



Physical Activity and Heart Rate Variability Among Middle Age to Older Adults with Heart Failure: The State of Science

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Article info

Article history:

Received : 26 March 2024

Revised : 22 April 2024

Accepted : 23 April 2024

Keywords:

Physical activity, Heart rate variability, Autonomic nervous system, Heart failure

Abstract

Physical activity or exercise relates to the physiological responses especially in heart rate variability (HRV). HRV is a predictor of prognosis of heart failure and cardiac functions. However, little is known about the relationship of physical activity, HRV improvement and autonomic regulation in heart failure of older adults. The purpose of this state of science review is to synthesize the evidence that shows the effects of physical activity or exercise, HRV and physiological outcomes. The literature searched includes 12 studies from four electronic databases (PsycInfo, Pubmed, Scopus and CINAHL). The findings revealed that physical activity or exercise will improve HRV. This review showed that physical activity improves cardiac autonomic function (nerohormornal activation, sympathetovocal balance, baroreceptor reflex) and inhibits alpha 2 antagonist to improve HR reserve and RR intervals and prevent premature ventricular contraction (PVC). However, the level of physical activity and intensity are not clear. Tailored interventions or community-based programs will be effective in order to maintain physical activity and functional outcomes. A higher HRV is related to the functional capacity compared to the lower. Therefore, healthcare providers should regularly assess heart rate variability among heart failure patients to determine the threshold and recovery for physical functioning in regards to the stress form physical activity.

Introduction

Physical activity can affect physiological response among older adults through improved lipid profile, increased maximal cardiac output and increased maximal oxygen consumption (Jakovljevic, 2018). Based on World Health Organization (WHO), physical activity is defined as bodily movement produced by the contraction of

skeletal muscles that requires energy expenditure (WHO, 2022).

Nevertheless, the lack of physical activity is increased by age, with approximately 33% of men and 50% of women among those who were 75 years who showed a lack of physical activity (WHO, 2015). The WHO noted that only 2.5–22% of older adults achieve the current WHO-recommended physical activity levels by 150-min a week (Meredith et al., 2023). To address a

lack of physical activity over the last decade, researchers have implemented interventions to improve physical activity among older adults to enhance their health benefits especially in cardiovascular outcomes.

The high level of physical activity and endurance training are related to resting bradycardia among adulthood resulting in the alteration of cardiovascular autonomic control. For older adults, dynamic exercise has demonstrated to cause a smaller increment heart rate than for younger people. Autonomic regulation of the cardiovascular system is involved by the sympathetic and parasympathetic pathway. Autonomic nervous system plays an important role in the modulation of the heart rate (Souza et al., 2021).

Heart rate variability (HRV) is widely used to measure the autonomic nervous system balance/imbalance that might provide prognostic information in cardiovascular events (Galetta et al., 2013). HRV is the temporal beat-to-beat variation in successive RR intervals on an electrocardiographic (Nicolini et al., 2012; Woo et al., 1997). Some researchers claimed that reduced HRV is associated to the poor prognosis among patients with cardiovascular disease and their conditions such as myocardial infarction, chronic heart failure, unstable angina and diabetes mellitus (Routledge et al., 2010). Likewise, reduced HRV indicates either attenuation in the autonomic regulation of sinoatrial node or failure of sinoatrial node to capture the regulation (Murad et al., 2012). HRV is useful to improve the diagnosis and risk stratification in patients with chronic heart failure and ventricular arrhythmia (Goernig et al., 2008). Physical activity or exercise may affect HRV and autonomic regulation.

Heart rate variability in heart failure patients

The mortality rate from sudden cardiac arrest in heart failure patients relates to arrhythmia (Huikuri & Stein, 2013). The annual mortality rate was 5.5% for SDNN (the standard deviation of normal RR intervals) >100 ms., 12.7% for SDNN=50-100 ms. and 51.4% for SDNN < 50 ms. Heart rates decrease after physical activity/exercise and is important since it is associated with mortality rate (Huikuri & Stein, 2013). HRV seems to provide more information on the risk of early non sudden cardiac death in heart failure (Sessa et al., 2018).

