Q2 Effects of a 16-w~~W~~eek h~~H~~igh-s~~S~~peed r~~R~~esistance ~~T~~training p~~P~~rogram on h~~H~~eart r~~R~~ate v~~V~~ariability i~~I~~ndices in c~~C~~ommunity-d~~D~~welling ~~I~~independent o~~O~~lder a~~A~~dults: Q1 A c~~C~~linical t~~T~~rial

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Alexandre Duarte Martins [1,2,3], Orlando Fernandes [1], ~~João Paulo~~João ~~Brito~~Paulo Brito [2,3,4], Bruno Gonçalves [1], Rafael Oliveira [2,3,4] and Nuno Batalha [1]

[1]Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Comprehensive Health Research Centre (CHRC), Universidade de Évora~~,~~, 7000-671 Évora, Portugal

[2]~~Santarém Polytechnic University,~~ Life Quality Research Center (CIEQV)~~, Santar~~, Santarém Polytechnic University, Complexo Andaluz, Apartado 279, 2001-904 Santarém, Portugal

[3]~~School of Sport,~~ Santarém Polytechnic University~~, Rio Maior, Portugal~~, School of Sport, Rio Maior, Av. Dr. Mário Soares, 2040-413 Rio Maior, Portugal

[4]~~Health Sciences and Human Development (CIDESD),~~ Research Center in Sport Sciences~~, Rio Maior, Portugal~~, Health Sciences and Human Development (CIDESD), 2040-413 Rio Maior, Portugal

~~Alexandre Duarte Martins, Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Comprehensive Health Research Centre (CHRC), Universidade de Évora, Largo dos Colegiais 2, Évora 7004-516, Portugal. Email: af_martins17@hotmail.com~~

Alexandre Duarte Martins, Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Comprehensive Health Research Centre (CHRC), Universidade de Évora, Colégio Luis António Verney, Rua Romão Ramalho, nº59, 7000-671 Évora, Portugal. Phone: +351 266 740 800; Email: af_martins17@hotmail.com

Abstract

This study explored the impact of a 16-week high-speed resistance training (HSRT) program on heart rate variability (HRV) indices in independent older adults. The participants were divided into either an intervention group (IG, $N = 40$) or a control group (CG, $N = 39$). The IG participated in supervised HSRT sessions three times weekly, comprising 5–6 exercises with 2–3 sets and 6–10 repetitions, which lasted 60–70 min. The CG did not engage in any exercise program. HRV indices, encompassing time, frequency, and non-linear, were recorded over a six-minute period. The ANCOVA results revealed significant improvements favoring the IG for mean RR ($\eta^2_p = 0.050$), systolic blood pressure ($\eta^2_p = 0.126$), and pulse pressure ($\eta^2_p = 0.157$). Additionally, within-group analyses revealed significant increases in stress index ($d_{unb} = 0.52$), sample entropy ($d_{unb} = 0.38$), and DFA α1 ($d_{unb} = 0.38$) exclusively in the CG. This study highlights the significant potential of the HSRT to induce favorable changes in parasympathetic activity and reduce arterial stiffness.

Keywords:

velocity-based training, exercise, non-linear analysis, autonomic nervous system

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What this paper adds

- This study provides insights into the effects of high-speed resistance training (HSRT) on heart rate variability (HRV) indices in older adults. While no statistically significant changes were observed, the trends suggest HSRT may offer a safe approach for modulating autonomic function in aging populations. The use of individualized velocity zones underscores HSRT's potential as a practical intervention for promoting cardiovascular health in older adults, warranting further investigation in this area.

Applications of the study findings

- To our knowledge, this is the first study to apply the velocity-based training method, originally developed for athletes, to older adults by using specific velocity zones. The real-time feedback provided by accelerometers on execution velocity motivated participants to perform the concentric phase as quickly as possible, enhancing both their effort and adherence to the program. Importantly, this approach was found to be safe for older adults.

- This study encourages further exploration of the HRV field by integrating more cost-effective tools like the Elite HRV®, Polar® H10, and Kubios® HRV software, which could increase the feasibility of HRV monitoring in clinical settings. Additionally, we recommend that future research includes new HRV indices, such as the stress index and non-linear domain measures, to provide a more comprehensive understanding of autonomic function.

Q3 Introduction

Aging significantly impacts the autonomic nervous system (ANS), leading to significant changes in heart rate (HR) regulation. These changes are primarily associated with vagal system dysfunction and elevated norepinephrine levels, resulting in decreased parasympathetic activity and increased sympathetic dominance at rest (Levy, 1971; Mark, 1995).

Heart rate variability (HRV) has emerged a well-established, non-invasive method for assessing ANS function, offering insights into the balance between sympathetic and parasympathetic regulation (Karvinen et al., 2013). Reduced HRV has been identified as a significant risk factor for heightened cardiovascular morbidity and mortality (van Boven et al., 1998).

Exercise interventions have demonstrated potential in mitigating the harmful effects of aging on the ANS, potentially inhibiting sympathetic activity, and activating parasympathetic activity at rest (Rosenwinkel et al., 2001). Among the types of exercise programs, resistance training (RT) has recently acquired attention, with the *American Heart Association* recommending it as a valuable intervention for older adults (Paluch et al., 2024). However, the effects of RT on ANS regulation remain unclear, with mixed findings reported in the literature (Bhati et al., 2019; Kanegusuku et al., 2015; Kingsley & Figueroa, 2016).

Kingsley and Figueroa (2016) highlighted the importance of the type and execution of muscle contractions in determining the RT-effects on ANS. In addition, they recommended studying these effects through different RT prescriptions and durations. Hence, the present study uses a high-speed resistance training (HSRT) program designed to focus on rapid concentric muscle actions (≤1 sec) followed by controlled eccentric phases (Sayers et al., 2016). This approach incorporates low to moderate external loads, which have been shown to preserve vagal activity while minimizing sympathetic drive (Kingsley & Figueroa, 2016; Machado-Vidotti et al., 2014).

