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HEART RATE ZONE-BASED TRAINING IN THE ERA OF WEARABLE TECHNOLOGIES: CARDIOVASCULAR ADAPTATIONS AND DIGITAL HEALTH IMPLICATIONS

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ABSTRACT

Purpose of research: Heart rate zone-based training is increasingly delivered through wearable technologies, mobile applications and digital health platforms. These tools make cardiovascular monitoring accessible to athletes and physically active individuals, but their interpretation requires physiological and technological understanding. The aim of this review was to evaluate cardiovascular adaptations associated with training across different heart rate zones and to discuss the role of wearable technologies in digital exercise monitoring.
Research materials and methods: A narrative review was conducted using peer-reviewed studies, systematic reviews, meta-analyses, randomized trials and scientific statements concerning heart rate zones, wearable devices, exercise intensity, VO_2max, lactate threshold, heart rate variability and endurance training.
Basic results: Low-intensity zones mainly improve aerobic efficiency, endothelial function and parasympathetic modulation. Moderate-intensity zones support sustainable cardiac output and lactate clearance. High-intensity zones stimulate VO_2max and maximal cardiac output, but excessive exposure may increase autonomic stress. Wearables improve access to real-time monitoring, although device accuracy and data interpretation remain important limitations.
Conclusions: Heart rate zone-based training is most useful when wearable-derived data are interpreted alongside physiological thresholds, perceived exertion and recovery markers.

KEYWORDS

Heart Rate Zones; Wearable Technologies; Digital Health; Cardiovascular Adaptations; Heart Rate Variability; Exercise Monitoring

CITATION

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1. Introduction

The digitalization of sport and health monitoring has changed the way exercise intensity is prescribed, controlled and interpreted. Wearable technologies, including sport watches, chest straps, optical heart rate sensors and smartphone-connected training platforms, allow users to collect real-time physiological data outside laboratory settings. This development has made heart rate zone-based training not only a sports medicine tool, but also a digital health strategy used by recreational athletes, coaches, patients and physically active populations. However, the growing availability of data does not automatically guarantee appropriate interpretation. Heart rate metrics require physiological context, awareness of device limitations and integration with subjective and performance-based markers.

Exercise training is one of the most effective non-pharmacological interventions for improving cardiovascular health, cardiorespiratory fitness and athletic performance. Regular endurance exercise induces central and peripheral adaptations that improve oxygen delivery, oxygen utilization and tolerance to increasing metabolic demands. These adaptations include changes in stroke volume, cardiac output, endothelial function, blood volume, autonomic regulation, skeletal muscle capillarization and mitochondrial oxidative capacity (Bassett and Howley 2000; Hellsten and Nyberg 2015). In sports medicine, the practical challenge is not whether exercise is beneficial, but how its intensity, volume and frequency should be distributed to maximize adaptation while minimizing excessive fatigue and maladaptation.

Heart rate monitoring has become one of the most commonly used tools for exercise intensity prescription, largely because wearable devices have transformed laboratory-derived concepts into everyday digital feedback. It is inexpensive, non-invasive and available through chest straps, sport watches and wearable technologies. Athletes and physically active individuals often structure training according to heart rate zones expressed as percentages of maximal heart rate, heart rate reserve, lactate threshold heart rate or ventilatory thresholds (Buchheit 2014; Mezzani et al. 2013). Despite its popularity, interpretation of heart rate zones remains complex because heart rate is influenced by hydration, sleep, heat, altitude, accumulated fatigue, medication, emotional stress and cardiac drift during prolonged exercise.

The physiological rationale for heart rate zone-based training is based on the relationship between exercise intensity and cardiovascular demand. At low intensities, energy production is predominantly aerobic and lactate remains relatively low. As intensity increases, sympathetic activation rises, heart rate accelerates, cardiac output increases and lactate production progressively exceeds clearance. Around the first and second ventilatory or lactate thresholds, the metabolic and autonomic characteristics of exercise change substantially. Therefore, zones based on individual thresholds may provide more precise information than zones based only on fixed percentages of maximal heart rate (Mezzani et al. 2013; Pelliccia et al. 2021).

Different training zones are expected to produce different adaptations. Low-intensity training is commonly used to develop aerobic base, enhance recovery and increase total training volume with relatively low autonomic stress. Moderate-intensity training improves sustainable aerobic power and may be particularly useful for recreational athletes. High-intensity interval training and near-maximal efforts are powerful stimuli for improving VO_2max, cardiac output and performance, but they require careful programming because they produce greater sympathetic and metabolic load (Rosenblat et al. 2020; Rosenblat et al. 2022; Ma et al. 2023).