HRV reflects the condition of autonomic regulation. According to the task force of the European Society of Cardiology and The North American Society

of Pacing and Electrophysiology (1996), the spectrum of HRV signal is typically evaluated from a beat-to-beat interval tachogram (time domain measure). High frequency (HF) refers to the energy in the power spectrum between 0.15-0.40 and responses to vagal activity. Low frequency (LF) refers to the energy in the power spectrum between 0.004-0.15 and responses to sympathetic, vagal activity and baroreflex sensitivity. LF/HF ratio responds to the sympathetic and parasympathetic activity (Felber Dietrich et al., 2006).

For older individuals, the impact of physical activity yields varying outcomes. Prior research has claimed that physical activity or exercise had no HRV effects with females (Madden et al., 2006). HRV did not reflect the variations in autonomic activity that followed increasing exercise intensities in both males and females (Perini et al., 2000). In chronic heart failure patients, decreased HRV has been associated with increased mortality (Rossi Caruso et al., 2011). Exercise can affect HRV and baroreflex sensitivity in heart failure patients with type 2 diabetes by reducing heart rate recovery (Neves et al., 2011). In addition, physical activity might affect heart rate variability among heart failure patients. Yet, little is known about the effect of physical activity or exercise on heart rate variability and whether interventions that are associated with improvement of HRV are associated with better physiological outcomes among heart failure patients in the last decade. Even though HRV has been applied in a large number of studies (over 10,000 citations), we have limited our review to applications of HRV with the heart failure population.

Therefore, the purpose of this state of science review is to synthesize the effect of physical activity or exercise intervention and heart rate variability among patients with heart failure. In addition, this review will discuss the physiological outcomes and gain insight on heart rate variability measurement in heart failure patients. This synthesis will provide direction for both practitioners and researchers to determine the feasibility of physical activity intervention affecting heart rate variability and cardiac outcomes.

We used Whittemore & Knaft's guideline (2005) for this review to identify the problem, search, evaluate, analyze the data and present the review.

We included the studies that meet the following criteria (a) peer review articles, (b) have physical activity and heart rate variability outcomes, (c) written in English and (d) used samples of middle age to older

adults defined as mean age greater than 45 years old and above. For exclusion criteria, we excluded studies that did not focus on heart rate variability and outcomes.

By following these review steps, we selected the specific articles. First, searches were performed in recent literature of intervention studies, published from 2006 to 2023 via PsycInfo, PubMed, SCOPUS and CINAHL. We used key words included physical activity or exercise and heart rate var* and heart failure and elderly

or older adults. Next, the references for those articles were reviewed for additional relevant articles. Then, the full articles were reviewed to determine if they met the inclusion criteria.

The search yielded 564 publications. After removing the duplicate articles, 547 papers were retained. Then, we screened the titles and abstracts to remove 476 publications due to being irrelevant to the aim of the study and the participants were not older adults. Among the remaining 71 papers, 59 were excluded because the studies were not related to physiological measurement of heart rate variability in chronic heart failure patients. Finally, 12 published studies were retained for this review. Several data were extracted on the including study design, characteristic and intervention development process based on significant findings as well as physiological responses related to the effects of the physical activity on heart rate variability.

We extracted the data based on the study design, sample size, population characteristic, HRV measurements, physical activity measurements and outcomes of HRV and physical activity/exercise following the inclusion criteria.

