Autonomic response to exercise as measured by cardiovascular variability

C C Grant (MSc)¹
J A Ker (MB ChB, MMed (Int), MD)²
¹Department of Sports Medicine, University of Pretoria
²Department of Internal Medicine, University of Pretoria

Abstract

Motivation. There is growing interest in the use of cardiovascular variability indicators as measures of autonomic activity, even though reported results are not always comparable or as expected. This review aims to determine the consistency of results reported on the autonomic response to exercise as measured by heart rate variability, blood pressure variability and baroreceptor sensitivity.

Method. An Ovid MEDLINE Database search for the period 1950 - March 2008 produced 46 articles for review. The published articles that evaluate the effect of exercise on the autonomic nervous system (ANS) are summarised in three categories: the response of the ANS during a bout of exercise, directly after exercise (recovery measurements), and after a long-term exercise programme.

Results. Articles on the effect of training on the ANS as measured by cardiovascular variability indicators show increased variability, decreased variability, and no change in variability.

Conclusion. Findings in this review emphasise that standardisation and refinement of these measuring tools are essential to produce results that can be repeated and used as reference. Standardisation is essential as these measurements are increasingly employed in studies regarding investigations of central autonomic regulation, those exploring the link between psychological processes and physiological functioning, and those indicating ANS activity in response to exercise, training and overtraining. This review shows that important aspects are inter-individual differences, duration and intensity of the exercise programme, and choice and specific implementation of variability analysis techniques.

Introduction

Heart rate variability (HRV), blood pressure variability (BPV) and baroreceptor sensitivity (BRS) are often used as measures of autonomic activity, even though reported results are not always comparable or as expected. It is known that endurance athletes have lower average resting heart rates than non-exercising individuals. However, other exercise-induced autonomic influences on cardiac control are far more controversial.

Autonomic control via sympathetic and parasympathetic modulation of the heart has been assessed by power spectral analysis of HRV and BPV. Different frequency bands reflect specific physiological stimuli and it is possible to estimate the involvement of the autonomic nervous system (ANS) influence and balance in heart rate (HR) regulation. With power spectral analysis of HR, two characteristic peaks between 0.04 Hz and 0.15 Hz (A) and between 0.15 Hz and 0.5 Hz (B) are used to quantify the autonomic balance in terms of the low-frequency (LF)/high-frequency (HF) ratio. Peak A is found in the region of Mayer waves (0.1 Hz) and is situated in the so-called LF area. It appears to be linked to the combined activities of the sympathetic and parasympathetic branches of the ANS. Peak B is synchronous with respiration, reflects vagal activity, is situated in the so-called HF area.

CORRESPONDENCE:
Mrs C C Grant
Section Sports Medicine
University of Pretoria
Tel: 27 12 3624496
Fax: 27 12 3623369
E-mail: Rina.Grant@up.ac.za

Fig. 1. Summary of the Ovid MEDLINE Database search.
and also gives an indication of respiratory sinus arrhythmia (RSA). During measurement of systolic BPV the LF peak corresponds with sympathetic activity while the HF peak is determined by mechanical effects of respiration on intrathoracic pressure and cardiac filling. The variability in blood pressure and identification of the corresponding physiological stimuli are difficult to identify. Indications are that the effect of respiration on intrathoracic pressure and cardiac filling.

**Results**

Published articles on the effect of exercise on the ANS as measured by HRV and BPV are summarised in three categories: the response of the ANS measured during a bout of exercise, and directly after a bout of exercise (recovery measurements), and the long-term effect of regular exercise on the ANS. The results of 10 articles on ANS response measured during exercise are shown in Table I. Some authors expressed concern about the measurement of spectral analysis of HRV during exercise, while others reported increases (↑) and no changes in variability indicators (↔) of sympathetic (SNS) and parasympathetic (PNS) influence.

**Method**

An Ovid MEDLINE Database search was conducted for the period 1950 - March 2008 (Fig. 1). The term 'ANS (physiology)' produced 203 articles, and 'baroreflex (physiology)' 2 084 articles. When linking the results with the term 'exercise' (38 434 articles) and then limiting the results to 'humans and English', 340 references were found. Only articles that used HRV (determined by time-domain analysis, Poincaré analysis and/or frequency-domain analysis), non-invasive BPV and BRS as indicators of autonomic function were selected, yielding 46 articles.

