Cardiac Bio-Markers and Self-Regulation: A Meta-analytic Review

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Cardiac Bio-markers and Self-regulation

- Growing interest in using bio-markers to index psychological characteristics
- Recent interest in heart-rate variability (HRV) as an index of self regulatory capacity
- Important to examine the relation between these variables
Two major theories suggest it exists
- Porges Polyvagal Theory
- Thayer and colleagues Neurovisceral Integration Model

Mixed findings in the literature

Important conceptual implications
- Emotion Regulation vs. Behavioral Regulation?

What is Heart Rate Variability

Many different terms: respiratory sinus arrhythmia, HRV, High-frequency HRV, cardiac vagal tone, etc.
What is Heart Rate Variability

- There are individual differences in how variable people’s heart rate activity is
  - High HRV means there is more flexibility in the interval between heart beats
  - Low HRV means heart beats tend to occur in a steadier pace (i.e., less flexibility)
- Higher HRV is considered to reflect better things (e.g., less risk for disease, more self-regulation)

Physiology underlying HRV

- CAN: multiple brain structures, including anterior cingulate, midbrain (e.g., amygdala), and brain stem (e.g., medulla)
- Autonomic Nervous System: parasympathetic nervous system (PNS) and sympathetic nervous system (SNS)
Both PNS and ANS provide input to the heart’s sinoatrial node (i.e., cardiac pacemaker) through the vagus nerve.

- PNS has a quicker and stronger influence on HRV at rest (Bernstrom et al., 1997).

Vagus nerve has a wide impact on multiple organs and therefore influences physiological states.

- Underlying physiology informed prominent theories as to why HRV might relate to self-regulation.
Porges’ Polyvagal Theory

- Evolutionary Framework
  - CAN came around to influence HRV because it helped increase engagement in social behaviors
- Three main neural circuits influence physiological states
  - Unmyelinated vagus (freezing behaviors)
  - Sympathetic-adrenal system (fight-flight behaviors)
  - Myelinated vagus (self-soothing, inhibiting arousal)

- Myelinated vagal input (e.g., PNS) inhibits SNS activity

- Presence of external stressor: releasing of vagal “brake”, which allows SNS activity to respond
  - Heart rate goes up, HRV reduces
    - Generally – larger reductions HRV are thought to reflect greater regulatory responses
Recent meta-analysis observed significant relation between HRV and activity in many of these brain areas (Thayer et al., 2012)

- Originally, HRV specified as a bio-marker of emotion regulation (Thayer & Lane, 2000)
- Recently expanded to consider HRV as a bio-marker of self-regulation conceptualized broadly (Thayer et al., 2009)
- Fits with models of self-regulation (e.g., Bridgett et al., 2015)
What is Self-regulation (SR)?

- Considered an aspect of temperament that allows flexible regulation of behaviors, cognitions, and emotions.

- Top-down SR fits best with propositions from previous HRV-related theories.
  - Delineated into: (a) emotional regulation and (b) behavioral regulation.

What is top-down SR?

- Top-down regulatory processes that serve to:
  - Emotion regulation: increase or decrease the intensity of an emotion.
  - Behavioral regulation: activate or inhibit behaviors:
    - Executive functioning
    - Effortful control
    - Self-control
  - Share common neurobiological underpinnings.
SR Neurobiological Underpinnings

- Multiple prefrontal cortical areas involved with emotion regulation and behavioral regulation
  - OFC, DMPFC, DLPFC, VLPFC, ACC

- Recent meta-analysis found significant relation between cognitive reappraisal – a type of emotion regulation – and prefrontal cortical activity (Buhle et al., 2014)

Extant Literature

- Makes sense that HRV may reflect SR given prefrontal cortical areas area involved with both variables
- However, substantial inconsistency in the literature
  - Many studies without significant findings
  - Within significant findings, relations vary significantly from small, medium, and large effects (i.e., $r's = .14$ to $>.50$).
Inconsistent Findings

- Since there are many inconsistencies, it is quite possible that several variables moderate this relation
  - Measurement
  - Age
  - Psychopathology

