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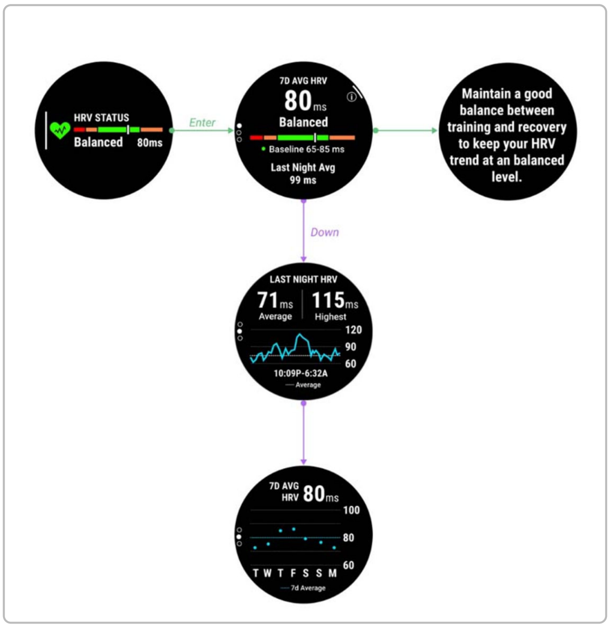
Heart Rate Variability (HRV) as a Biomarker for Athletic Recovery: A Coaching Manual

Heart Rate Variability (HRV) is a powerful, non-invasive biomarker that can help coaches and athletes gauge recovery, readiness, and overall autonomic balance. By analyzing subtle fluctuations in the time between heartbeats, HRV provides insight into how well an athlete's body is coping with training stress and recovering on a day-to-day basis. In this coaching manual, we'll break down the key concepts and data evaluation strategies for using HRV in athletic recovery, including the different metrics (time-domain vs. frequency-domain), recognizing signs of parasympathetic saturation and sympathetic overdrive (especially in overtraining scenarios), interpreting sudden versus gradual changes in HRV, and correlating HRV patterns with sleep stages and hormonal cycles. Throughout, we'll use a practical, data-driven approach – referencing current research and real-world examples (like Garmin's HRV monitoring features) – to help you effectively integrate HRV into your coaching toolkit.

Why HRV Matters for Athletes: During training and recovery, the autonomic nervous system (ANS) constantly balances the *"fight-or-flight"* responses of the sympathetic branch with the *"rest-and-digest"* functions of the parasympathetic branch [1] [2]. HRV reflects this balance. Generally, a **higher HRV** indicates a predominance of parasympathetic activity and a well-recovered, adaptable state, whereas a **lower HRV** suggests sympathetic dominance and can signal fatigue, stress, or insufficient recovery [2]. This makes HRV extremely sensitive to how an athlete's body responds to training loads and recovery interventions. Modern wearable technologies (such as Garmin, Whoop, and others) have embraced HRV as a core metric – for example, Garmin's devices continuously measure overnight HRV and provide an *HRV Status* indicator to help athletes maintain a balance between training and recovery. The goal of this manual is to help you interpret these HRV readings in context, much like a coach's "dashboard" for an athlete's internal stress and recovery state.



Example of Garmin's HRV Status display, summarizing an athlete's overnight HRV and 7-day trends. The device compares the 7-day average HRV (in milliseconds) to the athlete's established baseline range and classifies *status as Balanced, Unbalanced (high or low), Low, or Poor. This visual provides coaches a quick indication of whether an athlete's autonomic recovery is within normal bounds or showing signs of strain.* [3] [4]

Understanding HRV Metrics: Time-Domain vs. Frequency-Domain

When evaluating HRV data, it's important to understand the different types of metrics available. HRV can be quantified in multiple ways, but they broadly fall into two categories: **time-domain metrics** and **frequency-domain metrics**. Each provides unique insights into the athlete's autonomic nervous system status:

- **Time-Domain Metrics:** These metrics are derived from the direct measurements of intervals between heartbeats (often called RR intervals or NN intervals). They capture how much variability is present in the timing of successive heart beats over a given period. Two of the most widely used time-domain metrics are:
- **RMSSD (Root Mean Square of Successive Differences):** This is the statistical root mean square of the differences between consecutive normal heartbeats. RMSSD reflects short-term beat-to-beat variance in heart rate and is **highly sensitive to parasympathetic (vagal) activity** [5] [6]. In practical terms, a higher RMSSD means more variability between beats (greater vagal influence), while a lower RMSSD means less variability (suggesting stress or fatigue). Because of its strong correlation with high-frequency HRV and vagal tone [5] [7], RMSSD (often using its logarithm, LnRMSSD) has become the go-to daily HRV metric for many sports scientists and apps – it is reliable even in short recordings and less influenced by breathing rate than some other measures [7]. Coaches like it because it's easy to interpret: for example, a drop in an athlete's morning RMSSD compared to their baseline may indicate they haven't fully recovered from yesterday's workout.

- **SDNN (Standard Deviation of NN intervals):** This is the standard deviation of all normal RR intervals in the recording period. SDNN captures overall variability and **reflects combined sympathetic and parasympathetic influences** over longer periods [8]. In a 24-hour Holter ECG, SDNN is a gold-standard metric for overall HRV; higher SDNN over 24 hours indicates a healthy, responsive cardiovascular system. However, in the context of short-term readings (like a 1–5 minute measurement or an overnight period), SDNN is often interpreted with caution since it can be influenced by factors like trends or slower oscillations. For athletic recovery, SDNN is sometimes considered less sensitive than RMSSD to rapid autonomic changes. That said, a very low SDNN (compared to population norms or the athlete's history) can indicate an overall blunting of variability – potentially a red flag if seen chronically, as it might correlate with fatigue or overtraining.

- **Frequency-Domain Metrics:** These metrics arise from analyzing the HRV signal in the frequency spectrum (via algorithms like Fast Fourier Transform). Essentially, HRV fluctuations are broken down into frequency bands, each associated with certain physiological rhythms. The main frequency-domain metrics include:

- **HF (High-Frequency) Power:** This represents power in the ~0.15–0.4 Hz band, corresponding to fast oscillations in heart rate. HF power is also known as the *respiratory band* because it encompasses respiratory sinus arrhythmia – the natural rise and fall in heart rate with breathing. HF power is almost entirely due to **parasympathetic (vagal) modulation** [9]. A high HF power indicates strong vagal activity (often seen at rest or during recovery). For example, during deep relaxation or during sleep, an athlete's HF power tends to be elevated, reflecting restorative parasympathetic dominance. Lower HF power, on the other hand, is correlated with stress, anxiety, or reduced vagal tone [10] – coaches may notice that an athlete's HF HRV drops during periods of intense mental or physical stress.

