HRV functions of NeXus for Psychophysiology & Biofeedback

This NeXus white paper has been created to educate and inform the reader about the HRV functionality offered by NeXus Instruments with BioTrace+ software.

The NeXus-10 and other members of the NeXus family of physiological monitoring and feedback instruments are multi-modal systems that support a wide range of sensors and applications, including HRV, both for Research and clinical Biofeedback / Neurofeedback.

The BioTrace+ software for NeXus comes standard with many HRV functions, suitable for both HRV analysis and HRV training. Heart Rate Variability (HRV) is the measure of the naturally occurring beat to beat changes in heart rate frequency and a powerful non-invasive measure of the activity of the autonomic nervous system. BioTrace+ runs on Windows (XP/Vista™) based PC’s. The NeXus family of products has medical class IIa certification (EU) and is FDA (US) registered. Exclusive world wide distribution by Mind Media BV:

THE #1 in Europe for multi-modal, multi-channel physiological monitoring & feedback.

The picture above shows a BioTrace+ HRV screen design on a PC with dual monitors. Below it the wireless NeXus-10 is shown, a 10 channel physiological monitoring and biofeedback/neurofeedback platform.

Note: The BioTrace+ software for the NeXus-4, NeXus-10, NeXus-16 and NeXus-32 all offer the same HRV functionality.
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Heart Rate (HR) signal acquisition and sensors

NeXus/BioTrace+ detects heart rate (HR) by using one of two methods:

1) by using a **BVP** (blood volume pulse) sensor on the fingers, or
2) by using an **ECG** (electrocardiogram) signal on the chest or on the wrists.

The advantage of using the **BVP sensor** is ease of use. No special preparation is required and unless the hands are cold, a good pulse can be obtained easily. The disadvantage is that the BVP sensor should not be moved and cannot be used on moving objects (as in sports). The reason is, the blood is a ‘liquid’ and moving therefore causes artifacts.

The advantage of using the **ECG signal** is that it can both be used on subjects/clients who are moving and non-moving and it has a better time resolution (up to 2048 samples/sec). Therefore the BVP sensor is generally used for Biofeedback training and the ECG cable is generally used for research. Using ECG requires pregelled electrodes to be placed on the chest (preferred) or wrists. These 2 placements are shown below.

A=negative electrode, B=positive, C=ground.

Below a sample is shown of a BVP based BioTrace+ screen design, notice the large variability in the HR signal, displayed at the bottom in beats per minute. (between 65-85 bpm)
The picture below shows a sample of ECG based HRV signals from a different session and client. These screens are part of the (new) demo protocols of BioTrace since version 2008a.

This screen display a spectral analysis of the HRV in the top graph (between 0-0.4 Hz) where the LF (low frequency zone) is marked with a green color. In the middle the source ECG signal is shown and at the bottom the HR is shown in red.

**HRV monitoring and multi-modal sensors**

Because NeXus-10 is a multi-modal platform, the HRV measurement can be combined with other modalities such as:

1) Respiration (abdominal and chest based)
2) Bloodflow and temperature recordings
3) EMG (muscle tension)
4) Skin Conductance (sympathetic arousal level)
5) EEG (SCP, Delta, Theta, Alpha, Beta and Gamma activity)
6) Oximetry (relative oxygen saturation) SpO2.
7) Optionally: Oxygen flow and CO2 (Capnography) ** check for availability
8) Optionally: real time Bloodpressure monitoring. ** check for availability

Heart rate variability (HRV) is a powerful measure and has been researched thoroughly over the last decade. A search on the internet [www.pubmed.gov](http://www.pubmed.gov) database will show you that over 2000 studies have been published that mention HRV in their abstracts.