The HSRT protocol also incorporates velocity-based training zones, which optimize training adaptations and individualize intensity by targeting specific ranges within the strength-velocity continuum (e.g., 0.75–1.0 m/s *vs.* 1.0–1.5 m/s) (Mann, 2016; Mann et al., 2015). Moreover, the real-time monitoring of concentric velocities may enhance motivation and engagement among participants.

No prior studies have investigated the effects of a HSRT program on HRV indices in older adults while incorporating velocity training zones and tracking concentric phase velocity for each exercise using accelerometers. Therefore, this study aimed to assess the effects of a 16-week HSRT program on HRV indices in older adults. Thus, we hypothesized that the intervention group (IG) would exhibit greater improvements in parasympathetic HRV indices compared to the control group (CG) following the intervention (Kingsley & Figueroa, 2016; Machado-Vidotti et al., 2014).

Materials and Methods

Study Design

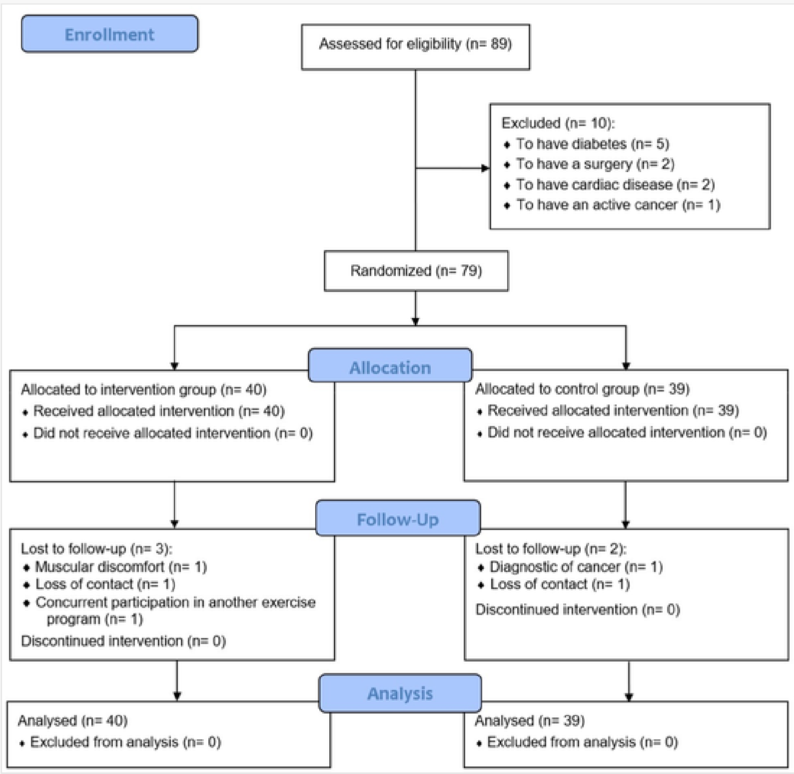
The present study is part of a longitudinal research project called "*Active Aging*~~;~~", in which the intervention began in March 2022. This non-randomized clinical trial was registered on *clinicaltrials.gov* (ID: NCT05586087) and conducted in compliance with the Declaration of Helsinki and according to the CONSORT guidelines. Ethical approval was obtained from the local university's Ethics Committee (code no. 22030).

A parallel two-group clinical trial was carried out over 20 weeks, with 16 weeks dedicated to the intervention and four weeks allocated for data collection (two~~2~~ weeks before and after the intervention).

Participants

The project was promoted through local newspapers and outreach to daycares, health centers, and older adult associations. Subsequently, 89 older adults expressed interest in participating in the project. Each prospective participant was then contacted and underwent a face-to-face interview as part of the initial screening process. The interviews aimed to confirm eligibility based on inclusion criteria: (a) age ≥ 65 years, (b) independent walking ability, and (c) ability to perform daily living tasks. Exclusion criteria included: (a) diabetes or cardiac diseases, (b) surgery within the last six months, and (c) active oncology disease. Ten participants were excluded based on these criteria (Figure 1).

Figure 1.



Flow chart of the present study.

During the individual interviews, participants who met the criteria were asked about their ability to take part in the exercise sessions. When participants were not available, they were placed in the CG and put on a waiting list to take part in other research projects. All participants were informed about the study's aims, potential benefits and risks and gave their written informed consent to be enrolled in the study.

At the conclusion of the screening process, 79 older adults were enrolled into two groups: the IG (N = 40, age, 68.50 ± 3.54 years) and the CG (N = 39, age, 72.08 ± 5.89 years). Both males and females were included in the study. The distribution of sexes (i.e., the biological attributes) within the IG and CG was as follows: [8 males, 32 females in IG] and [16 males, 23 females in CG]. The participants in the CG maintained their usual activities and did not engage in any new exercise programs throughout the study. Their physical activity levels were monitored using the *International Physical Activity Questionnaire—Short Form*, with results published elsewhere (Duarte Martins et al., 2024).

After the intervention, three participants from the IG (due to muscular discomfort, loss of contact, and participation in another exercise program at the same time) and two from the CG (due to a diagnosis of cancer and loss of contact) dropped out of the study.

Procedures

All assessments were scheduled in the morning between 8:30 a.m. and 10:30 a.m. Participants were instructed to arrive in a fast state, with an empty bladder, and have refrained from exercise, alcohol, and coffee consumption in the preceding 24 h. The measurements order was as follows: anthropometric, blood pressure, and HRV.

