Tracking your mental fitness with a wearable device: is HRV the right biomarker to use or is there a better one?

2-Dooz Research Labs

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Abstract

Most commercial wearables rely on **Heart Rate Variability (HRV)** as a proxy for the Autonomic Nervous System (ANS) to monitor stress and metabolic health. However, this paper argues that HRV is fundamentally flawed for real-time distress tracking due to signal noise, delayed latency, and lack of clinical standardization. Instead, the paper highlights **Finger Skin Temperature (FST)** as a superior, real-time leading indicator of the "fight-or-flight" response, enabling timely biofeedback interventions to mitigate stress-induced metabolic damage.

While HRV remains useful for long-term health trends when combined with lab work or CGMs, it fails as a real-time tool for mental fitness and stress intervention. **FST represents the most effective biomarker currently available for real-time distress detection on wearable hardware**. Further clinical research is recommended to formally validate FST-driven wearable interventions for managing stress-induced metabolic dysregulation.

Introduction

Most wearable devices, such as watches, bands and rings, can track Heart Rate Variability (HRV). This has been made possible by Photoplethysmography (PPG) sensors and sophisticated on-board signal processing. This technology was first targeted at professional athletes trying to improve their performance, but is now used by a larger population of users who want to understand and track their health and wellbeing, inclusive of metabolic health markers.

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[1] Name of journal publication was corrected to Frontiers in Physiology (Autonomic Neuroscience section).

What is metabolic health and what are wearable vendors doing?

From a strict clinical point of view, metabolic health is defined by 5 measurements – waist circumference, fasting blood glucose level, systolic blood pressure, triglycerides and HDL cholesterol. A doctor usually tracks these for a patient and works with them to keep these within acceptable range so as to avoid potential health issues such as diabetes and heart attacks.

A person may commonly be considered to have metabolic syndrome (indicating metabolic dysfunction) when they have at least three of these five factors:

1. Elevated blood pressure (≥130/85 mmHg)
2. Elevated fasting glucose (≥100 mg/dL)
3. Elevated triglycerides (≥150 mg/dL)
4. Reduced HDL cholesterol (<40 mg/dL for men, <50 mg/dL for women)
5. Increased waist circumference (abdominal obesity)

Conversely, optimal metabolic health typically means having all five markers in healthy ranges without a metabolic syndrome diagnosis.

Furthermore, a clinician may ask for other lab tests for a more nuanced determination of what is going on:

- Cortisol: Levels can indicate chronic inflammation, which can be a precursor for all of the metabolic syndrome markers;
- HbA1c (glycated hemoglobin): Reflects average blood glucose over 2–3 months; <5.7% is considered normal;
- HOMA-IR (Homeostatic Model Assessment for Insulin Resistance): Measures insulin resistance; lower values are better;
- C-reactive protein (CRP): Inflammation marker; elevated levels suggest chronic inflammation; and
- Uric acid: High levels are associated with gout, metabolic syndrome, and kidney disease.

The challenge is that these measurements have to be done in a doctor's office or in a lab, typically by means of a blood draw. These visits are infrequent and a lot can happen in between visits to the doctor. Wearable devices provide the ability to have continuous monitoring making it possible to see biometrics at any time: not just in a doctor's office.

Accurately tracking a person's metabolic health is not a simple matter. Some of the traditional metabolic health measurements can be done continuously, e.g. Continuous Glucose Monitor (CGM) or a blood pressure tracker, but these still require extra devices to be worn daily.

Wearable device vendors have been looking for an alternative biomarker that can correlate with metabolic health and that can fit into a small form factor. Most of them have settled on HRV for this purpose. The required PPG sensors can easily fit into a watch, wristband or ring form factor. An obvious question is, have the device vendors who are banking on HRV to track metabolic health made the correct choice? The answer ultimately comes down to how well HRV assesses stress.

How Stress Impacts Metabolic Health

Stress triggers hormonal and physiological changes that directly impair metabolic health markers. Chronic stress creates a cascade of effects that can worsen insulin sensitivity, blood sugar control, inflammation, and lipid profiles—essentially damaging multiple aspects of metabolic function simultaneously.

