Review

Not peer-reviewed version

The Future of Stress Management: Integration Smartwatches and HRV Technology

Ravinder Jerath * , Mohammad Syam * , Shajia Ahmed *

Posted Date: 19 July 2023

doi: 10.20944/preprints202307.1283.v1

Keywords: smartwatch; stress; wearable device; heart rate variability; comparative analysis

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1283.v1

Review

The Future of Stress Management: Integration Smartwatches and HRV Technology

Ravinder Jerath, Mohammad Syam and Shajia Ahmed *

[1] Charitable Medical Healthcare Foundation, Research Director of Mind Body Technology, Augusta, GA, United States; rj605r@aol.com (R.J.); msyam@augusta.edu (M.S.)
[2] Augusta University, Augusta, GA, United States
[3] Research Volunteer, Augusta, GA, United States
* Correspondence: shajia.ahmed4@gmail.com

Abstract: In the modern world, stress has become a pervasive concern that affects individuals' physical and mental well-being. To address this issue, many wearable devices have emerged as potential tools for stress detection and management, by measuring heart rate, heart rate variability (HRV), and various matrices related to it. This literature review aims to provide a comprehensive analysis of existing research on HRV tracking and Biofeedback using smartwatches and finger monitor/sensor pairing with reliable 3rd party mobile apps like Elite HRV, Welltory, and HRV4Training specifically designed for stress detection and management. we apply various algorithms and methodologies employed for HRV analysis and stress detection is discussed, including time-domain, frequency-domain, and non-linear analysis techniques. Prominent smartwatches, such as Apple Watch, Garmin, Fitbit, Polar, and Samsung Galaxy Watch, are evaluated based on their HRV measurement accuracy, data quality, sensor technology, and integration with stress management features. We describe the efficacy of smartwatches in providing real-time stress feedback, personalized stress management interventions, and promoting overall well-being. To assist researchers, doctors, and developers use smartwatch technology to address stress and promote holistic well-being, we discuss the data's advantages and limitations, future developments, and the significance of user-centred design and personalized interventions.

Keywords: smartwatch; stress; wearable device; heart rate variability; comparative analysis

1. Introduction

Over the past decade, wearable technology has gained significant traction, with smartwatches emerging as one of the most popular and widely adopted devices in this category. A smartwatch is a wrist-worn device equipped with various sensors, connectivity features, and a display screen, offering functionalities beyond traditional timekeeping (Rawassizadeh, Price, and Petre 2015). These devices have seen exponential growth in popularity due to their versatility, convenience, and ability to seamlessly integrate with smartphones and other smart devices. Smartwatches initially gained attention for their fitness and activity tracking capabilities. They provided users with the ability to monitor their physical activity, track steps, measure heart rate, and calculate calorie expenditure (Henriksen et al. 2018). The incorporation of advanced sensors, such as optical heart rate sensors and accelerometers, allowed users to gain insights into their health and wellness in real-time. Beyond fitness tracking, smartwatches quickly expanded their features and functionalities to include communication, notifications, mobile apps, music playback, and more (Chu et al. 2023).

As the capabilities of smartwatches advanced, manufacturers recognized the potential to address another pressing issue affecting individuals' well-being: stress management. The detrimental effects of chronic stress on physical and mental health have led to a growing demand for tools and techniques that help individuals monitor and alleviate stress levels (Johnson et al. 1992). This is where the integration of heart rate variability (HRV) analysis into smartwatches has garnered attention. HRV, which measures the variation in time intervals between consecutive heartbeats, is an indicator

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1283.v1

of autonomic nervous system activity (Shaffer and Ginsberg 2017; Singh et al. 2018). It has been widely studied and recognized as a valuable metric for assessing stress levels, emotional states, and overall well-being. By exploiting optical sensors and advanced algorithms, smartwatches can capture and analyze HRV data, providing users with insights into their stress levels and offering interventions to manage and reduce stress effectively (Dalmeida and Masala 2021; Chalmers et al. 2021). The integration of stress management features based on HRV analysis has positioned smartwatches as holistic wellness devices (Chalmers et al. 2021). By combining fitness tracking, communication, and stress management capabilities, these devices have the potential to empower individuals in maintaining a healthy lifestyle and have emerged as a promising solution at the intersection of technology and personal health.

Heart Rate Variability (HRV) refers to the fluctuation in the time intervals between consecutive heartbeats, also known as R-R intervals, as measured by electrocardiography (ECG) or optical sensors (Shaffer and Ginsberg 2017; Singh et al. 2018). It reflects the dynamic balance between the sympathetic and parasympathetic branches of the autonomic nervous system (ANS), which regulate our body's physiological responses to stressors (Kim et al. 2018). The ANS plays a crucial role in modulating stress by regulating heart rate, blood pressure, respiration, and other vital functions. The sympathetic branch of the ANS is responsible for the "fight-or-flight" response, activating the body to cope with stress, while the parasympathetic branch promotes relaxation and restoration (Waxenbaum, Reddy, and Varacallo 2023; Chu et al. 2023).

When individuals experience acute or chronic stress, the sympathetic branch of the ANS becomes dominant, leading to increased heart rate and decreased HRV. Conversely, during periods of relaxation and recovery, the parasympathetic branch prevails, resulting in decreased heart rate and increased HRV (Kim et al. 2018; Pham et al. 2021). Therefore, higher HRV is generally associated with a more adaptive stress response and better overall well-being (Kim et al. 2018; Lischke et al. 2018).

HRV analysis provides valuable insights into an individual's physiological state, including their stress levels, emotional states, and autonomic balance (Pham et al. 2021). By continuously tracking HRV throughout the day, these devices can provide real-time feedback on stress levels and suggest personalized interventions to help users regulate their stress response (Chalmers et al. 2021). These interventions may include breathing exercises, guided meditations, mindfulness prompts, or activity recommendations tailored to everyone's needs. Furthermore, comparing HRV patterns before and after implementing stress reduction techniques, individuals can objectively assess the impact of different strategies and make informed decisions about which methods work best for them and help them to enhance their self-awareness, adopt healthier coping mechanisms, and ultimately lead a more balanced and stress-resilient life (van der Zwan et al. 2015; Castro Ribeiro et al. 2023).

The purpose of conducting a literature review comparing smartwatches in managing stress using Heart Rate Variability (HRV) is to systematically analyze and synthesize existing research and knowledge on the effectiveness of different smartwatches as stress management tools. The review aims to compare the capabilities, features, and performance of smartwatches in measuring HRV and providing stress reduction interventions. By examining the literature, the review intends to identify the strengths, limitations, and gaps in the current body of knowledge to offer insights for future research, development, and practical application of smartwatches in stress management.

