The Promise of Heart Rate Variability Training: Advances in Knowledge, Technique, and Applications

Webinar for Thought Technology, Ltd.

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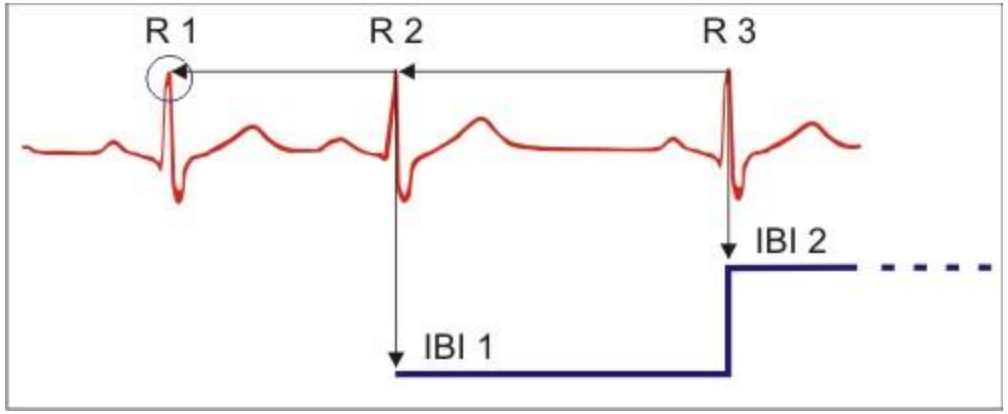
A Mindful Moment

- Begin by releasing the tensions of the day.
- Allow your body to relax, your mind to quiet, and your heart to open.
- Allow your breathing to become gentle, slow, and even.
- Allow yourself to open your mind and heart.

Heart Rate Variability Basics: What is It?

Heart Rate Variability

Heart rate variability (HRV) refers to the moment to moment change in the time intervals between adjacent heartbeats (McCraty & Shaffer, 2015).



Fundamentals of HRV Biofeedback

- A healthy heart is NOT a metronome (Shaffer, McCraty, & Zerr, 2014)
- Healthy, resilient physiological systems show large oscillations
- As the heart loses its variability, the risk for illness and death increases

Heart Rate Variability

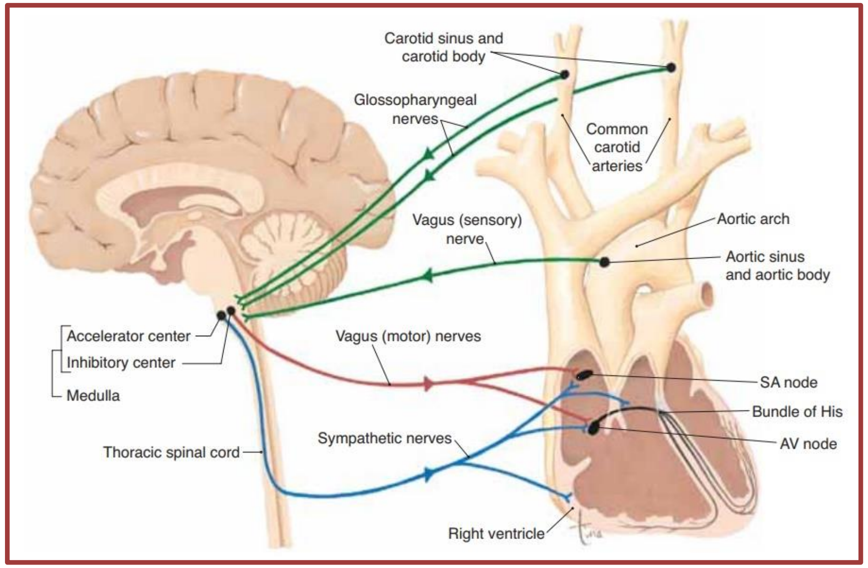
HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic autonomic nervous system (ANS) processes. Increased parasympathetic (vagal) input increases moment to moment oscillations in heart rate and increases health and performance benefits.

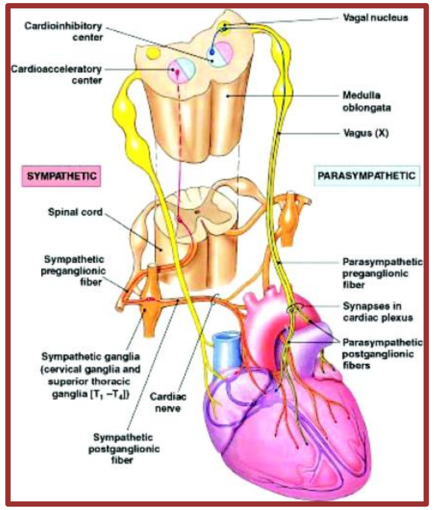
Heart Rate Variability

HRV is an emergent property of multiple interdependent regulatory systems, which operate on different time scales to help us adapt to environmental and psychological challenges.

Heart Rate Variability

The systems that generate HRV span the neuroaxis from the prefrontal and insular cortex, to the intrinsic cardiac nervous system and medulla oblongata, which function as integration centers.

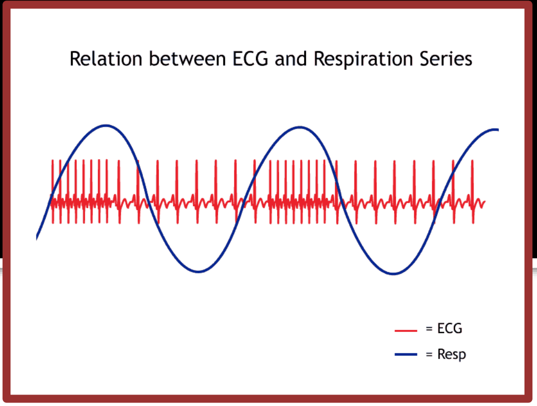




Heart Rate Variability

- Respiration and autonomic balance contribute to heart rate oscillations.
- Breath training is a core component in heart rate variability biofeedback.

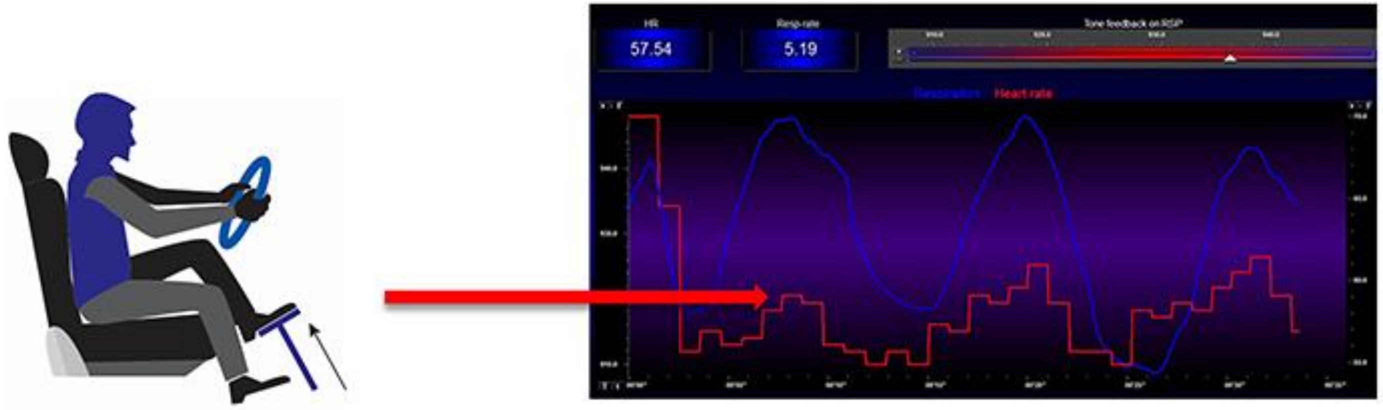
Heart Rate Variability: The RSA



- During the in-breath, HR increases. BP rises about 5 seconds later. Baroreceptors detect this rise and fire more rapidly. During the out-breath, HR decreases. BP falls 5 seconds later (Gevirtz & Lehrer, 2003; Lehrer & Vaschillo, 2008).
- This synchrony of respiration and cardiac activity is called the respiratory sinus arrhythmia or RSA.

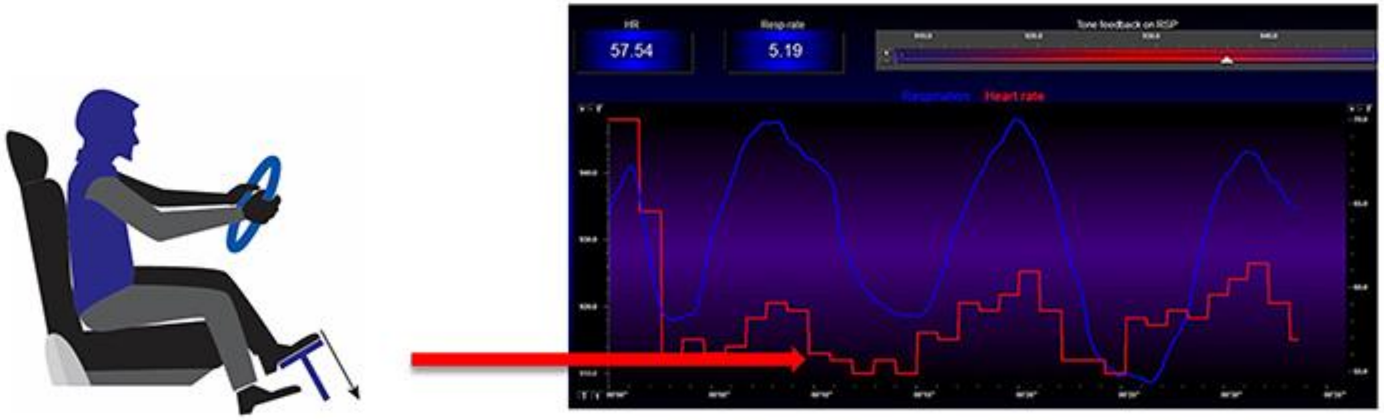
What is respiratory sinus arrhythmia?