- **LF (Low-Frequency) Power:** This corresponds to the 0.04–0.15 Hz band, which captures slower fluctuations in heart rate. LF power is a bit more complex – it is influenced by both sympathetic and parasympathetic activity (partly mediated by baroreflexes) [9]. Historically, LF was sometimes taken as an index of sympathetic activity, but it's now understood as a mixture. For instance, an increase in LF power might occur due to sympathetic activation *or* due to parasympathetic rhythms like baroreflex oscillations; context is key. What's important for coaches to know is that **the ratio of LF to HF** is often used as a rough indicator of autonomic balance:
  - **LF/HF Ratio:** A higher LF/HF ratio has been associated with a tilt toward sympathetic dominance (or reduced vagal tone), whereas a lower ratio suggests parasympathetic dominance [11] [12]. Under controlled conditions, this ratio can hint at the body's stress state – for example, during exercise or competition, an athlete's LF/HF might rise as sympathetic drive increases. Conversely, during meditation or deep recovery, LF/HF might fall. **However, note:** The LF/HF ratio should be interpreted carefully; it's not a perfect measure of SNS/PNS balance in all situations [13] [14]. The human ANS is not a simple seesaw – both branches can co-activate or have non-linear effects [13] [15]. As a coach, you should use LF/HF as one piece of the puzzle, ideally in tandem with time-domain measures and contextual clues (e.g., the athlete's condition).
- *(Other frequency bands:* **VLF** for very-low-frequency and **ULF** for ultra-low-frequency exist, but these require long recordings (hours to 24h) and are more relevant in clinical or research settings for circadian trends, inflammation, etc. We won't focus on them for daily athletic monitoring, except to note that very long-term HRV (like 24h SDNN or ULF power) can relate to overall health and recovery capacity [16] [17].)*

Choosing the Right Metrics: For practical athletic recovery monitoring, **RMSSD (time-domain)** is often the favored metric because it directly reflects vagal activity, is easy to compute with short readings, and correlates well with how recovered an athlete is [5] [18]. Many wearables and apps therefore report an "HRV score" based on RMSSD (sometimes a log-transformed value). **SDNN** might be looked at over longer periods or by devices that give a single overnight HRV number (which is often akin to SDNN over the night or the average of 5-minute SDNNs). **HF and LF** are valuable if you have access to them, especially to understand *why* HRV might be changing (for example, is it a drop in HF vagal tone or a spike in LF due to stress?). But even if you don't see the full spectral data, remember that *time-domain and frequency-domain measures are interrelated*: a high RMSSD usually coincides with high HF power (good recovery), and a low RMSSD often coincides with a high LF/HF ratio (stress-dominant) [5] [12].

Key Point:

> Higher HRV (especially via metrics like RMSSD or HF power) generally means the athlete is in a more relaxed, parasympathetically driven state – a *"green light"* for readiness. Lower HRV (e.g., low RMSSD or high LF/HF ratio) suggests the body is under stress or not fully recovered – a potential *"yellow or red light"* indicating caution [2]. Always compare these values to the athlete's own baseline or normal range; individual differences are huge, so each athlete's trends matter more than any one absolute number.

Parasympathetic Saturation vs. Sympathetic Overdrive: Recognizing Overtraining Patterns

When monitoring HRV for athletes, you'll encounter patterns that reflect how the nervous system responds to heavy training loads. In acute fatigue and early stages of overtraining, the **sympathetic** branch often dominates (driving HRV down), a state we'll refer to here as **sympathetic overdrive**. In some cases, especially with highly trained endurance athletes, you might observe an unusual scenario of **parasympathetic "saturation"** or dominance that blunts HRV responsiveness. Let's define and differentiate these:

- **Sympathetic Overdrive:** This term describes a state where an athlete's sympathetic nervous system is chronically ramped up – essentially stuck in "fight-or-flight" mode. It often manifests as persistently low HRV readings (and often elevated resting heart rate) over a period of days or weeks. Sympathetic overdrive can be caused by cumulative training stress, life stress, or inadequate recovery, and is frequently seen in **early overtraining or overreaching**. Coaches might notice that an athlete's morning HRV is consistently depressed well below their baseline, even after supposed rest days, coupled with reports of poor sleep or elevated morning heart rate – these are hallmark signs of sympathetic overdrive due to fatigue. In the physiology of overtraining, it's noted that initially **"the autonomic nervous system tilts, with sympathetic overdrive early on"** in the fatigue continuum [19]. In practical terms, an athlete in this state might feel *wired but tired* – restless, easily agitated, with reduced performance and poor recovery markers. Chronically low HRV here is a warning sign: the athlete's body is under excessive strain and not getting back to homeostasis. Research consistently shows that **low HRV correlates with high cortisol and stress** – the body is stuck in a catabolic, high-alert state [20]. If you see this pattern, it's a cue to dial back training load and prioritize recovery (both physical and mental). We'll discuss algorithmic responses to this in the next section, but as a coach, sympathetic dominance indicated by low HRV is your early alarm for potential overtraining syndrome if unaddressed.