2. HRV and Stress Management

HRV measures heartbeat interval variation. Balanced sympathetic and parasympathetic autonomic nervous system branches induce it. HRV is a popular stress and well-being statistic. HRV is a stress indicator:

ANS regulates heart rate and other involuntary activities. The SNS governs the "fight-or-flight" reaction, whereas the PNS controls the "rest-and-digest" response. These branches interact dynamically in HRV. High and low HRV imply a flexible ANS (Pham et al. 2021). It implies improved stress resistance and parasympathetic response. Lower HRV suggests lower variability and higher sympathetic dominance, which may be linked to persistent stress, weariness, or health issues.

 doi:10.20944/preprints202307.1283.v1

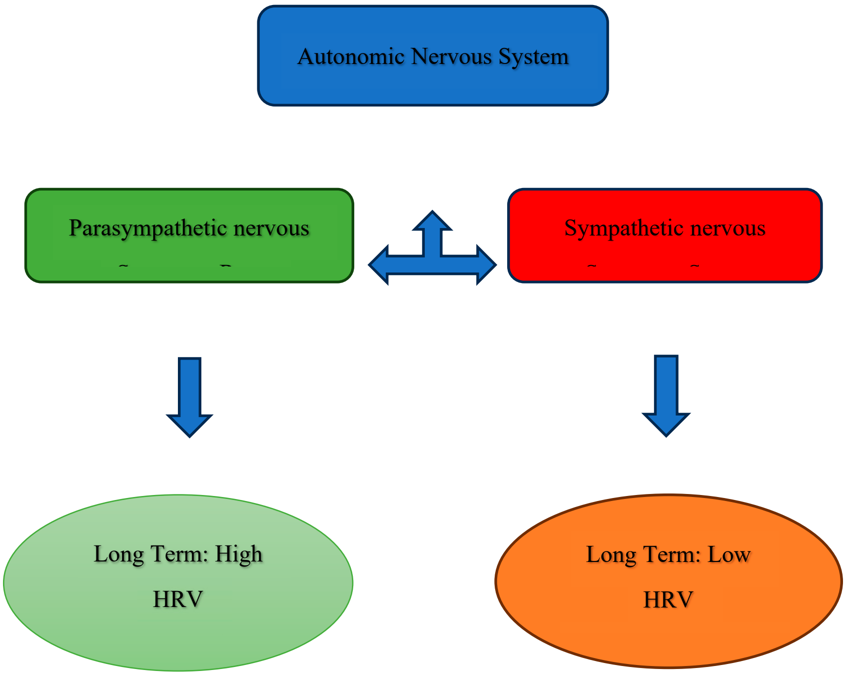

Figure 1. ANS (Autonomic Nervous System) – HRV (Heart Rate Variability) relationship with stress-resilience.

SNS activation raises heart rate and lowers HRV. Chronic stress disrupts SNS-PNS equilibrium, lowering overall HRV. Prolonged sympathetic dominance may cause cardiovascular illness, anxiety, and depression (Shaffer and Ginsberg 2017; Kim et al. 2018). Electrocardiography (ECG or EKG) measures HRV. HRV characteristics including time-domain and frequency-domain metrics give heart rate autonomic modulation information after data analysis.

HRV biofeedback boosts HRV and reduces stress. It activates and controls the neurological system to modulate baroreceptor reflex, respiratory sinus arrythmia, and other physiological systems that affect the lungs, cardiovascular system, and brain. It includes real-time HRV feedback and self-regulation tools to increase parasympathetic activity and reduce sympathetic arousal (Lehrer and Gevirtz 2014). HRV biofeedback helps with stress, anxiety, and performance.

HRV and stress reactivity vary. Age, fitness, genetics, lifestyle, and health issues may affect HRV (Kim et al. 2018; Tiwari et al. 2021). Thus, baseline HRV and these parameters must be considered while evaluating HRV readings.

HRV monitoring may assist manage stress for numerous reasons. HRV shows organ stress responses. HRV monitoring may identify stress early and prevent it (Kim et al. 2018; McCraty and Shaffer 2015). Stress may be detected early and prevented. HRV monitoring offers tailored stress evaluation. HRV fluctuations may indicate stress (Kim et al. 2018). People may understand their stress responses and build personalized stress management methods by studying their patterns. Real-time HRV biofeedback training teaches self-regulation (Aritzeta et al. 2022; Chung et al. 2021). Stress-reduction methods and HRV assessments may promote self-regulation. Biofeedback helps individuals control stress and relax.

Chronic stress harms mental and physical health. Monitor HRV to identify stresses and make healthy lifestyle changes. Regulating stress and increasing HRV improves stress management, resilience, and well-being (Kim et al. 2018; Chung et al. 2021). Additionally, HRV monitoring may help assess lifestyle changes. Sleep, exercise, diet, and relaxation may alter HRV (Myllymäki et al. 2012; Tseng et al. 2020). This feedback loop optimizes stress management tactics based on personal preferences. Thus, HRV monitoring incorporates the mind-body connection into holistic wellness. HRV connects mental and physical stress. HRV monitoring helps individuals manage stress and improve fitness.

HRV and stress reduction may be understood using the autonomic nervous system (ANS) and its involvement in stress response and regulation. The HRV-stress reduction theoretical framework is below:

The ANS regulates stress responses. The SNS and PNS are its branches. The SNS activates the "fight-or-flight" response in stressful conditions, raising heart rate, blood pressure, and HRV. The PNS stimulates the "rest-and-digest" response, which relaxes, lowers heart rate, and increases HRV (Singh et al. 2018; Kim et al. 2018; Waxenbaum, Reddy, and Varacallo 2023; Chu et al. 2023). HRV again shows SNS-PNS interaction. Higher HRV implies a more balanced, adaptive ANS with a stronger PNS involvement. Lower HRV indicates SNS dominance and impaired stress adaptation (Singh et al. 2018; Kim et al. 2018; Waxenbaum, Reddy, and Varacallo 2023). Stress reduction methods diminish ANS activity and promote PNS dominance. Deep breathing, meditation, awareness, progressive muscle relaxation, and biofeedback training are used (Russo, Santarelli, and O'Rourke 2017; Luberto et al. 2020).

Stress reduction improves HRV. These techniques engage the PNS, relaxing and improving HRV. Frequent PNS activation in stress reduction may affect ANS balance and promote stress resistance (Kim et al. 2018). HRV reduces stress via a positive feedback loop. Stress-reduction approaches boost HRV and elicit positive feedback(van der Zwan et al. 2015). This feedback loop promotes ongoing stress-reduction practice, improving HRV and stress. Thus, stress reduction and HRV increases improve stress resilience. ANS health improves stress management and emotional well-being (Can et al. 2020). Increased HRV indicates a flexible and adaptable ANS that responds to stimuli without over arousing (Pham et al. 2021).

This theoretical framework explains how HRV reduces stress. Empirical research and therapy assistance should be employed with this paradigm since stress reduction treatments affect HRV differently for each individual.

3. Smartwatches and Stress Management

Smartwatches are popular wearable devices to help reducing stress (Hickey et al. 2021). Smartwatches' stress-reduction potential are discussed below.

Most smartwatches monitor the wearer's heart rate throughout the day. Since stress and anxiety raise heart rate, smartwatches can show stress levels. Real-time heart rate data may reveal stress causes (Chalmers et al. 2021). Advanced smartwatches analyze HRV. HRV measures the fluctuation in heartbeat intervals to better assess stress and autonomic nervous system balance. HRV-analysis smartwatches may help customers manage stress (Shaffer and Ginsberg 2017; Kim et al. 2018).