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Author(s)</th>
<th>Title</th>
<th>Cardiovascular variability indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>Sandercock et al.</td>
<td>The use of HRV measures to assess autonomic control during exercise</td>
<td>Results from spectral analysis of HRV not as expected; more research needed: word of caution</td>
</tr>
<tr>
<td>5</td>
<td>Banach et al.</td>
<td>HRV during incremental cycling exercise in healthy, untrained young men</td>
<td>Spectral and time domain analysis of HRV ↓SDNN, RMSSD ↓LF, HF, LF/HF ↓Ptot</td>
</tr>
<tr>
<td>16</td>
<td>Freeman et al.</td>
<td>ANS interaction with the CV system during exercise</td>
<td>Encourage the use of HRV at rest and during exercise</td>
</tr>
<tr>
<td>14</td>
<td>Eryonucu et al.</td>
<td>The effect of ANS activity on exaggerated blood pressure response to exercise: evaluation by HRV</td>
<td>Used spectral analysis of HRV in a comparative study</td>
</tr>
<tr>
<td>29</td>
<td>Lucini et al.</td>
<td>Analysis of initial autonomic adjustments to moderate exercise in humans</td>
<td>Spectral analysis of HRV ↑LF suggest ↑TSNS ↓HF suggest ↓PNS ↔ and ↑LF of BPV</td>
</tr>
<tr>
<td>42</td>
<td>Saito and Nakamura</td>
<td>Cardiac autonomic control and muscle sympathetic nerve activity during dynamic exercise</td>
<td>Spectral analysis of HRV ↓LF power, ↓HF power, ↓total power ↑LF/HF; SNS↓ ↓HF/HF; PNS↓ ↓LF/HF/Ptot: PNS↓</td>
</tr>
<tr>
<td>26</td>
<td>Kamath et al.</td>
<td>Effects of steady-state exercise on the power spectrum of HRV</td>
<td>Spectral analysis of HRV ↓LF, ↓HF, ↓SNS↓, ↓PNS↓</td>
</tr>
<tr>
<td>3</td>
<td>Arai et al.</td>
<td>Modulation of cardiac autonomic activity during and immediately after exercise</td>
<td>Spectral analysis of HRV ↓HF ↓LF</td>
</tr>
<tr>
<td>51</td>
<td>Yamamoto et al.</td>
<td>Autonomic control of HR during exercise studied by HRV</td>
<td>Spectral analysis of HRV ↓HF; PNS↓ ↑LF/HF; PNS↓ ↓LF/HF/Ptot: ↓SNS↑ and ↔SNS</td>
</tr>
<tr>
<td>37</td>
<td>Perini and Veicsteinas</td>
<td>HRV and autonomic activity at rest and during exercise in various physiological conditions</td>
<td>Spectral analysis of HRV No change in HF and LF power during increased loads ↔HF, ↔LF</td>
</tr>
</tbody>
</table>

**Notes**

- LF = low frequency; HFR = high frequency; SDN = standard deviation of all intervals; Ptot = total frequency power; pNN50 = percentage of successive interval differences greater than 50ms; SNS = sympathetic nervous system; PNS = parasympathetic nervous system; SAP = systolic arterial pressure.
TABLE II. Articles on the response of the ANS measured directly after a bout of exercise (recovery measurements)