From a clinical and digital health perspective, accurate intensity prescription is relevant not only for athletes but also for patients in cardiovascular prevention and rehabilitation. Wearable technologies may support long-term engagement, self-monitoring and remote exercise guidance, but they may also create risks when users overinterpret unvalidated metrics or ignore symptoms because device data appear normal. Scientific recommendations emphasize that exercise intensity should ideally be individualized on the basis of functional evaluation, especially cardiopulmonary exercise testing when available (Mezzani et al. 2013; Pelliccia et al. 2021; Terada et al. 2025). This approach supports a transition from broad percentage-based prescription toward threshold-based and patient-specific exercise programming.

The aim of this review is to evaluate the cardiovascular adaptations associated with training across different heart rate zones and to discuss their practical significance in sports medicine, wearable technology-supported exercise monitoring, digital health and cardiovascular health.

2. Methodology

This article was designed as a narrative review with an evidence-based search strategy. The literature search was conducted using PubMed, Google Scholar and scientific guidelines from cardiovascular, sports medicine and digital health-related research. The following keywords and combinations were used: heart rate zones, wearable technologies, digital health, exercise intensity, cardiovascular adaptation, VO_2max, high-intensity interval training, moderate-intensity continuous training, lactate threshold, ventilatory threshold, training intensity distribution, heart rate variability, overtraining, endurance training, sports cardiology and exercise monitoring.

The inclusion criteria were: articles published in English, human studies, systematic reviews, meta-analyses, randomized controlled trials, observational studies in athletes or physically active adults, validation studies concerning wearable heart rate monitoring, and position statements relevant to exercise intensity prescription, cardiovascular adaptation and digital exercise monitoring. Priority was given to studies representing higher levels of evidence, particularly meta-analyses and controlled trials. Older landmark studies were included only when they provided foundational physiological concepts, such as VO_2max limitation, cardiovascular adaptation or training intensity distribution.

The exclusion criteria were: animal studies, articles unrelated to cardiovascular or exercise physiology outcomes, studies focused exclusively on pharmacological interventions and non-scientific sources. The synthesis was qualitative and organized according to the physiological effects of low-, moderate- and high-intensity heart rate zones. Because this was a narrative review rather than a systematic review, no formal risk-of-bias scoring or meta-analytic pooling was performed.

3. Results

3.1. Physiological basis of heart rate zones

Heart rate reflects the integrated response of the cardiovascular and autonomic nervous systems to exercise. During the transition from rest to exercise, heart rate initially rises due to parasympathetic withdrawal. With increasing workload, sympathetic activation becomes progressively more important, increasing chronotropy, myocardial contractility and peripheral vascular redistribution. These responses support increased cardiac output and oxygen delivery to working skeletal muscle (Bassett and Howley 2000; Hellsten and Nyberg 2015).

Most practical heart rate zone models divide intensity into three or five zones. A three-zone model is often based on physiological thresholds: zone 1 below the first lactate or ventilatory threshold, zone 2 between the first and second threshold, and zone 3 above the second threshold. Five-zone models are frequently used in commercial devices and coaching practice, but their boundaries may vary substantially between systems. This variability is important because the same percentage of maximal heart rate may represent different metabolic stress in different individuals (Buchheit 2014; Pelliccia et al. 2021).

A threshold-based model is generally more physiologically meaningful than a fixed percentage model. The first threshold marks the transition from low-intensity aerobic work to a domain where lactate and ventilation begin to rise more clearly. The second threshold reflects the highest intensity at which lactate production and clearance can remain approximately balanced for a limited period. Above this level, fatigue develops more rapidly due to metabolic acidosis, phosphocreatine depletion, neuromuscular stress and high sympathetic drive (Mezzani et al. 2013; Pelliccia et al. 2021).

VO_2max is a central indicator of cardiorespiratory fitness. It depends on maximal cardiac output and the ability of peripheral tissues to extract oxygen. The Fick principle explains that oxygen uptake is determined by cardiac output multiplied by the arteriovenous oxygen difference. Training in different zones may influence both components, although high-intensity training appears particularly effective for improving VO_2max when training volume is controlled (Bassett and Howley 2000; Rosenblat et al. 2022; Ma et al. 2023).

