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Concurrent training based on an individual load-velocity ratio assessment as a better alternative to continuous endurance training to improve hypertension

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Hypertension remains a major global public health problem as the leading modifiable risk factor for cardiovascular death worldwide, responsible for more than 10 million deaths per year. The aim of the present study was to compare the effect of strength training, based on an individual load-velocity ratio assessment, concurrent with endurance training, and endurance training on blood and metabolic biomarkers, body composition and physical fitness in adults with hypertension. A randomised, single-blind, 12-week, prospective clinical trial was conducted. The study included 75 volunteers with an average age of 54 years, all of whom were hypertensive and sedentary. The sample was randomly assigned into three groups, strength training, based on an individual load-velocity ratio assessment, concurrent with endurance training, endurance training alone group, and a control group. The concurrent training group obtained greater reductions in SBP, DBP and MAP than the endurance training group, up to 12.8 mmHg, 6.8 mmHg and 8.6 mmHg respectively. The findings of the present study indicate that performing strength training, based on an individual load-velocity ratio assessment, concurrent with endurance training 2 days per week for 12 weeks, leads to improvements in metabolic and blood biomarkers, body composition, and physical fitness, of adults with hypertension, with these adaptations being superior to those produced by endurance training alone.

Keywords High blood pressure, Exercise, Combined training, Strength training, Velocity of execution, Endurance

Presently, hypertension remains the main modifiable risk factor worldwide for premature cardiovascular deaths[1]. Large epidemiological studies have shown an inverse relationship between the incidence of hypertension and exercise[2,3], understood as the set of ordered, structured and systematised movements aimed at improving health or physical condition. The most important clinical guidelines recommend exercise for subjects with hypertension, giving priority to endurance training[4–6]. The effects of endurance training on hypertension have been studied and are well described in the literature, showing reductions in the range of -4.9 to -12 millimetres of mercury (mmHg) for systolic blood pressure (SBP) and − 3.4 to -5.8 mmHg for diastolic blood pressure (DBP)[7,8]. Some guidelines recommend incorporating strength training as well[4], but few individuals comply with their prescription in depth[8]. Strength training has shown improvements ranging from − 3.0 to -4.7mmHg for SBP and − 3.2 to -3.8mmHg for DBP[7,8]. In addition to these guidelines, the available evidence shows that concurrent training, understood as training that combines strength and endurance work in the same training session, has also shown great benefits on health, specifically on hypertension[9–11]. Different controlled trials[12–14] showed significant reductions in SBP and DBP levels with concurrent programme interventions[9,15–17].

However, there are large differences among the protocols applied (frequency, intensity, volume, recovery time and characteristics, selection, organisation and distribution of exercises) in the different studies conducted[3,9].

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Despite scientific evidence showing improvements in blood pressure levels and other metabolic markers with combined or concurrent training, further research is needed to gain a more specific understanding of the dose-response relationship of this type of training and to standardize such training programs[9,18,19]. Recent studies indicate that due to the heterogeneity of research quality and heterogeneity in research protocols, further research is needed to determine the effect of these types of programs. This study is the first to apply a concurrent training program, considering the loss of running speed when prescribing repetitions[9,20]. One of the main problems is the lack of precision in the quantification of the work stimulus in strength training, which makes it very difficult to establish a dose-response relationship, as it is not known whether the intensity with which the participants trained was the same as that programmed and applied, as well as not knowing the degree of fatigue reached by each participant in each set or training session. A major difficulty in designing strength training programmes is how to accurately quantify and control the workload in order to obtain the greatest health and fitness benefits[21]. In order to address this problem, the focus has been on the velocity of execution[22,23]. This form of effort programming has brought about a paradigm shift in the control of strength training[21,23,24]. Despite all of the research on strength training through speed of execution and its positive results as a tool for training programming in the young population and athletes[24,25], cancer survivors[26], multiple sclerosis and older adults[27], there is still a gap in the health field in relation to the design of exercise programmes with this methodology, and especially in subjects with hypertension. Training methods such as velocity-based training should be prioritized over the repetitions until failure method to minimize the risk of overexertion[28,29].

Therefore, the aim of the present study was to compare the effect of strength training, based on an individual load-velocity ratio assessment, combined with endurance training, and endurance training alone, on blood and metabolic biomarkers, body composition and physical fitness in adults with hypertension, by actually knowing the exercise dose applied in the training.