- Inhalation partially disengages the vagal brake, increasing HR. The intrinsic cardiac pacers speed the heart rate.
- This is purely parasympathetic. Graphics inspired by Dick Gevirtz

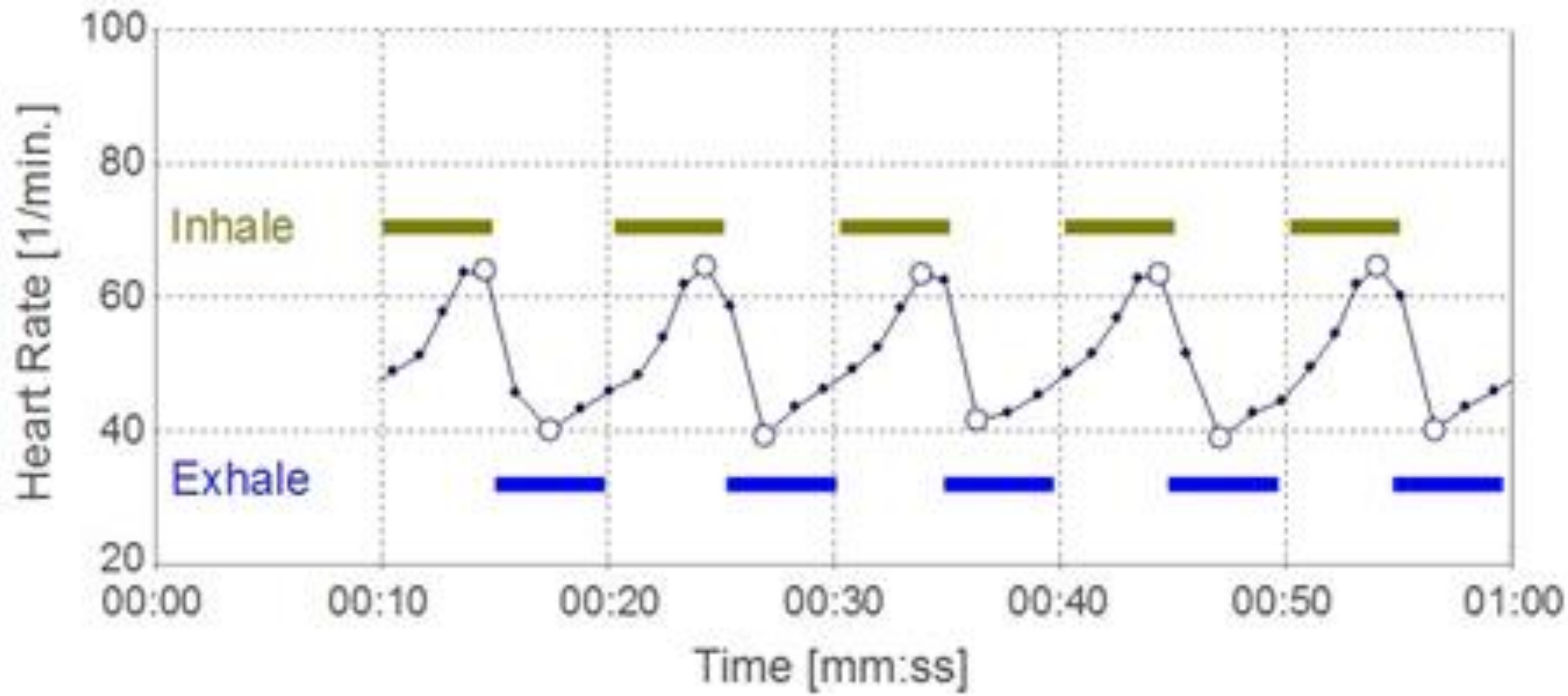


What is respiratory sinus arrhythmia?

- Exhalation reapplies the vagal brake, slowing HR

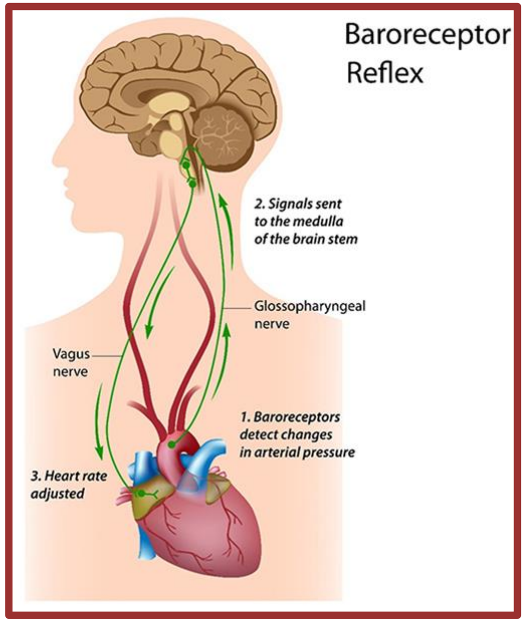


Respiratory Sinus Arrhythmia



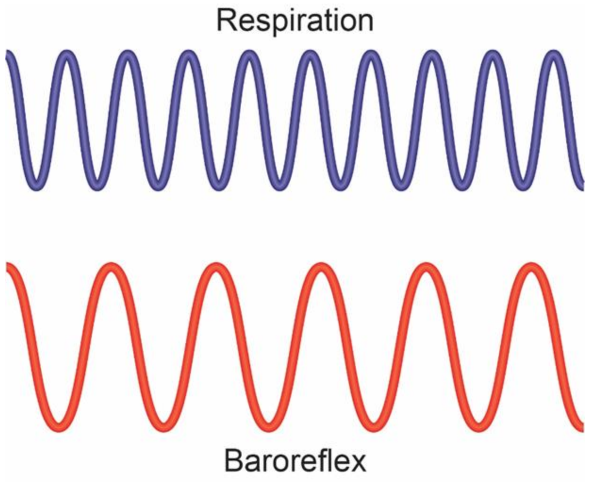
Heart Rate Variability: The Resonance Frequency

- Breathing at a specific rate, called the Resonance Frequency (RF), produces the largest organized oscillations in HR (Lehrer et al., 2000, 2016).
  - The RF varies by individual, but approximates to six breaths per minute
  - The breath rate producing the largest HRV is also the rate of the baroreceptor rhythm, the homeostatic mechanism governing blood pressure

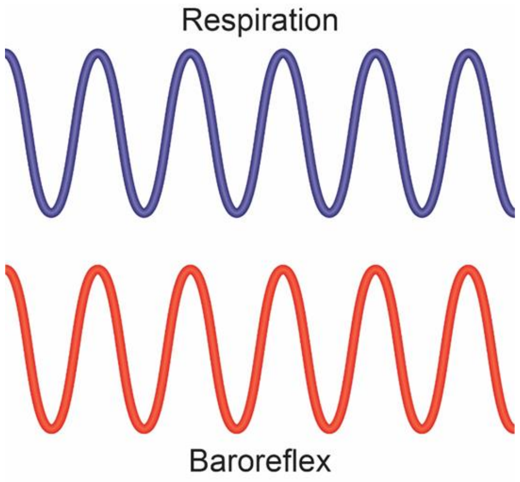


How does breathing affect the baroreflex?

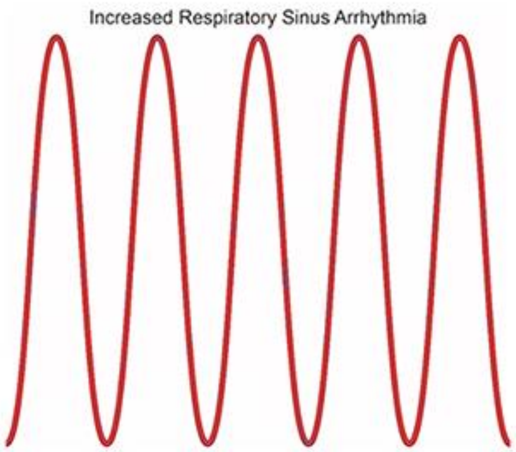
- Slow-paced breathing synchronizes breathing and the baroreflex