Many smartwatches track stress using heart rate, HRV, and other matrix. These devices may detect high stress levels and provide real-time reminders to do breathing exercises or mindfulness (Chalmers et al. 2021). Some smartwatches include relaxing or breathing techniques. These features guide users through deep breathing or mindfulness exercises, helping them relax in stressful times. The watches may give visual or tactile feedback to help users follow the workouts (Robinson 2023, March 1).

Sleeping sufficiently reduces stress. Smartwatches measure sleep duration, phases, and quality. Examining sleep patterns may disclose causes of stress and tiredness (de Zambotti et al. 2019). Exercise reduces stress. Smartwatches measure steps, distance, calories, and exercise. Smartwatches may reduce stress by encouraging regular activity and providing feedback (Huang, Huang, and Wu 2022; Carter et al. 2018).

Smartwatches can plan mindfulness or relaxation breaks. These reminders may encourage users to take short breaks, breathe deeply, or meditate for stress management and mental health (Bégin et al. 2022). Smartwatches also link to smartphone applications or online platforms for extensive data analysis. Users may analyze stress patterns, trends, and historical data to discover triggers and make educated lifestyle adjustments and stress reduction choices (Huhn et al. 2022).

Smartwatches detect and analyze HRV using optical heart rate sensors and advanced algorithms. Smartwatches assess heart rate variability: Smartwatches' undersides include optical heart rate sensors that touch the wearer's skin. LEDs illuminate the skin, while photodiodes detect the reflected light. Photoplethysmography (PPG) is this technique. LEDs send light into the skin, which the blood vessels absorb, and the photodiodes reflect. Photodiodes detect blood-induced light intensity changes. The wearer's pulse is shown as a PPG signal (Castaneda et al. 2018). Smartwatches use the PPG signal to calculate heart rate by analyzing the period between heartbeats. Smartwatches display real-time heart rate data (Meza et al. 2023). Algorithms analyze the raw PPG signal and derive HRV data in smartwatches. HRV monitoring relies on variations in pulse intervals (Polak et al. 2022).

Frequency-domain HRV analysis is commonplace. The FFT converts the raw PPG signal into the frequency domain. This transformation isolates signal frequency components (Shaffer and Ginsberg 2017; Jarrin et al. 2012). Frequency-domain analysis determines HRV parameters. HF, LF, and the LF/HF ratio are factors. HF power represents the parasympathetic nervous system, LF power represents sympathetic and parasympathetic activity, and LF/HF ratio indicates sympathetic nerve activity (Shaffer and Ginsberg 2017).

Smartwatches may evaluate stress using HRV and contextual data. Advanced algorithms and machine learning methods analyze HRV data, compare it to established patterns, and predict stress levels based on the individual's baseline and deviations (Dalmeida and Masala 2021; Chalmers et al. 2021). Smartwatches and smartphone apps display HRV data and stress assessment findings. HRV trends, stress levels, and stress management suggestions are available (Hao et al. 2017). Smartwatches simplify HRV monitoring, however their accuracy and precision might vary. Sensor quality, skin contact, motion artifacts, and algorithm design affect HRV data dependability. Clinical-grade HRV analysis may need medical equipment and professional interpretation.

Smartwatches are beneficial for stress management. Key advantages:

Smartwatches monitor heart rate, HRV, and stress in real time. Awareness helps people recognize stress and ponder on its causes. Recognizing stress patterns helps people reduce stress (Chalmers et al. 2021). Smartwatches provide continuous monitoring without extra equipment or difficult processes. They provide real-time heart rate, HRV, and stress data to users (Gupta, Mahmoud, and Massoomi 2022). Continuous monitoring helps people track their progress, identify triggers, and make stress management changes. Smartwatches track stress patterns over time. Historical data and trends may help people understand their pressures, find patterns, and make educated lifestyle choices and stress reduction decisions (Gupta, Mahmoud, and Massoomi 2022; Hrabovska, Kajati, and Zolotova 2023). These personalized insights may help people design personalized stress management plans.

Smartwatches guide users through stress-reduction activities like breathing and mindfulness. Step-by-step instructions, visual cues, and tactile feedback help consumers relax. This guidance emphasizes stress-reduction and stress management (Castro Ribeiro et al. 2023). Smartwatches also measure sleep and exercise. A healthy lifestyle includes exercise, sleep, and stress management. Smartwatches encourage healthy behaviors that reduce stress and improve well-being (Scheid and West 2019) (Lehrer et al. 2021).

Goal setting, progress monitoring, and reminders help smartwatches manage stress. These traits motivate and hold individuals accountable, encouraging them to actively reduce stress (Lui et al. 2022; Greiwe and Nyenhuis 2020). The smartwatch's remarks and accomplishments may encourage stress management. Smartwatches may connect to many smartphone applications, health platforms, and services. This integration uses meditation apps, guided relaxation programs, and online support groups to manage stress holistically. Smartwatches are hubs for stress-reduction goods and services (Bégin et al. 2022).

4. Compoarison of Smartwatches and Compatible Mobile App for Stress Management

Apple is the leading smartwatch brand in the world, with a market share of over 43% in 2023. Samsung is the second leading brand, with a market share of 8%. Garmin and Fitbit follow, with market shares of 12% and 7%, respectively. Polar has a market share of 3%. Other brands, such as Huawei, Noise, and imoo, make up the remaining market share (Laricchia 2023, June 2).

Apple's dominance in the smartwatch market is due to its strong brand reputation, its wide range of features, and its integration with the iPhone. Samsung's smartwatches are popular for their

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1283.v1

stylish design and their compatibility with Samsung smartphones. Garmin smartwatches are known for their fitness tracking features, while Fitbit smartwatches are popular for their sleep tracking features. The global smartwatch market is expected to grow in the coming years, as more people adopt these devices for fitness tracking, health monitoring, and other purposes.

Here is a comparison of Apple, Garmin, Fitbit, Samsung, Polar smartwatch, EliteHRV, Welltory, and HRV4Training for HRV monitoring and biofeedback system for stress management:

Feature	Apple Watch	Garmin	Fitbit	Samsung	Polar	Elite HRV	Welltory	HRV4Training
Biological Measurement	HR, PA, Falls, Respiration, Sleep and ECG	HR, PA, Respiration and Sleep	HR, PA, Respiration and Sleep	HR, PA, Respiration and Sleep	HR, PA, Respiration and Sleep	HR, Respiration, Sleep, PA, Diet, Lifestyle factor	HR, Respiration, Stress score, Recovery score	HR, Respiration, Training load, Training effect
HRV Tracking watch and watch series	Apple watch 3, 4, 5, 6, 7, 8 and SE	Fenix 6, Epix (Gen 2) Forerunner 245/245 music/245 S/245 S music, 945 LTE, 955/955 solar/955 plus, Instinct 2, Tactix 7, Venu 2	Sense, Versa 2,3, Charge 4,5, Inspire 2, Luxe	Galaxy 4 and 4 classic, Galaxy watch active 2, Galaxy watch 3, Fit, Fit 2	Polar Vantage V and V2, Grit X and X pro, M430, Ignite, Unite, polar 2	NA	NA	NA
Heart Rate variability Tracking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Graph of HRV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stress Tracking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stress Tracking watch	Apple watch 4, 5, 6, 7, 8	Fenix 6, Epix (Gen 2) Forerunner 245/245 music/245 S/245 S music, 945 LTE, 955/955 solar/955 plus,	Sense, Versa 2,3, Charge 4,5, Inspire 2, Luxe	Galaxy 4 and 4 classic, Galaxy watch active 2, Galaxy watch 3, Fit, Fit 2	Polar Vantage V and V2, Grit X and X pro, M430, Ignite, Unite, polar 2	NA	NA	NA