SR Measurement as Moderator

- Report vs. behavioral observations
- Debate in developmental lit (e.g., Kagan; Rothbart)
- Small relation ($r = .19$) b-n performance and report measures of EF (Toplak et al., 2013)
- Report measures often skewed by reporter characteristics (e.g., psychopathology, social desirability)
- Expected stronger relations between SR and HRV to emerge when observations (e.g., performance) were used given their objective nature
HRV Computation as a Moderator

- Multiple methods for computing HRV
  - Statistical: taking the standard deviation of the interbeat interval (ex. SDNN, RMSSD)
  - Frequency: partition HRV along different frequencies of the r-wave (i.e., spikes)
    - High frequency (.15 - .40 Hz) believed to reflect more pure PNS activity (ex. HF-HRV; RSA)
- Expected stronger relations between HRV and SR to emerge when frequency computations were used

HRV Measurement as a Moderator

- Multiple contexts during which HRV measured
  - Baseline
  - During regulatory tasks
  - Change from baseline to regulatory task
- Porges’ “vagal break”
- Explored whether the type of measurement affected the relation
Age as a Moderator

- Top-down prefrontal cortical structures go through maturation until early adulthood
- Both SR and HRV stabilize as people get older
- SR increases in mean-level ability until early adulthood
- Expected that stronger relations would emerge between SR and HRV in samples with older people

Psychopathology as a Moderator

- Unique relations between physiology and behavior proposed to occur at different levels of psychopathology (Beauchaine, 2001)
- Lower RSA among depressed individuals (Rottenberg, 2007)
- Explored whether psychopathology moderated relation between SR and HRV
Current Study Recap

- Test hypotheses from two prominent theoretical perspectives
  - SR ↔ HRV

- Assess magnitude of such relation (e.g., small, medium, large effect size)

- Determine whether HRV reflects emotion regulation or behavioral regulation better

- Determine whether variables moderate such relation

Method
Searching for Studies

- Searched 5 databases
  - PsychInfo, Pubmed, Google Scholar, Web of Science, and ProQuest Digital Dissertations

- Each combination of

<table>
<thead>
<tr>
<th>HRV Term</th>
<th>SR Term</th>
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<tbody>
<tr>
<td>Heart rate variability</td>
<td>Executive function</td>
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<tr>
<td>Respiratory sinus arrhythmia</td>
<td>Effortful control</td>
</tr>
<tr>
<td>Cardiac vagal tone</td>
<td>Emotion regulation</td>
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Identifying Studies

- Searches led to 9,133 studies

- Titles/abstracts reviewed for full-text review

- Met criteria for full-text review if:
  - 1) empirical, 2) reported measurement of SR, and 3) reported measurement of heart rate

- 313 studies met criteria for full-text review
Identifying Studies

- **Inclusion criteria**
  - Reported measurement of SR
  - Reported measurement of HRV
  - Written in English

- **Exclusion criteria**
  - Defined SR as an outcome associated with SR (e.g., psychopathology)
  - Included emotional reactivity (e.g., distress)
  - Experimental studies without baseline
  - Multiple studies with same data included once
  - Unpublished studies that matched published studies

- 62 studies with useable data met criteria

- 77 studies without data met criteria
  - Authors contacted for data
  - 19 authors replied with data

- N of studies = 81
  - 10,458 people and 503 effects
Coding Studies

<table>
<thead>
<tr>
<th>Study Characteristic</th>
<th>Codes</th>
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<tbody>
<tr>
<td>Source</td>
<td>Published or Unpublished</td>
</tr>
<tr>
<td>Research Design</td>
<td>Cross-sectional, longitudinal, experimental</td>
</tr>
<tr>
<td>Sample Size</td>
<td></td>
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<tr>
<td>Type of Sample</td>
<td>At-risk or Community/Healthy</td>
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<tr>
<td>Type of SR</td>
<td>Emotion regulation or Behavioral Regulation</td>
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<tr>
<td>SR Measure Method</td>
<td>Behavioral Observation or Report</td>
</tr>
<tr>
<td>Computing HRV</td>
<td>Frequency or Statistical</td>
</tr>
<tr>
<td>Context for HRV Measurement</td>
<td>Baseline, During Task, or Change</td>
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<tr>
<td>Statistics to Compute Effect Size</td>
<td>Correlations, Means, SD, F-test, t-test</td>
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Effect Size Computation