- **Parasympathetic Saturation:** On the flip side, there is a fascinating phenomenon where extremely fit athletes under heavy training loads exhibit what appears to be a paradox: **very low resting heart rates, but also suppressed HRV** – which is counterintuitive, since we normally expect low HR (a sign of fitness) to pair with high HRV. This scenario is termed *parasympathetic saturation*. It refers to a situation where parasympathetic activity is indeed very high (the vagus nerve is strongly slowing the heart), but beyond a certain point, adding more vagal input doesn't increase HRV and may even reduce the observed variability [21]. In essence, the heart's response to acetylcholine (the vagal neurotransmitter) can reach a saturating dose – once the vagal effect is maximal in slowing the heart, the beat-to-beat variability might actually diminish with further vagal tone [21]. Renowned physiologist Daniel Plews describes it as *"a heightened vagal tone [that] may give rise to sustained parasympathetic control of the sinus node, which may eliminate respiratory heart modulation and reduce HRV"* [22]. This is *critical for coaches to understand:* **a drop in HRV isn't always bad**, if it occurs in the context of parasympathetic saturation in an elite athlete. In such cases, a lower HRV during a high training load phase can be linked to *positive* adaptations and performance improvements [23]. It sounds odd, but think of it as the athlete's nervous system being "too good" at applying the brake (parasympathetic) – the HRV measurement loses its sensitivity because the heart is near its lower rate limit. **When and whom does this happen to?** Parasympathetic saturation is *rare* and usually limited to **elite endurance athletes** in periods of very high training volume, who have very low resting HR (often in the 30s-40s) [24]. If an athlete meets this profile and you observe a period of suppressed HRV concurrent with low resting HR and high performance, you might be seeing this phenomenon. One research paper noted that "in some circumstances, such as vagal saturation, decreases in cardiac parasympathetic indices of HRV… can be related to positive performance outcomes and consequently reductions in HRV should not be viewed negatively" [23]. In practice, an athlete might feel fine and be hitting training targets, yet their HRV is lower than normal – rather than immediately assuming they are under stress, consider their training context. **Identifying parasympathetic saturation** often involves looking at the relationship between HR and HRV: normally, HRV is higher when heart rate is lower; if you see an athlete with a very low heart rate but unexpectedly low HRV (and it's during a big training block), this uncoupling (little or negative correlation between HR and HRV) suggests parasympathetic saturation [25] [26]. Tools like HRV4Training Pro even include a feature to check for this by plotting HRV vs. RR-interval length [26].

Why These Concepts Matter: Most coaches are familiar with the straightforward case – fatigue = low HRV (sympathetic overdrive). And indeed, **the most common HRV response to overload training is a progressive decrease in HRV, driven by sympathetic activation and insufficient recovery [27].** But as we've discussed, **"high isn't always good and low isn't always bad."** An unusually high HRV can sometimes indicate maladaptation (we'll talk about this in a moment regarding trends), and an unusually low HRV in an elite endurance athlete might not always mean they are under-recovered (it could be vagal saturation). The Garmin HRV Status feature even accounts for this: it will flag your status as "Unbalanced – High" if your 7-day HRV average goes *above* your normal range, cautioning that an abnormally high HRV could be a sign of functional overreaching [3]. That is essentially Garmin's nod to the parasympathetic overreaching concept – a hyper-recovery mode that often follows heavy low-intensity volume. In contrast, Garmin flags "Unbalanced – Low" or "Low HRV" if the 7-day drops too low, indicating strain [4] [28].

Parasympathetic Overtraining vs. Sympathetic Overtraining: In sports science literature, overtraining syndrome has sometimes been classified into a sympathetic form (more common in power/speed athletes, marked by insomnia, agitation, high resting HR, low HRV) and a parasympathetic form (more common in endurance athletes, marked by apathy, low resting HR, *relative* high HRV or blunted HRV responsiveness). Parasympathetic *saturation* as discussed is a specific case and should not be confused as wholly benign; it's more about recognizing that the **context matters**. If an athlete is performing well and all signs are good except HRV is oddly low with a very low HR – you might suspect parasympathetic saturation rather than pathological overtraining. On the other hand, if performance is declining and HRV is trending high relative to baseline (especially with lots of low-intensity training), that could also indicate an overreaching state where the body is desperately trying to compensate by ramping up parasympathetic activity at rest [3]. In any case, use multiple data points: mood, performance, sleep, and other biomarkers (like morning cortisol if available) alongside HRV to differentiate true overtraining from these nuances. Often, **"sympathetic overdrive early on and a 'flat' parasympathetic pattern when depletion sets in"** is observed across the overtraining spectrum [19] – meaning initially HRV falls (sympathetic dominance), and in prolonged burnout, the autonomic system can become "flat" (little variability or responsiveness at all).

Coaching Tip: If you suspect **parasympathetic saturation** (in an elite athlete during heavy training), one recommendation from HRV experts is to modify how you measure HRV: try a morning reading when seated or standing instead of supine. Adding a little orthostatic stress can prevent saturating the vagal input and yield a more sensitive HRV reading [29]. However, if your athlete isn't an elite or the scenario doesn't match, don't jump to this conclusion – most likely a big drop in HRV is indeed due to fatigue. Conversely, if you see signs of **sympathetic overdrive** (chronically low HRV, high resting heart rate, poor sleep), intervene with recovery strategies immediately – before it evolves into full overtraining syndrome.

Interpreting HRV Trends: Sudden Drop vs. Gradual Decline

HRV is a dynamic metric – it fluctuates day-to-day due to myriad factors. Not every dip or spike requires action; what matters most are **trends** and the context of changes. A critical skill in using HRV for coaching is distinguishing between a **sudden acute change** and a **gradual chronic trend**, as they often imply different things about the athlete's condition:

- **Sudden Drop in HRV:** If you observe a sharp decline in an athlete's HRV from one day to the next (for example, a drop of >20% in their morning RMSSD or overnight HRV score compared to their recent average), this often signals an *acute stressor or fatigue*. Common causes for a sudden HRV drop include a very intense or long training session (acute training fatigue), a poor night's sleep, dehydration, emotional stress, or even the onset of an illness. Think of it as the body's immediate reaction – the sympathetic nervous system has jumped into high gear temporarily. **For instance:** An athlete's HRV might be cruising around 70 ms RMSSD, and the morning after a hard interval session it's 50 ms – this acute drop is the classic fatigue response and typically correlates with muscle soreness, higher perceived fatigue, etc. Another example: an athlete is about to get sick (viral infection); often HRV will plummet a day or two before noticeable symptoms, as the body mounts a stress response. In fact, one study noted that *"a sudden drop in HRV of more than 20% from the individual norm preceded the appearance of symptoms of infection by an average of 3.8 days."* [30] . The key with sudden drops is that they are *usually short-lived* if the stressor is removed. **What should an algorithm or coach do?** Generally, acknowledge the drop but avoid overreaction if it's just one day – instead, adjust the day's plan to be cautious. Many adaptive training programs will recommend a lighter recovery workout or rest day after a big HRV drop. This aligns with the idea of HRV-guided training: one skips or scales back high-intensity workouts if HRV is significantly down, to allow the body to rebound. It's worth noting that a single-night poor HRV can happen randomly too, so context is king (was there a clear cause?). The athlete should focus on recovery that day (good nutrition, hydration, relaxation techniques, sleep). Often, **acute HRV drops rebound in a day or two if managed well** [31] . Indeed, an *acute* drop that returns to normal or above within a few days is generally considered part of the normal training process – the so-called "fatigue then compensation" supercompensation model [32] [33] . If performance isn't suffering and the athlete feels okay, a one-off drop can simply be logged as a sign of hard work that should be balanced with rest. **However**, if an acute drop doesn't rebound (see next scenario), it may be the start of a trend.