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1283.v1

		Instinct 2, Tactix 7, Venu 2, Venu 2 plus						
Stress Management features	Breathe app, Mindfulness app	Stress Score, Body battery, Relaxation timer, Stress Predictor	Stress Management Score, EDA Scan, Relax app	Stress level, Breathe app, Stress management app	Nightly Recharge, Serene app, Recovery pro features	Stress Score, Breathing exercises, , Meditation sessions, Sleep tracking, Recovery recommendations	Stress Score, Breathing exercises, , Meditation sessions, Sleep tracking, Recovery recommendations	Stress Score, Breathing exercises, Recovery recommendations
HRV Biofeedback	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Personalization of Real time HRV Biofeedback watch	Minimum	Medium (Garmin Forerunner 945, Garmin Venu 2, and Garmin Vivoactive 4)	Medium (Fitbit Sense and Fitbit Versa 3)	Minimum	Medium (Polar Vantage V2, Polar Grit X Pro, and Polar Ignite)	High	High	Medium
Time Domain (RMSSD, SDNN) and Frequency Domain (HF, LF, LF/HF ratio)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Abnormal HR Alerts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Respiratory Rate	During Sleep	During Sleep	During Sleep and	During Sleep and	During Sleep and	Needs Chest Strap	Can measure	Needs Chest Strap

and Depth			While awake	While awake	While awake			
Compatible with Third party Apps	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Accuracy	Good	Good	Good	Good	Good	Excellent	Better than smartwatch	Better than smartwatch
Battery Life	Up to18 hours	From 24 hours up to 14 days	Up to 7 days	From 40 hours up to 4 days	From 30 hours up to 7 days	Up to 24 hours	Up to 12 hours	Varies
User Friendliness	Good	Good	Good	Good	Good	Good	Good	Excellent
Price	Starting at $399	Starting at $299	Starting at $299	Starting at $249	Starting at $299	Starting from $0-30/mon	Starting from $13-79/mon	Starting at $9.99/mon
Additional Features	Activity tracking, sleep tracking, GPS, Music, notifications, Payments (Apple 2014, sep 9)	Activity tracking, multisport tracking, GPS, Music, notifications, Payments (Garmin 2023)	sleep tracking, stress tracking, GPS, Music, notifications, Payments (Fitbit 2023)	Activity tracking, health tracking, GPS, Music, notifications, Payments (Samsung 2023)	Activity tracking, GPS (Polar 2023)	Heart rate variability analysis [HRV coherence, HRV spectral analysis] (HRV 2023)	Stress management insights, heart rate variability analysis (HRV coherence, HRV spectral analysis) (Welltory 2023)	Heart rate variability analysis (HRV coherence, HRV spectral analysis) (HRV4Training 2023)

(HR=Heart Rate, PA= Physical activity, HRV=Heart Rate Variability, ECG= Electrocardiogram, GPS= Global Positioning system, NA= Not Applicable) .

As you can see, all of the smartwatches on this list offer HRV tracking and stress tracking. However, there are some differences in the features that they offer. For example, the Apple Watch has a Breathe app that can help someone to relax and reduce their stress levels. The Garmin watches have a Stress Score that can give an indication of someone's overall stress levels. The Fitbit watches have a variety of stress management tools, such as guided breathing exercises. The Samsung watches have a Calm app that can provide someone with guided meditations and other relaxation techniques. And the Polar watches have a serene breathing exercise that can help someone to slow down their breathing and increase HRV. Ultimately, the best smartwatch for HRV and stress management for consumer will depend on their individual needs and preferences. If someone is looking for a watch with a variety of stress management features, then the Fitbit or Samsung watches may be a good option for them. If anyone is looking for a watch with a long battery life, then the Garmin watches

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 July 2023 doi:10.20944/preprints202307.1283.v1

may be a good option for them. And if anyone is looking for a watch with a high degree of accuracy, then the Apple Watch or Polar watches may be a good option for them.

In terms of accuracy, all of the smartwatches on this list are considered to be good. However, it is important to note that the accuracy of HRV measurements can vary depending on a number of factors, such as the user's body position, the ambient light, and the fit of the watch.

Finally, the battery life of the smartwatches on this list varies. The Apple Watch has a battery life of up to 18 hours, the Garmin watches have a battery life of up to 14 days, the Fitbit watches have a battery life of up to 7 days, the Samsung watches have a battery life of up to 4 days, and the Polar watches have a battery life of up to 7 days.

In short, all the smartwatch and mobile app listed above offer a variety of features for HRV monitoring and biofeedback. The best device for you will depend on individual's needs and budget. If you are looking for a device with a wide range of features, the Apple Watch, Garmin Forerunner 245, or Fitbit Sense are good options. If you are looking for a more affordable option, the Samsung Galaxy Watch 4 or Polar Vantage M2 are good choices. If you are looking for a device that is specifically designed for heart rate and HRV monitoring, the EliteHRV, Welltory, or HRV4Training are good options.

Here is a summary of the pros and cons of each device:

Company	Pros	Cons
Watch		
Apple Watch	• Wide range of features • Compatible with a variety of third-party apps • Well-integrated with the Apple ecosystem	• Expensive • Battery life can be short.
Garmin	• Accurate HRV tracking. • Long battery life • Durable design	• Few third-party app integrations • Not as user-friendly as the Apple Watch
Fitbit	• Affordable • Well-integrated with the Fitbit app • Offers a variety of stress management tools.	• HRV tracking is not as accurate as some other devices. • Battery life is not as long as some other devices.
Samsung	• Compatible with the Samsung ecosystem • Offers a variety of stress management tools. • Long battery life	• HRV tracking is not as accurate as some other devices. • Not as user-friendly as the Apple Watch
Polar	• Accurate HRV tracking. • Long battery life • Durable design	• Few third-party app integrations • Not as user-friendly as the Apple Watch
Third Party App		
Elite HRV	• Excellent accuracy • Easy to use. • Affordable	• No personalized biofeedback

		• No third-party app integrations
Welltory	• Excellent accuracy • Biofeedback • Third-party app integrations • Affordable	• Requires a smartphone. • Not as user-friendly as some other devices
HRV4Training	• Excellent accuracy • Biofeedback • Third-party app integrations	• Requires a chest strap. • Not as user-friendly as some other devices

5. Discusssion

Present smartwatches in the market offer a range of health benefits, including activity tracking, heart rate monitoring, sleep tracking, stress management through HRV monitoring, blood oxygen level monitoring, ECG monitoring, fall detection and emergency alerts, GPS tracking, menstrual cycle tracking, and health data integration (Peake, Kerr, and Sullivan 2018). These features enable users to track their physical activity, monitor their heart health, analyze sleep patterns, manage stress levels, track respiratory health, detect abnormal heart rhythms, receive emergency assistance, track outdoor activities, monitor menstrual cycles, and consolidate health data for a holistic view of well-being (Lu et al. 2020). However, it's important to note that the specific features and capabilities may vary across different smartwatch models and brands.