Heart rate variability is another relevant marker. HRV reflects fluctuations between consecutive heartbeats and is commonly used as a non-invasive indicator of autonomic regulation. In athletes, changes in resting HRV may help identify adaptation, accumulated fatigue or non-functional overreaching. However, HRV should not be interpreted in isolation, because it is affected by sleep, stress, illness, alcohol intake and measurement methodology (Manresa-Rocamora et al. 2021; Düking et al. 2021; Addleman et al. 2024).

3.2. Cardiovascular adaptations across different heart rate zones

3.2.1. Low-intensity heart rate zones

Low-intensity training usually corresponds to exercise below the first lactate or ventilatory threshold. In five-zone models, this is often described as zones 1–2. It is characterized by stable oxygen uptake, low lactate accumulation, relatively low sympathetic activation and a high contribution of fat oxidation. Because physiological strain is modest, athletes can accumulate substantial training volume in this domain without excessive disruption of recovery.

The cardiovascular adaptations to low-intensity training are mainly related to improved aerobic efficiency and peripheral oxygen utilization. Repeated low-intensity endurance exercise supports mitochondrial biogenesis, oxidative enzyme activity, skeletal muscle capillarization and endothelial function (Hellsten and Nyberg 2015). These adaptations improve the ability to generate adenosine triphosphate through aerobic metabolism and delay the reliance on anaerobic glycolysis at submaximal workloads.

From a central cardiovascular perspective, low-intensity endurance training contributes to increased plasma volume, improved venous return and enhanced stroke volume. Over time, trained individuals often demonstrate lower submaximal heart rate at the same absolute workload, reflecting improved cardiovascular efficiency. Increased parasympathetic tone and reduced resting heart rate are also frequently observed in endurance-trained athletes (Manresa-Rocamora et al. 2021; Esco et al. 2026).

Low-intensity zones are particularly important in polarized and pyramidal training models. Observational and conceptual data from endurance athletes indicate that a large proportion of total training time is often performed at low intensity, with smaller proportions allocated to moderate and high intensities (Seiler 2010; Oliveira et al. 2024). This does not mean that low-intensity training is always superior, but it suggests that high training volume can be sustained only when most sessions are kept below threshold.

Clinically, low-intensity training has a favorable safety profile and may be useful in cardiovascular prevention, return-to-exercise programs and early rehabilitation phases. However, for well-trained athletes, low-intensity training alone may be insufficient to maximize VO_2max or race performance. Its main role is to build the aerobic foundation that supports tolerance to higher-intensity work and reduces the relative cardiovascular cost of submaximal exercise.

3.2.2. Moderate-intensity heart rate zones

Moderate-intensity training is generally performed around or between the first and second physiological thresholds. It may correspond to tempo training, steady-state endurance sessions or prolonged work at a controlled but demanding intensity. In recreational athletes, this type of training often improves fitness because it provides a meaningful cardiovascular stimulus while remaining tolerable and repeatable.

The cardiovascular effects of moderate-intensity training include improved submaximal cardiac output, enhanced lactate clearance, increased exercise economy and better ability to sustain prolonged efforts. Compared with low-intensity exercise, moderate intensity produces greater sympathetic activation and higher myocardial oxygen demand. Compared with high-intensity intervals, however, it is usually less disruptive and easier to repeat frequently (Rosenblat et al. 2022; Ma et al. 2023).

A practical limitation is that excessive time in the moderate zone may create a threshold-heavy training distribution. This can increase cumulative fatigue while providing a smaller VO_2max stimulus than high-intensity training and less recoverability than low-intensity training. For this reason, some endurance training models avoid excessive accumulation of moderate-intensity work, especially in highly trained athletes preparing for competition (Seiler 2010; Oliveira et al. 2024).

Nevertheless, moderate-intensity continuous training remains clinically important. In public health and cardiovascular prevention, moderate-intensity aerobic exercise is strongly recommended and is associated with improved cardiorespiratory fitness and reduced cardiovascular risk. For many adults, moderate-intensity training may be more acceptable, sustainable and safer than frequent high-intensity training, especially in individuals with low baseline fitness or cardiovascular risk factors (Pelliccia et al. 2021; Terada et al. 2025).

3.2.3. High-intensity heart rate zones

High-intensity training includes exercise close to or above the second lactate or ventilatory threshold. In practice, this includes interval training, threshold intervals, repeated high-intensity bouts and near-maximal efforts. These sessions are associated with high sympathetic activation, elevated lactate production, increased ventilation and substantial cardiovascular demand.