- **Gradual Decline in HRV:** A slow, continuous downward trend in HRV over a series of days or weeks is more concerning for cumulative fatigue or under-recovery. This is when each day HRV is a bit lower than the last, or it remains depressed and keeps trending down relative to the athlete's baseline. A **persistently low HRV trend** is one of the earliest objective indicators of overtraining or non-functional overreaching [34] . For example, say an athlete's 7-day average HRV has been 70 ms, but over the last 10 days it has drifted down to 60, then 55, then 50 ms despite no single huge drop – this kind of gradual decline suggests the athlete is not fully recovering between sessions and stress is accumulating. Research and practical coaching reports indicate that *"a sustained drop over several days may indicate that the stress load is outweighing recovery"* [31] . In other words, the athlete is on a slow march toward burnout. **Chronic sympathetic dominance** is often at play here – cortisol might be chronically elevated, anabolic hormones suppressed, and the athlete might start to report persistent fatigue, monotony, poor mood, or plateauing performance. One guide succinctly states: *"A sudden drop in HRV may indicate acute fatigue, while consistently low HRV over weeks could signal chronic fatigue due to prolonged stress or overtraining."* [35] . From an algorithm perspective, seeing a downward trend lasting 3+ days is usually time to adjust the training plan: reduce volume/intensity, add rest days, focus on recovery modalities. Many HRV platforms use rolling weekly averages and will flag if the weekly (or monthly) average HRV is significantly below the baseline. For instance, Garmin's HRV Status will classify as "Low" if your 7-day average falls well below your historical baseline [28]. Coaches should not ignore these trends – it's far better to proactively deload for a few days than to push into a major overtraining episode that could require weeks off. It's also important to communicate with the athlete – often they might not *feel* terrible initially during a decline, as adrenaline can mask fatigue. HRV can thus serve as an early warning system: A progressive decrease of HRV with each passing day tells you that the athlete's autonomic resources are being drained and not replenished [36] [27].

To visualize this concept, consider two scenarios in a chart of daily HRV: 1. **Acute dip and recovery:** HRV is stable, one day it plunges, then within two days it's back to normal or even higher (perhaps after a rest day). This is often a healthy response to a hard training stimulus – a short-term fatigue that leads to adaptation. 2. **Chronic downward trend:** HRV is stable, then over a 2-week heavy training block it ticks down each day. The athlete's subjective fatigue also keeps mounting. This is a red flag – it's the pattern Pichot et al. observed in runners during a 3-week overload, where HRV dropped up to 43% by week 3; when they deloaded in week 4, HRV recovered and even overshot baseline as the athletes supercompensated [37] [38]. Use such trends to time deloads and tapers effectively.

- **Sudden Increase in HRV:** As a brief aside, what about a sudden **rise** in HRV? If an athlete's HRV jumps much higher than normal on a given day, that can be a sign of excellent recovery or a boost from restorative practices – but it can also sometimes be a sign of an atypical condition. Some athletes observe an HRV spike right before they get sick (sometimes the body's initial anti-inflammatory response), or after an extended rest period (parasympathetic rebound). Generally, a high HRV day isn't problematic; just ensure it matches the context (e.g., after a recovery day, it's expected to see HRV higher). Exceptionally high HRV relative to baseline could, as mentioned earlier, indicate a state of overreaching where the body is *overcompensating* with parasympathetic activity [3]. Garmin's classification of "Unbalanced – high HRV" is essentially warning about this scenario. So if you see an unexplained big HRV spike coupled with the athlete feeling fatigued or flat in performance, don't immediately assume it's great – it could be the other side of the overtraining spectrum (sometimes called parasympathetic overtraining).

Actionable Guidelines for Coaches/Algorithms:
When evaluating HRV changes, consider these steps:

1. **Compare to Baseline:** Determine if the change (drop or rise) is outside the athlete's normal day-to-day variability. Many systems use a rolling baseline (e.g., last 3-4 week average). If today's value is more than, say, 1 standard deviation outside that range, take note. Minor fluctuations within the normal range can be ignored or logged without action.
2. **Identify Recent Stressors:** Correlate the HRV change with training logs and life events. A sudden drop after a known hard training day or poor sleep night has an obvious cause – likely acute fatigue. A gradual decline over 10 days of heavy training points to cumulative overload. If HRV dropped without an obvious cause, probe for hidden stress (mental stress, emerging illness, etc.).
3. **Check Subjective and Objective markers:** Talk to the athlete or check their wellness self-reports. Are they feeling sore, unusually tired, moody, or noticing any signs like elevated resting heart rate or poor sleep quality? Often HRV will be reflected in these other indicators. If HRV is low but the athlete feels amazing and is hitting personal bests, think of the parasympathetic saturation case or a temporary anomaly; if HRV is low *and* they feel terrible, it's clearly sympathetic overdrive/fatigue.
4. **Adjust Training Load Accordingly:**

5. For a **sudden HRV drop**, consider pivoting that day's session to low intensity or active recovery. Communicate to the athlete why (e.g., "Your HRV dropped big time, indicating you're still stressed from something – let's do a light flush run instead of intervals and see if you rebound tomorrow"). One or two easy days after an acute HRV drop can prevent pushing the athlete into a deeper hole.
6. For a **gradual decline trend**, it's time to institute a more systematic deload. You might cut back training volume by 30-50% for a week, focus on sleep/nutrition, maybe incorporate techniques like massage, meditation, or other recovery modalities. Use the HRV to monitor if/when it starts to rise back toward baseline, which would indicate recovery is occurring. A rule of thumb: *Don't schedule any new high-intensity sessions until the trend at least stabilizes or turns upward.* An athlete in a downward HRV spiral needs a break, not another hard stimulus.
7. **Beware of Chronic Low Plateau:** If HRV stays depressed for weeks and doesn't improve even after rest, this could indicate a deeper issue (illness, overtraining syndrome, or other physiological imbalance). This might warrant medical evaluation or a very extended rest period. In overtraining syndrome, sometimes HRV can actually normalize or even increase but with the athlete still in a poor state (due to changes in autonomic regulation); that's why it's crucial to look at performance and overall health, not just chase HRV numbers.