Smartwatches offer several health benefits through HRV (heart rate variability) monitoring for stress management. By utilizing HRV data, smartwatches can provide valuable insights into an individual's stress levels and overall well-being. HRV, the variation in time intervals between heartbeats, is closely tied to the body's autonomic nervous system and can serve as an objective measure of stress (Chalmers et al. 2021)(Kim et al. 2018). Smartwatches equipped with HRV sensors can continuously monitor and analyze these fluctuations, offering users a comprehensive understanding of their stress response patterns. It is reported that HRV within-person reliability is more during sleep rather than wakefulness (Dudarev et al. 2023).

One of the primary health benefits of smartwatches through HRV for stress management is the ability to track and identify stress levels in real-time (Chalmers et al. 2021). By providing immediate feedback on HRV measurements, smartwatches can assist users in becoming more aware of their stress triggers and responses. This self-awareness can be a powerful tool for individuals seeking to manage their stress effectively. Additionally, smartwatches can offer stress management features such as guided breathing exercises or relaxation prompts based on HRV data (McLachlan and Truong 2023). These interventions can help users regulate their stress response and induce a state of relaxation and calmness.

Identifying discrepancies and gaps in the research for smartwatch comparisons for stress management reveals several important areas where the existing literature may be lacking. One prominent issue is the scarcity of extensive studies that directly compare the stress management capacities of different smartwatch models. Instead of conducting head-to-head comparisons, most studies tend to focus on specific features and the effectiveness of individual smartwatches. This limitation makes it challenging to determine which smartwatch models perform better in stress management scenarios (Zhang et al. 2022).

Another significant factor contributing to the discrepancies is the variation in HRV algorithms used by different smartwatch brands and models. Each brand may employ its own algorithm to compute HRV and interpret stress levels. Consequently, there can be inconsistencies in the reported stress levels or scores across different smartwatches. This variance in algorithms complicates the direct evaluation of the efficiency and accuracy of various smartwatches in stress management (Rodrigues et al. 2022).

The validity and reliability of HRV measurements and stress management functions also differ between smartwatch models. Some smartwatches may have undergone more rigorous scientific validation than others, resulting in variations in their accuracy and reliability in measuring and managing stress. This discrepancy further hinders the ability to compare and assess the performance of different smartwatches for stress management purposes (Stone et al. 2021)(Chalmers et al. 2021).

Most existing research on smartwatches for stress management focuses on short-term effects and user engagement, neglecting the investigation of long-term effects and sustained user involvement. It is crucial to conduct longitudinal studies to determine the long-term impact of smartwatches on stress reduction and to assess whether users continue to engage with the stress management capabilities of their smartwatches over an extended period. This longitudinal research would provide valuable insights into the effectiveness and user acceptance of smartwatches in managing stress over time (Ali et al. 2021).

Furthermore, many studies examining smartwatches for stress management have primarily targeted specific demographics, such as athletes or individuals with certain health concerns. While these studies may provide valuable insights for these particular populations, they may not offer a comprehensive understanding of how smartwatches perform across diverse user groups. Therefore, it is essential to expand research efforts to include a broader range of user demographics to gain a more representative view of the effectiveness and applicability of smartwatches for stress management (Shei et al. 2022).

Lastly, the lack of standardization in stress measurement and assessment techniques across different smartwatches poses a significant challenge. The absence of consistent protocols and metrics makes it difficult to compare and generalize research findings. To address this issue, collaborative efforts among researchers, smartwatch manufacturers, and healthcare practitioners are necessary. Such collaborations can contribute to the development of standardized guidelines and metrics for evaluating the stress management capabilities of smartwatches, ensuring a more consistent and reliable basis for comparison (Nelson et al. 2020).

Sum up, the research on smartwatch comparisons for stress management exhibits several discrepancies and gaps. These include limited comparable studies, HRV algorithm variations, issues with validation and reliability, insufficient investigation of long-term effects and user engagement, a narrow focus on specific demographics, and the lack of standardization in stress measurement and assessment techniques. To fill these gaps, it is imperative to conduct more extensive comparative studies, particularly those directly evaluating stress management capacities using standardized protocols. Longitudinal trials involving diverse user populations and collaborations among stakeholders can help address these discrepancies and contribute to the development of standardized guidelines for evaluating the stress management capabilities of smartwatches.

6. Limitations and Future Directions

It is important to consider the limitations of HRV data obtained from smartwatches. One limitation is the potential for inaccuracies in the measurements. Smartwatches may not provide the same level of accuracy as medical-grade devices due to factors like device placement, motion artifacts, and sensor limitations. Therefore, while smartwatches can offer valuable insights, they should not be considered as a substitute for professional medical advice or diagnostic tools (Alugubelli, Abuissa, and Roka 2022)(Hinde, White, and Armstrong 2021).

Another limitation is the individual variability in HRV. Factors such as age, fitness level, and underlying health conditions can influence HRV, abnormally high or low HRV in different pathophysiological conditions and smartwatches may not always account for these individual differences (Föhr et al. 2015)(Shaffer and Ginsberg 2017). Consequently, the stress assessments and recommendations provided by smartwatches may not always be tailored to an individual's specific circumstances.

Moreover, contextual interpretation is crucial when analyzing HRV data. Elevated HRV readings do not necessarily indicate high stress, as other factors like physical activity or excitement can influence HRV as well (Shaffer and Ginsberg 2017)(Kim et al. 2018). It's essential to consider the broader context of an individual's lifestyle and overall health when interpreting HRV data obtained from smartwatches.

Further, subjective perception plays a role in stress management. While HRV data can provide an objective measure of stress, it may not always align with an individual's subjective experience of stress. Each person may have their own unique ways of perceiving and responding to stress, which HRV data alone may not fully capture (Shei et al. 2022).

Lastly, smartwatches with HRV monitoring capabilities offer valuable health benefits for stress management. They provide real-time feedback, promote self-awareness, and offer stress management interventions. However, it's important to recognize the limitations of HRV data obtained from smartwatches, including potential inaccuracies, individual variability, the need for contextual interpretation, and the subjective nature of stress perception. Integrating smartwatch data with professional medical advice and personalized care can ensure a comprehensive and effective approach to stress management (Chalmers et al. 2021)(Hickey et al. 2021).