As you can see, besides looking only at the variability of the heart rate, NeXus will enable you to include the respiratory information and many other sensors, including brain activity.
Abdominal and Thoracic breathing

With NeXus-10 it is possible to combine HRV monitoring or feedback based on BVP or ECG with abdominal breathing and/or thoracic (chest) breathing. The BioTrace screenshot below shows an example of the NeXus breathing sensors. (recorded with 24 bit precision)

Because NeXus-10 allows up to 10 sensors to be measured the user has more options, for example measuring:

1) Skin Conductance for measuring sympathetic arousal.
2) High resolution skin temperature for measuring relative vasoconstriction and vasodilation
3) EMG for measuring muscle tone and EMG activity
4) EEG for measuring brain activity
5) Optionally real-time blood pressure monitoring could be added as well, but it should be noted that equipment capable of real time BP is very expensive.

Stress and Performance Testing

A multi-sensor approach (multi-modal recording) is often used with NeXus to assess the physiological response during stress profiles, stress testing and performance (sports) testing.

Psychophysiological stress tests come standard with the BioTrace+ software for NeXus.
HRV Biofeedback training

The variability of the heart rate (HRV) provides a non-invasive method for estimating the cardiac autonomic nerve activity. HRV changes under influence of our psychophysiological state such as during stress, relaxation, exercise but also depends on health and age. High HRV is generally regarded as positive. General norms for HRV during states of stress and relaxation are still under development, but for a middle aged adult, we propose the following subjective scoring: (values expressed in heart beats per minute during slow abdominal breathing at around 6 breaths/minute, using the BioTrace+ pacer)

<table>
<thead>
<tr>
<th>HRV</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Low</td>
</tr>
<tr>
<td>5-10</td>
<td>Average</td>
</tr>
<tr>
<td>10-15</td>
<td>Good</td>
</tr>
<tr>
<td>15-20</td>
<td>Very good</td>
</tr>
<tr>
<td>20-30</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

*Please note that these scores are not yet based on norms, and intended to be used for measuring relative progress or improvement of HRV before, during and after training.*

HRV training on NeXus is typically combined with a respiratory sensor. Factually it is a form of biofeedback driven relaxation training that aims to optimize and balance the functioning of the autonomic nervous system and cardiovascular system. Abdominal breathing is a method that has also been shown to able to reduce bloodpressure.

In the HRV training screen above the HR is shown left (in orange) in beats per minute. A typical person who is not moving and relaxing will have low values, like 60-70 bpm. The second bargraph (blue) shows the relative abdominal breathing. The client can observe how heart rate variability and respiration correlate. The goal is to breathe slowly and increase the HRV and coherence.

The flower animation on the screen will open, when the HR and respiration have a high coherence. (more than 0.5 linear correlation, or a user configurable value)
HRV and Respiration training

The BioTrace+ software has many physiological screen designs that come standard, each offering different types of audio-visual feedback. The screenshot below shows a balloon that responds to inhalation and exhalation, this animation is used for training abdominal breathing. Breathing in will expand the balloon, breathing out will make the balloon smaller. Simultaneously the breathing signal is used for volume feedback of ocean waves. Breathing in will increase volume, breathing out will decrease volume.

The screen below display a frequency analysis of the HRV. These graphics can be used for visual feedback.
**HRV and the breathing pacer**

The BioTrace+ software comes complete with a built-in breathing pacer. This pacer generates a sample signal (or template) that can be used by the user/client to train slow abdominal breathing. Under the configuration menu, the pacer dialog box can be opened:

![Respiratory PACER settings](image)

The user selects exactly how much time should be used for: T1: breathing in, T2: holding, T3: breathing out, T4: pausing. Thus a basic setting like 5 seconds (5000 ms) breathing in and 5 seconds breathing out, would result in a 10 second breathing cycle or 6 breaths per minute (60 seconds).

By pressing the ‘-’ or ‘+’ button or (or otherwise the keys on the keyboard when the dialog box is not shown), the pacer frequency can be adjusted in steps of 0.5 bpm.

![Respiration Pacer](image)
BioTrace+ offers the clinician many ‘screens’ to work with. The picture below shows one such feedback screen where the real-time feedback of HR and respiration activity is displayed in a (dual) linegraph and 3 bargraph instruments. The HRV shown in the first bargraph is computed in real-time and shows the level of variability over the last 15 seconds.