Measurements

Heart Rate Variability The study adhered to ~~Task Force (1996)~~Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996 guidelines incorporating recommendations from a key study for HRV measurements (Shaffer & Ginsberg, 2017). Participants underwent a ten-minute stabilization period in the dorsal decubitus position before a six-minute recording assessment. Sinus-origin heartbeat interval variation was gauged via a Polar® H10 HR connected to the Elite HRV® app (version 5.5.5, Elite HRV Inc., Asheville, USA) for recording and computation of HRV indices (Speer et al., 2020). The raw RR data, which were exported in a *.txt* file, were analyzed via Kubios® HRV software (version 3.5.0, University of Kuopio, Finland). Files were corrected for ectopic beats and artifacts using medium-level artifact correction (Moya-Ramon et al., 2022), with detailed algorithm descriptions in the Kubios software manual (Lipponen & Tarvainen, 2019). In the time domain, the computed indices included: (i) mean of RR intervals in milliseconds (ms) (mean RR); (ii) standard deviation of RR intervals in ms (SDNN); (iii) root mean square of successive RR interval differences in ms (RMSSD); (iv) percentage of successive RR intervals differing by >50 ms (pNN50); and (v) the stress index, which represents the square root of Baevsky's stress index (Baevsky & Berseneva, 2008). For the frequency domain, computed indices encompassed (i) LF (absolute power of the low-frequency band, 0.04–0.15 Hz, in ms^2); (ii) HF (absolute power of the high-frequency band, 0.15–0.4 Hz, in ms^2); (iii) the LF/HF ratio; and (iv) total power in ms^2. In the non-linear domain, indices included (i) p~~P~~oincaré plot standard deviation perpendicular to the line of identity in ms (SD1); (ii) poincaré plot standard deviation along the line of identity in ms (SD2); (iii) sample entropy (SampEn), measuring the probability of finding specific patterns in a short time series; and (iv) detrended fluctuation analysis, which describes short-term fluctuations (DFA α1). A single researcher conducted all the recordings and analyses.

Anthropometric and Blood Pressure The weight and height of the participants were measured through an electronic scale (TANITA®, MC 780 MA, Amsterdam, Netherlands) and a stadiometer (SECA® 220, Hamburg, Germany) to the nearest 0.01 kg and 0.1 cm, respectively. Each participant had to be dressed in light clothes with no shoes during the measurements. Afterwards, the body mass index (BMI) values were calculated via the standard formula: BMI = body mass (kg)/height^2 (m^2). Blood pressure was assessed using the Omron HEM-907 (Omron Healthcare Co. Ltd., Kyoto, Japan), with appropriately sized automated cuffs on the left arm. Two measurements, taken one~~1~~ min apart, were averaged after a five-minute seated rest period to ensure participant tranquillity. The device provided readings for systolic and diastolic blood pressure (SBP and DBP, respectively). Pulse pressure (PP) was subsequently calculated using the formula: PP = SBP – DBP.

High-Speed Resistance Training Protocol

The supervised training included one supervisor per exercise during each session. Lead investigators ensured uniformity by providing pre-session guidance to all supervisors. The HSRT program lasted 16 weeks, with three sessions per week (Mondays, Wednesdays, and Fridays) of 60–70 min. To offer more flexibility, each day included four sessions with five to ten participants, giving participants more scheduling options. Each session typically consisted of five to six exercises, with each exercise comprising two to three sets of six to ten repetitions (Fragala et al., 2019). Participants rested for ~~2~~two min between each set and exercise. Details of the biweekly, periodized training prescriptions are provided in Table 1.

Table 1.

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Overview of the h~~H~~igh-s~~S~~peed r~~R~~esistance t~~T~~raining ~~P~~program.

	Weeks 1–2	Weeks 3–4	Weeks 5–6	Weeks 7–8
Velocity target ranges (m/s)	>1.30	1.3 to 1.00	1.3 to 1.00	1.00 to 0.75

No. Exercises	5	6	5	6
No. Sets	2	3	3	3
No. Reps	10	10	10	8
Session RPE scores	11.06 ± 1.63	11.98 ± 1.27	12.02 ± 1.30	12.11 ± 1.24
Session heart rate (%HRmax)	57.00 ± 6.94	57.65 ± 6.55	58.46 ± 6.73	58.58 ± 6.61
Attendance rate (%)	100	97.41	97.04	99.62

	Weeks 9–10	Weeks 11–12	Weeks 13–14	Weeks 15–16
Velocity target ranges (m/s)	1.00 to 0.75	1.00 to 0.75	1.00 to 0.75	1.00 to 0.75
No. Exercises	6	5	6	5
No. Sets	2	3	3	3
No. Reps	10	8	10	6
Session RPE scores	11.61 ± 1.26	11.84 ± 1.60	11.42 ± 1.19	11.29 ± 1.15
Session heart rate (%HRmax)	59.01 ± 6.66	58.23 ± 6.00	57.26 ± 5.66	56.74 ± 6.01
Adherence rate (%)	95.93	97.04	98.89	97.78

Abbreviations: m/s, meters per second; No, number; RPE, rating of perceived exertion; %HRmax, percentage of heart rate maximum; %, percent.

The exercise sessions followed a standardized format, commencing with a 10 to 15-min warm-up phase, which incorporated activities such as brisk walking, joint mobilization exercises utilizing sand bottles, and engaging in recreational games at moderate-to-high intensity levels. The participants subsequently engaged in the main phase of the session, which encompassed 45–55 min. Finally, each session included a five to ten-minute cool-down phase involving stretching exercises. The main phase included the following upper- and lower-body exercises: squats on smith machine or with dumbbells (depending on each participant's ability); leg press, leg extension; calf raise; seated row; peck fly; lat pull down; and incline bench press (Technogym®, SPA, Cesena, Italy). Although eight machines were available, participants performed five or six exercises per session following a rotation scheme. During a typical six-exercise week, each session equally included three exercises for both the lower and upper body to ensure uniform workload distribution. In contrast, during a typical five-exercise week, the focus alternated between lower and upper body exercises each session (i.e., if Monday started with three lower and two upper body exercises, Wednesday would reverse this pattern, and the alternation continued subsequently).

This training protocol employs progressively increasing loads, tailored to the participants' mean concentric phase velocity for each set across all exercises. Specifically, the training protocol utilized three distinct velocity ranges to align with the intervention's objectives (Mann, 2016; Mann et al., 2015): during the 1st to 4th weeks, an average speed over 1.3 m/s was required (*starting strength*); from the 5th to 10th weeks, speeds were adjusted to between 1.3 and 1.0 m/s (*speed/strength*); and from the 11th to 16th weeks, speeds ranged from 1.0 to 0.75 m/s (*strength/speed*) (Table 1). If a participant consistently exceeded or fell below the target velocity ranges in two consecutive sessions, the load for the specific exercise was adjusted by 5% in the subsequent session. This individualized strategy ensured adherence to the prescribed velocity ranges for each week and each exercise, tailoring the training to the specific capabilities of each participant.