Results

Table 1 shows the training monitoring results (HR, %HRmax, and RPE) for each group in each week. Participants showed a HR average of 113.74 ± 11, a %HR max of 145.14 ± 13.17, and an RPE of 3.16 ± 0.92; there were no significant differences between the intervention groups. Tables 2 and 3 show the pre-post intervention results for EG1, EG2 and CG. The group * time interaction is also presented.

EG1 and EG2 showed significant improvements in SBP (mmHg), DBP (mmHg), mean arterial pressure (MAP) (mmHg), pulse pressure (PP) (mmHg), rate pressure product (RPP), resting heart rate (RHR), lean mass (kg), body fat (%), waist circumference (cm), glucose (mg/dl), right handgrip (kg), left handgrip (kg), upper limb MPV (m/s 50%), %RM UB, lower limb MPV (m/s 60%), and VO_2peak (ml/kg/min). These changes were significantly different from the CG changes. Specifically, EG1 showed greater improvements of up to -12.8 mmHg in SBP, -6.8 mmHg in DBP and − 8.6 in MAP over EG2. Improvements in PP, waist circumference, upper limb PWV (m/s 50%), 1RM (LB), lower limb PWV (m/s 60%) and VO_2peak (ml/kg/min) were also greater in EG1 than in EG2.

Discussion

The aim of this present study was to compare the effect of concurrent training, based on an individual load-velocity ratio assessment, and endurance training alone on blood and metabolic biomarkers, body composition and fitness of adults with hypertension. One of the main findings of this study was that both groups, concurrent training and endurance training, showed improvements in blood biomarkers, reducing SBP, DBP, MAP, PP, RPP and RHR. However, the concurrent training group obtained greater reductions in SBP, DBP and MAP than the endurance training group, up to -12.8 mmHg, -6.8 mmHg and − 8.6 mmHg respectively. The same dynamics was observed in PP. The results obtained in the present study, on the reduction of blood pressure levels, were significantly greater than those obtained in previous studies with this same training modality, despite the fact that the training frequency was lower. These improvements may be due to different mechanisms such as endothelium-

	EG1			EG2		
	HR average	%HR max	RPE	HR average	%HR max	RPE
Week 1	118.88 ± 15.88	66.56	3.20 ± 1.41	117.75 ± 13.61	66.75	3.21 ± 1.22
Week 2	116.32 ± 12.58	65.60	2.88 ± 1.33	118.25 ± 12.02	67.25	3.21 ± 0.98
Week 3	118.12 ± 11.50	66.84	3.20 ± 1.08	118.21 ± 14.02	67.25	3.33 ± 1.09
Week 4	115.60 ± 13.24	65.32	2.84 ± 1.18	118.21 ± 13.28	67.21	3.17 ± 1.20
Week 5	115.92 ± 14.75	65.68	3.00 ± 1.26	118.83 ± 13.35	67.50	3.37 ± 1.06
Week 6	115.32 ± 14.18	65.20	2.96 ± 0.93	117.21 ± 11.62	66.58	3.12 ± 0.95
Week 7	115.84 ± 12.72	65.12	2.84 ± 1.03	119.79 ± 13.38	68.13	3.46 ± 1.18
Week 8	116.80 ± 15.57	65.72	3.16 ± 1.28	119.17 ± 11.37	67.75	3.21 ± 1.18
Week 9	119.36 ± 13.39	67.16	3.16 ± 1.14	121.33 ± 11.62	68.75	3.38 ± 1.31
Week 10	117.32 ± 12.56	66.36	3.08 ± 1.08	118.50 ± 10.47	67.29	3.08 ± 0.97
Week 11	120.00 ± 16.03	67.80	3.52 ± 1.33	122.04 ± 11.72	69.42	3.54 ± 1.22
Week 12	113.96 ± 13.25	64.56	2.84 ± 0.94	117.79 ± 10.89	67.00	3.21 ± 1.02

Table 1. Training monitoring results.