Direct Effects on Metabolic Health Markers

Metabolic Marker	How Stress Worsens It
Fasting Blood Glucose	Cortisol increases hepatic glucose production; chronic stress impairs glucose clearance
Insulin Resistance (HOMA-IR)	Cortisol and sympathetic activation reduce insulin sensitivity in muscle and fat cells
Triglycerides	Stress increases lipolysis and fatty acid oxidation, raising circulating triglycerides
HDL Cholesterol	Chronic stress lowers HDL (protective cholesterol) levels
Blood Pressure	Sympathetic activation and cortisol cause vasoconstriction and sodium retention
Waist Circumference	Cortisol drives visceral fat accumulation, even without weight gain
Inflammation (CRP)	Stress activates inflammatory pathways, raising C-reactive protein and other inflammatory markers

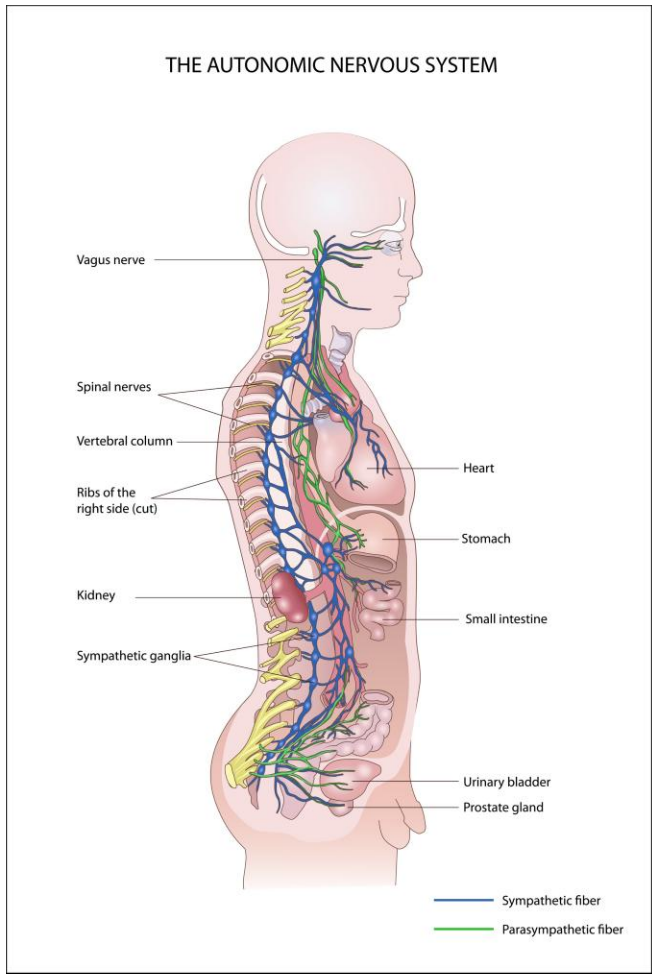
Someone under chronic stress can develop metabolic dysfunction even with normal weight and good diet, because the hormonal environment is working against them. This is why stress management is considered a core component of metabolic health—addressing it can improve fasting glucose, blood pressure, triglycerides, and HDL cholesterol independent of weight loss.

What is the ANS?

Think of the ANS as the control center for your body. It operates autonomously and manages all your involuntary, life-sustaining functions – circulation, digestion, breathing, temperature control, etc., without you having to think about it. It makes sure your internal organs are responding to your needs, such as eating, running from a bear or exercising.

The ANS consists of two components that counter-balance each other:

- **The Sympathetic Nervous System** (SNS). This is what drives the “fight-or-flight” response. In cases of stress, exercise, or threat, it gets your body ready for action. It does things such as dilating blood vessels in your muscles, increasing your heart rate to pump more oxygen, pulls blood away from your extremities to make it available to your muscles.



- **The Parasympathetic Nervous System** (PNS). The yin to the SNS yang. It does the opposite. It drives the “rest-and-digest” or “feed-and-breed” response. Once the source of stress has passed, the PNS takes over to conserve energy, repair tissue and gets your body back to a stable state. Some of the things it does are slowing down your heart rate, lowering your blood pressure, constricting your airways back to normal and healing your cells.