High-intensity interval training has consistently been shown to improve VO_2max in healthy adults, athletes and some clinical populations (Rosenblat et al. 2020; Rosenblat et al. 2022; Ma et al. 2023). The mechanisms include increased maximal cardiac output, improved stroke volume, enhanced peripheral oxygen extraction and improved mitochondrial function. When exercise volume is controlled, higher intensity often produces greater improvements in VO_2max than lower intensity, although individual responses vary (Rosenblat et al. 2022; Ma et al. 2023).

The cardiac stimulus of high-intensity training is strong because the heart operates near maximal output during repeated intervals. This may promote central adaptations such as increased stroke volume and improved ventricular filling. In athletes, long-term endurance training can lead to physiological cardiac remodeling, often referred to as athlete's heart. This remodeling is usually benign, but distinguishing physiological adaptation from pathology requires clinical expertise when symptoms, abnormal electrocardiographic findings or family history are present (Pelliccia et al. 2021).

High-intensity training also improves lactate tolerance and the ability to maintain performance at high percentages of VO_2max. These adaptations are highly relevant in endurance sports, team sports and combat sports, where repeated high-intensity efforts often determine performance. However, more intensity is not always better. Excessive high-intensity exposure may contribute to non-functional overreaching, autonomic imbalance, sleep disruption, persistent fatigue and increased injury risk (Manresa-Rocamora et al. 2021; Addleman et al. 2024; Esco et al. 2026).

For this reason, high-intensity heart rate zones should be used strategically. They are most effective when combined with adequate recovery and supported by a sufficient aerobic base. Monitoring tools such as session rating of perceived exertion, resting heart rate, HRV, sleep quality and subjective fatigue may help prevent inappropriate training load accumulation (Buchheit 2014; Düking et al. 2021; Addleman et al. 2024).

3.3. Heart rate variability and recovery monitoring

HRV has become increasingly popular in sports medicine because it provides insight into autonomic regulation. Higher resting vagally mediated HRV is often interpreted as a marker of recovery and parasympathetic predominance, whereas suppressed HRV may indicate fatigue, stress or illness. Systematic reviews suggest that autonomic heart rate indices, including HRV and heart rate recovery, can provide useful information about training status, although results depend on methodology and context (Düking et al. 2021; Addleman et al. 2024; Esco et al. 2026).

HRV-guided training may be particularly useful when combined with heart rate zones. For example, an athlete with reduced HRV and elevated resting heart rate may benefit from replacing a high-intensity session with low-intensity training or rest. Conversely, stable or improved HRV may support progression of training load. This approach aligns with individualized exercise prescription and may reduce the risk of excessive sympathetic stress (Manresa-Rocamora et al. 2021; Düking et al. 2021).

However, HRV is not a diagnostic tool by itself. Measurement conditions should be standardized, preferably in the morning, using the same device and body position. Recent evidence emphasizes the value of repeated measurements and trend analysis rather than isolated single-day values when monitoring training adaptation and recovery status (Esco et al. 2026). Interpretation should account for training phase, psychological stress, illness, sleep and hydration. Wearable technologies can support monitoring but vary in accuracy, especially during exercise. Chest strap-based measurements are generally more reliable for exercise heart rate than optical wrist sensors, particularly during high-intensity intervals or rapid changes in pace.

3.4. Practical implications for sports medicine and digital health

Heart rate zone-based training has several practical advantages. It allows athletes to control intensity, prevents easy sessions from becoming unintentionally hard and helps coaches distribute training load across the week. It is also useful in clinical exercise prescription, where safety and individual tolerance are central concerns.

A practical heart rate zone model should ideally be based on individual testing rather than generic formulas. Maximal heart rate prediction equations are convenient but can be inaccurate in individuals. Lactate testing, ventilatory thresholds or cardiopulmonary exercise testing provide more precise zone boundaries. When laboratory testing is unavailable, field tests, talk test, perceived exertion and repeated performance data may help refine training intensity (Mezzani et al. 2013; Terada et al. 2025).

Table 1 presents a simplified practical interpretation of common heart rate zones. The exact percentages should be adapted to the athlete, sport, testing method and clinical context.

Table 1. Practical interpretation of heart rate zones

Zone	Approximate intensity	Main physiological profile	Main training purpose
Zone 1	Very low / recovery	Low lactate, high recovery potential	Recovery, warm-up, cool-down
Zone 2	Low aerobic	Predominantly aerobic metabolism, stable effort	Aerobic base, fat oxidation, endurance volume
Zone 3	Moderate / tempo	Increased lactate production but sustainable effort	Tempo endurance, exercise economy
Zone 4	Threshold / high	Near second threshold, high cardiovascular strain	Lactate threshold, sustained performance
Zone 5	Very high / maximal	Near-maximal oxygen uptake, high sympathetic activation	VO_2max, repeated high-intensity capacity

The most important clinical message is that training zones are not isolated categories but parts of a continuum. Cardiovascular adaptation results from the interaction of intensity, duration, frequency, recovery, training history and individual physiology. A well-designed program usually combines low-intensity volume with carefully dosed moderate- and high-intensity work.