The first ~~2~~two weeks of the intervention focused on familiarizing participants with the exercises, including proper posture, movement patterns, and breathing techniques to ensure safety and effectiveness.

The participants' mean concentric phase velocity for every single set and exercise was monitored throughout the intervention using BEAST™ sensors (Beast Technologies, Brescia, Italy) (Vallejo et al., 2020). Each session featured at least six accelerometers, connected via Bluetooth to six separate cell phones, providing real-time feedback on instantaneous concentric velocity for each repetition to both participants and supervisors. At the end of each set, the devices autonomously calculated the mean concentric velocity. In addition, participants were verbally encouraged by supervisors to perform each exercise's concentric phase quickly and explosively through a full range of motion, while maintaining control during the eccentric phase, which lasted two to three seconds.~~3~~ s.

The rating of perceived exertion (RPE) scale, developed by Borg (1982) was employed to gauge participant effort. This subjective measure asks participants to assess their exertion from 11 (moderate) to 13 (somewhat hard) levels. Prior to the intervention, all participants underwent an orientation session where they were introduced to and familiarized with the scale, ensuring accurate self-assessment of exertion during exercise sessions. The participants also used HR monitors (Polar® M200) to record their HR during the training sessions. The predicted maximum HR (HRmax) was calculated via a formula based on age: HRmax = 206.9 – (0.67 × Age), proposed by Gellish et al.

(2007). Finally, no adverse events occurred during the intervention period, and the participants' attendance was registered.

Statistical Analyses

A priori sample size calculation was conducted using G*power software (University of Dusseldorf, Germany) (Faul et al., 2009), based on conditions outlined by Vieira et al. (2022): ANCOVA with fixed effects, main effects and interaction: f = 0.32, α = 0.05, power (1-β err prob) = 0.80, df = 1, number of groups = 2 and number of covariates = 1. The analysis indicated a minimum of 79 participants were required to achieve 80% power for rejecting the null hypothesis. All analyses were subsequently performed using the Statistical Package for the Social Sciences (IBM Corp., USA), significance set at $p < .050$ (two-tailed). An estimation technique approach was employed to overcome the shortcomings associated with traditional N–P null hypothesis significance testing (Cumming & Calin-Jageman, 2017; Ho et al., 2019).

The primary analysis was initially conducted using an intention-to-treat design, with missing values imputed via the expectation–maximization algorithm [two cases in the CG (5%) and three cases in the IG (7.5%)]. An *independent samples t-test* was then used to analyze the outcomes between groups at baseline. Subsequently, all outcomes were processed through analysis of covariance (ANCOVA), with post-intervention values as the dependent variable and pre-intervention values as the covariate, focusing on the group effect (CG *vs.* IG).

To complement the main results, differences in delta changes (post- minus pre-intervention values) between groups, as well as pre-to-post- differences within each group, were computed for all outcomes using specific spreadsheets (Cumming & Calin-Jageman, 2017). Gardner-Altman estimation plots display individual pre-to-post changes, group means, and mean differences with 95% confidence intervals (CIs) (Cumming & Calin-Jageman, 2017; Ho et al., 2019).

The effect sizes (ESs) were then calculated according to Cohen (1988), using Cohen's $d_{unbiased}$ (d_{unb}) through a specific spreadsheet (Cumming & Calin-Jageman, 2017). While the ESs for ANCOVA were expressed as partial eta-squared values (η_p^2) and interpreted using the following thresholds: 0.010–0.059 (small), 0.060–0.140 (medium), and greater than 0.140 (large), the pairwise comparisons' ESs, expressed as d_{unb}, were categorized as: less than 0.20 (trivial), 0.20–0.49 (small), 0.50–0.80 (medium), and greater than 0.80 (large). This unbiased estimate ensures the sampling distribution means equal the population parameter being estimated (Cumming & Calin-Jageman, 2017).

Results

Participants and Adherence

At baseline, there was a statistically significant difference between groups on age (d_{unb} = 0.73 [0.28, 1.19]). Specifically, the participants in the CG were older than those in the IG were (supplemental Table). The intervention had an adherence rate of 97.60%, ranging from 80% to 100%.

Heart Rate Variability

At baseline, there were no significant differences between the groups. Additionally, the ANCOVA results, summarized in Table 2, demonstrated significant intervention effects of the group factor in favor of the IG after the program.

Table 2.

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table. To view the actual presentation of the table, please click on the PDF located at the top of the page.

Analysis of cCovariance (ANCOVA) rResults cConsidering the gGroup Fgactor for hHeart rRate vVariability.

Measures	Control group			Intervention group			ANCOVA		
	Pre	Post	M_{diff} [95% CI]	Pre	Post	M_{diff} [95% CI]	*F*	*p*	η^2_p
General									
SBP (mmHg)	137.51 ± 16.18	136.62 ± 13.27	−0.89 [−5.24 to 3.44]	135.18 ± 14.91	127.56 ± 11.89[Comment: I made some minor changes here.]*,§	−7.61 [−12.26 to −2.97]§	10.958	**0.001**	0.126 [a]
DBP (mmHg)	80.82 ± 8.82	80.13 ± 9.17	−0.69 [−3.38 to	80.82 ±	80.00 ± 8.89	−0.83 [−3.65 to	0.006	0.938	0.001