In the “fight-or-flight” mode, the amygdala prompts the hypothalamus to initiate the release of epinephrine and norepinephrine, to ensure non-essential organs (e.g., skin, gut, prefrontal cortex, etc.) are inhibited, by means of vasoconstriction, in deference to more critical systems such as the pulmonary, cardiovascular, and skeletal muscle systems; from an evolutionary perspective these systems are deemed more critical for fight-or-flight.

Similarly, for thermal regulation purposes, by means of evaporative cooling, acetylcholine is triggered to increase sweat production, including in the hands which have a high concentration of sweat glands[2]. Regarding the hands, the net result of vasoconstriction and evaporative cooling is a discernible drop in finger skin temperature (FST). Mechanistically stress induced fight-or-flight can be tracked via the FST biomarker. And, regarding the heart, the release of adrenaline causes the heart to beat faster and stronger, which can be observed via HRV.

The ANS under Chronic Distress

Acute activation of the "fight-or-flight" response is a normal part of life and is mediated by the release of the stress hormones cortisol and adrenaline. During exercise or running away from a bear, these hormones facilitate a more optimal physical response.

However, someone who is in a constant state of distress will stay in the "fight-or-flight" mode. That keeps their body in a continual state of releasing the stress hormones, cortisol and adrenaline. This leaves the organs in an ongoing state of imbalance, due to the suppression of SNS activity, and can lead to chronic problems such as diabetes, PTSD and cancer.

How the FST and HRV biomarkers respectively detect ANS dysregulation during distress and the implications of ANS dysregulation for metabolic health are the central considerations in the remainder of this document.

What is HRV?

Heart rate (HR) is the number of times your heart beats every minute. However, there is variation in the time interval between consecutive heartbeats. This variability is called HRV and reflects the interaction between the Autonomous Nervous System (ANS) and the cardiovascular system. HRV can be measured in a clinical setting using ECG (Electrocardiogram) or through PPG sensors on wearable devices. ECG is still considered the gold standard for HRV measurements.

Because it is at the intersection of the cardiovascular system and the ANS, HRV has shown promise as a biomarker for tracking metabolic health, athletic performance, sleep, et

[2] Sweat glands in the hand are more than double those in the forearm / wrist. Thus, the thermogenic effect of high-stress (i.e., distress) is more pronounced in the hand than it is at the wrist.

cetera. Still, it is important to understand the limitations of HRV on wearable devices, which provide sub-gold-standard performance.

Limitations of HRV

In January 2026, Professor A. Banerjee published a paper in Frontiers in Physiology (Autonomic Neuroscience section) titled, "Understanding the shortcomings of heart rate variability as a tool for autonomic analysis," which has a good analysis of work done on HRV and its limitations. Professor Banerjee discusses how Machine Learning can be used to overcome some of those limitations. The widely read article is highly recommended.

For this discussion, relevant limitations are presented in the context of using wearable device HRV for tracking mental health fitness. These are:

- **Lack of standardization**: There is no standard for measuring HRV. It depends upon so many factors such as recording duration, time of day, breathing control, body position and more. There are more than 70 variables to consider in an ECG waveform. Because of lack of standardization, every vendor has developed proprietary algorithms and their own version of metabolic and mental resilience. Also, most consumer wearables have not been clinically validated against "gold standard" ECG measurements in diverse populations.
- **Differences between short term and long term HRV**: short term HRV is usually derived from a 5-minute recording and long term is usually is over 24 hours or more. Both have different benefits. Long term HRV fits in well with wearables which a user wears all the time. It is a good fit for sleep where you can monitor a user's HRV over 8-10 hours of sleep.
- **Sensitivity to artifacts and signal quality**: HRV is very sensitive to what is going on the body at any moment in time. For wearables, specifically, motion or breathing pattern variations during measurement time will impact the HRV measurements.
- **Complex interpretation**: One of the reasons there is no standardization in HRV measurements is that it is complex to interpret and is influenced by so many factors. Age, sex, medications, physical fitness are just some of the factors that affect HRV. This is why wearable vendors tell users to look at HRV trends not actually HRV values. Their recommendations tend to be about long term trends, not hour by hour and definitely not about minute by minute.
- **Specific to the heart, not the entire body**: HRV is being touted as proxy for the ANS. One has to be careful about that. HRV is an indicator of how the ANS interacts with the heart. It does not consider all of the other organs that are controlled by the ANS.