Breathing at
typical rates



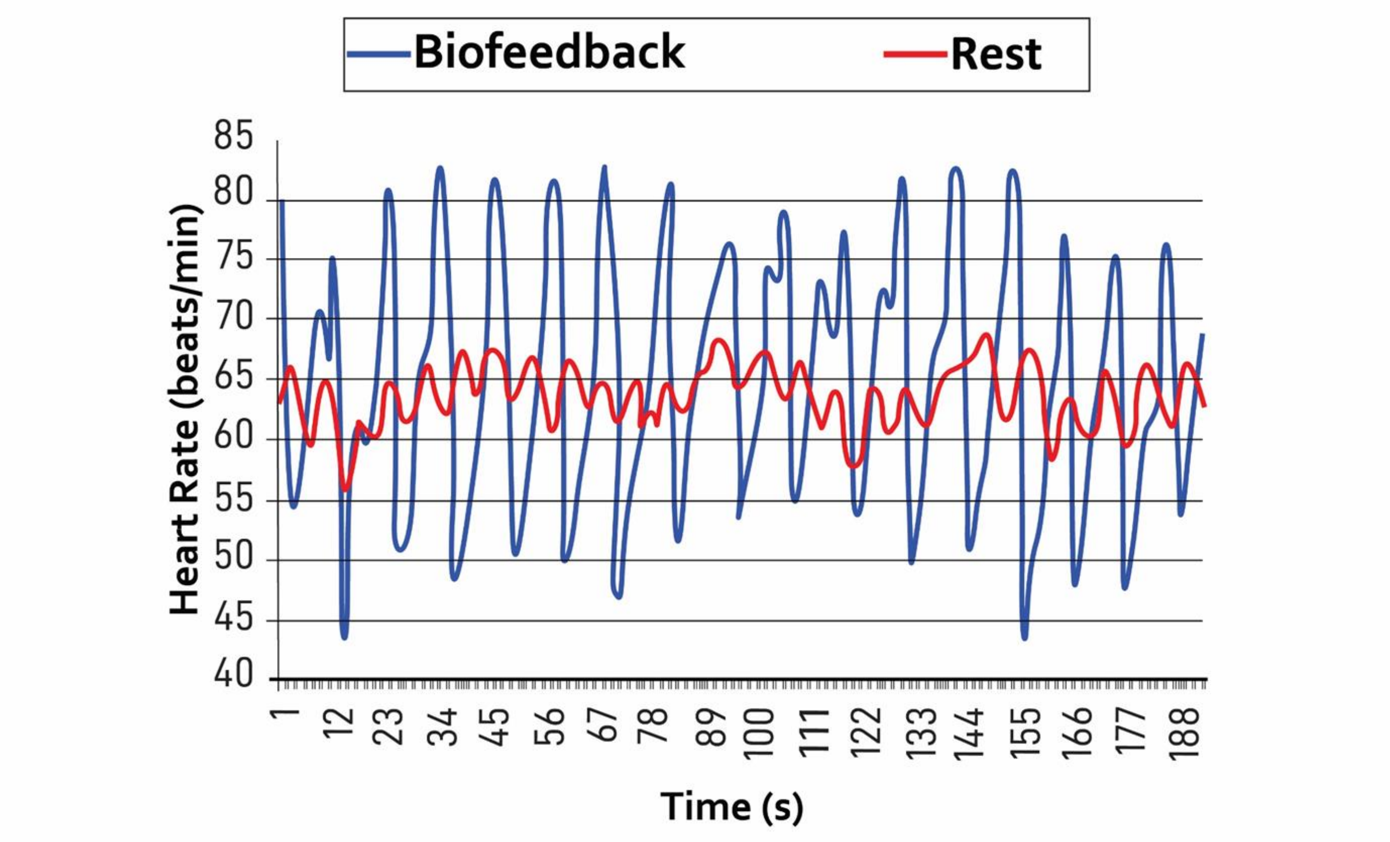
RF breathing
4.5-6.5 bpm



Increased
RSA

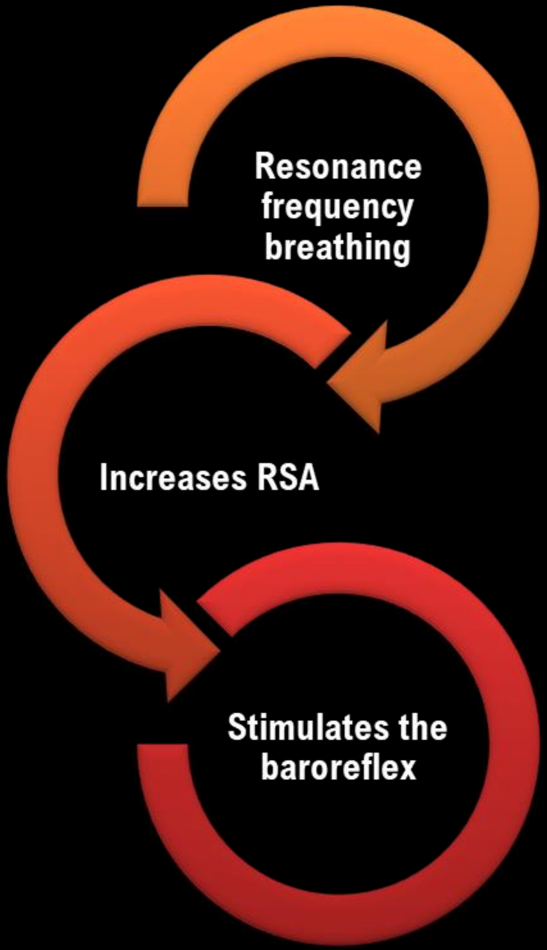
Graphic adapted from Elite Academy

How does breathing affect the baroreflex?



Graphic courtesy of Gevirtz, Lehrer, and Schwartz

How does breathing affect the baroreflex?



Heart Rate Variability: Resonance Frequency Training

- The most widely-used HRV biofeedback protocol identifies the RF and guides the individual to breathe at this rate.
  - HRV biofeedback begins with a RF assessment.
  - The practitioner guides the client to breathe for 2-3 minutes at rates between 4.5 and 7.5 breaths/min. and determines the breathing rate with the largest HRV.
  - The HRV statistics used to determine the largest HRV include HR Max-Min, RMSSD, LF power, and phase synchrony.

Heart Rate Variability: Resonance Frequency Training

- Once the RF is determined, the treatment shifts to the patient practicing smooth, paced breathing at the RF breath rate
- The RF practice exercises can be guided in office with sophisticated biofeedback systems, or guided at home with breath pacers or user-friendly consumer grade HRV instruments

HRV Biofeedback: Evidence-Based Applications

Heart Rate Variability

- Resonance Frequency HRV training has been shown to reduce symptoms in a wide variety of medical and mental health disorders
- For any disorder that is accompanied by autonomic dysregulation, HRV training may be therapeutic.
- Resonance Frequency HRV training is also widely used to enhance wellness and optimal performance

Medical & Mental Health Conditions: At Least Emerging Evidence of Benefit from HRV Training

- Asthma
- Cancer Pain
- Chronic Obstructive Pulmonary Disease
- Chronic Muscle Pain
- Congestive Heart Failure
- Coronary Artery Disease
- Fibromyalgia
- Headache
- Hypertension & Prehypertension
- Irritable Bowel Syndrome
- Pre-Hypertension
- Pre-Eclempsia
- Recurrent Abdominal Pain
- Sleep disorders
- Anxiety
- Depression
- PTSD
- Schizophrenia
- Substance Abuse/Cravings
- Traumatic Brain Injury

Medical Disorders

- Asthma (Feldman et al., 2016; Harding & Maher, 1982; Lehrer et al., 2000, 2004, 2006, 2018; Taghizadeh et al., 2019)
- Cancer pain (Burch et al., 2020)
- Chronic obstructive pulmonary disease (Giardino, Chan, & Borson, 2004)
- Coronary artery disease (Cowan et al., 1992; Del Pozo, Gevirtz, Scher, & Guarneri, 2004; Nolan et al., 2005)
- Fibromyalgia (Hassett et al., 2007; Meuss et al., 2013)
- Headache (Minen et al., 2021)
- Heart failure (Swanson et al., 2009)

Medical Disorders (cont.)

- Hypertension and pre-hypertension (Lin et al., 2012; Reinke, Gevirtz, & Mussgay, 2007; Steffen et al., 2017; Wang et al., 2010)
- Immunity (Lehrer et al., 2010)
- Insomnia (McLay & Spira, 2009)
- Irritable bowel syndrome (Dobbin, Dobbin, Ross, Graham, & Ford, 2013; Stern, Guiles, & Gevirtz, 2014; Thomas, 2010; Thompson, 2010)
- Neck pain (Hallman et al., 2011)
- Preeclampsia (Cullins et al., 2013; Siepmann et al., 2014)
- Prehypertension (Lin et al., 2012)
- Recurrent abdominal pain (Ebert, 2013; Sowder, Gevirtz, Shapiro, & Ebert, 2010; Stern et al., 2014)

Mental Health Disorders

- Anxiety disorders (Aritzeta et al., 2017; Beckham et al., 2013; Chung et al, 2021; Dedeepya et al., 2014; Dziembowska et al., 2016; Henriques, Keffer, Abrahamson, & Horst, 2011; Mikosch et al., 2010; Murphy, 2009; Prinsloo, Derman et al., 2013; Prinsloo, Rauch, et al., 2013; Ratanasiripong et al. (2012); Reiner, 2008; Schäfer et al., 2018; Skolnich et al., 2014; Thurber, 2007; Wells et al., 2012; White et al., 2014)

- Depression (Breach, 2012; Bunthumporn, 2012; Caldwell & Steffen, 2019; Hassett et al., 2007; Karavidas et al., 2007; Katsamanis, 2016; Lin et al., 2019; Patron et al., 2013; Siepmann et al., 2008; Zucker et al., 2009)

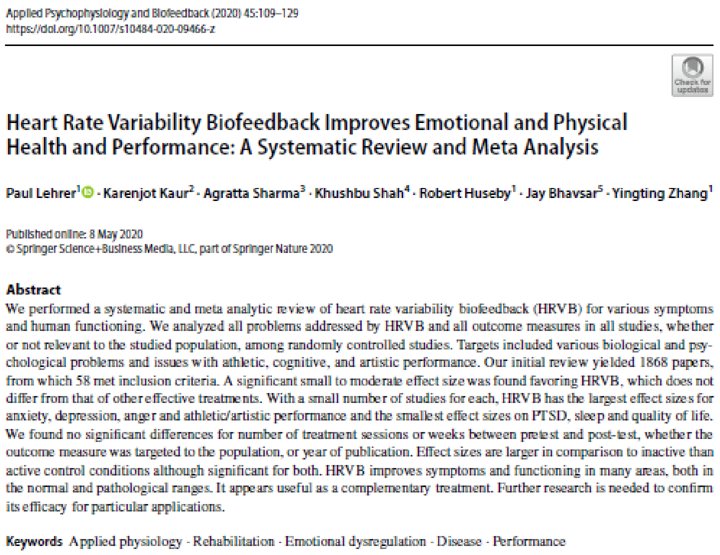
- PTSD (Bell et al., 2019; Ginsberg, Berry, & Powell, 2010; Lande et al., 2010; Polack et al., 2015; Reyes, 2014; Schuman & Killian, 2018; Tan, Dao, Farmer, Sutherland, & Gevirtz, 2011; Tan, Wang, & Ginsberg, 2016; Zucker, Samuelson, Muench, Greenberg, & Gevirtz, 2009)

Mental Health Disorders

- Schizophrenia (Clamor et al., 2016; Stein & Nikolic, 1989; Trousselard et al., 2016).
- Substance abuse and cravings (Eddie, Kim, Lehrer, Deneke, & Bates, 2014; Eddie, Vaschillo, Vaschillo, & Lehrer, 2015; Penzlin et al., 2015, 2017)

Heart Rate Variability: Paul Lehrer et al. Meta-analysis (2020)

- A research team based at Rutgers University: Paul Lehrer, Karenjot Kaur, Agratta Sharma, Khushbu Shah, Robert Huseby, Jay Bhavsar, and Yingting Zhang
  - The team reviewed 1868 published papers on HRV, 58 studies meeting inclusion criteria
  - This meta-analysis applied the most stringent methodological standards and highlighted only the 58 studies with the best research designs, and minimal risk of bias.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Heart Rate Variability Biofeedback Improves Emotional and Physical Health and Performance: A Systematic Review and Meta Analysis

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Abstract
We performed a systematic and meta analytic review of heart rate variability biofeedback (HRVB) for various symptoms and human functioning. We analyzed all problems addressed by HRVB and all outcome measures in all studies, whether or not relevant to the studied population, among randomly controlled studies. Targets included various biological and psychological problems and issues with athletic, cognitive, and artistic performance. Our initial review yielded 1868 papers, from which 58 met inclusion criteria. A significant small to moderate effect size was found favoring HRVB, which does not differ from that of other effective treatments. With a small number of studies for each, HRVB has the largest effect sizes for anxiety, depression, anger and athletic/artistic performance and the smallest effect sizes on PTSD, sleep and quality of life. We found no significant differences for number of treatment sessions or weeks between pretest and post-test, whether the outcome measure was targeted to the population, or year of publication. Effect sizes are larger in comparison to inactive than active control conditions although significant for both. HRVB improves symptoms and functioning in many areas, both in the normal and pathological ranges. It appears useful as a complementary treatment. Further research is needed to confirm its efficacy for particular applications.