Outcome	Group	Pre-test (M ± ED)	Post-test (M ± ED)	Difference post-pre (M ± ED)	*p*	95% CI (Mpost-Mpre)	Group*time interaction		
							F	Sig	ES
SBP (mmHg)	EG1	142.441 ± 7.53	121.76 ± 8.52	− 21.68 ± 1.43**##	< 0.001	− 24.52; − 18.84	52.00	< 0.001	0.59
	EG2	144.12 ± 8.81	135.24 ± 8.98	− 8.88 ± 1.43**	< 0.001	− 11.72; − 6.04			
	CG	147.92 ± 11.84	146.56 ± 11.53	− 1.36 ± 1.43	0.343	− 4.20; 1.48			
DBP (mmHg)	EG1	88.28 ± 5.73	74.36 ± 5.10	− 13.92 ± 1.08**##	< 0.001	− 16.067; − 11.773	26.92	< 0.001	0.43
	EG2	89.68 ± 6.95	82.56 ± 6.26	− 7.12 ± 1.08*	< 0.001	− 9.267; − 4.973			
	CG	92.16 ± 7.28	89.32 ± 6.95	− 2.84 ± 1.08	0.01	− 4.987; − 0.693			
MAP (mmHg)	EG1	106.52 ± 5.28	90.12 ± 5.34	− 16.40 ± 1.00**##	< 0.001	− 18.393; − 14.407	50.50	< 0.001	0.58
	EG2	107.84 ± 6.06	100.12 ± 6.37	− 7.72 ± 1.00**	< 0.001	− 9.713; − 5.727			
	CG	110.60 ± 7.25	108.28 ± 7.80	− 2.32 ± 1.00	0.023	− 4.313; − 0.327			
PP (mmHg)	EG1	55.16 ± 7.49	47.40 ± 7.68	− 7.76 ± 1.45**#	< 0.001	− 10.642; − 4.878	10.43	< 0.001	0.23
	EG2	54.44 ± 10.08	52.68 ± 7.17	− 1.76 ± 1.45	0.227	− 4.642; 1.122			
	CG	55.76 ± 11.32	57.20 ± 8.52	1.44 ± 1.45	0.323	− 1.442; 4.322			
RPP	EG1	11254.00 ± 1735.96	8507.64 ± 1309.88	− 2746.36 ± 251.20**##	< 0.001	− 3247.117; − 2245.603	30.94	< 0.001	0.46
	EG2	11321.60 ± 1442.08	9957.36 ± 1358.10	− 1364.24 ± 251.20**	< 0.001	− 1864.997; − 863.483			
	CG	11827.56 ± 1474.97	11875.68 ± 1132.23	48.12 ± 251.20	0.849	− 452.637; 548.877			
RHR	EG1	78.40 ± 11.06	69.72 ± 8.49	− 8.68 ± 1.68**	< 0.001	− 12.032; − 5.328	8.99	< 0.001	0.20
	EG2	78.80 ± 11.03	73.72 ± 9.35	− 5.08 ± 1.68*	0.003	− 8.432; − 1728			
	CG	80.00 ± 8.23	81.28 ± 8.07	1.28 ± 1.68	0.449	− 2.072; 4.632			
BMI (kg/m^2)	EG1	27.43 ± 4.88	27.26 ± 4.57	− 0.18 ± 0.16	0.275	− 0.495; 0.143	0.27	0.76	0.01
	EG2	32.75 ± 5.09	32.56 ± 5.06	− 0.19 ± 0.16	0.234	− 0.511; 0.127			
	CG	31.91 ± 5.00	31.87 ± 5.10	− 0.04 ± 0.16	0.803	− 0.359; 0.279			
LBM (Kg)	EG1	28.99 ± 6.74	29.57 ± 6.77	0.58 ± 0.15**	< 0.001	0.279; 0.881	7.55	< 0.001	0.17
	EG2	30.84 ± 6.80	31.35 ± 6.81	0.51 ± 0.15**	< 0.001	0.207; 0.809			
	CG	30.56 ± 5.98	30.39 ± 5.92	− 0.17 ± 0.15	0.258	− 0.473; 0.129			
BFP (%)	EG1	32.63 ± 10.27	31.56 ± 9.76	− 1.07 ± 0.34*	0.002	− 1.739; − 0.405	4.41	0.02	0.11
	EG2	39.43 ± 8.04	38.47 ± 8.14	− 0.96 ± 0.34*	0.005	− 1.631; − 0.297			
	CG	37.70 ± 8.45	37.89 ± 8.70	0.20 ± 0.34	0.56	− 0.471;0.863			
VF (cm^2)	EG1	125.19 ± 58.84	119.75 ± 54.33	− 5.44 ± 2.13*	0.013	− 9.68; − 1.208	2.78	0.07	0.07
	EG2	183.40 ± 58.34	178.28 ± 58.00	− 5.12 ± 2.13*	0.018	− 9.36; − 0.888			
	CG	165.26 ± 54.59	166.10 ± 55.82	0.85 ± 2.13	0.691	− 3.388; 5.084			
Waist circumference (cm)	EG1	98.76 ± 10.54	92.16 ± 10.59	− 6.60 ± 0.84**#	< 0.001	− 8.265; − 4.935	19.25	< 0.001	0.35
	EG2	110.48 ± 13.13	107.28 ± 15.12	− 3.20 ± 0.84**	< 0.001	− 4.865; − 1.535			
	CG	105.80 ± 12.33	106.52 ± 12.65	0.72 ± 0.84	0.391	− 0.945; 2.385			