In addition to the preceding limitations, wearable device HRV may suffer from poor signal quality because of poor skin contact. Moreover, optical sensors in wrist-worn devices are prone to artifacts from arm movement, tattoos, skin tone variations and sweat. The result of poor signal quality is noisy data leading to inaccurate HRV calculations; making real-time wearable device HRV stress assessments unreliable and thus ineffective for metabolic health tracking and management.

Moreover, the lack of clear context, or use-case conflation may present a particularly challenging situation for consumer wearable devices that are intended to be used to track physical fitness, sleep, metabolic health, stress, illness, et cetera. This makes it difficult to pin-point a change in HRV to any particular context, resulting in noisy data sets, which again may limit the effectiveness of wearable device HRV for metabolic health tracking and management.

What does that tell us about HRV?

Though unreliable for real-time assessments, measuring HRV with a wearable device can be useful for long term tracking of a user's metabolic health[3], but in itself, is not enough. When used in conjunction with other biosensors, such as a CGM or a continuous BP band, with lab work and with information gleaned from doctor visits, HRV can be a useful tool.

As for being a proxy for the ANS and the monitoring of mental fitness, it is not the right biomarker. The question is what is the right biomarker for the ANS?

ANS Detection and Intervention: HRV vs FST

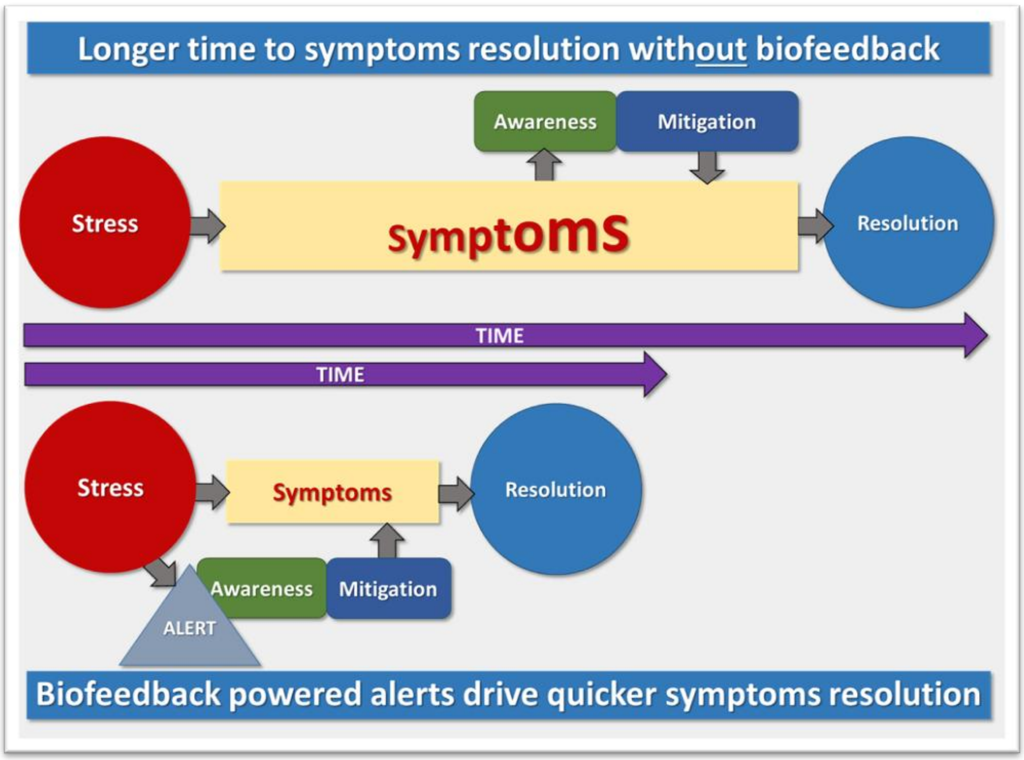
Accompanying the deleterious effects on metabolic health, chronic distress can cause a number of other unwanted physical side-effects, including migraine, neck pain, back pain, stomach ache, chest pain, and shortness of breath. Being able to observe and facilitate the mitigation of the ANS on a continuous basis, i.e. detect the "fight-or-flight" (FoF) mode of the SNS as soon as it happens and control the PNS to calm down the body, is a key requirement for a wearable device.