			1.99]	10.19		2.00]			
PP (mmHg)	56.69 ± 11.48	56.49 ± 11.48	−0.21 [−4.14 to 3.73]	54.35 ± 12.42	47.56 ± 8.85*,§	−6.79 [−11.15 to −2.43]§	14.140	**<0.001**	0.157[b]
Mean HR (bpm)	62.74 ± 9.16	63.08 ± 7.71	0.33 [−1.66 to 2.33]	63.10 ± 11.42	59.80 ± 7.47	−3.30 [−7.12 to 0.52]	4.884	**0.030**	0.060[a]
Min HR (bpm)	57.87 ± 8.06	58.08 ± 6.66	0.21 [−1.62 to 2.03]	57.45 ± 9.52	55.05 ± 7.81	−2.40 [−5.41 to 0.61]	4.228	**0.043**	0.053[c]
Max HR (bpm)	69.46 ± 10.51	69.28 ± 9.51	−0.18 [−2.83 to 2.47]	69.25 ± 11.65	65.68 ± 7.91	−3.58 [−7.58 to 0.42]	3.953	**0.050**	0.049[c]
Time domain									
Mean RR (ms)	974.92 ± 137.86	965.74 ± 115.59	−9.18 [−38.46 to 20.09]	975.75 ± 152.14	1011.00 ± 117.92	35.25 [−15.61 to 86.11]	3.989	**0.049**	0.050[c]
SDNN (ms)	31.04 ± 19.77	26.17 ± 23.56	−4.86 [−10.37 to 0.64]	34.21 ± 33.33	34.19 ± 37.21	−0.02 [−7.66 to 7.61]	1.301	0.258	0.017[c]
RMSSD (ms)	31.24 ± 17.98	27.59 ± 16.85	−3.64 [−7.47 to 0.18]	30.86 ± 18.24	33.07 ± 22.92	2.21 [−6.65 to 11.07]	1.777	0.187	0.023[c]
pNN50 (%)	8.12 ± 11.02	5.41 ± 12.48	−2.71 [−5.97 to 0.55]	9.97 ± 18.26	11.60 ± 20.68	1.64 [−2.98 to 6.26]	2.943	0.090	0.037[c]
Stress index	13.24 ± 6.05	16.26 ± 5.30*	3.03 [1.17 to 4.88]	13.07 ± 5.58	13.84 ± 7.36	0.77 [−1.58 to 3.12]	3.152	0.080	0.040[c]
Frequency domain									
LF (ms^2)	274.49 ± 228.22	242.62 ± 208.62	−31.87 [−122.95 to −31.87]	353.03 ± 297.90	318.38 ± 260.53	−34.65 [−147.31 to 78.01]	1.367	0.246	0.018[c]
LF (nu)	52.04 ± 18.84	55.47 ± 18.09	3.43 [−3.22 to 10.08]	52.39 ± 17.30	49.14 ± 21.96	−3.25 [−9.09 to 2.59]	2.681	0.106	0.034[c]
HF (ms^2)	313.18 ± 351.21	315.69 ± 282.20	2.51 [−89.18 to 94.21]	262.63 ± 234.82	342.70 ± 308.19	80.08 [−31.04 to 191.19]	0.639	0.427	0.008
HF (nu)	47.88 ± 18.82	44.44 ± 18.06	−3.45 [−10.08 to 3.19]	47.51 ± 17.19	50.77 ± 21.89	3.26 [−2.56 to 9.09]	2.708	0.104	0.034[c]
Ratio LF/HF	1.54 ± 1.44	1.69 ± 1.19	0.15 [−0.37 to 0.67]	1.45 ± 1.14	1.62 ± 1.54	0.16 [−0.24 to 0.56]	0.017	0.897	0.001
TP (ms^2)	431.89 ± 298.38	417.95 ± 246.21	−13.95 [−129.71 to 101.81]	485.63 ± 319.18	537.45 ± 350.19	51.83 [−92.96 to 196.61]	2.748	0.102	0.035[c]
Non-linear domain									
SD1 (ms)	26.96 ± 21.75	20.77 ± 24.73	−6.19 [−12.77 to 0.38]	22.92 ± 16.01	24.92 ± 18.54	2.00 [−4.78 to 8.79]	2.202	0.142	0.028[c]
SD2 (ms)	33.95 ± 18.95	29.66 ± 23.31	−4.29 [−9.43 to 0.85]	34.17 ± 19.69	33.44 ± 18.91	−0.73 [−7.40 to 5.95]	0.872	0.353	0.011[c]
SampEn	1.60 ± 0.35	1.73 ± 0.32*	0.13 [0.01 to 0.25]	1.64 ± 0.39	1.65 ± 0.33	0.01 [−0.09 to 0.12]	2.265	0.136	0.029[c]

DFA α1	0.89 ± 0.27	0.99 ± 0.28*	0.11 [0.01 to 0.21]	0.87 ± 0.24	0.89 ± 0.32	0.03 [−0.06 to 0.12]	2.174	0.144	0.028 [c]

Abbreviations: CI, confidence interval; SBP, systolic blood pressure; DBP, diastolic blood pressure; mmHg, millimeter of mercury; PP, pulse pressure; HR, heart rate; bpm, beats per minute; ms, milliseconds; SDNN, standard deviation of RR; RMSSD; root mean square of successive RR interval differences; pNN50, percentage of successive RR intervals differing by >50 ms; LF, low frequency; HF, High frequency; nu, normalized units; TP, total power; SampEn, Sample entropy; DFA, detrended fluctuation analysis.

Pre- and post-values data are presented as the mean and standard deviation, whereas mean difference as the mean and 95% confidence interval.

Values in bold represent significant differences at $p<.05$.

*, $p<.05$ vs. pre-values.

§, $p<.05$ vs. control group's delta.

