Anxiety

- Yeragani et al. (1991) -- decreased standing HRV in Panic Disorder
- Yeragani et al. (1995) – relative mid-frequency (0.07 Hz to 0.15 Hz) power higher in PD
  - Inference: greater cardiac sympathetic activity in patients with PD, compared to those with depression
- Rechlin et al. (1994) – low frequency activity more dominant in PD, high frequency activity more dominant in depression
  - Inference: increased SNS activity in PD, increased parasympathetic activity in depression

HRV and Asthma

- Paul Lehrer, Lehrer, P., Evgeny Vaschillo, Bronya Vaschillo, Shou-En Lu, Anthony Scardella, Mahmood Siddique, & Robert Habib (2004). Biofeedback treatment for asthma. *Chest, 126,* 352-361.
  - UMDNJ—Robert Wood Johnson Medical School, New Jersey
  - Major Thoracic journal--*Chest*
- Rigorous empirical study of 94 outpatients with asthma.

HRV and Asthma (cont.)

- Interventions: 4 conditions
  - HRV biofeedback and abdominal breathing training
  - HRV biofeedback alone
  - Placebo EEG biofeedback
  - Wait list control

- Outcome Measures
  - Daily asthma symptom log
  - Twice daily peak expiratory flow measures
  - Spirometry respiratory measures
  - Measures of oscillation resistance (pneuomgraphy)

HRV and Asthma (cont.)

- Results
  - Subjects in both HRV groups used less asthma medicine
  - Minimal differences between two active intervention groups
  - Improvements measured one full level of asthma severity (American Thoracic Society measures)
  - Forced oscillation pneumography also showed improvement in pulmonary function
  - Placebo group showed improvement in self-report of asthma symptoms, not in functional capacity

HRV and COPD

- Nicholas Giardini, Leighton Chan, Soo Borson, University of Washington
- "Combined HRV and Heart Oxymetry Biofeedback for COPD," APB, *29* (2), 121-133.
- Interventions
  - 5 sessions biofeedback, training paced breathing and increase in HRV
  - 4 sessions of walking, using respiration techniques learned in biofeedback, and self-monitoring with pulse oxymetry

HRV and COPD (cont.)

- Outcome Measures:
  - 6 minute walk distance test (6MWD), well-validated measure of functional capacity
  - St. George's Respiratory Questionnaire (SGRQ)– a measure of overall quality of life
- Results
  - Clinically significant increases in both 6MWD and SGRQ quality of life
  - 8 of 10 participants showed clinically significant improvements in both measures

HRV and Cardiac Health

- Jessica Del Pozo, Richard Gevirtz, Bret Scher, & Erminia Guarneri (2004). Biofeedback treatment increases heart rate variability in patients with known coronary artery disease. *American Heart Journal*, *147*, E11.
- California School of Professional Psychology, Alliant International University, San Diego

HRV and Cardiac Health (cont.)

- Interventions: 69 participants, random assignment to two conditions
  - Conventional cardiac rehabilitation
  - 6 sessions, abdominal breath training, respiratory and HRV biofeedback
  - 20 minutes/day home breath practice
- Outcome Measures
  - HRV as measured by SDNN, the standard deviation of the normalized interbeat interval—the R wave to R wave interval in milliseconds

HRV and Cardiac Health (cont.)

- Results
  - Pre-treatment the groups did not differ significantly on SDNN
  - The conventional care group actually decreased SDNN
  - The HRV group increased SDNN, from 28 to 42 ms
    - SDNN increases with biofeedback were of magnitude that the researchers infer high likelihood of clinical improvement
    - The cardiac risk status, measured by SDNN, improved for some participants from the “unhealthy” to the “compromised health” range (from < 50 ms to > 50 ms)
  - This research did not measure clinical improvement

HRV as a Risk Factor

- HRV has been widely reported to be a risk factor for CHD, for all cause mortality, and even cancer mortality.
- SDNN < 50 ms vs. > 50 ms
  - Mortality risk differs often by 3-4
  - This means that a shift in SDNN (standard deviation of R-R on ECG) from low to moderate decreases risk of mortality by 4 to 1
  - Kleiger et al. 1987, *American Journal of Cardiology*

Heart Rate Variability -- Statistical Analysis

- Time series measures calculate variability using SD of mean consecutive difference of successive R-R intervals
- FFT identifies dominant frequencies in variability mathematically, based on IBI, analogous to FFT of EEG
- Yeragani et al. (2000) advocate use of “fractal dimension analysis” to take into account non-linear complexity of biological systems, and use of QT intervals

Heart Rate Variability (HRV) Biofeedback

- Computer interfaced biofeedback systems provide direct feedback of heart rate variability
- Signal displays include abdominal and chest respiration, heart rate, and the raw EKG
- Fast Fourier Transform (FFT) widely used in spite of critiques

Respiration, HRV, and the Emotions

- Close links among breathing, HRV, and emotions
- Slowing and deepening respiration calms the emotions
- Cultivating gentler, positive emotions, deepens breathing and transforms HRV
- Naras Bhat calls this the "Mother Theresa Effect"

Heart Math Institute Quick Coherence® Tool

- Heart focus
- Heart breathing
- Heart feeling

Quick Coherence® Tool

Heart Focus

- Close your eyes (optional)
- Focus your attention in the area of your heart. If you like, you can put your hand over your heart.