The importance of being able to accurately detect and measure distress can be understood in terms of the Stress Progression Model (SPM)—see figure below. Many ailments, e.g., cancer and heart disease, which can be correlated to chronic stress, share the tenet that early detection and intervention play an important role in the achievement of a successful

[3] The exception may be those dealing with chronic stress. Their HRV baselines may incorrectly incorporate their chronic stress as "normal."

outcome. Likewise, the SPM asserts that the early awareness of stress induced symptoms can lead to their faster resolution. The thought is that if a conservative intervention (e.g., meditative breathing) is pursued early enough in the progression of a stressful state, then induced symptoms can successfully and more quickly be interrupted.

Stress Progression Model



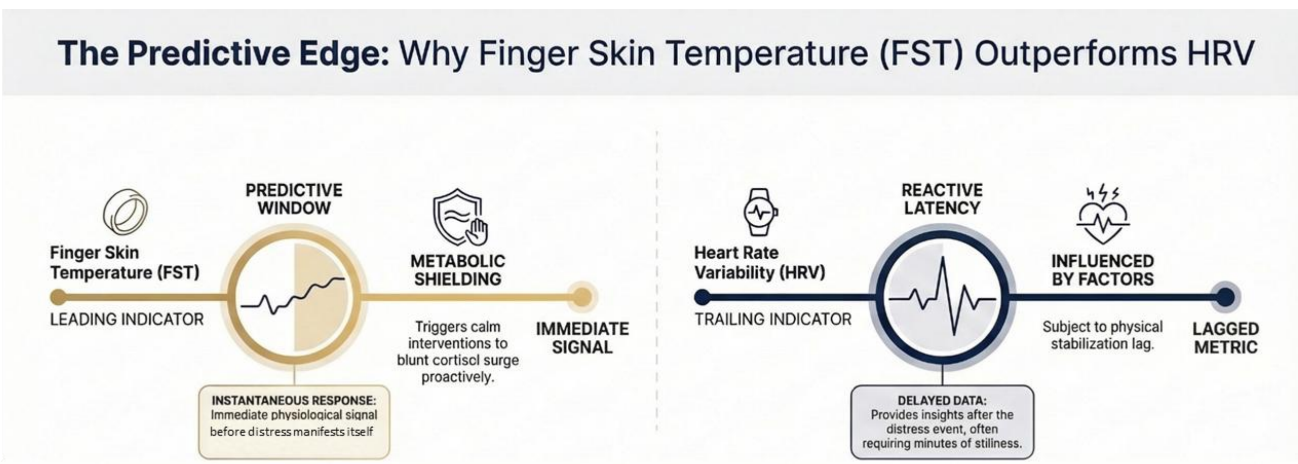
Consider a biofeedback-powered meditative breathing intervention for a distress induced FoF activation. As shown in the SPM figure, a primary objective is to expedite the awareness of symptoms of distress by means of biofeedback triggered app notifications (i.e., Alerts), which announce the start of a software implemented guided, interventional meditative breathing session (i.e., Mitigation). Theoretically this accelerates the resolution of the distress induced symptoms by means of the more optimally timed use of meditative breathing to reduce and / or shorten the release of the cortisol and adrenaline stress hormones. Moreover, continuous use of the system teaches users to associate their specific stress inducing activities with their corresponding triggers; allowing trained users to independently initiate a more-timely meditative breathing session for each new encounter with distress.

In the context of the SPM, even though HRV can be used to observe the ANS, as discussed earlier, it cannot reliably detect FoF activation as it happens. Distress detection is significantly delayed: eliminating the possibility of an early intervention. Delayed HRV detection of FoF activation can result in the unabated progression of physical symptoms of distress, e.g., migraines, back pain, blood glucose elevation, et cetera.

As previewed earlier, FoF activation results in vasoconstriction and evaporative cooling in the hands, causing a timely, discernible drop in finger skin temperature. Regarding metabolic health, by monitoring the Finger Skin temperature (FST) biomarker, it is possible to detect in real time that someone is experiencing distress and to facilitate an intervention to curtail the effect of the released stress hormones before they can significantly impact blood glucose levels.

As for intervening the ANS, breathing is the most effective way to regulate the PNS. Breathing is unique in that in that it is both involuntary (automatic) and voluntary (you can control it). A long exhale stimulates the vagus nerve which can slow down your heart rate.