3.4.1. Internal and external training load in heart rate zone prescription

Heart rate zones should be interpreted as one component of internal training load rather than as a complete description of exercise stress. Internal load reflects the physiological and psychological response of the athlete to a given training stimulus, whereas external load describes the work completed, such as running speed, cycling power, distance, acceleration, elevation gain or number of repeated high-intensity efforts (Lima-Alves et al. 2022; Dudley et al. 2023). Two athletes may complete the same external workload but experience markedly different internal loads because of differences in fitness, fatigue, heat exposure, hydration, glycogen availability, sleep quality or psychological stress.

This distinction is particularly important when heart rate zones are used to guide training across different sports. In continuous endurance exercise, heart rate is usually a useful marker of internal load because oxygen uptake and heart rate are relatively closely related at steady state. In intermittent sports, however, rapid accelerations, decelerations, collisions, changes of direction and short recovery periods can produce high neuromuscular and metabolic stress that is not fully captured by average heart rate. Therefore, in team sports and repeated-sprint disciplines, heart rate monitoring should be combined with external load measures and perceived exertion.

The session rating of perceived exertion method is a practical tool that can complement heart rate monitoring. It provides an integrated estimate of how hard the whole session felt and may capture fatigue that is not visible in heart rate alone. This is clinically relevant because heart rate can be suppressed during accumulated fatigue, dehydration, medication use or parasympathetic hyperactivity, while perceived exertion may remain high. Combining heart rate zones, session RPE and training duration allows a more complete estimate of training stress than relying on heart rate alone (Lima-Alves et al. 2022; Dudley et al. 2023).

A practical monitoring model may include three layers. The first layer is the planned zone distribution, such as how much time should be spent below threshold, around threshold and above threshold. The second layer is the actual physiological response measured by heart rate, HRV and heart rate recovery. The third layer is the athlete-reported response, including perceived exertion, muscle soreness, sleep quality and mood. When these layers are consistent, the training stimulus is easier to interpret. When they diverge, for example when a normally easy zone 2 session feels unusually difficult, the discrepancy may indicate insufficient recovery, illness or excessive accumulated load.

3.4.2. Threshold-based prescription versus percentage-based zones

Many commercial devices automatically generate heart rate zones using fixed percentages of maximal heart rate. Although this method is simple, it may be imprecise because maximal heart rate prediction equations have substantial individual error. A percentage that corresponds to low-intensity training in one athlete may correspond to moderate or threshold intensity in another. For this reason, threshold-based prescription is generally preferable when the goal is accurate physiological control.

The most precise approach is to determine training zones using laboratory or field testing. Cardiopulmonary exercise testing can identify ventilatory thresholds, maximal oxygen uptake and abnormal cardiovascular responses to exercise. Lactate testing can estimate the first and second lactate thresholds. Field-based alternatives, such as time trials, critical speed or functional threshold power, may be useful when laboratory testing is unavailable. These methods do not eliminate variability, but they create a more individualized framework than generic percentage zones (Mezzani et al. 2013; Pelliccia et al. 2021; Terada et al. 2025).

In practice, the selection of a zone model should depend on the population. Competitive endurance athletes benefit from a more precise threshold-based approach because small differences in intensity may influence adaptation, fatigue and race preparation. Recreational athletes may use simpler percentage-based models if the main goal is general health, provided that they also monitor perceived exertion and symptoms. Clinical populations require additional caution. In individuals with cardiovascular disease, diabetes, hypertension or arrhythmia history, intensity prescription should be linked to medical assessment and functional testing whenever possible (Pelliccia et al. 2021; Terada et al. 2025).

A common practical problem is cardiac drift during prolonged exercise. During long sessions, heart rate may gradually rise despite stable pace or power output. This can occur because of dehydration, increased body temperature, reduced stroke volume and sympathetic activation. As a result, an athlete may appear to move into a higher heart rate zone even though external intensity is unchanged. In such cases, rigidly reducing pace to stay within the original zone may not always be necessary, but persistent or excessive drift can indicate insufficient aerobic conditioning, heat stress or inadequate fueling.