By interpreting sudden vs. gradual HRV changes in this way, you can use HRV as a real-time feedback tool to periodize training intelligently. Athletes often want to push through fatigue, but the HRV trend empowers coaches to say with confidence, "You may feel like you can keep pushing, but your nervous system is telling a different story – let's prioritize recovery now so you don't crash later." Conversely, when HRV is trending up or consistently strong, it can green-light more intensive training blocks, since the athlete is coping well. This adaptive approach has been shown to improve outcomes: HRV-guided training groups often achieve better fitness gains with fewer injuries than fixed training plans [39] [40].

HRV, Sleep Stages, and Hormonal Connections (Cortisol & Growth Hormone)

Recovery isn't just about training load – it's heavily influenced by **sleep quality** and the body's hormonal environment. HRV provides a window into how sleep and key recovery hormones interact. In this section, we'll explore how HRV varies across sleep stages (REM vs NREM) and what that means for recovery, and how HRV relates to the rhythms of cortisol and growth hormone – two hormones critical to stress and recovery.

HRV During Sleep: Sleep is a prime time for recovery, and HRV tends to be higher at night than during the day (assuming restful sleep). However, not all sleep is equal – there are stages: Non-REM (which includes light sleep stages N1, N2 and deep slow-wave sleep N3) and REM (Rapid Eye Movement, dream sleep). The autonomic nervous system behaves differently in these stages: - During **deep Non-REM sleep (slow-wave sleep, N3)**, the body is in a very relaxed, restorative state. The parasympathetic nervous system dominates strongly. Heart rate is at its lowest and very regular, blood pressure drops, and breathing is slow and steady. In terms of HRV: **High-frequency (HF) power increases in deep NREM, and the overall sympatho-vagal balance shifts toward parasympathetic** [11]. In fact, deep sleep has some of the highest vagal tone of the 24-hour cycle. Coaches will often see that an athlete's highest HRV readings at night coincide with periods of deep sleep. However, interestingly, because heart rate is so stable in deep sleep, some measures of total variability might appear lower than in lighter sleep – but beat-to-beat (short-term) variability is higher. Studies have shown that compared to wakefulness, NREM sleep (especially N3) is associated with *lower overall variability but higher beat-to-beat vagal modulation* [41] [42]. In simpler terms, there may be fewer drastic swings in heart rate in deep sleep, but the influence of each breath in modulating the heart (RSA) is heightened. Most wearables that track HRV will show an upward trend during periods of deep sleep on the nightly HRV graph. This is a good sign – it means the athlete's body is spending time in recovery mode at night. - During **REM sleep**, the scenario changes. REM is sometimes called "paradoxical sleep" because while the body is immobile (muscle atonia), the brain is quite active (similar to awake), and there can be surges of autonomic activity. **REM sleep tends to shift balance toward sympathetic activity**. Heart rate and blood pressure can fluctuate more in REM, and breathing becomes irregular. The HRV spectral profile in REM shows **higher low-frequency (LF) power and often a higher LF/HF ratio, indicating relatively more sympathetic influence or reduced vagal influence** [11] [12]. In fact, researchers often find that **parasympathetic activity decreases during REM compared to NREM**, and markers of sympathetic activity (like LF or certain stress hormones) rise [43] [12]. What does this mean in practice? It's normal for HRV (especially the RMSSD or HF component) to drop during REM-heavy periods of the night. If you look at a continuous HRV plot overnight (as some advanced apps or devices allow), you'll see HRV not as a flat line but ebbing and flowing – those drops usually correspond to REM episodes or brief arousals. For example, an athlete might average 80 ms HRV overnight, but closer inspection shows it ranged from 50 ms (during REM or awake moments) to 110 ms (during deep sleep). **Both are important** – REM is a necessary stage of sleep for cognitive recovery, even if it's less parasympathetically driven. But if an athlete has very disturbed sleep (excessive awakenings, less deep sleep), often we see overall lower overnight HRV and more of the sympathetic signature at night than desirable [44] [45]. - **Light sleep (N1, N2):** These intermediate stages typically also favor parasympathetic, but not as profoundly as N3. HRV in N2 is still generally higher than in REM, but lower than in N3. It's in flux and can be influenced by minor awakenings.

To summarize sleep stages and HRV: **NREM (especially deep N3) = high vagal, high HRV; REM = relatively lower HRV, more sympathetic bursts** [11] [12]. A healthy night's sleep cycles through NREM and REM in roughly 90-minute cycles, and typically the first third of the night has more deep NREM (thus often higher HRV early night), and the last third has more REM (often slightly suppressed HRV towards morning). Coaches using devices like the Oura Ring or Garmin might note the lowest resting heart rate and highest HRV occur in the early night when slow-wave sleep is prevalent – a sign of good recovery. By early morning, as REM and the natural **cortisol awakening response** kick in, heart rate rises a bit and HRV may taper.