[Comment: The expression "Effect Size (...) thresholds" should appear near to the information on the table footnotes. After I sw the documento in the PDF version, I think that it is correct]Effect size (η^2_p) thresholds:

Table Footnotes

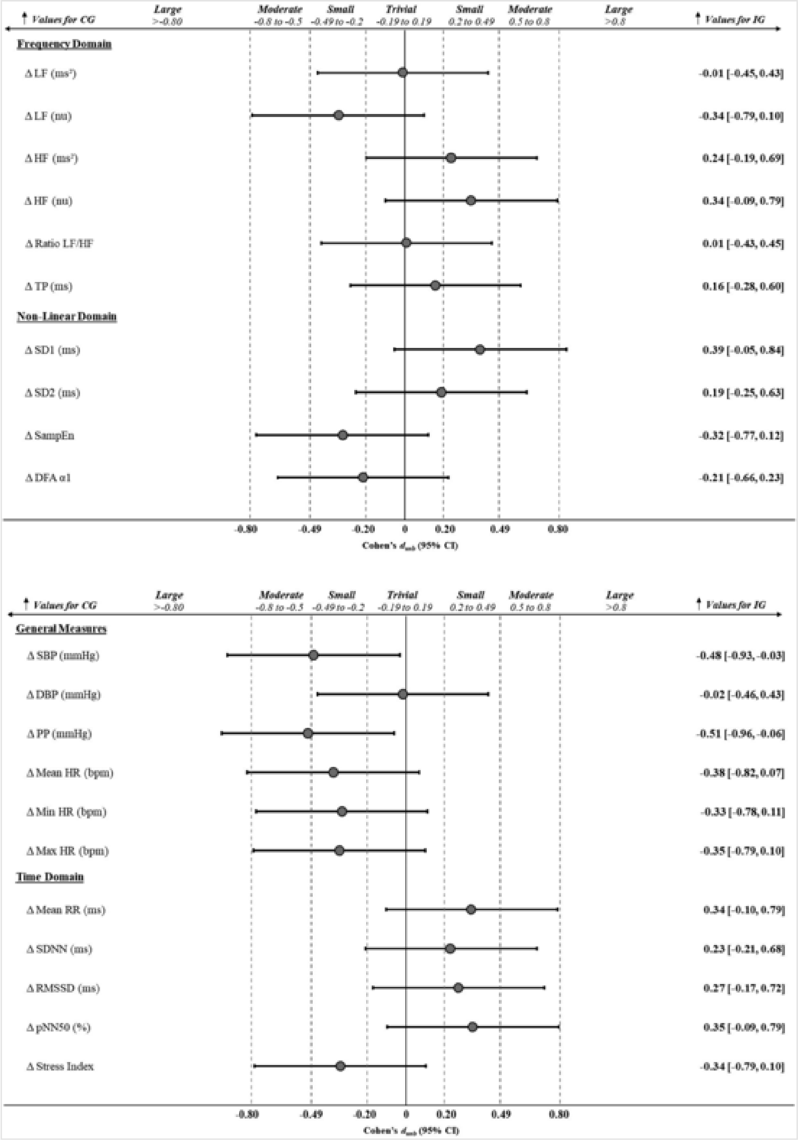
[a]medium effect: 0.060 to 0.140.

[b]large effect: >0.140.

[c]small effect: 0.010 to 0.059.

To complement the results, Figure 2 displays Cohen's d_{unb} (delta changes) between groups. Significant differences were observed for SBP and PP, favoring the IG (p = .036, d_{unb} = −0.48, p = .026, d_{unb} = −0.51, respectively). Other measures revealed small ESs without significant differences, including mean RR (d_{unb} = 0.34), RMSSD (d_{unb} = 0.27), pNN50 (d_{unb} = 0.35), stress index (d_{unb} = −0.34), HF (nu) (d_{unb} = 0.34), SampEn (d_{unb} = −0.32), and SD1 (d_{unb} = 0.39).

Figure 2.



[Comment: This is a problema here. Figure 2 is made up of two images. The correct order has been changed.
The correct order is, fisrt, the image with the general measures and time domains, and after that, the Frequency domain, and non-linear domain.]Cohen's d_{unb} for comparison of the delta changes (post- minus pre-intervention values) occurred for all measures between groups. The error bars indicate the uncertainty in the true mean changes with 95% confidence intervals. Abbreviations: CG,

control group; IG, intervention group; ms, milliseconds; SDNN, standard deviation of RR; RMSSD; root mean square of successive RR interval differences; pNN50, percentage of successive RR intervals differing by >50 ms; LF, low frequency; HF, high frequency; nu, normalized units; TP, total power; SampEn, sample entropy; DFA, detrended fluctuation analysis.

Within-group analyses revealed significant increases in the CG for the stress index (p = .002, d_{unb} = 0.52), SampEn (p = .035, d_{unb} = 0.37), and DFA α1 (p = .039, d_{unb} = 0.38). In contrast, the IG demonstrated significant decreases in SBP (p = .002, d_{unb} = −0.55), and PP (p = .003, d_{unb} = −0.62). The visual representations for all pre-to-post-intervention changes for all measures, and the ESs magnitudes for these changes are depicted in the supplemental file.

Discussion

This study examined the effects of a 16-week HSRT program on HRV in older adults. The findings align with previous research on the unclear effects of RT on HRV (Grässler et al., 2021; Kanegusuku et al., 2015; Kingsley & Figueroa, 2016). However, the observed trends suggest that HSRT may have the potential to increase parasympathetic activity at rest, as indicated in min and max HR, mean RR, RMSSD, and HF (nu). HSRT also appeared to prevent increased sympathetic tone and chaotic behavior, as indicated by the stress index and SampEn, respectively. Moreover, the IG exhibited significant enhancements in SBP and PP, potentially reducing the risk of cardiovascular events (Kannel, 2000).

The time domain indices reflect variability in the intervals between successive heartbeats (Shaffer & Ginsberg, 2017). While ANCOVA indicated a significant between-group difference in mean RR (*small* ES), it is important to note that mean RR does not directly measure variability (Sacha, 2014). Nevertheless, this result, combined with the significant difference in min HR, suggests that the IG experienced increased vagal tone post-intervention, which is linked to improved autonomic regulation and a reduced risk of cardiovascular diseases (Thayer et al., 2010). These findings align with Lin et al. (2022), who reported a 5% increase in mean RR after 24 weeks of high-load RT.