3.4.3. Wearable technologies, digital health and exercise behavior

Wearable devices have increased access to heart rate monitoring and have made zone-based training widely available to recreational athletes. Sport watches, chest straps and optical sensors can provide real-time feedback, long-term trend analysis and integration with training platforms. This has practical value because athletes can more easily avoid unplanned intensity, control recovery sessions and identify changes in resting heart rate or HRV. From a social and behavioral perspective, wearable technologies may also influence exercise adherence by providing feedback, goal-setting functions, reminders and visual progress indicators. These functions can support self-regulation and health behavior change, especially among recreational users who do not have direct access to coaches, laboratories or clinical exercise specialists.

However, device accuracy varies. Chest strap monitors measure electrical activity and are generally more reliable during high-intensity intervals, rapid changes in pace and sports with arm movement. Wrist-worn optical devices estimate heart rate using photoplethysmography and may be affected by skin contact, motion artifact, sweat, ambient temperature, sensor position and skin characteristics. Systematic evidence suggests that many commercial wearable devices can estimate heart rate reasonably well in controlled conditions, but accuracy differs by device, exercise mode and intensity (Fuller et al. 2020; Doherty et al. 2024; Quinn et al. 2024).

This limitation has direct implications for heart rate zones. A small measurement error may be acceptable during easy continuous running, but it can become clinically and practically important near threshold or during short high-intensity intervals. If the device underestimates heart rate during intervals, the athlete may unintentionally exceed the planned intensity. If it overestimates heart rate during low-intensity sessions, the athlete may unnecessarily reduce training stimulus. Therefore, athletes using wrist-based sensors for precise zone training should verify unusual values with perceived exertion, pace, power output or a chest strap.

The increasing use of wearable technologies also raises issues of digital literacy. Users must understand that heart rate zones are estimates rather than absolute biological categories, and that training decisions should not be based solely on automated color-coded zones generated by commercial platforms. Digital feedback can promote motivation and self-awareness, but it can also encourage excessive training, anxiety about metrics or inappropriate comparison with other users. Therefore, wearable-supported training should be framed as assisted decision-making rather than automated medical or coaching advice.

Wearable technologies should be understood as decision-support tools rather than diagnostic instruments. They can improve training awareness, but they should not replace clinical evaluation when symptoms occur. Chest pain, unexplained dyspnea, syncope, palpitations or unusual exercise intolerance require medical assessment regardless of heart rate zone data. This distinction is especially important because recreational athletes may interpret wearable metrics as medical reassurance, even though most commercial devices are not designed to diagnose cardiovascular disease.

3.4.4. Individual variability in cardiovascular adaptation

Cardiovascular adaptation to training is highly individual. Some athletes show rapid improvements in VO_2max after high-intensity training, whereas others respond more strongly to higher volumes of low-intensity work. Differences in baseline fitness, age, sex, genetics, training history, nutrition, sleep, altitude exposure and psychological stress can all influence adaptation. Therefore, a single heart rate zone model cannot be expected to produce the same outcome in every athlete.

The concept of responder variability is important in sports medicine. A program that improves VO_2max in a group average may still be ineffective or excessively fatiguing for a subset of individuals. Monitoring repeated responses over time is therefore more useful than relying only on the initial training plan. For example, if an athlete fails to improve despite high adherence, possible explanations include insufficient intensity, excessive fatigue, poor recovery, inadequate nutrition or inaccurate zone boundaries. Conversely, if performance improves but HRV remains chronically suppressed and perceived fatigue increases, the program may be producing short-term gains at the cost of maladaptation risk.

Sex and age may also modify responses to heart rate zone-based training. Maximal heart rate, autonomic regulation, recovery kinetics and hormonal status can differ between individuals and across the lifespan. Older adults may benefit substantially from moderate and high-intensity aerobic training, but progression should be more gradual and should account for comorbidities, medication use and orthopedic limitations. In women, menstrual cycle phase, hormonal contraception and iron status may influence perceived exertion, recovery and endurance performance, although current evidence is still insufficient to create universal zone-adjustment rules.

For these reasons, individualized prescription should be viewed as an iterative process. Initial zones may be established through testing, but they should be refined using training response, performance outcomes, recovery markers and symptoms. This approach is consistent with precision exercise medicine, where the goal is not simply to prescribe a standard intensity, but to match the training stimulus to the adaptive capacity of the individual.