Keywords Applied physiology · Rehabilitation · Emotional dysregulation · Disease · Performance

Heart Rate Variability: Paul Lehrer et al. Meta-analysis (2020)

- Conclusions:
  - HRVB has largest effect sizes for anxiety, depression, anger, and athletic/artistic performance enhancement.
  - HRVB has smaller yet significant effect sizes on PTSD, sleep, and quality of life.
  - HRVB improves symptoms and functioning in many areas, both in the normal and pathological ranges
  - HRVB is a useful complementary treatment, adding additional efficacy when combined with standard treatments.

HRV Training: Mechanisms and Pathways

- The most widely cited mechanism is the role of vagal pathways in activating medial prefrontal cortical areas, which in turn indirectly regulate subcortical affect centers.
  - The vagus nerve delivers parasympathetic nervous system effects.
- A second mechanism is the direct impact of vagal afferent pathways on affect regulation centers: the locus coeruleus, orbitofrontal cortex, insula, hippocampus, and amygdala (Grundy, 2002; Lehrer & Gevirtz, 2014).
- A third mechanism is the strengthening of homeostasis in the baroreceptor (Lehrer et al., 2003; Lehrer & Gevirtz, 2014; Vaschillo et al., 2002).
  - The baroreceptor are blood pressure sensors and have direct impact on cardiovascular disorders.

HRV: Autonomic Dysregulation and Cardiovascular Disorders

- Schroeder et al. (2003) followed a population-based cohort of 11,061 individuals, aged 45 to 54 for 9 years.
- Among 7,099 persons without hypertension at baseline, low HRV predicted greater risk for onset of hypertension.
- The authors observed that "decreases in autonomic nervous function precede the development of clinical hypertension"

HRV Activation and Pre-frontal Cortex

- Wendt and Thayer (in press) propose that "vagally mediated HRV can serve as an index of pre-frontal cortex (PFC) functionality."
  - The PFC is the executive control center of the cortex.
- Conversely, they proposed that lower HRV can serve as a *transdiagnostic marker of psychopathology.*
- Similarly, Beauchaine and Thayer (2015) hypothesized that reduced vagally mediated HRV indicates a *general vulnerability factor*, i.e., impaired functionality of the PFC and/or its connectivity with subcortical brain regions.

HRV Training: Promising New Applications and Special Approaches

Heart Rate Variability Mobile Devices and Phone Apps

Consumer Oriented Devices

- Consumer oriented HRV training devices have been utilized both clinically and in research for over a decade
  - The StressEraser was one of the first portable training device, developed by the Helicor Corporation and made available for home training in research studies
  - Example, Zucker (2009) utilized home training with the StressEraser in initial research on PTSD and depression
  - Research protocols have either provided in-office training supplemented by home training, or increasingly provided in-office orientation and only home training

Top Portable HRV Devices and Apps

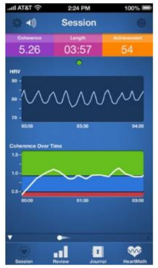
- Devices enabling *HRV monitoring*: passive devices that record HRV but provide no feedback for training
  - Viiiva -- a passive chest HR monitor, used primarily to track HR during workouts, transmitting via Bluetooth & ANT
  - WHOOP -- an advanced technology wrist monitor transmitting data via Bluetooth
  - Biostrap HRM – all in one HR monitoring, transmitting via Bluetooth & ANT
  - Polar H10 HR sensor – gold-standard HR sensor, using Bluetooth & ANT

Evolution in Instrumentation: From Hard Wired Devices to Fiber-Optic to Bluetooth to ANT

- Hard-wired devices anchored the trainee in close proximity with the biofeedback instrument (and computer) and entailed potential electrical shock risk.
  - Optimally, optical isolation technology insulated the patient from AC current.
- Fiber optic cables enabled the trainee to move about the space more flexibly and eliminated electrical shock risk.
- Bluetooth enabled much greater freedom of movement while monitoring.
- ANT - Advanced and Adaptive Network Technology – specifically enables networking of sensor data, with multiple devices at once.

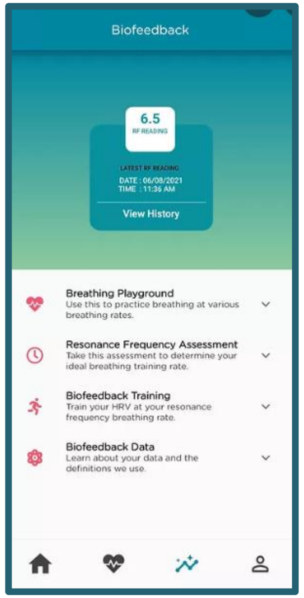
Top Portable HRV Devices and Apps

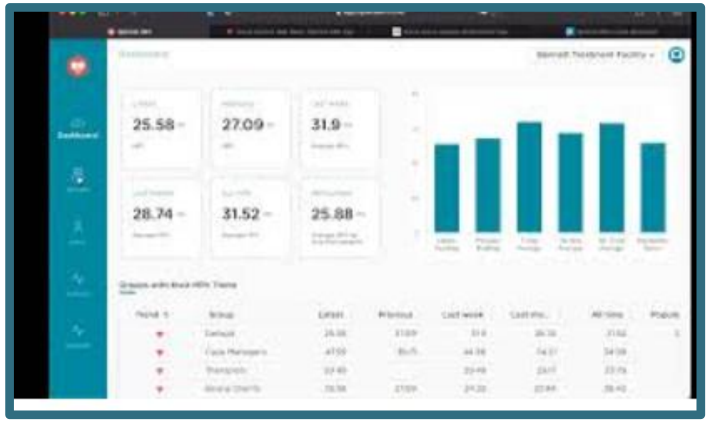
- Devices enabling *HRV training*: providing feedback to enable increases in HRV
  - eVu TPS system – compact portable sensor providing physiological monitoring and training, 3 physiological signals, Bluetooth transmission
  - HeartMath EmWave2 – standalone device providing visual feedback to guide increasing HRV, transmits via WiFi and USB
  - HeartMath Inner Balance – ear clip sensor records HR displayed for training on smart phone or tablet, transmits via Bluetooth or a wire, sophisticated visual displays
  - Lief Therapeutics – utilizes adhesive patches to monitor HR, medical grade ECG recording, feedback via smart phone displays and vibration to signal stress related decreases in HRV



Resonance Frequency Assessment on Consumer Oriented Devices

- Software enabling *Resonance Frequency (RF) Assessment*: Identifying the breath frequency that produces the largest oscillations in HR, the greatest SDNN or RMSSD, and the closest phase synchrony
  - *OptimalHRV* provides software monitoring HRV, a reliable RF assessment, and training.
  - This software works with the HeartMath Bluetooth sensor, Polar Strap, Kyto, Coresense, and other Bluetooth-enabled sensors





Top Portable HRV Devices and Apps

- Breath Pacers Guide Trainees to Breathe at the Resonance Frequency
  - The smart phone apps, *Awesome Breathing, Breath-Pacer, Breathe2Relax, Breathing Zone, MyCalmBeat, and BreathePlus* provide breath pacers to guide breath training, meditation, and breathing practice
  - The InnerBalance and many other consumer oriented devices provide breath pacers as well.

Anxiety Episodes in Recreational Scuba Divers

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

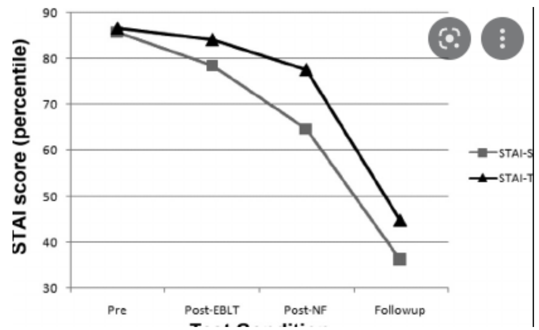
- Brian Imber (2019) conducted a doctoral dissertation research project training recreational scuba drivers.
- From 2010 to 2017, 398,907 individuals achieved introductory level certification in scuba.
- Serious accidents and deaths during scuba are significant albeit not common. One study reported 947 fatalities during diving between 1992 and 2003.
- About 19% of diving accidents are due to anxiety or panic, with anxiety triggering increased air consumption, emergency ascents, and other hazards.

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Imber recruited nine certified recreational scuba divers with elevated state anxiety
- Participants ranged in age from 26 to 62, with scores of 35 or more on State Anxiety, on the State Trait Anxiety Inventory (STAI)
- Each participant performed a pre-training open water dive, five one-hour training sessions, and a post-training open water dive, with physiological monitoring and pre- and post-training questionnaires

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Measures:
  - Psychometric questionnaire (pre- and post-):
    - State-Trait Anxiety Inventory (STAI) (Spielberger, 2015)
    - Profile of Mood States (POMS) (Heuchert & McNair, 2012)
    - Generalized Expectancy for Success Scale (GESS) (Hale, Fiedler, & Cochran, 2006)
  - Physiological Measures (pre- and post-)
    - Thought Technology ProComp Infiniti ECG (HR and HRV), Respiration Sensor (Breath Rate), Blood Volume Sensor (HR, HRV)



Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Measures:
  - Physiological Measures (during dives)
    - The Scuba Pro GALILEO SOL\LUNA dive computer measures air consumption, airflow rate, dive time, and heart rate, and skin temperature.

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Imber developed a training protocol combining HRV training with a well-documented cognitive behavioral intervention for anxiety in five one-hour sessions.
  - Stress-inoculation training (SIT) followed a five-step protocol developed by Donald Meichenbaum and Dennis Turk.
  - SIT included psycho-education about anxiety and active practice of HRV skills and other coping skills during exposure to videos of problem dives.
  - HRV training included assessment of RF, in-office brief practice breathing at RF, and home training with *breath pacer* set at RF.

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Results:
  - Participants completing the training showed significant reductions in air consumption and heart rate in the post-training dive. High air consumption and high HR are positive markers for anxiety and potential indicators of a problem dive.
  - Participants completing the training showed a positive change in mood (decreased mood disturbance, decreased anxiety, increased vigor) while scuba diving, comparing pre-to-post intervention.