The chart below summarizes the differences between FST and HRV regarding the ANS, mental fitness, and metabolic health.



Comparative Performance Metrics

	Finger Skin Temperature (FST)	Heart Rate Variability (HRV)
Sensitivity	Highly specific to "fight or flight" activation.	Influenced by movement, caffeine, and posture.
Latency	Instantaneous response to distress triggers.	Requires minutes of stillness for clean readings.
Actionability	Provides a "Trigger Alert" before the spike.	Provides a "Stress Score" after the fact.

How can FST be used for continuous monitoring of mental fitness?

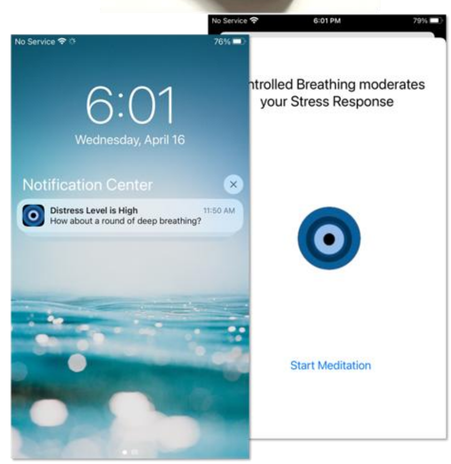
As earlier discussed, FST gives an instantaneous indication of the amygdala triggering the fight-or-flight reaction. A smart Ring, supporting FST, can gather that information and, in combination with a smartphone based app, can track an individual's stress levels both continuously and over time, as shown in the accompanying screenshots in this section.

Distress can be accurately described as a failed or maladaptive adaptation to stressors: when an organism's physiological or psychological coping mechanisms are insufficient, prolonged, or dysregulated, the initial stress response becomes harmful and produces distress (persistent negative emotions, impaired functioning, or pathology).

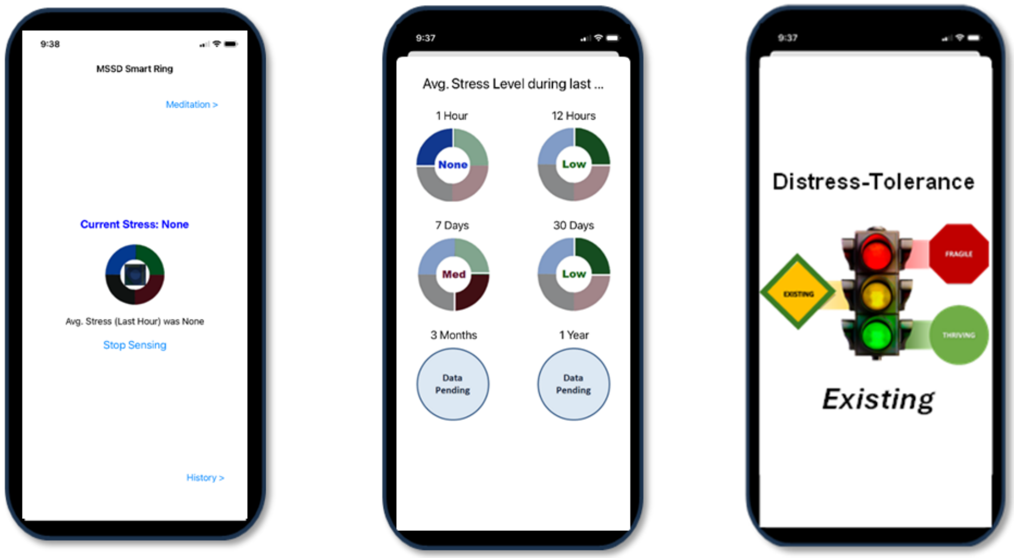
Increased tolerance to stress, reduces the likelihood of distress. The higher one's tolerance, the more effectively one can navigate life's inevitable setbacks.

The smartphone app's functionality can be extended by an AI model, to perform:

- A baseline assessment to determine the distress-tolerance of an individual;
- A real-time estimate of distress-tolerance based on FST biofeedback; and
- Assessments regarding the need for clinical intervention.



FST powered distress detection, meditative breathing powered de-escalation, and AI powered distress-tolerance tracking comprise a comprehensive system for metabolic health. Combining FST with tools such as this can help individuals that have suffered from trauma or are chronically stressed out.