The future direction of smartwatch applications for stress management is poised to bring significant advancements and hold valuable clinical implications. As technology continues to evolve, we can anticipate more sophisticated features and capabilities that enhance the effectiveness of stress management apps on smartwatches (Maritch 2019). One area of focus is improving the accuracy of stress assessments by refining HRV measurements through advanced algorithms and sensor enhancements. By leveraging machine learning and artificial intelligence, smartwatches can analyze HRV data in real-time, allowing for more precise and personalized stress monitoring (Vos et al. 2023).

The integration of machine learning algorithms can enable smartwatches to learn individual patterns, recognize unique stress response profiles, and provide tailored recommendations for stress management. These recommendations could include guided breathing exercises, mindfulness techniques, or adaptive relaxation prompts based on the user's specific needs and preferences. Additionally, smartwatches could employ biofeedback mechanisms that provide real-time feedback on HRV and stress levels, helping users develop effective self-regulation techniques (Vos et al. 2023)(Tonacci et al. 2020).

The clinical implications of these advancements are significant. Smartwatches equipped with robust stress management apps can empower individuals to proactively monitor and manage their stress levels. By gaining a deeper understanding of their stress responses and receiving personalized interventions, users may be able to mitigate the negative impact of chronic stress on their physical and mental health. This proactive approach to stress management could potentially reduce the risk of stress-related conditions such as cardiovascular disease, anxiety disorders, and burnout. Also, it should include more integration with their physician electronic records to have better individual interpretation and changes to the lifestyle and in persistent chronic anxiety cases directed cognitive and medical treatment (Bayoumy et al. 2021; Greiwe and Nyenhuis 2020; Liao et al. 2019).

Next, the integration of smartwatch data into clinical settings holds promise for healthcare professionals. With consent and appropriate privacy measures, clinicians could access patients' stress data from their smartwatches to gain valuable insights into their stress levels and response patterns. This data can inform clinical assessments, treatment plans, and the evaluation of treatment efficacy. By incorporating smartwatch data into the clinical workflow, healthcare providers can offer more personalized and evidence-based stress management interventions (Sabry et al. 2022).

In summary, the future of smartwatch applications for stress management looks promising. With advancements in technology, machine learning algorithms, and data analytics, smartwatches have the potential to become powerful tools for individuals to monitor and manage their stress levels effectively. Moreover, the clinical implications are significant, offering healthcare professionals valuable insights and tools to enhance patient care and improve stress management strategies (Sabry et al. 2022; Chakrabarti et al. 2022).

7. Conclusions

Smartwatches equipped with HRV monitoring capabilities play a valuable role in various activities and stress management. These devices offer a range of features, including activity tracking, heart rate monitoring, sleep tracking, and stress management interventions based on HRV data. Its HRV data has provided a very useful information of personal health regarding level of stress, self-management of stress factors and understanding of sleep and personal health. By providing real-time feedback, promoting self-awareness, and offering personalized stress management techniques, smartwatches empower individuals to monitor and manage their stress levels effectively. However, it is important to acknowledge the limitations of HRV data obtained from smartwatches, such as accuracy, individual variability, contextual interpretation, and the subjective nature of stress perception. Integrating smartwatch HRV data with professional medical advice and personalized care can ensure a comprehensive and effective approach to stress management. Overall, smartwatch HRV monitoring has the potential to enhance well-being by assisting individuals in achieving a healthier balance in their activities and stress levels.

Author Contributions: RJ developed the theory and wrote abstract. MS wrote the main manuscript and SA helped in writing part of discussion and conclusion. All authors did the literature review and contributed to the article and approved the submitted version.

Acknoledgements: All funding provided by Charitable Medical Healthcare Foundation and Mind Body Technology.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Available Statement: Not applicable.

Conflicets of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Ali, S. M., D. A. Selby, K. Khalid, K. Dempsey, E. Mackey, N. Small, S. N. van der Veer, B. McMillan, P. Bower, B. Brown, J. McBeth, and W. G. Dixon. 2021. 'Engagement with consumer smartwatches for tracking symptoms of individuals living with multiple long-term conditions (multimorbidity): A longitudinal observational study', *J Multimorb Comorb*, 11: 26335565211062791.

Alugubelli, N., H. Abuissa, and A. Roka. 2022. 'Wearable Devices for Remote Monitoring of Heart Rate and Heart Rate Variability-What We Know and What Is Coming', *Sensors (Basel)*, 22.

Apple. 2014, sep 9. 'Watch - Apple', Accessed June 7. https://www.apple.com/watch/.

Aritzeta, A., A. Aranberri-Ruiz, G. Soroa, R. Mindeguia, and A. Olarza. 2022. 'Emotional Self-Regulation in Primary Education: A Heart Rate-Variability Biofeedback Intervention Programme', *Int J Environ Res Public Health*, 19.

Bayoumy, K., M. Gaber, A. Elshafeey, O. Mhaimeed, E. H. Dineen, F. A. Marvel, S. S. Martin, E. D. Muse, M. P. Turakhia, K. G. Tarakji, and M. B. Elshazly. 2021. 'Smart wearable devices in cardiovascular care: where we are and how to move forward', *Nat Rev Cardiol*, 18: 581-99.

Bégin, C., J. Berthod, L. Z. Martinez, and M. Truchon. 2022. 'Use of Mobile Apps and Online Programs of Mindfulness and Self-Compassion Training in Workers: A Scoping Review', *J Technol Behav Sci*, 7: 477-515.

Can, Y. S., H. Iles-Smith, N. Chalabianloo, D. Ekiz, J. Fernández-Álvarez, C. Repetto, G. Riva, and C. Ersoy. 2020. 'How to Relax in Stressful Situations: A Smart Stress Reduction System', *Healthcare (Basel)*, 8.

Carter, D. D., K. Robinson, J. Forbes, and S. Hayes. 2018. 'Experiences of mobile health in promoting physical activity: A qualitative systematic review and meta-ethnography', *PLoS One*, 13: e0208759.

Castaneda, D., A. Esparza, M. Ghamari, C. Soltanpur, and H. Nazeran. 2018. 'A review on wearable photoplethysmography sensors and their potential future applications in health care', *Int J Biosens Bioelectron*, 4: 195-202.

Castro Ribeiro, T., P. Sobregrau Sangrà, E. García Pagès, L. Badiella, B. López-Barbeito, S. Aguiló, and J. Aguiló. 2023. 'Assessing effectiveness of heart rate variability biofeedback to mitigate mental health symptoms: a pilot study', *Front Physiol*, 14: 1147260.

Chakrabarti, S., N. Biswas, L. D. Jones, S. Kesari, and S. Ashili. 2022. 'Smart Consumer Wearables as Digital Diagnostic Tools: A Review', *Diagnostics (Basel)*, 12.

Chalmers, T., B. A. Hickey, P. Newton, C. T. Lin, D. Sibbritt, C. S. McLachlan, R. Clifton-Bligh, J. Morley, and S. Lal. 2021. 'Stress Watch: The Use of Heart Rate and Heart Rate Variability to Detect Stress: A Pilot Study Using Smart Watch Wearables', *Sensors (Basel)*, 22.