Table 2. Effect of combined training and endurance training on blood biomarker and body composition. SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; PP: Pulse Pressure: RPP: Rate Pressure Product; RHR: Resting Heart Rate; BMI: Body Mass Index; LBM: Lean Body Mass; BFP: Body Fat Percentage; VF: Visceral Fat. *Significantly different from CG value at the $p < 0.05$ level. **Significantly different from CG value at the $p < 0.01$ level. #Significantly different from other EG $p < 0.05$ level;. ##Significantly different from other EG value at the $p < 0.01$ level.

dependent vascular function and structure and sympathetic nervous system regulation, which are altered and may contribute to blood pressure elevation[7,30,31]. Endothelial dysfunction is a determinant factor in vascular function, and it is largely dependent on the bioavailability of nitric oxide (NO), which induces vessel relaxation and regulates blood pressure[32,33]. Strength training may act as a regulator of NO bioavailability by increasing vascular AMPK/PPARδ and suppressing endoplasmic reticulum stress, thereby improving and maintaining endothelial function[34,35]. These results may be in line with previous studies that showed how strength training significantly improved the endothelial function in different population groups[36,37]. In addition, this training modality may also improve vascular structure by increasing artery diameter and reducing vascular intima-media wall thickness[38]. On the other hand, in patients with hypertension, it is common to find an overactivation of the sympathetic nervous system and a reduction in parasympathetic control[30,39]. This physiological imbalance can also be normalised and regularised by strength training as previous research has shown[40,41].

In terms of body composition variables, lean mass, body fat, and waist circumference, both groups showed significant improvements as compared to the CG. Physical exercise induces changes in body composition through skeletal muscles, which are able to release hundreds of myokines into the bloodstream during muscle contraction that are able to interact with the muscle itself and with the rest of the body's organs, resulting in great health benefits[42,43]. These benefits include fat loss and increased muscle mass. The secretion of some of these