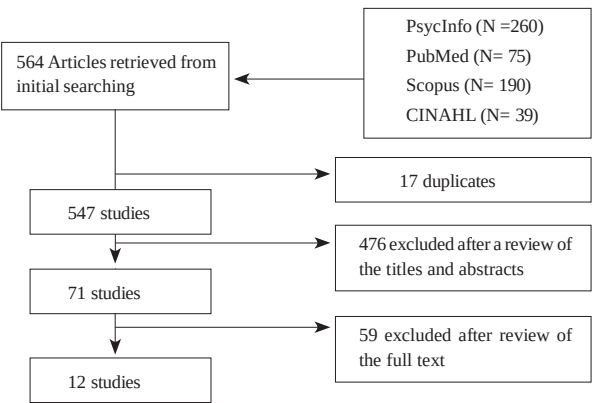


Fig. 1 Literature review results

Table 1 Literature synthesis

Author/ year /country	Subjects	Study design/ purpose	Physical activity and HRV measurement	Significant findings / physiological outcomes
Reis et al. (2014) Brazil	- 10 Chronic heart failure (CHF) patients (aged 62±7 years) (Ejection fraction: EF < 45%) and 9 matched-age healthy volunteer.	- Observational, cross-sectional study. - To examine the impact of inspiratory muscle strength on the magnitude of respiratory sinus arrhythmia.	- Maximal respiratory pressure (MIP) was assessed from residual volume, and total lung capacity. - HRV was determined at rest and during breathing maneuver (DB-M) by electrocardiograph.	- Heart rate variability at rest in CHF patients: impaired cardiac autonomic modulation at rest during DB-M. - Heart variability during deep breathing maneuver: Positive correlation between MIP and inspiratory-expiratory differences (r=.79) E/I ratio (r=.83) during DB-M. - Cardiac autonomic control of heart rate was related with inspiratory muscle weakness in CHF.
Piotrowicz et al. (2015) Poland	111 CHF patients (NYHA class II-III, EF≤40%).	- Randomized control trial. - To examine the influence of Nordic walking training (NW) on autonomic nervous system (ANS): HRV and heart rate turbulence. - Patients were randomized (2:1) to 8 weeks NW (five times weekly) at 40-70% of maximal heart rate (Heart rate reserve) (n=77) and control group (n=34).	- 24-hr Holter ECG monitoring and indices of autonomic nervous system activity analysis. - cardiopulmonary exercise treadmill test. - Borg scale. - Heart rate reserve. - ANS activity was recruited on eligible patients who were in sinus rhythm.	- NW had a significant improvement on sympathovagal balance by low frequency/high frequency ratio (LF/HF) only in the training group. - Heart rate variability had no significantly differences in either group.

Table 1 (Cont.)

Author/ year /country	Subjects	Study design/ purpose	Physical activity and HRV measurement	Significant findings / physiological outcomes
Gademan et al. (2007) The Netherland	849 CHF patients (550/299 exercise/control) in 23 reviews studies	- Review of literature - To determine the effect of exercise training on autonomic derangement and neurohumoral activation in chronic heart failure.	- Baroreflex and HRV (bradycardia) - Sympathetic nervous system (epinephrine and norepinephrine ratio).	- Baroreflex plays an important role that is a negative feedback loop in the neurohumoral excitation process in CHF. Baroreflex sensitivity (BRS) is related to HRV. Baroreflex-mediated spontaneous blood pressure fluctuation. Lower HRV is likely related to lower vagal involvement.
Rossi Caruso et al. (2011) USA	N= 20, 10 CHF (aged 57±7 years) and 10 healthy controls (aged 59±9 years); NYHA class III/IV, EF < 45% and hemodynamically stable.	- Experimental design - To examine the acute effect of deep breathing exercise and walking on heart rate variability among CHF patients	- HRV was assessed using a Polar® system (Polar electro, Kempele, Finland). The heart rate signals are captured to the polar advantage receiver unit via electro-magnetic field. - R-R intervals were collected during 10 min in rest, walking and during recovery. - Heart rate monitoring if increased >20bpm will be terminated for walking session. - Deep breathing exercise (Borg dyspnea index) and walking for 4 min.	- HR was significantly higher during and after walking with CHF. - CHF patients showed a significantly decreased $\alpha 2$ during deep breathing. - Deep breathing exercise and walking are safe and promote advantageous HRV in patients with CHF.
Lai et al. (2012) Taiwan	120 orthotropic heart transplants recipients, ECG was sinus rhythms, stable condition and be able to perform activity.	- Descriptive, cross-sectional study - To examine the relationship between physical activity and heart rate variability in orthotropic heart transplant recipients.	- The seven-day physical activity recall questionnaire (record amount physical activity per week). - HRV was assessed using standard three channels ECG electrodes that connected to the monitor system (QRS complex and RR interval analysis). - The power density of low frequency (LF) and high frequency (HF) components.	- Overall HRV of orthotropic heart transplant recipients were lower than those of healthy groups. - Heart transplant recipients who performed moderate physical activity had increased HF (nu) and HF (ms-2) of HRV.
Kiselev et al. (2013) Russia	55 male patients (aged 50±3 years) with EF < 50% and 35 males (52±6 years) with EF>50%.	- Experimental design - To examine the dynamic characteristics of LF oscillations in the heart rate of CHF patients during bicycle exercise (BE) test, under 0.1 Hz controlled breathing.	- A tachogram (R-R interval series) record was performed to analyze HRV (LF .04-.15) were used in which HRV spectrum frequency power was calculated. - BE test with loads of 25 W.	- HRVs have predictive value on long term outcome in patient with low EF. - BRS is a clinical component in CHF patients. - Slow breathing did not influence on BRS.
Nakayama et al. (2014) Japan	41 patients (aged 59-83 years) with mild hypertension and/or stable angina pectoris.	- Nonrandomized six months prospective longitudinal study. - To investigate the effects on HRV of home-based daily activity and to determine the relationship between daily activity and sympathovagal balance.	- Active strength was assessed using metabolic equivalent (MET) intensity level of daily activity. - Active mass was calculated regarding to the calorie consumption. - HRV was assessed using 24-hr ambulatory electrocardiogram, RR interval analysis (baseline and after six months).	- An increase in active mass improved HRV outcomes with increased HF and decreased LF/HF during sleep. - Life activity improved HRV and clinical prognosis.