Hormonal Release: Cortisol vs. Growth Hormone (GH) and HRV: The autonomic patterns at night tie closely to two major hormones: - **Growth Hormone (GH):** This is the body's primary anabolic and recovery hormone, stimulating muscle repair, tissue growth, and regeneration. GH is predominantly secreted during deep slow-wave sleep, especially in the first sleep cycle of the night. When an athlete goes into deep NREM sleep, not only does vagal activity peak, but **growth hormone surges** – the pituitary gland releases a large pulse of GH shortly after sleep onset (usually ~30-70 minutes in, coinciding with the first deep sleep episode). Research has long established the *"temporal association between SWS and GH secretion during nocturnal sleep"* [46]. This is one reason why **good sleep (and plenty of deep sleep) is irreplaceable for athletic recovery**: you literally need that parasympathetically dominated time for GH-mediated repair processes. What does HRV tell us here? If an athlete has a lot of high-HRV deep sleep, we can infer they likely got robust GH release. In fact, interventions that enhance deep sleep (like certain forms of hypnosis or acoustic stimulation) have been shown to both increase GH and tilt the ANS towards more parasympathetic activity (higher HF HRV) during sleep [47] [48]. One study found that boosting SWS led to a fourfold increase in GH levels and concomitant reduction in sympathetic markers, demonstrating the linkage between high-quality deep sleep, high HRV, and anabolic recovery hormones [47] [48]. **Key point:** If your athlete's overnight HRV data shows strong parasympathetic activity at night, it likely means their body had the ideal conditions to release hormones like GH that promote recovery. On the contrary, if their sleep is shallow or frequently disrupted (hence lower HRV and higher heart rate at night), they may be missing out on some of the GH benefits – something to address via better sleep hygiene or reduced late-day stress. -

Cortisol: Cortisol is often dubbed the "stress hormone." It is catabolic and elevates blood sugar, and while it has normal diurnal patterns, it also rises under any kind of stress (physical or psychological). Cortisol and HRV generally move in opposite directions: **high cortisol states usually coincide with low HRV** [20]. During a normal circadian cycle, cortisol is low at night (allowing deep sleep), then starts to rise in the early morning hours, peaking around the time you wake up – this is called the Cortisol Awakening Response (CAR). That morning spike in cortisol is like nature's caffeine, mobilizing energy to start the day, but it also is associated with a shift out of the parasympathetic recovery state. This helps explain why in the last few hours of sleep (when REM is more frequent and cortisol is rising toward its peak) we see HRV trending lower and sympathetic tone increasing [49]. In other words, as morning nears, your body is preparing for wakefulness by upping sympathetic activity and cortisol, which **suppresses HRV**. Now, in a balanced scenario, this is fine and natural. However, problems arise when cortisol is chronically elevated at the wrong times – e.g., due to overtraining or stress, an athlete might have elevated evening cortisol (impairing sleep and keeping HRV low at night), or a blunted morning cortisol (indicating burnout). Overtraining research shows that in early overreaching, **morning cortisol can run high; with deeper fatigue, it may flatten** (meaning the adrenal system gets exhausted) [50]. Since HRV is a reflection of autonomic nervous system status, it can provide indirect clues to these hormonal states. For instance, if an athlete's HRV is not rising at night as it should, one possibility is that cortisol (or other stress mediators) are too elevated when they should be low. Additionally, coaches sometimes measure morning HRV in tandem with hormone tests; while day-to-day correlation of HRV and cortisol can be complex, overall **there's a negative correlation: higher baseline cortisol levels tend to accompany lower HRV** [20]. Some practitioners have noted that *"cortisol levels can signal impending overtraining long before physical symptoms,"* and one might catch this by noticing HRV trending down while maybe the athlete's subjective effort feels harder [51]. In summary, if you see unexplained HRV suppression, consider hormonal stress – high cortisol could be a culprit (and that could be due to lifestyle stress, too much caffeine, illness, etc., not just training).

Integrating Sleep and Hormone Insights: The best recovery scenario for an athlete is: **Long, high-quality sleep with ample deep NREM** (high HRV, GH release) and normal REM (some sympathetic activity, but not excessive awakenings). This yields a big nighttime parasympathetic surge and GH spike, then a healthy morning cortisol peak to wake up. This athlete will likely show up in your logs with strong overnight HRV, a well-rested morning subjective feeling, and good training readiness. On the flip side, consider an athlete who is overreaching: they train late into the evening, have poor sleep (low deep sleep percentage, perhaps due to high cortisol or sympathetic activation), and thus lower overnight HRV. They might also have elevated resting heart rates at night. Their recovery hormones like GH might be suboptimal due to reduced SWS, and their cortisol might be abnormally high at night (reducing HRV) and then either too high or eventually flat in the morning. Over time, this pattern wreaks havoc on recovery and performance.

As a coach, you can actually use HRV and sleep data to have very concrete discussions with athletes about lifestyle: *"I see your HRV was low most of the night and didn't follow the normal pattern – did you have trouble sleeping? Were you on your phone late or stressed?"* Often, fixing those issues (darkening the room, cutting off screens, relaxing routines) will improve sleep stages and hence overnight HRV. Some wearables now even correlate HRV with sleep phases and give coaches a report. For example, the athlete who has an Oura Ring might share that their deep sleep was only 30 minutes and their HRV stayed low; that's a flag to work on sleep habits. Another athlete might show 2 hours of deep sleep and high HRV – a sign their body is primed for recovery (and indeed, such nights often result in better performance the next day).

Growth Hormone and HRV in Training: Another angle – training itself can influence GH and HRV. Heavy resistance training or high-intensity intervals can transiently raise anabolic hormones and later on boost deep sleep. If an athlete is recovering well, you might see their nighttime HRV actually go *up* on days after heavy training, which sounds counterintuitive but could be due to a rebound in parasympathetic activity and deeper sleep to compensate (some moderate aerobic work also stimulates parasympathetic rebound [52]). If you see the opposite – heavy training leads to progressively lower nighttime HRV and poor sleep – that athlete might be under too much strain hormonally. Monitoring HRV thus helps ensure the *hormonal milieu* is conducive to adaptation, not maladaptation.

Cortisol:HRV Practical Example: Suppose an athlete has a stressful job and you notice that even on rest days their HRV is suppressed in the evenings (perhaps their wearable shows “Body Battery” not recharging well, a Garmin metric influenced by HRV). This could be due to evening cortisol remaining high from work stress, which will reduce their nighttime HRV and recovery. The coach might introduce relaxation techniques (like guided breathing, which directly can increase HF HRV by engaging vagal activity [53] [54]) to lower sympathetic tone before bed. Over a few weeks, you might see their overnight HRV baseline rise as those interventions pay off, indicating a healthier recovery state. They might even subjectively report feeling more refreshed and notice performance improvements.