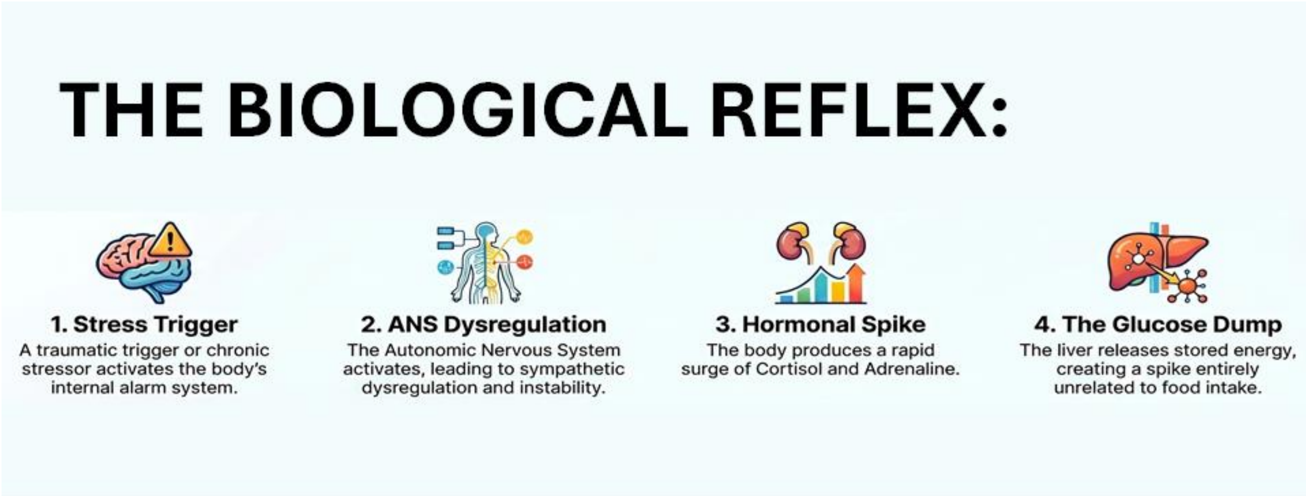
Can FST help with metabolic health?

2-Dooz estimates that **20 million (U.S.) prediabetics also suffer from post-trauma-distress (PTD).** The key clinical insight is that chronic distress is not just a mental health challenge, but it is a biological reflex that can independently drive metabolic failure. As discussed before, chronic distress, such as that arising from PTD, can dysregulate the ANS, which will in turn affect all critical organs in the body. Understanding what the ANS is doing and interacting with, in the context of PTD, offers an opportunity to help prevent or alleviate metabolic problems.

A good example is managing blood glucose levels. A healthy person, or someone with pre-diabetes, wants to keep their glucose levels within acceptable levels. Today, over-the-counter (OTC) CGMs have become very popular for those wanting to track their glucose levels, to help them manage their food intake.

However, a spike in glucose is not only caused by food. It can also be due to ANS dysregulation, precipitating cortisol and adrenaline spikes. And, since PTD can trigger ANS dysregulation, PTD can cause blood glucose spikes.

For those struggling with PTD and prediabetes, FST powered wearable devices can be used to detect PTD triggered ANS dysregulation. Theoretically, FST powered wearable solutions for PTD should help to slow the progression of prediabetes to diabetes for prediabetes who also suffer from PTD.



Conclusions and future direction

What have we learnt? HRV is a promising wearable device biomarker, but is not optimal for tracking metabolic health and is definitely not capable of the real-time detection of distress. A lot of work has to be done to make it more useful: most importantly the standardization of what HRV means and the lack of implementation consistency across vendors and platforms have to be addressed. For now, HRV has limited applicability to sub-clinical use-cases only.

FST is, today, the best biomarker for tracking distress and is easily integrated into any wearable device. In the context of mental fitness and metabolic health, it shows great potential because of its clinically proven strong correlation to the ANS. Though in its infancy, FST shows great promise for use as a wearable technology for helping to manage metabolic health, inclusive of diabetes. More clinical research is desperately needed to confirm that FST powered wearable solutions can slow the progression of prediabetes to diabetes for prediabetes who also suffer from PTD.