Table 2. Practical strengths and limitations of heart rate zone-based training

Aspect	Practical value	Main limitation	Recommended solution
Low-intensity zones	Allow high training volume with low fatigue	May be insufficient alone to maximize VO_2max	Combine with periodic higher-intensity sessions
Moderate zones	Improve sustainable aerobic performance	Can accumulate fatigue when overused	Monitor session RPE and weekly load
High-intensity zones	Strong stimulus for VO_2max and performance	Higher autonomic and musculoskeletal stress	Use strategically with planned recovery
HRV monitoring	Helps assess recovery and autonomic trends	Sensitive to sleep, stress and measurement conditions	Standardize morning measurement
Wearable devices	Improve accessibility and real-time feedback	Accuracy varies by device and exercise mode	Confirm with chest strap, RPE, pace or power
Threshold testing	Improves individualization of zones	Requires equipment or expertise	Use CPET, lactate testing or validated field tests

3.5. Clinical safety and risk management

The cardiovascular benefits of exercise are well established, but sports medicine must also consider safety. Most healthy individuals can train safely across a wide range of intensities, but high-intensity zones increase acute cardiovascular demand. During vigorous exercise, heart rate, systolic blood pressure, myocardial oxygen consumption and catecholamine levels rise substantially. In susceptible individuals, particularly those with undiagnosed cardiovascular disease, this may increase the risk of adverse events. Therefore, the use of high-intensity heart rate zones should be adapted to age, symptoms, risk factors and training history.

Pre-participation screening is especially relevant for adults returning to exercise after long inactivity, individuals with known cardiovascular disease and athletes with warning symptoms. Symptoms such as exertional chest pain, syncope, unexplained shortness of breath, sustained palpitations or disproportionate fatigue should not be interpreted as normal training responses. In such cases, medical evaluation is more important than adjusting heart rate zones. Sports cardiology guidelines emphasize the role of clinical assessment and individualized exercise advice in athletes and active individuals with cardiovascular disease (Pelliccia et al. 2021).

In cardiac rehabilitation, heart rate zones may be useful, but they should be prescribed more cautiously than in healthy athletes. Beta-blockers, calcium channel blockers and other cardiovascular medications can alter heart rate response, making percentage-based zones less reliable. In such populations, perceived exertion, symptoms, workload, blood pressure response and cardiopulmonary exercise testing may be more informative than heart rate alone. This is one reason why professional guidance is recommended when exercise intensity is prescribed for patients with cardiovascular disease (Mezzani et al. 2013; Terada et al. 2025).

Another safety issue is the relationship between high-intensity training and overtraining-related maladaptation. Overtraining is not caused by high intensity alone; it develops when training stress chronically exceeds recovery capacity. Nevertheless, frequent sessions in zones 4–5 may accelerate maladaptation if they are combined with insufficient sleep, inadequate energy availability, psychological stress or excessive competition load. Early warning signs include persistent fatigue, declining performance, mood changes, sleep disturbance, elevated perceived exertion at normal workloads and abnormal autonomic markers (Manresa-Rocamora et al. 2021; Addleman et al. 2024; Esco et al. 2026).

A risk-managed training plan should therefore include planned recovery weeks, gradual progression and monitoring of both objective and subjective responses. The goal is not to avoid high-intensity training, but to use it when the athlete is prepared to adapt. This is particularly important in recreational athletes, who may copy elite training sessions without having the aerobic base, recovery resources or monitoring support of professional athletes.

3.6. Future directions

Future research should aim to standardize heart rate zone definitions. At present, studies differ in whether zones are based on maximal heart rate, heart rate reserve, lactate thresholds, ventilatory thresholds or device-specific algorithms. This heterogeneity limits comparison between studies and complicates practical recommendations. A more consistent reporting framework should include the method used to determine zones, the time spent in each zone, the external workload, the athlete population and recovery conditions.

Another important direction is the integration of heart rate zones with multi-modal monitoring. Future training systems may combine heart rate, HRV, sleep, perceived exertion, power output, pace, environmental data and biochemical markers. Such models could provide more individualized recommendations than heart rate zones alone. However, these systems require validation in independent studies before they can be considered reliable clinical or performance tools.

Longitudinal studies are also needed. Many trials on training intensity last only a few weeks or months, whereas cardiovascular remodeling and performance development occur over years. Long-term studies could clarify how different distributions of low-, moderate- and high-intensity training influence cardiac structure, autonomic function, arrhythmia risk, performance durability and health outcomes. This is especially relevant for masters athletes and individuals who perform high volumes of endurance training for decades.