In summary, HRV is interconnected with sleep physiology and endocrine function: - High HRV at the right times (night/deep sleep) correlates with growth and recovery processes. - Low HRV at the wrong times (night) or chronically correlates with stress hormones like cortisol being out of balance. - Use HRV trends alongside sleep tracking to optimize an athlete’s recovery schedule. Encourage behaviors that maximize that high-HRV deep sleep window (consistent sleep schedule, cool dark environment, etc.). - Be mindful that **if HRV readings seem out of whack, hormones might be the hidden factor** – consider if the athlete’s lifestyle or training is affecting their cortisol/GH rhythms. In cases of severe overtraining, endocrine tests (cortisol, testosterone, etc.) plus HRV can provide a fuller picture: often you’ll see low HRV and elevated cortisol, or in burnout, paradoxically low cortisol (adrenal fatigue concept) with flat HRV.

Practical Coaching Strategies for Evaluating HRV Data

Finally, let’s compile some practical guidelines – a step-by-step coaching manual on how to evaluate and apply HRV data for your athletes:

1. Establish Individual Baselines and Normal Ranges

Every athlete is unique. HRV norms are highly individual – what’s “high” for one person might be “average” for another. So, first ensure each athlete has a baseline. Have them record HRV regularly (many coaches use a consistent morning measurement, or rely on nightly wearable data). After about 2-3 weeks, you’ll have a sense of their typical range [55] [56]. For example, Athlete A might usually be around 30–50 ms RMSSD, Athlete B around 70–90 ms. Document these along with subjective notes. Many devices automatically compute this personal baseline (Garmin requires ~3 weeks of nightly data to establish HRV Status baselines [57]). When interpreting data, always frame it as “relative to *their* norm.” A raw HRV of 40 ms could mean fine for one athlete, but for another it could be alarmingly low. Also track their *variation* – some people are naturally more variable day-to-day, others are very consistent. Knowing this helps distinguish meaningful changes from noise [58] [59].

2. Use Both Acute Readings and Trends

Check the daily HRV readings (or the overnight average) for acute signals, *and* review weekly trends: - **Daily Check:** Look at this morning’s HRV (or last night’s). Is it outside the athlete’s normal band? Use a simple color-coding or notation: green for within/above baseline, yellow for slightly below, red for significantly below. Many apps do this automatically. Daily checks tell you if something immediate is up (e.g., a big drop). - **Trend Check:** Look at the rolling 7-day or chronic trend. Is there a monotonic decline? Or perhaps an improving trend? For example, you might notice "This week is trending lower than last week on average." Trends are often more reliable indicators of whether the training load is sustainable. A one-day low HRV can happen randomly, but a week-long low is likely real fatigue. Garmin's HRV widget, for instance, shows the 7-day trend against baseline and flags "Balanced" vs "Unbalanced" [60] [61]. Aim for balanced most of the time – if it's unbalanced high or low for too long, adjust training. - **Coefficient of Variation (CV):** An advanced concept some coaches use is the CV of weekly HRV – basically how much HRV bounces around day-to-day. An elevated CV (very erratic HRV) along with a drop in average can indicate accumulating fatigue [62] [63]. A stable or reducing CV with a steady high HRV is a good sign. In team sports, monitoring the whole squad's HRV trends can even predict who might be at risk of injury or illness, as those with downward trends are the ones to perhaps pull back on.

3. Correlate with Training Phases and Performance

Contextualize HRV with what's going on: - In a **high load training block**, expect HRV to drop somewhat – that's normal as long as performance is maintained. But you want it to rebound after deload weeks. If HRV keeps dropping week after week through what should have been a recovery week, the athlete might be not absorbing the training. - In a **taper or rest phase**, HRV should climb (or return to baseline from any suppressed state). Many athletes see their highest HRV on rest days or toward end of a taper – indicating freshness. If HRV isn't coming up with rest, suspect lingering stress or incomplete recovery. - **Before competition:** Some athletes get pre-competition anxiety that lowers HRV acute (fight-or-flight response) [64]. This doesn't necessarily harm performance if it's just excitement – e.g., an Olympic lifter might hit a PR even with low HRV that day due to adrenaline. So don't overreact to a single low number on race day if the athlete feels ready. It might be normal psych-up. On the other hand, if an athlete is over-trained, HRV might be chronically low *and* performance is down. - **Performance outcomes:** Use HRV alongside metrics like times, power outputs, and subjective ratings. Over time, you might see patterns: "Whenever HRV is below X, you struggle in the workout." or "When HRV is high, your intervals go great." This individualizes the meaning. Some studies even found improved performance in groups that only did intense training when HRV was above baseline [65] [66]. You can experiment with HRV-guided session planning for willing athletes.

4. Identify Patterns Unique to the Athlete

Some athletes might have consistently low morning HRV but still do fine – perhaps their HRV rises more at night. Others might be very sensitive to travel or dehydration (which tank HRV). For example, you might notice every time an athlete takes a transatlantic flight, their HRV drops 15% for two days – so next time, you proactively plan recovery days after travel. Or an athlete's HRV might dip specifically after heavy strength sessions more than after long runs – indicating what type of stress hits their system hardest. Over months, these insights allow truly personalized coaching.

Also note any **parasympathetic saturation candidates**: if you coach elite endurance athletes, keep an eye out for the low HR + low HRV combo during mega mileage weeks. If you confirm it's not illness or true overtraining (i.e., they feel good and perform well), you might adjust their HRV measurement routine (e.g., measure upon standing) for better sensitivity as discussed earlier. This is an exception, but valuable to remember.

5. Educate and Involve the Athlete

Make sure the athlete understands why you're using HRV and what it means. This helps compliance (like wearing the device regularly, or doing the morning measurement properly). It also prevents them from freaking out at normal fluctuations. Emphasize that HRV is not a “grade” but a feedback tool. For instance, if they see a red low HRV, it’s not “bad” in a moral sense – it’s information that they should respond to. Many athletes become motivated when they see HRV improvements with better recovery practices. You can set up friendly challenges, e.g., “Let’s see if more hydration and an extra hour of sleep this week bumps your HRV back into green.” When athletes take ownership, you get better data and better outcomes.