Even though no other time-domain indices showed statistically significant differences between groups, it is important to highlight the observed trends and changes in these measures. For instance, the IG revealed a *small* intervention effect for SDNN (Figure 2), as evidenced by the stabilization of pre-to-post intervention values, contrasted with a 16% decrease in the CG. This unclear result could suggest that RT programs may not significantly enhance the SDNN (overall ANS activity) (Shaffer & Ginsberg, 2017). Similarly, previous studies (Su et al., 2022; Wanderley et al., 2013) reported no significant improvements in SDNN following RT programs, further supporting the idea that RT may not strongly influence this aspect of autonomic regulation. For the RMSSD and pNN50, both indicators of parasympathetic activity (~~Shaffer & Ginsberg, 2017; Task Force, 1996~~Shaffer & Ginsberg, 2017; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), the ANCOVA presented a *small* ES, along with a delta-positive ES favoring the IG. Pre-to-post changes showed *small* declines in the CG (11% for RMSSD, 33% for pNN50) and *trivial* increases in the IG (7% and 16%, respectively). These trends suggest improved parasympathetic tone, supported by the ANCOVA results for HR Min and Max, potentially indicating decreased inflammatory response at rest (Heffernan et al., 2009) through vagal modulation (Bhati et al., 2019). Similar findings have been observed in RT studies (Gerage et al., 2013; Su et al., 2022), where vagal modulation may result from adaptations in baroreflex and cardiopulmonary reflexes (Rowell, 1974).

This study addressed the stress index, a metric that is highly sensitive to sympathetic tone (Baevsky & Berseneva, 2008). The ANCOVA results revealed a *medium* intervention effect between groups, favoring the CG. This result, accompanied with the *small* delta change in the CG, indicates an increase in sympathetic tone in the CG post-intervention. While no explanation can be given for CG, since their participants maintained their conditions throughout the study, HSRT appears to be effective in preventing age-related increases in sympathetic tonus in older adults (Simpson et al., 2014), warranting further confirmation in future research.

The study also yielded unclear results in the frequency domain, particularly in the LF index, which reflects both sympathetic and parasympathetic activity. The LF index is linked to baroreflex gain and plays a crucial role in ANS modulation via baroreflex action (Bhati et al., 2019; Grässler et al., 2021; Shaffer & Ginsberg, 2017). However, this modulation did not occur as expected in the present study. The ANCOVA revealed a *small* intervention effect between groups for both LF (nu) and (ms^2). While the pre-to-post intervention changes for LF (ms^2) showed *small* decreases in both groups (12% for CG and 9% for IG), LF (nu) presented contradictory results. These outcomes contribute to the study's ambiguity when compared to existing literature. Despite the fact that Gerage et al. (2013) also reported contradictory results between LF (nu) and LF (ms^2) after a RT program, Lee et al. (2022) reported that RT increased LF (ms^2) more than aerobic exercise (27% *vs.* 11%), while Cavina et al. (2021) found a 55% improvement following a pPilates program.

For HF (ms^2) and HF (nu), both indicators of parasympathetic activity, the pre-to-post intervention increases of 30% and 7% for the IG in HF (ms^2) and (nu), respectively, along with the *small* delta change favoring the IG (Figure 2), suggest positive trends. However, the ANCOVA, adjusted for pre-values, revealed only a *small* intervention effect between groups for HF (nu). This result aligns with findings from previous RT programs. For instance, Gerage et al. (2013) reported *small* intervention effects without significant differences after RT. Additionally, Wanderley et al. (2013) observed a 109% increase in HF (ms^2) after a RT, but the heterogeneity in the data precluded significant changes. Lastly, with respect to the TP index, which is indicative of total variability (Grässler et al., 2021), the study did not reveal a significant intervention effect. However, the ANCOVA results indicated a *small* intervention effect in favor of the IG. This, along with the delta results (Figure 2) and the pre-to-post *small* effect changes in the IG (10%), suggests a *small* increase in variability for the IG and a decrease for the CG. This result contrast with Figueroa et al. (2008), who demonstrated a significant effect on variability in females with fibromyalgia after RT. The reasons for increased variability in exercise programs remain unclear, with some attributing it to reduced angiotensin II levels, which inhibits vagal activity (Sacha, 2014), whereas other authors suggest that increased nitric oxide concentrations may modulate vagal activity (Chowdhary & Townend, 1999). This *small* observed effect on variability deserves further attention in future research.

Literature predominantly explores the impact of RT programs on the time and frequency domains, leaving a gap regarding the effects on the non-linear domain. A pioneering study conducted by Gerage et al. (2013) in older females revealed no significant differences following a RT program, but they noted a trivial positive effect in SD1 (6%) and SD2 (7%). Similarly, the present study found no significant differences between groups, but did reveal a *small* intervention effect favoring the IG for both indices after the intervention. Furthermore, the results for the CG are consistent with those of Gerage et al. (2013), showing *small* negative effects in both indices. SD1 and SD2 represent parasympathetic activity and overall beat-to-beat variability (sympathetic and parasympathetic activity), respectively (Grässler et al., 2021). The observed increases in SD1 may suggest a protective effect on vagal activity in participants who underwent RT, which aligns with the findings from previous studies (Bhati et al., 2019; Gerage et al., 2013).

The SampEn measures the probability of finding specific patterns within a short time series (Heffernan et al., 2009), with low values indicating greater regularity and predictability, while high values suggest more random or chaotic behavior (Stergiou, 2020). In the present study, the ANCOVA and delta results both indicated a *small* intervention effect favoring the CG, aligning with the pre-to-post changes, which showed a significant 8% increase in the CG, which may suggest that the CG developed a more complex pattern of HR fluctuations, potentially indicating a certain degree of randomness in the cardiac system. Previously, two key studies by Heffernan et al. (2007, 2009) performed in young populations demonstrated that RT programs can significantly increase SampEn post-intervention. The contradictory findings in the present study may be attributed to differences in the populations studied, as well as the fact that baseline SampEn values in this study were higher compared to those in the previous research.

For DFA $\alpha 1$, values near 1 (pink noise) help biological systems avoid excessive order or chaos, with the loss of fractal complexity compromising control systems and reducing adaptability (Iyengar et al., 1996). The ANCOVA revealed a *small* effect favoring the CG after the intervention. Although both groups increased their values and approached 1, only the CG showed a significant pre-to-post increase. To date, few studies have examined the effects of exercise programs on DFA $\alpha 1$ (Cavina et al., 2021; Heffernan et al., 2008) and the results remain unclear. Given its potential as a promising yet understudied indicator (Stergiou, 2020), DFA $\alpha 1$ should be included in future research.