Finally, more research is needed in women, adolescents, older adults and clinical populations. Much of the existing endurance training literature is based on young or middle-aged men. Broader representation would improve the precision of exercise prescription and reduce the risk of applying findings too broadly. In the future, heart rate zone-based training should move toward a more individualized and inclusive model that accounts for physiology, clinical status and real-world training behavior.

4. Discussion

This review shows that heart rate zone-based training sits at the intersection of exercise physiology, sports medicine and digital health. The available evidence indicates that training in different heart rate zones produces complementary cardiovascular adaptations. Low-intensity training supports aerobic efficiency and autonomic recovery, moderate-intensity training improves sustained submaximal performance and high-intensity training provides a potent stimulus for VO_2max and maximal cardiovascular function. These findings support the use of heart rate zones as a practical framework for exercise prescription, provided that the limitations of heart rate monitoring and wearable-derived data are understood.

One of the most consistent findings in the literature is the effectiveness of high-intensity interval training for improving VO_2max. Meta-analyses show that HIIT can produce substantial improvements in cardiorespiratory fitness and endurance-related outcomes, especially when programs are appropriately designed (Rosenblat et al. 2020; Rosenblat et al. 2022; Ma et al. 2023). However, this does not eliminate the need for low-intensity training. In endurance athletes, low-intensity volume appears essential for developing the aerobic base and maintaining a sustainable training load.

Training intensity distribution is therefore a key issue. Polarized and pyramidal models both emphasize a high proportion of low-intensity work, but they differ in the amount of moderate and high-intensity training. Current evidence suggests that the optimal distribution may depend on performance level, sport, training history and phase of the season (Seiler 2010; Oliveira et al. 2024). Competitive endurance athletes may benefit from polarized approaches during some periods, while recreational athletes may improve effectively with pyramidal or moderate-intensity dominant programs.

The clinical relevance of this topic is also substantial. In cardiac rehabilitation and cardiovascular prevention, exercise intensity prescription must balance efficacy and safety. Position statements emphasize the importance of individualized evaluation and threshold-based prescription when possible (Mezzani et al. 2013; Pelliccia et al. 2021). For patients or individuals with cardiovascular risk, high-intensity training may be beneficial but should be introduced carefully and preferably after appropriate medical assessment.

A major limitation of heart rate zone training is methodological inconsistency, which becomes even more relevant when zones are generated automatically by consumer devices. Different devices and coaching systems define zones differently. Some use percentages of maximal heart rate, others use heart rate reserve or threshold heart rate. This makes direct comparison between studies and training programs difficult. Moreover, heart rate is a delayed physiological marker and may not accurately reflect sudden changes in intensity, particularly during short intervals.

Future research should focus on standardized zone definitions, long-term cardiovascular outcomes and integration of wearable data with physiological testing. In the context of innovative technologies, research should also examine how digital interfaces, feedback design, alerts and app-based coaching influence user behavior, adherence, risk perception and training decisions. Artificial intelligence and continuous monitoring may improve individualized prescription, but these tools require validation in independent studies. Research should also evaluate sex-specific responses, aging-related differences and the safety of high-intensity heart rate zone training in clinical populations.

5. Limitations

This review has several limitations. First, it is a narrative review rather than a systematic review, so no formal risk-of-bias assessment or meta-analysis was performed. Second, heart rate zone definitions vary widely between studies, devices and sports disciplines. Third, many findings from endurance athletes may not directly apply to team sport athletes, strength athletes or clinical populations. Finally, cardiovascular adaptations are influenced by age, sex, genetics, training history, sleep, nutrition and environmental factors, which may modify individual responses to exercise intensity.

6. Conclusions

Training across different heart rate zones induces distinct but complementary cardiovascular adaptations, and wearable technologies have made this approach accessible beyond laboratory and elite sport environments. Low-intensity zones improve aerobic efficiency, peripheral oxygen utilization and parasympathetic regulation. Moderate-intensity zones support sustainable performance and lactate clearance, while high-intensity zones strongly stimulate VO_2max, maximal cardiac output and high-intensity exercise tolerance.

Heart rate zone-based training is a useful tool in sports medicine and digital exercise monitoring, but it should not rely solely on generic percentage formulas or uncritically interpreted wearable algorithms. The most effective approach is individualized and combines heart rate data with physiological thresholds, perceived exertion, performance outcomes and recovery monitoring. Proper distribution of training intensity may improve performance and cardiovascular health while reducing the risk of excessive autonomic stress and maladaptation.

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