Table 1 (Cont.)

Author/ year /country	Subjects	Study design/ purpose	Physical activity and HRV measurement	Significant findings / physiological outcomes
Felber Dietrich et al. (2006) Switzerland	1742 high risk of cardiovascular disease population (Mean of age 60.4 years).	- Cohort study. - To examine the relationship between cardiovascular risk factors and HRV in a general population and to provide normal values for various HRV measurements in healthy population who were aged ≥ 50.	- HRV was measured by Holter recording. The normal RR intervals and the following frequency domain variables were calculated: Total power (TP) (≤ 40 Hz), ULF power (≤ 0.033 Hz), LF power (.04-.15 Hz), HF power (.05-.40 Hz) and the LF/HF ratio. - Light physical activity (≤ 2 days/week; > 2 days/week). - Heavy physical activity (≤ 1 hr/week; > 1 hr/week).	- Men and women had heavy physical activity (> 1 hr/week, 31.2 and 19.5%, respectively). - Each hr of heavy physical activity was related to a 3.6% increase in HF range power and a 4.2 % increase in LF power.
Guiraud et al. (2013) France	18 CHF patients with stable condition EF $<40\%$, aged 53 ± 12.0 years, NYHA class 2.0 ± 0.9 .	- Randomized crossover study. - To examine the effect of high-intensity interval exercise (HIIE) and an isocaloric moderate-intensity continuous exercise (MICE) improves vagal tone and decrease arrhythmias in CHF.	- HRV was assessed using resting ECG and 24-hr holter ECG. - The recording was performed at a 200-Hz sampling rate. The ELATEC Holter analysis HRV and QT software was used for analysis. - A continuous progressive exercise protocol was performed on a cycle ergometer. - MICE and HIIE were estimated to be isocaloric.	- HIIE improved autonomic profile of CGF patients. - HR were significant decreased after HIIE (68 ± 3 bpm) in 24-h post training period. - HIIE decreased premature ventricular contraction (PVCs) and associated to lo LF/HF ratio ($r=.66$, $p<.01$).
Soares-Miranda et al. (2014) USA	985 older adults in community-based cardiovascular health study.	- Longitudinal study. - To study the physical activity and HRV indices.	- Modified Minnesota physical activity questionnaire. - HRV indices include time domain, frequency domain and nonlinear measure was assessed 24-hr. - Daytime and nighttime baroreceptor and respiratory autonomic variation.	- Leisure time activity and walking were associated with more advantageous and specific indices of autonomic function in older adults.
Murad et al. (2012) USA	- 66 heart failure patients (aged 69 ± 5 years) and EF range 29-26%.	- A Randomized control, single-blinded trial - To examine the effect of supervised endurance exercise training on HRV with heart failure have a preserved EF (HFPEF) and Heart failure with reduce EF (HFREF).	- Exercise training for 3 times per week for 16 weeks under medical supervision (Total 48 session); exercise at 40-50% of Heart rate reserve (HRR) for the first two week, Then intensity of exercise was increased to 60-70% HRR and duration increased 15-20 min. - HRV: cardiac monitor, ECG recording, commercially available software (PREDICT II HRVECG), normal RR intervals (SDNN).	- Exercise training increased RR interval (SDNN) in male and female. - Exercise training improved HRV in older heart failure patients with both HFPEF and HFREF.
Sandercock et al., (2007) UK	- 38 patients with cardiovascular disease in cardiac rehabilitation (aged 65.6 ± 11.6 years) program and 23 healthy control (Aged 64.9 ± 9 years).	- Randomized control trial. - To examine the changes in spectral measures of HRV derived from 5-min ECG recordings in patients completing 8 weeks of cardiac rehabilitation program.	- HRV was assessed using ECG monitoring, RR interval analysis. - The standard deviation of normal RR intervals (SDNN) and the root mean square of the differences between successive RR intervals (RMSSD). - Physical activity levels were assessed.	- Significant increases in raw LF and HF power derived from short-term ECG recordings. - Cardiac rehabilitation associated favorable alterations in autonomic control.