With this training screen, the clinician can see visually the following parameters:

**Linegraphs:**

1) Linegraph: the *Respiration waveform* (blue) overlapped with the actual heart-rate (HR in red)

**Bargraphs from left to right:**

2) The average level or HRV in beats per minute of the most recent 15 seconds
3) The percent activity in the LF (low frequency zone) of the HRV.
4) The level of coherence between the RSP (respiration) and HRV.

*Note: if all three bargraphs are high, the training results are assumed to be better than when one bargraph is low, as the heart rate variability is high, while most of the activity is in the LF zone AND the HRV correlates highly with the respiration. However it must be stated that more research is needed before we can say what is the general optimum ‘state’.*
HRV monitoring for researchers, up to 24 hours

The NeXus-10 is a small portable device which is capable of recording up to 10 multi-modal physiological signals simultaneously. Data can be acquired in two ways:

1) Through a wireless BlueTooth connection to the PC (up to 10M) for live recordings
2) By recording the signals on a flash (SD) memory card, up to 24 hours. (duration depends on battery power capacity)

The picture below, shows a NeXus-10 recording of 8 hours of ECG based HRV combined with abdominal respiration, recorded on an industry standard SD flash memory card.

1st graph: Shows the abdominal respiration waveform
2nd graph Show the respiration rate
3rd graph The HR (heart rate) in beats per minute, based on ECG
4th graph The percentage of HRV activity in the LF band. (0.04-0.15 Hz)
So besides online HRV monitoring, NeXus-10 can also record HR, Respiration and other activity on a flash memory card. A user can carry a NeXus-10 around and record several hours of HR data for later analysis. The results of the HRV analysis can be printed out in an HRV report. A sample of such a report of 8 hours of ECG based HRV is shown below.

Remark: note how the LF peak near 0.1 Hz is clearly visible in the HRV spectrum on the left.
HRV statistics

The BioTrace+ software supports many data processing and computation functions, including many for HRV. A list of the current statistical variables that can be generated is shown below:

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NNMin</td>
<td>ms</td>
<td>The smallest IBI found (NN = IBI)</td>
</tr>
<tr>
<td>NNMax</td>
<td>ms</td>
<td>The largest IBI found</td>
</tr>
<tr>
<td>NNMean</td>
<td>ms</td>
<td>The mean values of all IBI values</td>
</tr>
<tr>
<td>SDNN</td>
<td>ms</td>
<td>The standard deviation of all NN intervals</td>
</tr>
<tr>
<td>RMSSD</td>
<td>ms</td>
<td>The RMS of all interval differences</td>
</tr>
<tr>
<td>NN50</td>
<td>count</td>
<td>The number of differences &gt; 50 ms</td>
</tr>
<tr>
<td>pNN50</td>
<td>%</td>
<td>The percentage of NN50 intervals</td>
</tr>
<tr>
<td>VLF</td>
<td>ms squared</td>
<td>The very low frequency component 0-0.04 Hz</td>
</tr>
<tr>
<td>LF</td>
<td>ms squared</td>
<td>The low frequency component 0.04-0.15 Hz</td>
</tr>
<tr>
<td>HF</td>
<td>ms squared</td>
<td>The high frequency component 0.15-0.4 Hz</td>
</tr>
<tr>
<td>LF/HF</td>
<td>ratio</td>
<td>The ratio of the LF and HF components</td>
</tr>
<tr>
<td>%LF</td>
<td>%</td>
<td>The percentage of LF in the entire spectrum</td>
</tr>
<tr>
<td>%HF</td>
<td>%</td>
<td>The percentage of HF in the entire spectrum</td>
</tr>
<tr>
<td>BPM</td>
<td>rate</td>
<td>The BPM rate of the highest LF spectral peak</td>
</tr>
</tbody>
</table>

HRV export of IBI table (ms values)

Please note: the table of IBI values that BioTrace+ generates, can be exported to other software for further offline analysis.