Finally, although not the primary aim of this study, the HSRT program led to significant reductions in SBP and PP (Table 1). These findings are clinically meaningful, as improvements in PP may indicate a reduction in arterial stiffness, and reductions in SBP can substantially lower the risk of cardiovascular events (Kannel, 2000). Additionally, these results suggest that HSRT may provide benefits for hypertension prevalence and improved ANS control (Okada et al., 2012).

Despite the study's findings, few limitations must be acknowledged. First, the lack of randomization in group allocation may have introduced bias. Second, neither the assessor, intervention technicians, nor participants were blinded to the study objectives. Third, sympathetic and parasympathetic activity were measured indirectly, and breathing was not controlled during assessments. Although data collection met international HRV standards (five~~5~~ minutes to 24 h), the ~~6~~six-minute recording period may be considered a limitation. Finally, due to recruitment challenges and the limited availability of participants for the exercise sessions, the sex factor was not included in the statistical analyses. Acknowledging this limitation enhances transparency, helping to contextualize the findings and their applicability.

Conclusion

This clinical trial adds to the debate on the effects of RT programs on HRV in older adults. While statistical significance was not achieved, trends suggest that HSRT may positively impact parasympathetic activity at rest and help counter age-related increases in sympathetic tone and heart rhythm irregularities. Furthermore, findings suggest that HSRT may improve SBP and PP, which are critical indicators of cardiovascular health in older adults.

Lastly, the individualized velocity zones used highlight its potential to be a safe strategy for this population.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical Statement

Ethical Approval

The University of Evora approved all study procedures with clearance number 22030. All study procedures were followed in a compliance with the Declaration of Helsinki and according to the CONSORT (Consolidated Standards of Reporting Trials) guidelines. This clinical trial was registered on clinicaltrial.gov (ID: NCT05586087).

Informed Consent

All participants were informed about the study's aims, potential benefits and risks and gave their written informed consent to be enrolled in the study. All the informed consent procedures and documents involved in the study were reviewed and approved by the University of Evora.

ORCID iDs

Alexandre Duarte Martins https://orcid.org/0000-0003-1524-5601

Orlando Fernandes https://orcid.org/0000-0001-7273-8774

João Paulo Brito https://orcid.org/0000-0003-4357-4269

Bruno Gonçalves https://orcid.org/0000-0001-7874-4104

Rafael Oliveira https://orcid.org/0000-0001-6671-6229

Nuno Batalha https://orcid.org/0000-0001-8533-7144

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Alexandre Duarte Martins~~DM~~, upon reasonable request.*

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The corrections made in this section will be reviewed and approved by a journal production editor. The newly added/removed references and its citations will be reordered and rearranged by the production team.

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Supplemental Material

sj-pdf-1-jag-10.1177_07334648251332437.pdf

Supplemental Material - Effects of a 16-Week High-Speed Resistance Training Program on Heart Rate Variability Indices in Community-Dwelling Independent Older Adults: A Clinical Trial

Supplemental Material for Effects of a 16-Week High-Speed Resistance Training Program on Heart Rate Variability Indices in Community-Dwelling Independent Older Adults: A Clinical Trial by Alexandre Duarte Martins, Orlando Fernandes, João Paulo Brito, Bruno Gonçalves, Rafael Oliveira, and Nuno Batalha in Journal of Applied Gerontology

Supplemental Material

Supplemental material for this article is available online.

Queries and Answers

Q1

Query: Please note that there is a mismatch in the article title between manuscript and titlepage. As per style, we have followed the manuscript. Please check and confirm, amend if necessary.

Answer: Please update to

"Effects of a 16-week high-speed resistance training program on heart rate variability indices in community-dwelling independent older adults: A clinical trial"

Q2

Query: Please confirm that affiliations and corresponding author are displayed correct.

Answer: Thank you for your comment. I adjusted the affiliations.

Q3

Query: Please check whether the section heading styles are displayed correctly.

Answer: It is correct.

Q4

Query: Please confirm that reference “Mann (2016)” is displayed correct.

Answer: Thank you for your suggestion. I changed it.

Q5

Query: Please provide the issue number for references “Duarte Martins et al. (2024), Moya-Ramon et al. (2022), Shaffer and Ginsberg (2017) and Task Force (1996).”

Answer: Thank you for your suggestion.

I confirmed that:

Duarte Martins et al. (2024); Moya-Ramon et al. (2022); Shaffer (2017) do not have the issue number. Additionaly, I updated the Task Force (1996) reference.

Q6

Query: Please note that we cannot add/amend ORCID iDs for any article at the proof stage. Following ORCID’s guidelines, the publisher can include only ORCID iDs that the authors have specifically validated for each manuscript prior to official acceptance for publication.

Answer: At the Ethical Statement, I added the ORCID iDs for the rest of the authors. I could not add the ORCID at top of the manuscript, when I clicked on fetch, the system attributed my ORCID to the rest of the authors.

Q7

Query: Please confirm that all author information, including names, affiliations, sequence, and contact details, is correct.

Answer: Thank you. I updated the information.

Q8

Query: Please review the entire document for typographical errors, mathematical errors, and any other necessary corrections; check headings, tables, and figures.

Answer: Thank you. I checked the information. I added a comment on Table 1.

Q9

Query: Please confirm that the Funding and Conflict of Interest statements are accurate.

Answer: I checked. I added a comment on the Funding.

Q10

Query: Please ensure you have clearly identified all materials (e.g., text excerpts, illustrations, photographs, charts, maps, figures, tables, other visual material, etc.) that are not original to your article. Please refer to your publishing license and the Sage website at Preparing your manuscript | SAGE Publications Inc (

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Q11

Query: Please note that this proof represents your final opportunity to review your article prior to publication, so please do send all of your changes now.

Answer: Thank you very much for your attention.

I have carefully reviewed the document. If you need further clarifications, do not hesitate to contact me.