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Results:
  - Participants completing the training showed a positive increase in self-efficacy (GESS scores) while diving, comparing pre- to post-training dives.

Heart Rate Variability Can Reduce Anxiety Episodes in Recreational Scuba Divers

- Conclusion:
  - “This research study utilized Stress Inoculation Training and Heart Rate Variability Biofeedback, a novel mind-body stress coping skill for scuba divers that incorporates slow rhythmic breathing at a physiologically optimal specific individual breathing rate, augmented with cognitive restructuring. This highly structured and directed mind-body intervention was found to indicate its feasibility to be effective in mitigating the symptoms of high anxiety (or panic) induced by high stress during recreational scuba diving among research participants who experience this problem” (Imber, 2019, p. 77).

Reducing Test Anxiety Using a Portable Biofeedback Respiratory Training Device

Test Anxiety in College Students

- Defining the Problem
  - Test anxiety appears when individuals believe their skills are being evaluated and they fear negative outcomes in this evaluation.
  - Past studies have reported that 20 to 40 % of college students experience test anxiety of sufficient severity that it interferes with performance (Cizek & Berg, 2006; Embse et al., 2013).
  - Test anxiety affects student performance before, during, and after tests (Beilock, 2008; Bonaccio et al., 2012; Rothman, 2004).
  - Test anxiety also undermines student QOL (Dehghan-nayeri & Adib-Hajbaghery, 2011; Mendlowicz & Stein, 2000).

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- Rosenberg & Hamiel (2021) recruited 39 undergraduate students with high test anxiety and qualified 34 for the study.
- In this study they implemented a guided self-help treatment, using a self-help tool, with minimal guidance by a clinician.
- They utilized the CalmiGo® device.
  - This device senses the current length of exhalation and guides the user to extend the length of the exhalation, using sound, light, and vibration feedback.
  - This training reduces the rate of breathing.

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- Rosenberg & Hamiel (2021) assigned 34 participants to three groups:
  - A biofeedback group that received the CalmiGo device and a handout with information about text anxiety.
  - A group who received instructions to engage in self-directed breathing exercises (to slow their breathing) and received the handout.
  - A group who received only the handout.

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- **Measurements**:
- All three groups completed pre- and post-measurements utilizing:
  - Test Anxiety Inventory (TAI)
  - Depression Anxiety Stress Scales (DASS-21)
  - World Health Organization Quality of Life Group (WHOQOL-Brief)
- All three groups also completed the Perceived Change Questionnaire (PCQ) post-intervention only.

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- Results
  - TAI results:
    - Participants in the biofeedback group achieved a significant decrease on the TAI.
    - Participants in the self-directed group and the handout only groups achieved a smaller and non-significant decrease on TAI.
    - The change on TAI scores for the biofeedback group was significantly different compared to the other groups.
  - DASS21 results:
    - Participants in the biofeedback group achieved a significant decrease on the total score and stress subscale on the DASS21..
    - Participants in the self-directed group and the handout only groups did not achieve significant decreases on DASS21 scores.

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- Results
  - WHOQOL-Brief results:
    - Participants in the biofeedback group achieved a significant improvement on the psychological wellbeing QOL subscale, not on the total score or physical QOL subscale.
    - Participants in the self-directed group and the handout only groups achieved no significant decreases on the WHOQOL-Brief.
  - PCQ results:
    - 100 % of participants in the biofeedback group achieved a significant decrease in perceived stress, 50% of those in self-directed breathing perceived a decrease in stress.
    - 40% of participants in the handout only groups perceived an increase in stress.
    - Both interventions appeared to moderate perceived stress, with biofeedback having a greater impact.

Application of a Consumer-Grade Portable Biofeedback Device to Train Breathing

- Discussion
  - The results show that self-directed interventions to modify breathing produced positive effects in students with test anxiety.
  - The benefits were greater and more consistent across measures for those using the biofeedback device.
  - The participants in the biofeedback group also practiced their exercises more frequently (more times per day) than the self-directed breathing group.
  - The addition of a biofeedback device appears to provide additional therapeutic benefit for self-help breathing training.

Applying a Wearable HRV Biofeedback Device with Anxiety

Anxiety Disorders are Widespread and Impact Quality of Life and Medical Costs

- Demographics and Impact: US
  - 19.1 % of US adults have had an anxiety disorder -- over 40 million US adults
  - Many anxiety disorders are co-morbid with other chronic health conditions; 59 % of individuals with GAD also suffer MDD
  - Patients with anxiety and depression suffer more chronic and recurrent forms of medical illness
  - Only 36.9% of persons with anxiety in the US receive treatment
    - Chung et al. (2021)

Anxiety Disorders are Widespread and Impact Quality of Life and Medical Costs

- Demographics and Impact: Globally
  - Globally, anxiety disorders are the second leading mental health-related cause of disability
  - The global incidence of anxiety disorders increased significantly from 1990 to 2019, from 31.13 million to 45.82 million current cases, and 0.6 million new cases in 2019.
    - Individuals aged 15–19 and 40–44 had the highest estimated DALYs rate.
    - Both the incidence rate and the disability burden for women has consistently exceeded those for men.
      - Xiong et al. (2022)

Reducing Symptoms of Anxiety with HRV Biofeedback Wearable and Remote Stress Management Coach

- Chung et al. (2021) recruited 14 adults with clinical anxiety
- Measurements administered within the Lief mobile app
  - Generalized Anxiety Disorder (GAD-2) Questionnaire -- anxiety
  - Patient Health Questionnaire (PHQ-2) -- depression
- Inclusion/Exclusion
  - Included participants scoring 3 or higher on GAD-2, indicative of clinically significant anxiety
  - Excluded participants scoring 5 or 6 on PHQ-2, indicative of MDD
  - Excluded participants with heart disease, those on anxiety medication, or seeking treatment for anxiety/depression

Reducing Symptoms of Anxiety with HRV Biofeedback Wearable and Remote Stress Management Coach

- Intervention: Wearable Biofeedback
  - Lief Smart Patch – uses ECG to collect HR, HRV, and accelerometer data
  - Lief advantages:
    - Worn for several hours through the day
    - Delivers HRV feedback *in the moment – in the course of everyday life.*
    - *Discreet* form factor – worn under clothing, delivers HRV exercises by vibration
    - ECG-based measurement, more accurate than PPG-based devices.

Lief System: Training Principles

- The Lief system does not use a Resonance Frequency (RF) protocol.
  - It does not measure the RF and direct the trainee to breathe at a specific rate.
- The Lief feedback guides users to exhale when HR drops, and inhale when HR increases.
- The result is an amplification of RSA amplitude.

Lief System: Training Principles

- The Lief system uses multiple three-minute training sessions
- The trainee feels the vibration guiding breathing and sees an RSA linegraph on the Lief smart phone app
- The Lief system compares HRV in the first 30 seconds of each session to HRV in the last 30 seconds of each session, and presents summary data after each session
- Lief uses the actual RSA linegraph for real time feedback and presents post-session comparisons using RMSSD (root mean square of successive differences)

Remote Stress Management Coaching

- Bi-weekly during the 8-week study, subjects participated in ten-minute telephone coaching sessions:
  - Coaching 1: Introduction to HRV, instructions on wearing and using the Lief system, including the 3-minute training sessions
  - Coaching 2: Identifying and discussing triggers for stress and anxiety and reviewing how to apply HRVB for overall wellness, to prepare for challenges, and to cope during challenges

Remote Stress Management Coaching

- Coaching 3: Deconstructing the stress response – triggers, physiological reaction, thoughts, feelings, behaviors
- Coaching 4: Managing difficult emotions using "RAIN" mindfulness strategies – Recognize, Allow, Investigate, Non-Identify

Lief Sessions during Study

- Participants were instructed to wear the Lief Smart Patch for 4 hours at least 40 days during the 56-day period of the study
- Participants committed to completing 3 Lief-guided breathing sessions at least 40 of 56 days
- Participants committed to complete GAD-2 and PHQ-2 every two weeks, using the Lief mobile app to complete questionnaires

Chung et al.: Compliance

- All participants participated in remote coaching sessions
- All participants completed GAD-2 and PHQ-2 bi-weekly
- The majority of participants wore their Lief system at least forty days and completed at least one 3-min HRVB session on 40 days
- Less than ½ of participants completed the prescribed three 3-min sessions on 40 of 56 days
    - Age, gender, and baseline test scores did not predict compliance