This table is shown in the HRV Analysis preview dialog box shown on the next pages. This table is a straightforward ASCII table with interbeat interval in milliseconds on each line. Most third party HRV analysis software, can import these ASCII files.

An example is shown below of this ASCII file in the Windows Notepad editor.
HRV Analysis preview: 2 examples

The user can select segments of data and perform HRV analysis on these parts. Such segments should be at least 5 minutes, but can be up to several hours. After this selection a dialog box is shown with the results: a table of IBI (interbeat intervals) is also presented on the left, which can be exported into ASCII format.

**Example 1: HRV analysis during a stress test**

[Image of HRV analysis during a stress test]

**Example 2: HRV analysis during slow abdominal breathing**

[Image of HRV analysis during slow abdominal breathing]

**Remark:** note how in example 2 the Power spectrum shows a clear peak around 0.1 Hz. In this case this peak corresponds to 6.3 cycles per minute. (BPM)
Virtual channel computations

Besides the standard HRV statistics, BioTrace+ can be configured to compute many so called ‘virtual channels’ which are user definable. An example of the session overview mode, showing 8 such ‘virtual channels’ for HRV and respiration is shown below:

In this screen, the following parameters are shown:

1\textsuperscript{st} graph: The BVP pulse signal over 5 minutes (directly from the BVP sensor)
2\textsuperscript{nd} graph The abdominal respiration wave form (directly from the RSP sensor)
3\textsuperscript{rd} graph The HR (heart rate) in beats per minute
4\textsuperscript{th} graph The relative bloodflow (vasoconstriction/vasodilation)
5\textsuperscript{th} graph The percent of HRV activity in the LF frequency area (0.04-0.15 Hz)
6\textsuperscript{th} graph The relative respiration amplitude. (relative ‘depth’ of breathing)
7\textsuperscript{th} graph The ‘amplitude’ of the HRV in beats per minute.
8\textsuperscript{th} graph The coherence (linear correlation) of abdominial respiration and HR.

Many of these parameters are computed by the BioTrace+ software on the fly and can be configured by the user through the data processing and signal processing options.

Remark: The HR (heart rate) can be expressed either in beats per minute (bpm) or as time intervals. BioTrace+ gives the user both options. Researchers are more used to expressed HR in terms of the interval between two beats. (IBI or interbeat interval, in milliseconds)
The virtual channels are configurable data processing functions which the user can build or edit. BioTrace+ supports 80-128 of these channels, or more. A example of a list of these channels can be viewed on the left. A example of a virtual channel definition for the percent power of LF activity in the 0.04 to 0.15 Hz is shown on the right.

Examples (Sept. 2008) of BioTrace+ data processing functions are:

- Linear Algebra (addition, subtraction, ratios, multiply, averaging)
- Digital filters (IIR and FIR bandpass, lowpass, highpass, bandstop, DC removal etc.)
- Frequency analysis (Bandpass amplitude, % power, mean, median and dominant frequency)
- Coherence and correlation (Cross Spectrum coherence, linear correlation)
- General signal processing (RMS amplitude, mean amplitude, pulse rate, heart rate, respiration frequency, respiration amplitude, etc.)

The user can use these functions to create data channels, which on their term can be used as inputs for other virtual channels. (stacking of channels)

Example: for instance the **HR (heart rate)** could be computed from the ECG signal, and the **RSP Rate** (respiration rate) could be computed from a breathing sensor. Then a third virtual channel could be defined as the **Ratio** of the **HR** and the **RSP rate** by using this first two channels as its input.
Artifact Rejection for HRV

Below a BioTrace+ dialogbox is shown were the user can define criteria for rejection of HR artifacts. These can occur when the signal is too noisy (EMG) contains spikes (electrode movement) or when the heart skips a beat.

This feature is particularly useful when large data sets (IBI tables) have to be processed, and where manual artifacting alone would take much time.

BioTrace+ allows both manual and automatic artifact removal, or a combination of both.

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For more information about NeXus, our BioTrace+ software and HRV functions, please feel free to contact the Mind Media team at sales@mindmedia.nl.

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