Findings

This state of science review consisted of 12 research publications that met the inclusion criteria. Studies were conducted by researchers in the United States (Murad et al., 2012; Rossi Caruso et al., 2011; Soares-Miranda et al., 2014), Brazil (Reis et al., 2010), France (Guiraud et al., 2013), Japan (Nakayama et al., 2014), Poland (Piotrowicz et al., 2015), Russia (Kiselev et al., 2013), Switzerland (Felber Dietrich et al., 2006), Taiwan (Lai et al., 2012), the Netherlands (Gademan et al., 2007) and United Kingdom (Sandercock et al., 2007).

Sample sizes ranged from 18 to 849 older adults with heart failure and cardiovascular disease (CAD high risk with heart transplant receiver). The research design were varied including six experimental studies (Guiraud et al., 2013; Kiselev et al., 2013; Murad et al., 2012; Piotrowicz et al., 2015; Reis et al., 2010; Rossi Caruso et al., 2011), two cross-sectional studies (Lai et al., 2012; Reis et al., 2010), two longitudinal studies (Nakayama et al., 2014; Soares-Miranda et al., 2014), a cohort study (Felber Dietrich et al., 2006) and an article review (Gademan et al., 2007).

1. Physical activity and HRV among heart failure of older adults

For the specific type of physical activity or exercise among heart failure patients, two studies were exercise training (Gademan et al., 2007; Murad et al., 2012), high intensity interval exercise (HIIE) and an isocaloric moderate-intensity continuous exercise (MICE) (Guiraud et al., 2013), deep breathing exercise (Piotrowicz et al., 2015; Rossi Caruso et al., 2011), and bicycle exercise (Kiselev et al., 2013).

For HRV, the components of HRV in this review consisted of time and frequency domain analyses including HF, LF and LF/HF ratio, total power (TP) and ULF power (Felber Dietrich et al., 2006). Five studies used 24-hr Holter monitoring to assess HRV (Felber Dietrich et al., 2006; Guiraud et al., 2013; Nakayama et al., 2014; Piotrowicz et al., 2015; Soares-Miranda et al., 2014).

We found eleven studies showed the positive impact of physical activity or exercise on HRV. One study showed HRV had no difference in Nordic walking training (NW) (Piotrowicz et al., 2015). Nevertheless, NW had a significant improvement on sympathovagal balance.

2. Physical activity and HRV and Physiological Outcomes

This review revealed the relationship between physiological outcome measurement and physical activity among older heart failure patients. Two studies showed that exercise training among CHF patients had effect on baroreflex sensitivity (Gademan et al., 2007; Kiselev et al., 2013). Baroreceptor control blood pressure affected heart rate variability (Kiselev et al., 2013).

Felber Dietrich et al. (2006) found that heavy physical activity associated to a 3.6% increase in HF range power and a 4.2% increase in LF power. The LF/HF ratio is an indicator for assessing HRV improvement which relates to autonomic nervous system. For those who were transplant recipients, physical activity increased HF (nu) and HF (ms²). Kiselev et al. (2013) found that bicycle exercise improved heart function and dynamic stability. From the findings of state of science review, we concluded that physical activity or exercise influences heart rate variability and physiological outcomes in heart failure patients.