Heart Breathing

- As you focus on the area of the heart, pretend you are breathing through that area.
- Breathe slowly and gently (to the count of 5 or 6) until your breathing feels smooth and balanced – not forced

- As you continue to breathe, you will find a natural inner rhythm that feels good.

Heart Feeling

- Continue to breathe through the area of the heart and find a positive feeling, like appreciation for someone or something.
- You can recall a time when you felt appreciation or care and re-experience that feeling. It could be for a pet, a special place in nature, or an activity that was fun
- Once you have found a positive feeling – sustain this feeling by continuing heart focus, heart breathing and heart feeling
- If you can't feel anything, it's okay, just try to find a sincere attitude of appreciation or care.

Components in Meditation

- *Quiet Environment*
- *Comfortable Position*
- *Passive Mental Attitude*
- *Sense of Harmony with the World*
- *Focusing Device*

Psychophysiology of Meditation

- Paul Lehrer studied EKG and respiration in Zen monks and nuns in Japan
- Low serum lipid rates and low rates of CV disease
- Rinzai Zen monks spend hours a day in meditation with very slow breathing
- Rinzai monks practice "tanden breathing"
  - Breathing slowly
  - Focusing each breath
  - Focus on area below navel

Respiration and Heart Activity in Zen Meditation

- Respiration rates slow to range associated with "low frequency" heart rate variability (.05-.15 Hz)
  - Low frequency HR variability increased
  - Higher frequency (.15-.4 HZ) HR variability decreased
- One Rinzai master breathed at one breath/min.
  - Increase in very low frequency (< .05 HZ) cardiac waves
- Support for theory that slow breathing "resonates" with cardiac function and produces low frequency cardiac oscillation with benefit for cardiac health

– Lehrer, Sasaki, & Saito (in press)

Instrumentation to Measure HRV

- Photoplethysmograph (PPG)
  - The PPG utilizes a light sensor to indicate relative blood volume in an area, such as the thumb pad
  - The PPG provides a measure of Blood Pulse Volume, as well as an approximate measure of HR
  - PPG data can also be subjected to spectral analysis to study Heart Rate Variability

Instrumentation to Measure HRV

- Electrocardiogram (EKG)
  - The EKG measures cardiac activity electrically and provides a moment to moment precise record of the electrophysiology of the heart
  - The EKG is also used to derive Heart Rate as well as spectral measures of Heart Rate Variability
  - Both PPG and EKG are useful with cardiovascular disorders, anxiety, and stress management

EKG versus PPG

- PPG is optical detection sensor, sensing blood pulse volume
  - Placement is usually on the thumb pad, more user friendly
- The medical EKG requires chest/trunk placement
  - For biofeedback EKG wrist placement is adequate
- For Research: Greater data quality using EKG
  - R-wave in the EKG signal is sharp, distinct
  - Peak in PPG wave is round, not as distinct

EKG vs. PPG

- Measuring IBI requires precision in identifying beats
  - The EKG has smaller margin of error
  - More reliable computation of HRV
- EKG signal less prone to noise
  - Less time on artifact rejection
  - Less missed or extra beats in EKG IBI data

- For clinical biofeedback training, the modern PPG has adequate precision

How to Record an Accurate EKG and Heart Rate

- Site preparation – wipe the skin with alcohol or a skin prep wipe
- If your electrodes require gel, use EKG type conductive gel
- If using pre-gelled electrodes, a dab of supplementary gel will enhance the signal

EKG Electrode Placement 1

- Chest placement – optimal
  - Blue = Positive, Yellow = Negative, Black = Ground
  - Negative electrode on right shoulder—above heart
  - Positive electrode over sternum at center or left, below heart and across heart from negative
  - Ground on left upper chest, near shoulder

Electrode Placement 2

- Wrist Placement
  - Blue = Positive, Yellow = Negative, Black = Ground
  - Negative electrode on right wrist, palmer side
  - Positive electrode on left wrist, palmar side, across heart from negative
  - Ground on left wrist, above positive

Electrode Placement 3

- Wrist/Leg Placement
  - Blue = Positive, Yellow = Negative, Black = Ground
  - Negative electrode on right wrist, palmer side
  - Positive electrode on left leg, above knee, across heart from negative
  - Ground on left wrist

Terminology 1

- P wave – excitation starts from the S-A node leading to contraction of the atria
- QRS complex – consisting of three deflections in electrical

activity including the contraction of the ventricles

- R wave – the sharp spike upward in ECG as electrical activation spreads through the ventricles (dominant feature of ECG)
- T wave – Repolarization of the ventricles, setting stage for next sequence

Terminology 2

- BPM – beats per minute, number of R waves per minute
- IBI – Interbeat interval, time between one R wave and the next, in milliseconds
- R to R interval – peak to peak interval, same
- SDRR – Standard deviation of the R to R interval
- HR Max – HR Min – a measure of the difference between high and low HR in each cycle