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Author/s</th>
<th>Title</th>
<th>Cardiovascular variability indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Heffernan et al.</td>
<td>Cardiac autonomic modulation during recovery from acute endurance v. resistance exercise</td>
<td>Spectral analysis of HRV After endurance: ↓total power, ↑LF/HF; ↑total power of HRV, ↑LF/HF</td>
</tr>
<tr>
<td>49</td>
<td>Terziotti et al.</td>
<td>Post-exercise recovery of autonomic cardiovascular control: a study by spectrum and cross-spectrum analysis in humans</td>
<td>Spectral analysis of HRV and BPV ↑LF of systolic blood pressure ↓HF activity of heart rate ↓decreased BRS</td>
</tr>
<tr>
<td>22</td>
<td>Hayashi et al.</td>
<td>Cardiac autonomic regulation after moderate and exhaustive exercises</td>
<td>Coarse-graining spectral analysis of HRV ↓HF ↑LF/HF</td>
</tr>
<tr>
<td>40</td>
<td>Racczak et al.</td>
<td>Cardiovagal response to acute mild exercise in young healthy subjects</td>
<td>Time domain and spectral analysis of HRV and BRS ↑SDNN ↓LF and HF ↓BRS</td>
</tr>
<tr>
<td>26</td>
<td>Kamath et al.</td>
<td>Effects of steady state exercise on the power spectrum of HRV</td>
<td>Spectral analysis of HRV ↑LF activity</td>
</tr>
<tr>
<td>23</td>
<td>Heffernan</td>
<td>Arterial stiffness and baroreflex sensitivity following bouts of aerobic and resistance exercise</td>
<td>BRS via the sequence technique ↓BRS after resistance and aerobic exercise. Greater reduction after resistance</td>
</tr>
<tr>
<td>9</td>
<td>Brown and Brown</td>
<td>Resting and post-exercise cardiac autonomic control in trained master athletes</td>
<td>Time domain and spectral analysis of HRV ↓SDRR , ↓total power, ↓HF, ↓LF</td>
</tr>
<tr>
<td>28</td>
<td>Lucini et al.</td>
<td>Selective reductions of cardiac autonomic responses to light bicycle exercise with aging in healthy humans</td>
<td>Spectral analysis of HRV and BPV ↓HRV decreases with age BRS via sequence technique</td>
</tr>
<tr>
<td>15</td>
<td>Figueroa et al.</td>
<td>Endurance training improves post-exercise cardiac autonomic modulation in obese women with and without type 2 diabetes</td>
<td>Spectral analysis of HRV ↓HF, LF, BRS</td>
</tr>
<tr>
<td>3</td>
<td>Arai et al.</td>
<td>Modulation of cardiac autonomic activity during and immediately after exercise</td>
<td>Spectral analysis of HRV ↓HF, LF</td>
</tr>
</tbody>
</table>

LF = low frequency; HFR = high frequency; SDN = standard deviation of all intervals; Plot = total frequency power; pNN50 = percentage of successive interval differences greater than 50ms; SNS = sympathetic nervous system; PNS = parasympathetic nervous system; SAP = systolic arterial pressure.

Discussion

Articles published on cardiovascular variability measured during exercise concluded that the interpretation of variability measurements is difficult because indicators reflecting sympathovagal interactions at rest do not behave as expected during exercise and that the increased respiratory effort had a confounding effect on HF bands. It is also suggested that the presence of cross-sectional differences between HRV in athletes and non-athletes should be noted and that one should not use HRV data to determine autonomic control during exercise. Doubt was expressed on the applicability of the HRV power-spectrum analysis, with its present interpretation, to assess the sympathovagal interaction during exercise. However, other authors encouraged the use of HRV components at rest and during exercise as prognostic indicators, but called for the refinement of exercise measurements. Eryonucu et al. used HRV as an indicator of ANS activity before, during and after exercise in a comparative study. Two other studies reported increased sympathetic influence (measured by LF and LF/HF) on autonomic cardiac control during graded exercise, including increased, peripheral, vascular sympathetic activation at 30% of maximum exercise in the study by Saio and Nakamura. These results were in direct conflict with studies indicating significant suppression of both SNS and PNS autonomic cardiac control during graded exercise measured by the LF and HF of the power spectrum of HRV.