The purpose of this state of science review was to synthesize the effects of physical activity or exercise intervention and heart rate variability among middle age to older adults with heart failure on physiological outcomes. This review provides a comprehensive knowledge of physical activity or exercise on autonomic function (HRV).

The significant results derived from several countries and levels of evidence indicates that participants in exercise training programs, which consisted of high intensity interval exercise, improved autonomic function among CHF patients and increased RR intervals as well as prevention of premature ventricular contraction (PVCs) (Murad et al., 2012; Guiraud et al., 2013). This finding supports the effect of physical activity or exercise endurance and relates to autonomic function resolve in patients with CHF (Lai et al., 2012). Exercise training could be considered as an alternative approach for autonomic dysfunction in patients with CHF.

The ability of the heart rate to recover after exercise is related to sympathovagal balance and baroreceptor (Piotrowicz et al., 2015). The neurohormonal excitation is processing throughout the sympathetic nervous system which occur during exercise (Gademan et al., 2007). Rossi Caruso (2011) reported that CHF patient had decreased of $\alpha 2$ during a deep breathing

exercise. HRV can be presented as an indicator of outcome measures and associated favorable alteration in autonomic control in patients undergoing cardiac rehabilitation (Sandercock et al., 2007). The above study results indicate that exercise or physical activity provides a benefit to autonomic control.

This review found that aerobic exercise training (Nordic walking training) is effective in improving heart rate reserve and improving sympathovagal balance by low LF/HF ratio (Piotrowicz et al., 2015). Lower HRV is related to lower vagal involvement (Gademan et al., 2007). LF/HF ratio shows a relationship between baroreflex sensitivity and vagal modulation rather than sympathovagal balance (Gademan et al., 2007). The results of this review revealed that exercise training has considerable effects on HRV in patients with CHF, including increase in vagal tone and modulation of sympathovagal balance activity (Kiselev et al., 2013; Piotrowicz et al., 2015).

Reduced HRV in patients with CHF is related to neurohormonal activation and attenuation of cardiac vagal tone (Murad et al., 2012). Deep breathing exercise is safe and advantageous for HRV (Rossi Caruso et al., 2011). Deep breathing exercise relates to maximum respiratory pressure (MIP) and cardiac autonomic function relates to inspired muscle weakness (Reis et al., 2010). However, slow breathing does not have an influence on the baroreceptor system (Kiselev et al., 2013).

For HRV assessment, the different HRV assessment contexts can influence the results on short term and long-term evaluation, especially in ECG monitoring and interpretation. For instance, a finding showed a significant increase in raw LF and HF power from short term ECG recording acute effect of breathing exercise (Sandercock et al., 2007). HRV outcomes decreases LF/HF ratio during sleep (Schlagintweit et al., 2023).

The strengths of this review found that most of the studies were related on significant findings and outcomes as relationship among cardiac autonomic function (neurohormonal activation, sympathovagal balance, baroreceptor), HR reserve and RR intervals. Five studies of randomized control trials (RCT) showed causal relationship between exercise and HRV improvement.

However, this review consists of limitations. Firstly, this review is at risk of potential bias because there was only one author during data extraction process. Secondly, there was only a few specific evidence of physical activity among older adults with heart failure and HRV measurements in clinical trial studies. Thirdly, it is still unclear about the intensity, timeline and optimal level of physical activity that affect HRV among patients with heart failure.

Implication for the future research

The factors such as ethnicity, sex and physiological measurements of HRV are not well understood. Because of the different types of setting, it may be barrier to determine the real impact of physical activity or exercise on HRV improvement. Researchers should conduct the RCT of physical activity and compare physiological response with both healthy and chronic illness population.

For nursing implications, the finding will provide information to determine the physiological measurement that relates to the signs and symptoms of heart failure in older adults. The early use of HRV measurement is important to identify patients at high risk and nurse should be aware to detect the risk of arrhythmia. For this review, some studies showed functional ability among older adults with heart failure by NYHA classification.

Nurses should become concerned and offer initial assessment for patients in their ability to engage in physical activity or exercise.