6. Integrate HRV with Other Recovery Indices

HRV shouldn’t be used in isolation. Always consider it alongside: - **Resting Heart Rate (RHR):** Often, high RHR + low HRV is a stronger flag for fatigue than either alone. A normal HR with low HRV might be more parasympathetic saturation or measurement nuance. Many systems combine these (e.g., some readiness scores use both). - **Sleep metrics:** As detailed, poor sleep will show up in HRV. Use the qualitative (hours, sleep stages) with HRV to fully assess recovery. If HRV is off, check if the athlete only slept 4 hours, etc. - **Subjective scores:** Don’t ignore how the athlete says they feel. HRV is great but not infallible. If an athlete’s HRV is low but they swear they feel amazing and their performance is peaking, you must interpret the data in context (maybe it’s taper anxiety or that rare parasympathetic blunting). Conversely, if HRV is normal but they feel terrible, investigate – the HRV might be temporarily maintained but other systems are lagging (e.g., psychological stress can sometimes not immediately reflect in morning HRV). - **Other Biomarkers:** If available, things like blood markers (e.g., cortisol, testosterone:cortisol ratio, CK for muscle damage, etc.) can corroborate HRV findings. For example, consistently low HRV and consistently high cortisol would strongly indicate overtraining risk [19] [51]. Use HRV as the accessible daily marker, and periodic blood tests as needed for confirmation in high-level cases.

7. Avoid Common Pitfalls

- **Panicking Over One Low Value:** Don’t scratch a key workout just because one morning HRV was low – look for confirmation in how the athlete feels and tomorrow’s reading. It’s the sustained low trend that is more important. One low value could even be a sensor error or an artifact of a late dinner or some acute stress that might resolve.
- **Forgetting the Big Picture:** HRV is one aspect of training feedback. If an athlete’s HRV is slightly down but everything else says they’re fine (great mood, great performance, normal RHR), you might simply monitor a bit more rather than change course. Conversely, if HRV is fine but other signs of fatigue are present, don’t let a good HRV lull you into overtraining someone. There are times HRV can stay artificially high – e.g., some overtrained states or if someone is tapering and starting to detrain, HRV might rise but performance can drop. So, context!
- **Not Standardizing Measurements:** If you do morning readings, ensure the athlete does it the same way each time (same time of day, same posture, ideally after waking and voiding but before coffee or exercise). Changes in routine (one day they measure standing rushing to work, another day lying in bed) can cause variability unrelated to recovery. If using wearables, ensure they wear it consistently and the device has a good signal. The more consistent the data source, the more trust you can place in trends.

8. Leverage Technology but Maintain Coach’s Intuition

Devices like Garmin, Whoop, Polar, etc., now provide readiness scores that crunch HRV, sleep, and other metrics into simple labels (e.g., “Recovery: 32% – pay attention!” or “Training Readiness: High”). These are useful summaries, especially for athletes who may not dive into the raw data. As a coach, use those as a starting point, but always apply your judgment. Sometimes you will deliberately override a metric – for example, an athlete has a big competition and the system says “recovery low”; you’re not going to tell them to skip the competition! Instead, you'd adjust strategy (longer warm-up, mental focus, etc., acknowledging they're not 100%). In many cases, though, these systems help reinforce your recommendations: if you tell an athlete to rest and their watch also flashes a low readiness score, they'll be more likely to comply.

9. Use HRV Biofeedback for Recovery

Not only can HRV measure recovery, it can be a training tool *for* recovery. Practices such as deep breathing exercises, meditation, or HRV biofeedback sessions can increase HRV acutely and help an athlete shift into a parasympathetic state. Some athletes use guided breathing apps that show in real time their HRV (often using a chest strap) and try to maximize it via slow, diaphragmatic breathing. This is like training the recovery system. It can be especially useful for athletes who struggle to unwind (those with high sympathetic drive). Even 5-10 minutes of slow (6 breaths per minute) breathing can raise HF HRV and potentially improve subsequent sleep or recovery [53] [54]. Encourage these habits as part of the overall recovery plan.

10. Monitor Long-Term Progress

Over the course of a season or year, hopefully you see the athlete's baseline HRV either hold or even improve slightly as their fitness and resilience increase. Many times, effective training will raise resting vagal tone – some studies show athletes who improved VO_2max also saw progressive increases in HRV [67] [68]. If you see a long-term downward drift in baseline HRV over months, that could indicate the training program is too stressful without enough rest (or other lifestyle factors are degrading their recovery capacity). Intervene accordingly. On the flip side, if an athlete's baseline HRV climbs too much above their norm and stays there, check if they are detraining (sometimes reduced training load or illness can paradoxically raise HRV short-term). The optimal zone is a stable or slowly improving HRV baseline that correlates with performance improvements. Remember, **the ultimate goal is performance**, not maxing out HRV – HRV is a means to ensure the athlete is adapting well. As one paper pointed out, athletes who personalized their training based on HRV got better results with less risk [69] [70] – a win-win.

Conclusion: By differentiating between time- and frequency-domain HRV metrics, you gain a full picture of an athlete's autonomic function; by understanding phenomena like sympathetic overdrive and parasympathetic saturation, you can correctly interpret HRV changes in the context of overtraining; by distinguishing sudden drops from gradual trends, you can take timely action to prevent minor fatigue from becoming major burnout; and by linking HRV with sleep and hormonal patterns, you appreciate why recovery is a 24-hour process influenced by nighttime restorative phases.

In applying this knowledge, you transform HRV from just a number on a screen into a rich decision-support tool. It's like having an ongoing conversation with the athlete's nervous system: it tells you when to push, when to pull back, and when something might be wrong under the hood. Listen to it, corroborate it with the athlete's feedback, and adjust the training plan proactively. The result will be athletes who train hard **and** smart – maximizing adaptation while minimizing the risk of overtraining. And as a coach, there's nothing more satisfying than seeing your athletes thrive, armed with the insights that data like HRV provides, backed by the wisdom of careful analysis and responsive training adjustments.

References: The concepts and guidance above are supported by a breadth of research and expert observations. Key sources include scientific reviews of HRV metrics [5] [7], sports science articles on HRV-guided training and fatigue monitoring [37] [38] [36], as well as practical insights from HRV practitioners and platforms (e.g., Marco Altini on parasympathetic saturation [21] [23], and Garmin's official documentation on their HRV features [71] [3]). By integrating these sources, this manual provides an evidence-based approach to using HRV as a biomarker for athletic recovery and performance. Keep learning and stay updated, as research in this field is ongoing – but hopefully, this guide has equipped you with a firm foundation to make the most of HRV data in your coaching practice.

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