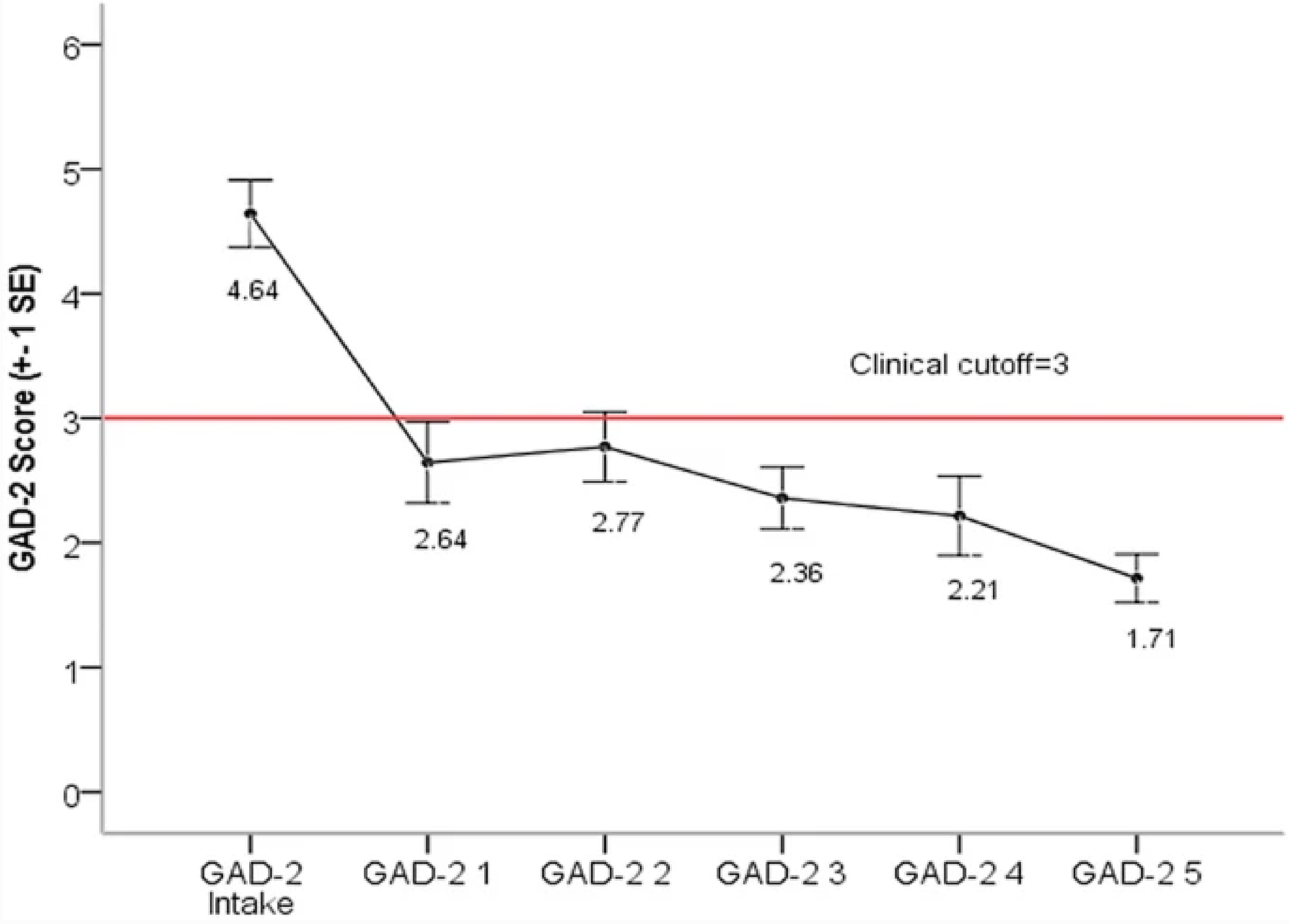
Chung et al.: Results

- Anxiety: Participants mean GAD-2 scores dropped three points from a basal 4.6 to a final 1.7 on a 6-point scale
- Only 14 % of participants scored over the clinical threshold of anxiety at the close of the study
- Depression: Participants mean PHQ-2 scores also dropped significantly from 2.93 to 1.29
- Comparison of basal HRV to end of session HRV showed that participants significantly increased their RMSSD in the training sessions.

Results

- GAD-2 Scores Across Course of Study

Fig. 1



Mean GAD-2 scores across 6 time points

Chung et al.: Discussion

- This study included no comparison of baseline HRV pre-treatment to a baseline HRV post-treatment, which would have strengthened the study in assessing training impact
- We expect to see an increase in HRV from the beginning to the end of a training session
  - It is more significant to see an increase in baseline HRV from Day 1 to Day Final when *not* doing breathing practices

Chung et al.: Discussion

- The major weaknesses of this study are the small sample size and the absence of a control
- However, the study implements a user-friendly wearable technology in self-directed training, assisted by telephone coaching
- This study offers promise for inexpensive interventions with only minimal expenditure of professional time

Chung et al.: Discussion

- Participants showed clinically significant reductions in both anxiety and depression
  - 86% of the participants moved from above to below the clinical anxiety threshold with this brief training
- This training protocol offers an option in the pandemic time, for patients to engage in HRV training with no face-to-face contact

Female Sexual Arousal Disorder

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder

- One in four women in the US report at least intermittent sexual arousal dysfunction.
  - The prevalence rates for diagnosed arousal dysfunction vary with age, from 3.3 % between ages of 18 and 44, to 7.5 % in women between ages of 45 and 64, to 6% above the age of 65.
  - Low resting HRV is associated with poor resting sexual arousal in women.
- Several research studies have examined the impact of behavioral interventions to increase HRV in women with arousal dysfunction.

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder (cont.)

- A single session of autogenic training increased HRV levels, improved arousal, and improved genital sensations (Stanton & Meston, 2016), and specifically improved subjective arousal in women with sexual arousal problems (Stanton et al., 2018).
- Stanton et al. (2019) conducted a study implementing autogenic training and HRV biofeedback for 78 women with diminished sexual arousal.
  - Participants were randomized to receive: 1) HRV training only, 2) HRV Training plus Autogenic Training, or 3) a Waitlist Control Condition.

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder (cont.)

- The HRV training consisted of two - three 20 min. biofeedback sessions at home, using a Polar Bluetooth HR sensor and fitness tracker and an Elite HRV app, with a visual breathing aid.
- The Autogenic Training consisted of listening to a 14-minute Autogenic Training recording.

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder (cont.)

- Participants were seen for three face-to-face laboratory sessions, during which overall sexual function and arousal function were measured along with heart rate variability.
- Measures included two paper and pencil questionnaires, an electrocardiogram, and vaginal photoplethysmography (PPG, monitoring vaginal blood flow during a neutral condition and during arousal).
  - The vaginal PPG measures both vaginal blood volume and vaginal pulse amplitude, reliable correlates of arousal.

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder (cont.)

- The study monitored both vaginal physiological arousal and subjective perceptions of vaginal arousal.
- Both physiological and subjective arousal measures were assessed during three 10-minute audiovisual films, including neutral and erotic segments.

Heart Rate Variability Training can Increase Sexual Arousal in Women with Female Sexual Arousal Disorder (cont.)

- Results:
  - Participants in both the HRVB and the HRVB plus AT conditions showed increases in HRV and in subjective and physiological measures of arousal.
  - In the HRVB group only, the magnitude of increases in HRV correlated with the increases in perceived vaginal arousal.
  - The results provide tentative support for the conclusion that HRV increases are a mechanism for increase in subjective arousal.

Breath Training and Respiratory Biofeedback

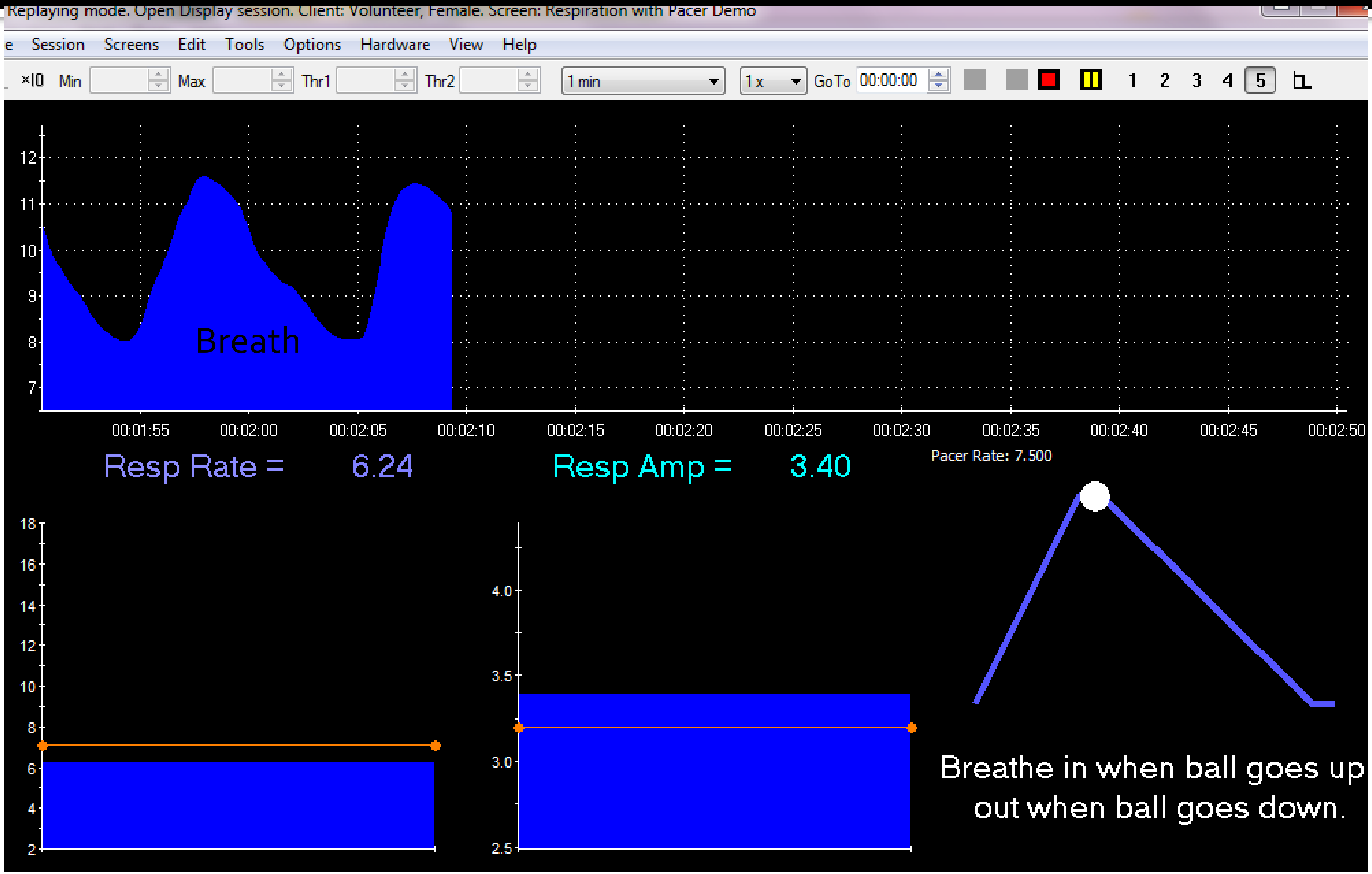
Breath Training Provides an Evidence-Based Independent Treatment

- Today biofeedback practitioners primarily consider breath training as a component in HRV biofeedback.
- There is an independent literature on breath training and respiratory biofeedback as independent therapies.
- Respiratory biofeedback uses a "respirometer" to track expansion and contraction of the abdomen and chest with breathing.
- Respiratory biofeedback also uses a capnometer to measure CO_2 in the exhalation.