Conclusion

This state of science review supports exercise training effect on HRV that improves cardiac autonomic function. Increasing physical activity/exercise will have positive effects on the cardiovascular outcomes and HRV. Arrhythmia and low cardiac output are a common concern for health care providers and HRV can predict the cardiac events. HRV is a physiological measure that can predict the prognosis of heart failure and cardiac function related to the baroreceptor and autonomic system related to physical activity. Moreover, the review which includes indices of both sympathetic and parasympathetic activity provides a big picture of the role of the autonomic nervous system and regulation in heart failure.

References

- Felber Dietrich, D., Schindler, C., Schwartz, J., Barthelemy, J.C., Tschopp, J.M., Roche, F., ... Ackermann-Liebrich, U. (2006). Heart rate variability in an ageing population and its association with lifestyle and cardiovascular risk factors: Results of the SAPALDIA study. *Europace*, 8(7), 521-529.
- Gademan, M.G., Swenne, C.A., Verwey, H.F., van der Laarse, A., Maan, A.C., van de Vooren, H., ... van der Wall, E.E. (2007). Effect of exercise training on autonomic derangement and neurohumoral activation in chronic heart failure. *Journal of Cardiac Failure*, 13(4), 294-303.
- Galetta, F., Franzoni, F., Tocchini, L., Camici, M., Milanese, D., Belatti, F., ... Santoro, G. (2013). Effect of physical activity on heart rate variability and carotid intima-media thickness in older people. *Internal and Emergency Medicine*, 8(Suppl 1), S27-29.
- Goernig, M., Schroeder, R., Roth, T., Truebner, S., Palutke, I., Figulla, H.R., Leder, U., & Voss, A. (2008). Peripheral arterial disease alters heart rate variability in cardiovascular patients. *Pacing and Clinical Electrophysiology: PACE*, 31(7), 858-862.
- Guiraud, T., Labrunee, M., Gaucher-Cazalis, K., Despas, F., Meyer, P., Bosquet, L., ... Pathak, A. (2013). High-intensity interval exercise improves vagal tone and decreases arrhythmias in chronic heart failure. *Medicine and Science in Sports and Exercise*, 45(10), 1861-1867.
- Huikuri, H.V., & Stein, P.K. (2013). Heart rate variability in risk stratification of cardiac patients. *Progress in Cardiovascular Disease*, 56(2), 153-159.
- Jakovljevic, D.G. (2018). Physical activity and cardiovascular aging: Physiological and molecular insights. *Experimental Gerontology*, 109, 67-74.
- Kiselev, A.R., Gridnev, V.I., & Posnenkova, O.M. (2013). Dynamics of low-frequency oscillations in heart rate in chronic heart failure patients during load tests under 0.1 Hz controlled breathing. *Health Science Journal*, 7(1), 90-98.
- Neves, V.R., Kiviniemi, A.M., Hautala, A.J., Karjalainen, J., Piira, O.P., Catai, A.M., Mäkikallio, T.H., ... Tulppo, M.P. (2011). Heart rate dynamics after exercise in cardiac patients with and without type 2 diabetes. *Frontiers in Physiology*, 2, 57.
- Lai, F.C., Chang, W. L., & Jeng, C. (2012). The relationship between physical activity and heart rate variability in orthotopic heart transplant recipients. *Journal of Clinical Nursing*, 21(21-22), 3235-3243.
- Madden, K.M., Levy, W.C., & Stratton, J.R. (2006). Exercise training and heart rate variability in older adult female subjects. *Clinical & Investigative Medicine*, 29(1), 20-28.
- Meredith, S.J., Cox, N.J., Ibrahim, K., Higson, J., McNiff, J., Mitchell, S., ... Lim, S.E.R. (2023). Factors that influence older adults' participation in physical activity: a systematic review of qualitative studies. *Age and Ageing*, 52(8), afad145.
- Murad, K., Brubaker, P.H., Fitzgerald, D.M., Morgan, T.M., Goff, D.C., Jr., Soliman, E.Z., ... Kitzman, D.W. (2012). Exercise training improves heart rate variability in older patients with heart failure: A randomized, controlled, single-blinded trial. *Congestive Heart Failure*, 18(4), 192-197.
- Nakayama, N., Negi, K., Watanabe, K., & Hirai, M. (2014). Life activities improve heart rate variability in patients with mild hypertension and/or the initial stage of heart failure. *Journal of Clinical Nursing*, 23(3-4), 367-373.
- Nicolini, P., Ciulla, M.M., De Asmundis, C., Magrini, F., & Brugada, P. (2012). The prognostic value of heart rate variability in the elderly, changing the perspective: From sympathovagal balance to chaos theory. *Pacing and Clinical Electrophysiology*, 35(5), 622-638.
- Perini, R., Milesi, S., Fisher, N.M., Pendergast, D.R., & Veicsteinas, A. (2000). Heart rate variability during dynamic exercise in elderly males and females. *European Journal of Applied Physiology*, 82(1-2), 8-15.
- Piotrowicz, E., Buchner, T., Piotrowski, W., & Piotrowicz, R. (2015). Influence of home-based telemonitored Nordic walking training on autonomic nervous system balance in heart failure patients. *Archives of Medical Science*, 11(6), 1205-1212.
- Reis, M.S., Arena, R., Archiza, B., de Toledo, C.F., Catai, A.M., & Borghi-Silva, A. (2014). Deep breathing heart rate variability is associated with inspiratory muscle weakness in chronic heart failure. *Physiotherapy Research International: The Journal for Researchers and Clinicians in Physical Therapy*, 19(1), 16-24.
- Reis, M.S., Arena, R., Deus, A.P., Simões, R.P., Catai, A.M., & Borghi-Silva, A. (2010). Deep breathing heart rate variability is associated with respiratory muscle weakness in patients with chronic obstructive pulmonary disease. *Clinics*, 65(4), 369-375.
- Rossi Caruso, F.C., Arena, R., Mendes, R.G., Reis, M.S., Papa, V., & Borghi-Silva, A. (2011). Heart rate autonomic responses during deep breathing and walking in hospitalised patients with chronic heart failure. *Disability Rehabilitation*, 33(9), 751-757.
- Routledge, F.S., Campbell, T.S., McFetridge-Durdle, J.A., & Bacon, S.L. (2010). Improvements in heart rate variability with exercise therapy. *The Canadian Journal of Cardiology*, 26(6), 303-312.
- Sandercok, G.R., Grocott-Mason, R., & Brodie, D.A. (2007). Changes in short-term measures of heart rate variability after eight weeks of cardiac rehabilitation. *Clinical Autonomic Research*, 17(1), 39-45.
- Schlagintweit, J., Laharnar, N., Glos, M., Zemmann, M., Demin, A.V., Lederer, K., ... Fietze, I. (2023). Effects of sleep fragmentation and partial sleep restriction on heart rate variability during night. *Scientific Reports*, 13(1), 6202.
- Sessa, F., Anna, V., Messina, G., Cibelli, G., Monda, V., Marsala, G., ... Salerno, M. (2018). Heart rate variability as predictive factor for sudden cardiac death. *Aging*, 10(2), 166-177.