Chu, B., K. Marwaha, T. Sanvictores, and D. Ayers. 2023. 'Physiology, Stress Reaction.' in, *statpearls* (StatPearls Publishing

Copyright © 2023, StatPearls Publishing LLC.: Treasure Island (FL)).

Chung, A. H., R. N. Gevirtz, R. S. Gharbo, M. A. Thiam, and J. P. J. Ginsberg. 2021. 'Pilot Study on Reducing Symptoms of Anxiety with a Heart Rate Variability Biofeedback Wearable and Remote Stress Management Coach', *Appl Psychophysiol Biofeedback*, 46: 347-58.

Dalmeida, K. M., and G. L. Masala. 2021. 'HRV Features as Viable Physiological Markers for Stress Detection Using Wearable Devices', *Sensors (Basel)*, 21.

de Zambotti, M., N. Cellini, A. Goldstone, I. M. Colrain, and F. C. Baker. 2019. 'Wearable Sleep Technology in Clinical and Research Settings', *Med Sci Sports Exerc*, 51: 1538-57.

Dudarev, Veronica, Oswald Barral, Chuxuan Zhang, Guy Davis, and James T. Enns. 2023. 'On the Reliability of Wearable Technology: A Tutorial on Measuring Heart Rate and Heart Rate Variability in the Wild', *Sensors*, 23: 5863.

Fitbit. 2023. 'Smartwatches | Shop Fitbit'.

Föhr, T., A. Tolvanen, T. Myllymäki, E. Järvelä-Reijonen, S. Rantala, R. Korpela, K. Peuhkuri, M. Kolehmainen, S. Puttonen, R. Lappalainen, H. Rusko, and U. M. Kujala. 2015. 'Subjective stress, objective heart rate variability-based stress, and recovery on workdays among overweight and psychologically distressed individuals: a cross-sectional study', *J Occup Med Toxicol*, 10: 39.

Garmin. 2023. 'Sport watches | Smartwatches'. https://www.garmin.com/en-US/c/wearable-smartwatches/.

Greiwe, J., and S. M. Nyenhuis. 2020. 'Wearable Technology and How This Can Be Implemented into Clinical Practice', *Curr Allergy Asthma Rep*, 20: 36.

Gupta, S., A. Mahmoud, and M. R. Massoomi. 2022. 'A Clinician's Guide to Smartwatch "Interrogation"', *Curr Cardiol Rep*, 24: 995-1009.

Hao, T., K. N. Walter, M. J. Ball, H. Y. Chang, S. Sun, and X. Zhu. 2017. 'StressHacker: Towards Practical Stress Monitoring in the Wild with Smartwatches', *AMIA Annu Symp Proc*, 2017: 830-38.

Henriksen, A., M. Haugen Mikalsen, A. Z. Woldaregay, M. Muzny, G. Hartvigsen, L. A. Hopstock, and S. Grimsgaard. 2018. 'Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables', *J Med Internet Res*, 20: e110.

Hickey, B. A., T. Chalmers, P. Newton, C. T. Lin, D. Sibbritt, C. S. McLachlan, R. Clifton-Bligh, J. Morley, and S. Lal. 2021. 'Smart Devices and Wearable Technologies to Detect and Monitor Mental Health Conditions and Stress: A Systematic Review', *Sensors (Basel)*, 21.

Hinde, K., G. White, and N. Armstrong. 2021. 'Wearable Devices Suitable for Monitoring Twenty Four Hour Heart Rate Variability in Military Populations', *Sensors (Basel)*, 21.

Hrabovska, Nikola, Erik Kajati, and Iveta Zolotova. 2023. 'A Validation Study to Confirm the Accuracy of Wearable Devices Based on Health Data Analysis', *Electronics*, 12: 2536.

HRV4Training. 2023. 'HRV4Training'.

HRV, Elite. 2023. 'Elite HRV: Best Heart Rate Variability Monitor & App'. https://elitehrv.com.

Huang, W. Y., H. Huang, and C. E. Wu. 2022. 'Physical Activity and Social Support to Promote a Health-Promoting Lifestyle in Older Adults: An Intervention Study', *Int J Environ Res Public Health*, 19.

Huhn, S., M. Axt, H. C. Gunga, M. A. Maggioni, S. Munga, D. Obor, A. Sié, V. Boudo, A. Bunker, R. Sauerborn, T. Bärnighausen, and S. Barteit. 2022. 'The Impact of Wearable Technologies in Health Research: Scoping Review', *JMIR Mhealth Uhealth*, 10: e34384.

Jarrin, D. C., J. J. McGrath, S. Giovanniello, P. Poirier, and M. Lambert. 2012. 'Measurement fidelity of heart rate variability signal processing: the devil is in the details', *Int J Psychophysiol*, 86: 88-97.

Johnson, E. O., T. C. Kamilaris, G. P. Chrousos, and P. W. Gold. 1992. 'Mechanisms of stress: a dynamic overview of hormonal and behavioral homeostasis', *Neurosci Biobehav Rev*, 16: 115-30.

Kim, H. G., E. J. Cheon, D. S. Bai, Y. H. Lee, and B. H. Koo. 2018. 'Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature', *Psychiatry Investig*, 15: 235-45.

Laricchia, F. 2023, June 2. 'Global smartwatch market share 2020-2022, by vendor'.

Lehrer, Christiane, U. Yeliz Eseryel, Annamina Rieder, and Reinhard Jung. 2021. 'Behavior change through wearables: the interplay between self-leadership and IT-based leadership', *Electronic Markets*, 31: 747-64.

Lehrer, P. M., and R. Gevirtz. 2014. 'Heart rate variability biofeedback: how and why does it work?', *Front Psychol*, 5: 756.

Liao, Y., C. Thompson, S. Peterson, J. Mandrola, and M. S. Beg. 2019. 'The Future of Wearable Technologies and Remote Monitoring in Health Care', *Am Soc Clin Oncol Educ Book*, 39: 115-21.

 doi:10.20944/preprints202307.1283.v1

Lischke, A., R. Jacksteit, A. Mau-Moeller, R. Pahnke, A. O. Hamm, and M. Weippert. 2018. 'Heart rate variability is associated with psychosocial stress in distinct social domains', *J Psychosom Res*, 106: 56-61.

Lu, L., J. Zhang, Y. Xie, F. Gao, S. Xu, X. Wu, and Z. Ye. 2020. 'Wearable Health Devices in Health Care: Narrative Systematic Review', *JMIR Mhealth Uhealth*, 8: e18907.

Luberto, C. M., D. L. Hall, E. R. Park, A. Haramati, and S. Cotton. 2020. 'A Perspective on the Similarities and Differences Between Mindfulness and Relaxation', *Glob Adv Health Med*, 9: 2164956120905597.

Lui, G. Y., D. Loughnane, C. Polley, T. Jayarathna, and P. P. Breen. 2022. 'The Apple Watch for Monitoring Mental Health-Related Physiological Symptoms: Literature Review', *JMIR Ment Health*, 9: e37354.