Biofeedback Instrument: The Respirometer

- Respirometer, Also Known as a Pneumograph or Breath Band
  - Measuring respiration rate and breathing patterns
  - Useful in psychotherapy and breathing training
  - A respirometer uses a flexible sensor band that is placed around the chest and/or abdomen.
  - A respirometer measures relative expansion/contraction of chest and abdomen, relative length of inhale and exhale, and respiration rate.
  - The respirometer line graph also shows the *architecture* of each breath

Respiratory Feedback



Biofeedback Instrument: The Capnometer

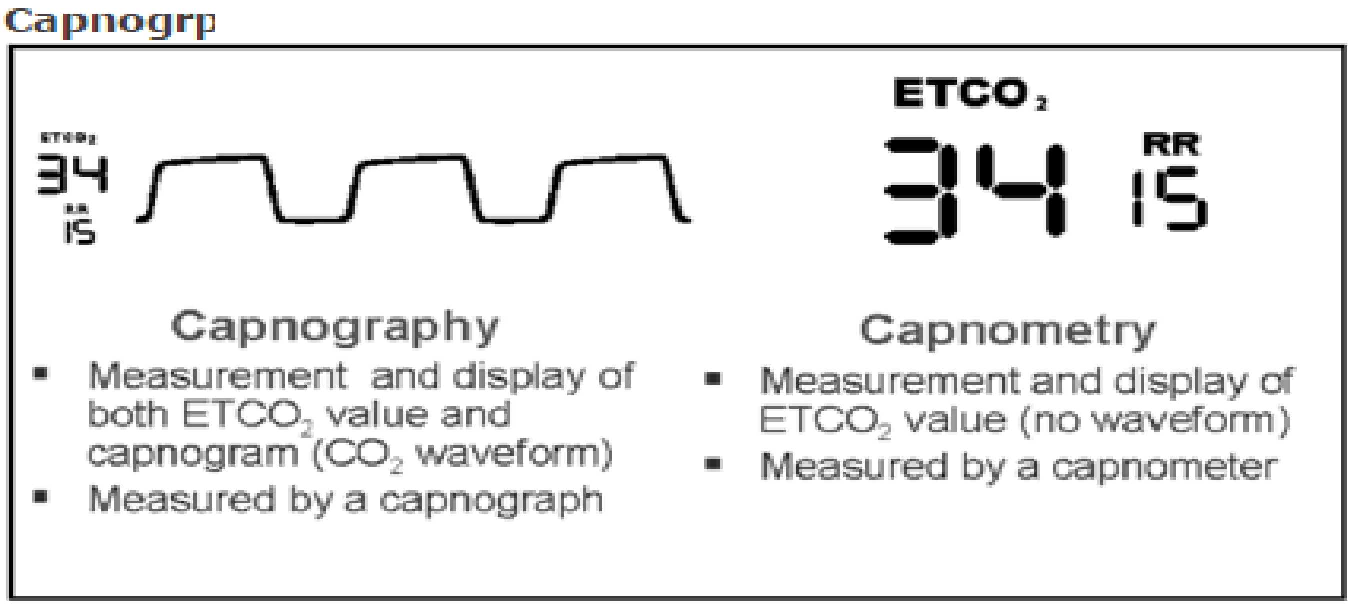
- Measures *end tidal CO2* levels and Oxygen saturation
  - Asthma and COPD
  - Anxiety disorders, PTSD
  - Many patients with chronic illnesses

Capnometer Application

Plastic canula inserted into nostril

- Analyzes the CO2 level and oxygen level in exhaled air

Respiratory Feedback



Many newer capnometers provide a computer interface providing waveform displays as well as digital displays of CO2 levels, and pulse rate, facilitating training. Many also display O2.

The Physiology and Psychology of Respiration

- Robert Fried, Christopher Gilbert, and Inna Khazan have published extensively on the physiology of respiration and the physiological pathways for the efficacy of breathing as a treatment.
- Breathing faster or slower affects CO_2 levels in our airways and in the bloodstream
- Maladaptive breathing, over-breathing, and hyperventilation all refer to breathing that produces abnormal CO2 levels, vasoconstriction, oxygen deficits in the brain, and other physiological dysregulation.

Simplicity of Breathing

- Breathing faster or slower affects basic intracellular chemistry
- Carbon dioxide and oxygen levels in the bloodstream are critical to real and subjective well-being
- Hyperventilation changes the acid/base balance in the bloodstream and organ tissue

Normal Breathing: co2

- Normal breathers show level paCO2 levels, around 40 Torr (mmHg)
- Normal breathers recover rapidly to normal breathing and normal paCO2 levels after over-breathing
- Normal breathers find the effort to over-breathe uncomfortable

Biochemistry and Physiology of Hyperventilation

- Rapid breathing "blows off" CO_2
- Reduces CO_2 in respiratory airstream
- Produces respiratory alkalosis
- Lowers arterial CO_2 (hypocapnia)
- Induces cerebral vasoconstriction and hypoxia
- Increases SNS arousal and later fatigue

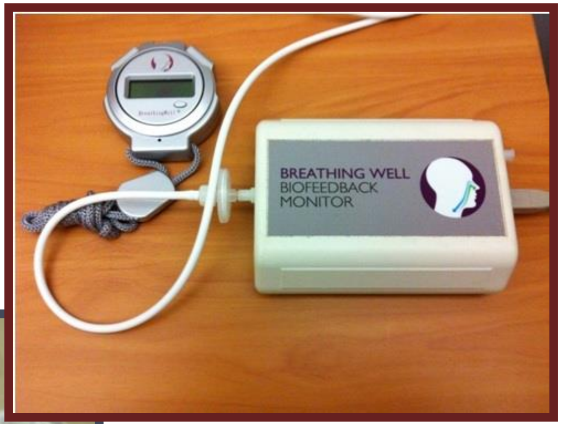
BIOCHEMISTRY AND PHYSIOLOGY OF HYPERVENTILATION

- "As a consequence of hyperventilation, the decrease in PCO_2 will reduce the caliber of the arteries and thereby impede the flow of blood to body tissue (ischemia), and the increase in blood pH will reduce the amount of oxygen that hemoglobin can release to the body tissue (hypoxia). Therefore, the heart must pump more frequently and with greater vigor in order to compensate for the decrease in pCO_2 and increase in pH." (Ley, 1987, p.309)

Vocabulary

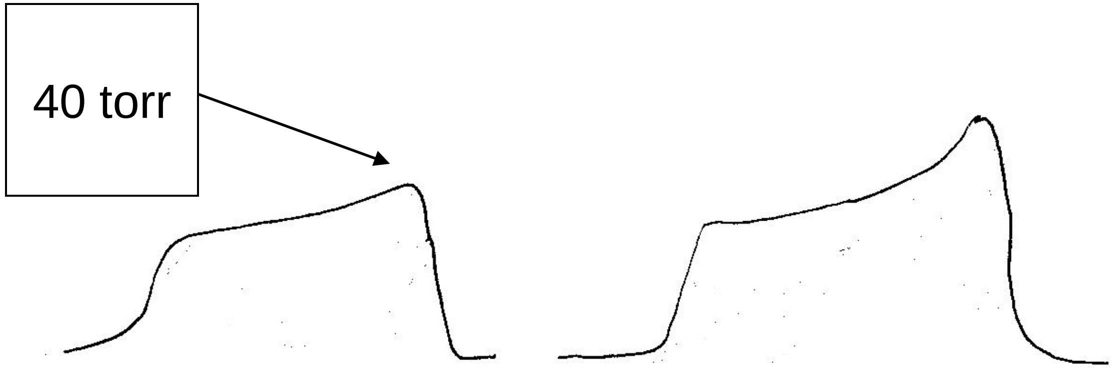
- Partial CO_2 (Pa CO_2) – the amount of CO_2 in the blood stream or in the airstream internally
- End tidal CO_2 (ET CO_2) – the amount of CO_2 in the expiratory breath at the nose or nostrils (the end of the "tidal flow" of respiration)
  - Reliable $PaCO_2$ requires blood sample or indwelling arterial catheter
  - ET CO_2 is accessible for measurement with a nostril tube leading to a "Capnometer"
- CO_2 content is measured in pressure, as in so many mm of Mercury (mm HG)
  - One mm of HG is referred to as one *Torr*

Capnometers for Respiratory Assessment and Training

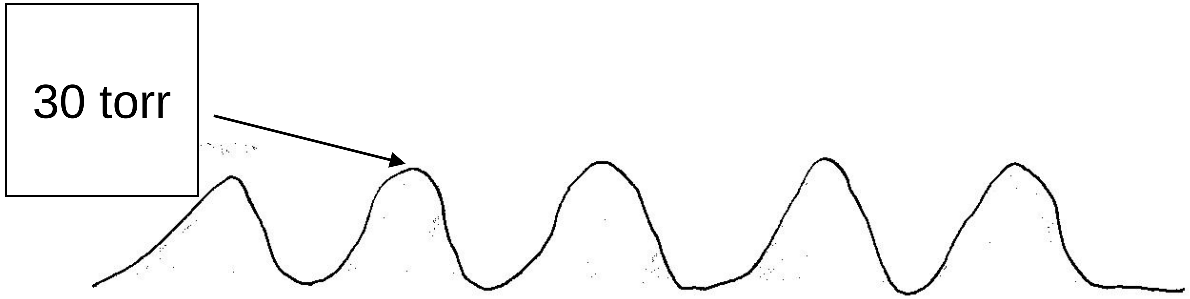


Capnographic Tracings

A) Normal



B) Dysfunctional



Hypocapnia

- Hyperventilation ≥ 16 BPM
- End tidal CO_2 < 33 Torr (mmHg)
- Hypocapnia causes a rise in blood PH
- The body restores the blood PH balance by renal excretion of bicarbonate ion
- This buffering process produces changes in intracellular chemistry

Breathing and pH in Tissue

Incorrect breathing can cause pH imbalances:

- Hypoventilation causes Respiratory Acidosis (<pH): too much CO_2 retained by shallow and slow breathing.
- Hyperventilation causes Respiratory Alkalosis(>pH): CO_2 blown off by deep and rapid breathing.