- Pearson’s r statistic
  - Most studies provided zero-order correlations
  - Computed 4 studies
- ESs w/in studies averaged to maintain independence
- ES estimates coded
  - Higher HRV related to better SR
  - Greater reduction in HRV during change related to better SR
- Transformed ESs in order to adjust for sampling error
Results

Overall ES

- Used a fixed effects model
- Small effect: $r = .11$ (95% CI .09 - .13)
- Fail-Safe N: 2,779
- Q statistic = 169.18 – significant heterogeneity
3 studies excluded: did not report or aggregated both

Significant omnibus. Each contrast compared

Baseline
Task
Change
**Age**

![Age Graph]

**Psychopathology**

Excluded 1 study sampling only individuals with Motor Neuron Disease

![Psychopathology Graph]
Discussion
Main Purpose

- Test relation between SR and HRV:
  - Significant relation
    - Validates propositions from Porges and Thayer and colleagues perspectives
- Assess magnitude of relation
  - Small effect based on Cohen’s criteria
- Determine potential moderators
  - Effect qualified by certain variables

Theoretical Implications

- Some researchers consider HRV solely as an index of emotion regulation, while others focus solely on behavioral regulation
- HRV validated as a measure of self-regulation conceptualized in a broad sense
We expected stronger relations to emerge when behavioral observations were used to measure SR

Results did not support hypothesis

Both methods useful when considering the relation b-n SR and HRV given significant ESs emerged across both measurement methods

Limitation: many observations reflect BR constructs whereas many reports reflect ER construct

Expected frequency statistics to demonstrate stronger relations b-n SR and HRV than statistical

Results did not support hypothesis

Fit with findings that different techniques are highly correlated (typically r > .85) (Bernstrom et al., 1997)

Limitation: relatively small number of studies (n = 19) used statistics – more power may be required to detect such an effect
Methodological Implications
HRV measurement context

- Explored whether baseline, task, or HRV change moderated relation between SR and HRV
- Baseline produced stronger relations than HRV change
  - Surprising considering Porges’ “vagal brake”
  - Maybe HRV change is moderated
    ▪ Psychopathology (Beauchaine, 2001)
    ▪ Type of environmental task likely important (Sulik et al., 2015)
    ▪ Ordering of tasks involved with HRV change (Sulik et al., 2015)
- Still important to note that SR and HRV significantly related across all categories

Methodological Implications
Sample Characteristics: Age

- Expected HRV and SR to demonstrate stronger relations in older samples
- Found support for this hypothesis
- Likely based on prefrontal cortical development corresponding to increasing ability and stabilization of SR/HRV across lifespan
- Evidence that this relation has a developmental trajectory
  ▪ Critical brain development periods (i.e., early childhood, adolescence) may demonstrate periods where relation strengthens the most
- Could not test: Few adolescent samples – need more studies at this age
No evidence that psychopathology moderated the relation between HRV and SR

Possible that no difference exists
- Small effect of depression on HRV: 2% of variance
- Previous meta did not observe psychopathology to moderate relation b-n HRV and adaptive outcomes (e.g., pathology symptoms, academic functioning)

Possible that differences exist that we were unable to detect
- Many of the at-risk/clinical samples contained health controls as a comparison
  - Possible dilution of moderator effect

Heterogeneous reason for being at-risk/clinical (e.g., prenatal substance abuse to social anxiety)

Maybe specific facets of psychopathology/risk moderate the relation
- However, recent theory proposes HRV as a risk factor for general vulnerability to psychopathology (Beauchaine & Thayer, 2015)
Some evidence of a publication bias

- Published demonstrated stronger relations than unpublished
- Comparison does not mean no effect, potentially an overestimate of the effect
- Robust Fail-Safe N (2,778)

Small effect, but still a significant effect
Validates HRV as a marker of broad SR

Additional limitations
- Sex
- Personality Characteristics (e.g., behavioral inhibition, Sulik et al., 2013)
- Nonlinear effects
Acknowledgments

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Questions??