Maritch, M.; Berube, C.; Kraus, M.; Lehmann, V.; Zueger, T.; . 2019. 'Improving Heart Rate Variability Measurements from consumer smartwatches with machine learning'.

McCraty, R., and F. Shaffer. 2015. 'Heart Rate Variability: New Perspectives on Physiological Mechanisms, Assessment of Self-regulatory Capacity, and Health risk', *Glob Adv Health Med*, 4: 46-61.

McLachlan, Craig S., and Hang Truong. 2023. 'A Narrative Review of Commercial Platforms Offering Tracking of Heart Rate Variability in Corporate Employees to Detect and Manage Stress', *Journal of Cardiovascular Development and Disease*, 10: 141.

Meza, Claudia, Jesus Juega, Jaume Francisco, Alba Santos, Laura Duran, Maite Rodriguez, Jose Alvarez-Sabin, Laia Sero, Xavier Ustrell, Saima Bashir, Joaquín Serena, Yolanda Silva, Carlos Molina, and Jorge Pagola. 2023. 'Accuracy of a Smartwatch to Assess Heart Rate Monitoring and Atrial Fibrillation in Stroke Patients', *Sensors*, 23: 4632.

Myllymäki, T., H. Rusko, H. Syväoja, T. Juuti, M. L. Kinnunen, and H. Kyröläinen. 2012. 'Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality', *Eur J Appl Physiol*, 112: 801-9.

Nelson, B. W., C. A. Low, N. Jacobson, P. Areán, J. Torous, and N. B. Allen. 2020. 'Guidelines for wrist-worn consumer wearable assessment of heart rate in biobehavioral research', *NPJ Digit Med*, 3: 90.

Peake, J. M., G. Kerr, and J. P. Sullivan. 2018. 'A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep in Physically Active Populations', *Front Physiol*, 9: 743.

Pham, T., Z. J. Lau, S. H. A. Chen, and D. Makowski. 2021. 'Heart Rate Variability in Psychology: A Review of HRV Indices and an Analysis Tutorial', *Sensors (Basel)*, 21.

Polak, A. G., B. Klich, S. Saganowski, M. A. Prucnal, and P. Kazienko. 2022. 'Processing Photoplethysmograms Recorded by Smartwatches to Improve the Quality of Derived Pulse Rate Variability', *Sensors (Basel)*, 22.

Polar. 2023. 'Sports Watches | Fitness Trackers'. https://www.polar.com/us-en/all-watches.

Rawassizadeh, Reza, Blaine A. Price, and Marian Petre. 2015. 'Wearables: has the age of smartwatches finally arrived?', *Commun. ACM*, 58: 45-47.

Robinson, L.; Segal, J. 2023, March 1. 'Relaxation Techniques for Stress Relief'. https://www.helpguide.org/articles/stress/relaxation-techniques-for-stress-relief.htm.

Rodrigues, E., D. Lima, P. Barbosa, K. Gonzaga, R. O. Guerra, M. Pimentel, H. Barbosa, and Á Maciel. 2022. 'HRV Monitoring Using Commercial Wearable Devices as a Health Indicator for Older Persons during the Pandemic', *Sensors (Basel)*, 22.

Russo, M. A., D. M. Santarelli, and D. O'Rourke. 2017. 'The physiological effects of slow breathing in the healthy human', *Breathe (Sheff)*, 13: 298-309.

Sabry, F., T. Eltaras, W. Labda, K. Alzoubi, and Q. Malluhi. 2022. 'Machine Learning for Healthcare Wearable Devices: The Big Picture', *J Healthc Eng*, 2022: 4653923.

Samsung. 2023. 'Smartwatches & Fitness Trackers | Wearable | Samsung US'.

Scheid, J. L., and S. L. West. 2019. 'Opportunities of Wearable Technology to Increase Physical Activity in Individuals with Chronic Disease: An Editorial', *Int J Environ Res Public Health*, 16.

Shaffer, F., and J. P. Ginsberg. 2017. 'An Overview of Heart Rate Variability Metrics and Norms', *Front Public Health*, 5: 258.

Shei, R. J., I. G. Holder, A. S. Oumsang, B. A. Paris, and H. L. Paris. 2022. 'Wearable activity trackers-advanced technology or advanced marketing?', *Eur J Appl Physiol*, 122: 1975-90.

Singh, N., K. J. Moneghetti, J. W. Christle, D. Hadley, D. Plews, and V. Froelicher. 2018. 'Heart Rate Variability: An Old Metric with New Meaning in the Era of using mHealth Technologies for Health and Exercise Training Guidance. Part One: Physiology and Methods', *Arrhythm Electrophysiol Rev*, 7: 193-98.

Stone, J. D., H. K. Ulman, K. Tran, A. G. Thompson, M. D. Halter, J. H. Ramadan, M. Stephenson, V. S. Finomore, Jr., S. M. Galster, A. R. Rezai, and J. A. Hagen. 2021. 'Assessing the Accuracy of Popular Commercial Technologies That Measure Resting Heart Rate and Heart Rate Variability', *Front Sports Act Living*, 3: 585870.

Tiwari, R., R. Kumar, S. Malik, T. Raj, and P. Kumar. 2021. 'Analysis of Heart Rate Variability and Implication of Different Factors on Heart Rate Variability', *Curr Cardiol Rev*, 17: e160721189770.

 doi:10.20944/preprints202307.1283.v1

Tonacci, Alessandro, Alessandro Dellabate, Andrea Dieni, Lorenzo Bachi, Francesco Sansone, Raffaele Conte, and Lucia Billeci. 2020. 'Can Machine Learning Predict Stress Reduction Based on Wearable Sensors' Data Following Relaxation at Workplace? A Pilot Study', *Processes*, 8: 448.

Tseng, T. H., H. C. Chen, L. Y. Wang, and M. Y. Chien. 2020. 'Effects of exercise training on sleep quality and heart rate variability in middle-aged and older adults with poor sleep quality: a randomized controlled trial', *J Clin Sleep Med*, 16: 1483-92.

van der Zwan, J. E., W. de Vente, A. C. Huizink, S. M. Bögels, and E. I. de Bruin. 2015. 'Physical activity, mindfulness meditation, or heart rate variability biofeedback for stress reduction: a randomized controlled trial', *Appl Psychophysiol Biofeedback*, 40: 257-68.

Vos, G., K. Trinh, Z. Sarnyai, and M. Rahimi Azghadi. 2023. 'Generalizable machine learning for stress monitoring from wearable devices: A systematic literature review', *Int J Med Inform*, 173: 105026.

Waxenbaum, J. A., V. Reddy, and M. Varacallo. 2023. 'Anatomy, Autonomic Nervous System.' in, *statpearls* (StatPearls Publishing Copyright © 2023, StatPearls Publishing LLC.: Treasure Island (FL)).

Welltory. 2023. 'Welltory - Heart Rate Variability App & HRV Monitor'.

Zhang, S., Y. Li, S. Zhang, F. Shahabi, S. Xia, Y. Deng, and N. Alshurafa. 2022. 'Deep Learning in Human Activity Recognition with Wearable Sensors: A Review on Advances', *Sensors (Basel)*, 22.