Cardiovascular variability measured during recovery from a single bout of endurance exercise indicated that the total power of HRV...
<table>
<thead>
<tr>
<th>Reference number</th>
<th>Author/s</th>
<th>Name</th>
<th>Cardiovascular variability indicator</th>
</tr>
</thead>
</table>
| 15               | Figueroa et al.   | Endurance training improves post-exercise cardiovascular autonomic modulation in obese women with and without type 2 diabetes | Spectral analysis of HRV  
BRS via sequence technique  
+HRV and BRS: no baseline changes |
| 47               | Spierer et al.    | Exercise training improves cardiovascular and autonomic profiles in HIV | Spectral analysis of HRV  
BRS via alpha index  
THF  
LF/THF |
| 4                | Aubert et al.     | Low-dose exercise does not influence cardiac autonomic control in healthy sedentary men aged 55 - 75 years | Spectral analysis of HRV  
+LF, HF, LF/HF |
| 31               | Martinelli et al. | HRV in athletes and non-athletes at rest and during head-up tilt    | Spectral analysis of HRV  
 TDNN  
+LF, HF: SNS/PNS  
+HRV |
| 45               | Sharma et al.     | Short term physical training alters cardiovascular autonomic response amplitude and latencies | Time domain and spectral analysis of HRV  
+HRV indicators |
| 37               | Perini and Veicsteinas | HRV and autonomic activity at rest and during exercise in various physiological conditions | Spectral analysis of HRV  
Fitness level has no influence |
| 10               | Buchheit and Gindre | Cardiac parasympathetic regulation: respective associations with cardiorespiratory fitness and training load | Time domain and spectral analysis of HRV  
THF, RMSSD, PNN50  
Total power and LF  
BRS |
| 39               | Raczkak et al.    | Long-term exercise training improves ANS profile in professional runners | Time domain and spectral analysis of HRV  
RMSSD  
THF |
| 36               | Okazaki et al.    | Dose-response relationship of endurance training for autonomic circulatory control in healthy seniors | Spectral analysis of HRV  
BRS via transfer function gain  
TDrr, LF, HF  
BRS |
| 32               | Melo et al.       | Effects of age and physical activity on the autonomic control of heart rate in healthy men | Time domain and spectral analysis of HRV  
RMSSD  
THF |
| 19               | Goldsmith et al.  | Exercise and autonomic function                                      | Review  
SNS activity  
LN SNS activity |
| 17               | Goldsmith et al.  | Physical fitness as a determinant of vagal modulation                | Spectral analysis of HRV  
THF |
| 27               | Kiviniemi et al.  | Cardiac vagal outflow after aerobic training by analysis of high-frequency oscillation of the R-R interval | Spectral analysis of HRV  
THF |
| 12               | Cooke et al.      | Effects of training on CV and sympathetic responses to Valsalva’s maneuver | Time domain analysis of HRV, BRS  
TDrr  
BRS |
| 13               | Costes et al.     | Influence of exercise training on cardiac BRS in patients with COPD   | BRS via the slope of the baroreflex sequences between systolic blood pressure changes  
BRS |
| 34               | Monahan et al.    | Regular aerobic exercise modulates age-associated declines in cardiovagal baroreflex sensitivity in healthy men | BRS via linear regression between BP en RR intervals during a Valsalva maneuver  
BRS |
| 11               | Carter et al.     | Effect of endurance training on autonomic control of heart rate – review | Review  
SNS activity  
LSNS activity |
| 25               | Iellamo et al.    | Conversion from vagal to sympathetic predominance with strenuous training in high-performance athletes | Spectral analysis of HRV  
BRS via the sequences method  
100% training load reverse effects: LF↓,HF↓, BRS↓ |
| 8                | Bowman et al.     | Effects of aerobic exercise training and yoga on the baroreflex in healthy elderly persons | BRS via the alpha index  
+BR |

**TABLE III. Articles on the long-term autonomic effects of regular exercise**
TABLE III. Articles on the long-term autonomic effects of regular exercise – continued

<table>
<thead>
<tr>
<th></th>
<th>Authors</th>
<th>Intervention</th>
<th>Autonomic Effect</th>
<th>Spectral Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>Nagai et al.</td>
<td>Moderate physical exercise increases cardiac ANS activity in children with low HRV</td>
<td>Spectral analysis of HRV</td>
<td>↑LF, ↑HF</td>
</tr>
<tr>
<td>38</td>
<td>Pigozzi et al.</td>
<td>Effects of aerobic exercise training on 24hr profile of HRV in female athletes</td>
<td>Time domain and spectral analysis of HRV</td>
<td>±LF, ±HF (daytime)</td>
</tr>
<tr>
<td>18</td>
<td>Goldsmith et al.</td>
<td>Comparison of 24-hour parasympathetic activity in endurance-trained and untrained young men</td>
<td>Report conflicting results</td>
<td>Spectral analysis of HRV</td>
</tr>
<tr>
<td>20</td>
<td>Gulli et al.</td>
<td>Moderate aerobic training improves autonomic CV control in older women</td>
<td>Spectral analysis of HRV and BPV</td>
<td>↑BRS, ↑LF (RR), LF (SAP)</td>
</tr>
<tr>
<td>21</td>
<td>Hautala et al.</td>
<td>Cardiovascular autonomic function correlates with the response to aerobic training in healthy sedentary subjects</td>
<td>Baseline vagal (HF) influences</td>
<td>determines effect of exercise training</td>
</tr>
</tbody>
</table>

LF = low frequency; HF = high frequency; SDNN = standard deviation of all intervals; Ptot = total frequency power; pNN50 = percentage of successive interval differences greater than 50ms; SNS = sympathetic nervous system; PNS = parasympathetic nervous system; SAP = systolic arterial pressure.