- Soares-Miranda, L., Sattelmair, J., Chaves, P., Duncan, G., Siscovick, D.S., Stein, P.K., ... Mozaffarian, D. (2014). Physical activity and heart rate variability in older adults: The cardiovascular health study. *Circulation*, 129(21), 2100-2110.
- Souza, H.C.D., Philbois, S.V., Veiga, A.C., & Aguilar, B.A. (2021). Heart rate variability and cardiovascular fitness: What we know so far. *Vascular Health and Risk Management*, 17, 701-711.
- Whittemore, R., & Knafl, K. (2005). The integrative review: Updated methodology. *Journal of Advanced Nursing*, 52(5), 546-553.
- Woo, M.A., Moser, D.K., Stevenson, L.W., & Stevenson, W.G. (1997). Six-minute walk test and heart rate variability: lack of association in advanced stages of heart failure. *American Journal of Critical Care*, 6(5), 348-354.
- World Health Organization (2015). *Global strategy on diet, physical activity, and health: Physical activity and older adults*. Retrieved December 20, 2023, from http://www.who.int/dietphysicalactivity/factsheet_olderadults/en/
- World Health Organization (2022). *Physical activity*. Retrieved December 20, 2023, from <https://www.who.int/news-room/fact-sheets/detail/physical-activity>