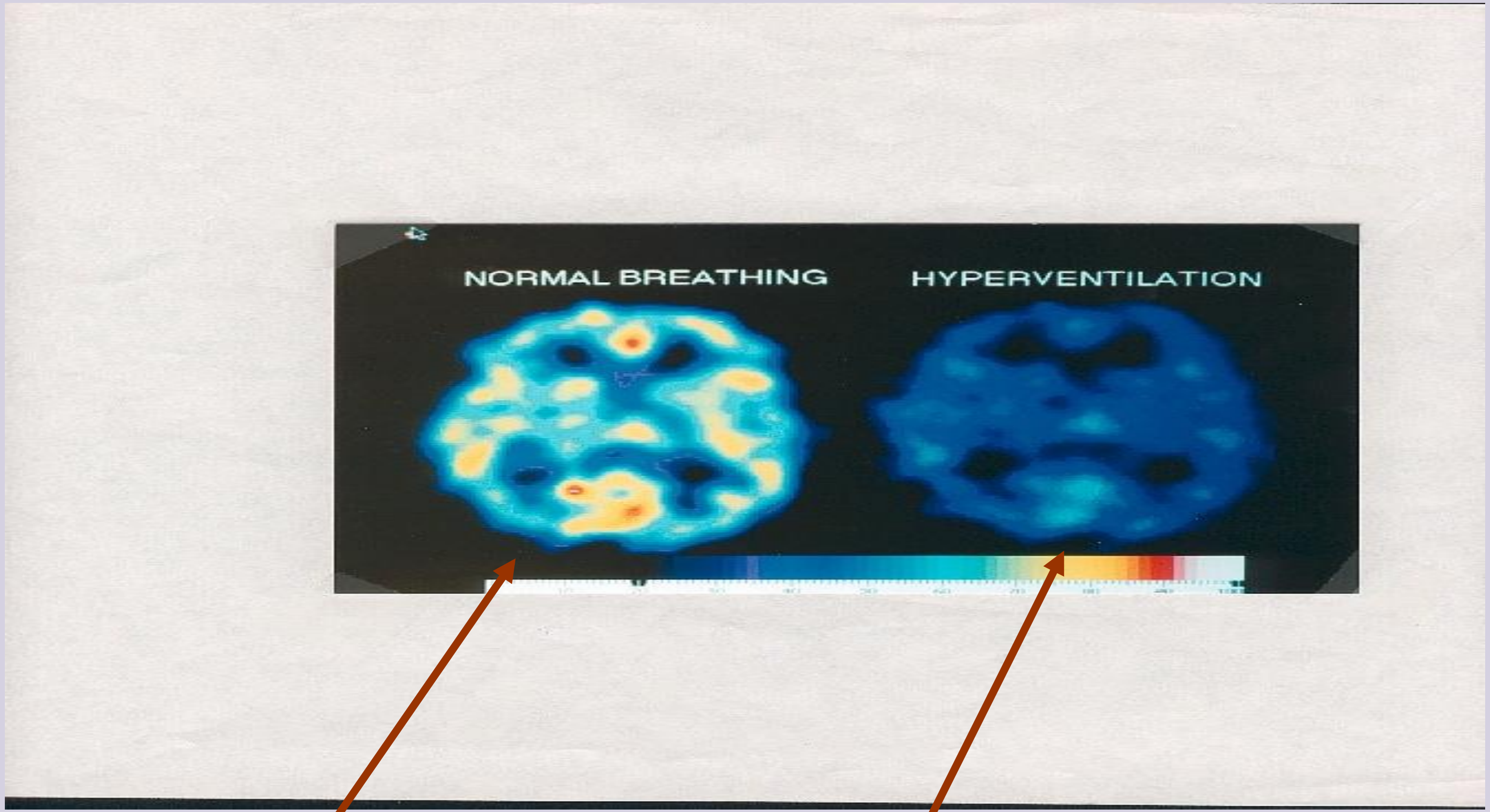
Symptoms of Chronic Hyperventilation

- Cardiovascular -- palpitations, tachycardia, pain in the chest wall over the heart, Raynaud's phenomenon
- Neurological --
  - Central: dizziness, disturbance of consciousness and vision
  - Peripheral: paraesthesiae, tetany (muscle cramping)
- Respiratory -- shortness of breath, asthma symptoms, chest pain

Hyperventilation Symptoms (Cont.)

- Gastrointestinal -- difficulty swallowing, pain in the upper abdomen, swallowing air
- Musculoskeletal -- muscle pain, tremors, tetany
- Psychic -- tension, anxiety
- General -- fatigue, weakness, exhaustion, sleep disturbance, nightmares

Hypcapnia Decreases Cortical Blood Flow and Cerebral Activation



This is your brain
on normal breathing.

This is your brain
on hyperventilation.

Table 1. Nijmegen questionnaire. Respondents are asked to ring the score that best describes the frequency with which they experienced the symptoms listed

Symptom	Never	Seldom	Sometimes	Often	Very often
Chest pain	0	1	2	3	4
Feeling tense	0	1	2	3	4
Blurred vision	0	1	2	3	4
Dizziness	0	1	2	3	4
Confusion or loss of touch with reality	0	1	2	3	4
Fast or deep breathing	0	1	2	3	4
Shortness of breath	0	1	2	3	4
Tightness across chest	0	1	2	3	4
Bloated sensation in stomach	0	1	2	3	4
Tingling in fingers and hands	0	1	2	3	4
Difficulty in breathing or taking a deep breath	0	1	2	3	4
Stiffness or cramps in fingers and hands	0	1	2	3	4
Tightness around the mouth	0	1	2	3	4
Cold hands or feet	0	1	2	3	4
Palpitations in the chest	0	1	2	3	4
Anxiety	0	1	2	3	4

Interpreting the Nijmegen Scale

Scoring Instructions for the Nijmegen Questionnaire:

- The points accompanying each endorsed answer are totaled.
- Scores of 23 or greater are designated as clinically significant.
- Several research studies show that high scores on the Nijmegen Questionnaire indicate the presence of abnormal breathing and a variety of somatic and mental symptoms based on breath patterns. (See Thomas et al., 2001).
- With scores > 23, the presence of hypocapnia is probable.

Respiratory Biofeedback: Applications to Anxiety and PTSD

Respiratory Biofeedback: Applications to Anxiety

- Roth, Meuret, Ritz, Kim, and colleagues have published a series of research studies showing breathing abnormalities in patients with anxiety disorders.
- Meuret et al. (2001) published a treatment protocol using a capnometer, a device to monitor exhaled CO_2, to provide feedback to patients with anxiety, normalizing breath patterns and CO_2.
- A series of follow up studies showed reductions in symptoms of anxiety disorders with capnometric biofeedback training.

Application of Capnometry-Guided Home Training for PTSD (Ostacher et al., 2021)

- PTSD is marked by symptoms of hyperarousal, difficulties with emotional regulation, negative affect, and autonomic dysfunction (APA, 2013).
- PTSD has a physiological correlate in common with panic disorder (PD): CO_2 sensitivity.
- CO_2 challenge tests have been shown to provoke onset of PD symptoms in patients with PD.
- CO_2 challenge tests similarly provoke onset of PTSD symptoms in patients with PTSD.

Overlap between PD and PTSD

- There is overlap in key somatic symptoms in samples of patients with PD and PTSD: palpitations, shortness of breath, chest pain, and dizziness.
- Individuals with PD have heightened risk for developing PTSD, and patients with PTSD have heightened risk for PD.
- Several studies report reductions in PD symptoms using capnometry-guided training (Meuret et al., 2008, 2009; Kim et al., 2012, 2015). Subjects increase $etCO_2$ levels and reduce the rate of breathing using capnometric feedback.

Application of an Evidence-Based Treatment for PD to a Sample of Patients with PTSD

- Given the physiological similarities between PD and PTSD patients, Ostacher et al. (2021), decided to draw on a capnometric biofeedback training protocol already extensively researched for PD and apply it to PTSD.
- Several studies on PD utilized a digital device, labeled as a Capnometry Guided Respiratory Intervention (CGRI).
- One commercial CGRI system, the Freespira ®, was selected for their research.

Ostacher et al. Research Study

- Participants: Adults with primary diagnosis of PTSD and a CAPS-5 score of $\geq$ 30 and a CGI-S score of $\geq$ 4.
- Participants:
  - Were excluded if currently in a psychotherapy process targeting PTSD.
  - Were excluded for COPD, based on CAT.
  - Were required to hold medication dosages stable during the study.
  - 55 participants completed the baseline assessment (36 males and 19 females), 48 completed treatment, 42 the 2-month follow up, and 38 the 6-month follow up.

Measures

- Clinician Administered PTSD Scale (CAPS-5)
- Clinical Global Impression-Severity Scale (CGI-S)
- Patient Health Questionnaire 9-item Depression Scale (PHQ-9)
- Panic Disorder Severity Scale (PDSS)
- Short Form Health Survey (SF-36)
- Chronic Obstructive Pulmonary Disease Assessment Test (CAT)

Capnometry-Guided Training

- Participants were trained onsite to use the CGRI device (Freespira®).
- Training goals included progressively lower respiration rates each week (RR = 13 by week 1, 11 by week 2, 9 by week 3, and 6 by week 4) and $etCO_2$ level of 40 mmHg.
- The Freespira® uses programmed training sequences of 17 minutes, and participants were instructed to complete this Freespira® training twice daily for four weeks.

Criteria for Therapeutic Success

- A positive response was defined as a 6-point decrease in CAPS-5 score from baseline to 2-month follow up.
- Later the positive response was re-defined as a 13-point decrease, due to completion of norming studies on the CAPS-5, and the data were re-analyzed.
- Remission was defined as no longer meeting DSM-5 criteria for PTSD and having a CAPS-5 score < 25.

Results

- 88 % of the subjects achieved the criteria for a positive response
- 48 % of subjects reached the criteria for remission.
- Mean CAPS-5 scores (PTSD symptoms) decreased from 49.5 to 27.1, with an effect size of d'=1.3 (categorized as a large effect size).
- Therapeutic improvement continued through a six-month follow up.

Results (cont.)

- Decreases were also seen in the PDSS, PHQ-9, CHRT-SR, and CGI-S at 2-month follow up, with maintenance of improvement at 6 months.
  - Indicating improvements in panic symptoms, depressive mood, health risk, and global severity.
- etCO2 levels increased modestly from baseline to end of treatment, from 36.2 mmHg to 37.9 mmHg.
- RR showed moderate decrease from RR= 14.9 to RR = 12.8 at end of treatment.

Results (cont.)

- Those subjects who were hypocapnic at baseline showed larger increases in $etCO_2$, from 32.4 to 36.3 mmHG.
- The hypocapnic subjects also showed larger improvements on the CAPS-5, with a higher effect size.
- Adherence to prescribed practice (Adherence = X/56) was rated at 77%.
  - Adherence calculations were conducted on those subjects completing > 14 sessions in 4 weeks.

Conclusions

- The researchers concluded that the Capnometric training protocol provided therapeutic benefit in application to PTSD subjects.
- The protocol produced physiological as well as behavioral changes.
- The therapeutic benefits and physiological changes were greatest in participants with significant hypocapnia.
- The authors concluded that success in achieving physiological changes improves perceived self-efficacy.

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