TABLE IV. Possible confounding factors

<table>
<thead>
<tr>
<th>Inter-individual variation</th>
<th>Baseline cardiovascular autonomic function</th>
<th>Age</th>
<th>Gender</th>
<th>Fitness</th>
<th>BMI</th>
<th>Diet</th>
<th>Alcohol consumption</th>
<th>Smoking</th>
<th>Analysis techniques</th>
<th>Time and frequency domain measures do not describe non-linear features in HR behaviour</th>
<th>Use of DA, ApEn</th>
<th>Length of sampling time (tachogram)</th>
<th>Training/exercise</th>
<th>Length of training period</th>
<th>Intensity of training</th>
<th>Type of exercise: resistance or endurance</th>
</tr>
</thead>
</table>

Articles on the effect of an endurance training programme over a period of time also showed a wide range of results. One study reported no change in baseline BRS and HRV values after a 16-week fitness programme, while another found increased BRS when comparing fitness levels. Aubert et al. also found no evidence of significant changes in resting autonomic modulation of the sinus node after a low-volume, moderate-intensity 1-year exercise programme. Comparing 11 young sedentary participants and 10 endurance-trained cyclists Martinelli et al. found no difference in power-spectral components of HRV at rest. However, a lower HR and higher values for time domain HRV indicators were reported during rest and head-up tilt, concluding that resting bradycardia seems to be more related to changes in intrinsic mechanisms than to ANS control modifications. Sharma et al. found no statistically significant changes in autonomic cardiovascular control measured by HRV after a physical training programme of 15 days. Perini and Veicsteinas reported no influence of factors such as age and fitness level, while Buchheit and Gindre showed that modifications in autonomic activities induced by training are visible in HRV power spectra at rest. Rackzak et al. reported increased LF reactivity (SNS) and BRS after a moderate aerobic training programme in older women. This study reported increased HRV and BRS in Masters Athletes compared with decreased values for sedentary seniors. Several other studies also concluded that regular physical activity increases vagal influence on the HR and BRS, while the sympathetic tone may be decreased by training at rest. However, Iellamo et al. found a reversal of these effects after a period of training at 100% training load. Very intensive training shifted the CV autonomic modulation from PNS toward SNS predominance. Intrinsic mechanisms rather than ANS control modifications. Sharma et al. found a reversal of these effects after a period of training at 100% training load. Very intensive training shifted the CV autonomic modulation from PNS toward SNS predominance. Intrinsic mechanisms rather than ANS control modifications. Sharma et al. found a reversal of these effects after a period of training at 100% training load.
conventional non-spectral and spectral measures of cardiovascular variability. Hautala et al. suggested that high vagal activity at baseline is associated with improvement in aerobic power caused by aerobic exercise training. We also observed that some studies used non-homogeneous participant groups with regard to age, gender and BMI, while others did not include these in the participant description. Factors often not taken into consideration are baseline blood pressure, blood cholesterol and diet. The effect of duration and intensity of the training programme as well as the type of exercise (endurance or resistance) may have been underestimated in studies on the ANS and exercise. In this review training periods from 15 days to 1 year were studied and the different degrees of exercise intensity used were not even mentioned in many articles. The choice and specific analysis techniques implemented may also play a role in the observed conflicting results. The recommended sampling time (tachogram for HRV analysis is 5 minutes, but different time windows were selected by different authors – 5 minutes, 10 minutes, 15 minutes and 24 hours. The articles studied used mostly traditional measures of variability, such as time and frequency. However, it is known that non-linear phenomena are involved in cardiovascular control. Therefore, the use of analysis techniques that acknowledge this fact should be co-implemented and reported with traditional measures. Examples include the measurement of fractal scaling exponents (describes the fractal-like correlation properties of R-R interval data) and ApEn (quantifies the amount of complexity in the time series data).

Conclusions

This review demonstrates the wide variety of results published during the past decades on the effect of training on the ANS as measured by cardiovascular variability indicators. It is clear from the results that standardisation and refinement of these measuring tools are essential to produce repeatable results that can be used as references in other studies. This is necessary as these measurements are increasingly employed in studies ranging from investigations of central autonomic regulation; to studies exploring the link between psychological processes and physiological functioning; to the indication of ANS activity in response to exercise, training and overtraining. Important aspects to consider when developing standardised procedures are inter-individual differences, duration and intensity of the exercise programme, and the choice and implementation of a specific variability analysis technique. Much more research needs to be done to fully describe and accurately quantify the effect of exercise on the ANS.

References