Outcome	Group	Pre-test (M ± ED)	Post-test (M ± ED)	Difference post-pre (M ± ED)	*p*	95% CI (Mpost-Mpre)	Group*time interaction		
							F	Sig	ES
CT (mg/dl)	EG1	199.72 ± 30.11	192.08 ± 29.21	− 7.64 ± 5.52	0.17	− 18.636; 3.356	6.08	< 0.001	0.15
	EG2	190.12 ± 41.09	183.12 ± 24.57	− 7.00 ± 5.52	0.209	− 17.996; 3.996			
	CG	191.76 ± 28.51	208.00 ± 29.89	16.24 ± 5.52	0.004	5.244; 27.236			
HDL (mg/dl)	EG1	54.44 ± 9.93	55.32 ± 11.29	0.88 ± 1.07	0.413	− 1.25; 3.01	0.85	0.43	0.02
	EG2	48.04 ± 7.06	49.72 ± 10.25	1.68 ± 1.07	0.12	− 0.45; 3.81			
	CG	48.76 ± 11.10	48.48 ± 12.49	− 0.28 ± 1.07	0.794	− 2.41; 1.85			
LDL (mg/dl)	EG1	120.62 ± 24.78	114.14 ± 24.55	− 6.47 ± 5.01	0.201	− 16.461; 3.517	6.34	< 0.001	0.15
	EG2	116.32 ± 36.92	108.22 ± 23.88	− 8.10 ± 5.01	0.111	− 18.085; 1.893			
	CG	116.82 ± 23.25	131.34 ± 31.29	14.52 ± 5.01	0.005	4.531; 24.505			
TG (mg/dl)	EG1	122.32 ± 59.16	113.72 ± 43.21	− 8.60 ± 8.08	0.291	− 24.726; 7.526	2.134	0.126	0.06
	EG2	126.16 ± 51.06	124.88 ± 39.08	− 1.280 ± 8.089	0.875	− 17.406; 14.846			
	CG	133.44 ± 64.33	147.96 ± 79.97	14.520 ± 8.089	0.077	− 1.606; 30.646			
Glucose (mg/dl)	EG1	98.16 ± 14.69	91.36 ± 10.77	− 6.800 ± 1.366**	< 0.001	− 9.524; − 4.076	15.99	< 0.001	0.31
	EG2	106.84 ± 13.44	99.84 ± 13.77	− 7.000 ± 1.366**	< 0.001	− 9.724; − 4.276			
	CG	97.24 ± 22.48	99.80 ± 19.94	2.560 ± 1.366	0.65	− 0.164; 5.284			
Handgrip RA (Kg)	EG1	32.36 ± 10.20	34.52 ± 11.45	2.16 ± 0.59**	< 0.001	0.983; 3.337	4.50	0.01	0.11
	EG2	34.40 ± 8.36	36.80 ± 10.30	2.40 ± 0.59**	< 0.001	1.223; 3.577			
	CG	32.64 ± 9.63	32.76 ± 9.76	0.12 ± 0.59	0.84	− 1.057; 1.297			
Handgrip LA (Kg)	EG1	30.00 ± 9.61	31.96 ± 11.10	1.96 ± 0.59**	0.001	0.787; 3.133	6.43	< 0.001	0.15
	EG2	32.44 ± 8.06	35.56 ± 11.04	3.12 ± 0.59**	< 0.001	1.947; 4.293			
	CG	30.20 ± 8.18	30.36 ± 8.22	0.16 ± 0.59	0.786	− 1.013; 1.333			
1RM (UB)	EG1	46.24 ± 23.68	65.12 ± 30.34	− 23.12 ± 2.31**##	< 0.001	− 27.715; − 18.525	0.81	0.45	0.02
	EG2	52.08 ± 21.08	61.16 ± 25.30	− 26.04 ± 2.31**	< 0.001	− 30.635; − 21.445			
	CG	54.24 ± 24.27	52.20 ± 23.20	− 27.12 ± 2.31	< 0.001	− 31.715; − 22.525			
Upper limb MPV (m/s 50%)	EG1	0.96 ± 0.03	1.20 ± 0.06	0.237 ± 0.013**##	< 0.001	0.211; 0.263	119.48	< 0.001	0.77
	EG2	0.97 ± 0.02	1.08 ± 0.07	0.112 ± 0.013**	< 0.001	0.086; 0.139			
	CG	0.97 ± 0.02	0.92 ± 0.04	− 0.050**±0.013	< 0.001	− 0.077; − 0.024			
1RM (LB)	EG1	73.08 ± 35.12	98.32 ± 41.42	− 29.23 ± 2.82**#	< 0.001	− 34.856; − 23.608	0.26	0.77	0.01
	EG2	74.48 ± 38.23	91.80 ± 42.49	− 29.79 ± 2.82**	< 0.001	− 35.416; − 24.168			
	CG	79.92 ± 32.18	76.44 ± 30.73	− 31.97 ± 2.82	< 0.001	− 37.592; − 26.344			
Lower limb MPV (m/s 60%)	EG1	0.99 ± 0.02	1.21 ± 0.05	0.225 ± 0.014**#	< 0.001	0.197; 0.253	98.01	< 0.001	0.73
	EG2	0.99 ± 0.02	1.15 ± 0.07	0.161 ± 0.014**	< 0.001	0.133; 0.189			
	CG	0.99 ± 0.02	0.95 ± 0.05	− 0.039 ± 0.014	0.006	− 0.067; − 0.011			
VO2p (ml/kg/min)	EG1	25.09 ± 3.82	30.87 ± 4.41	5.78 ± 0.34**#	< 0.001	5.108; 6.452	87.68	< 0.001	0.71
	EG2	22.18 ± 4.33	26.78 ± 5.29	4.60 ± 0.34**	< 0.001	3.929; 5.274			
	CG	21.62 ± 3.58	21.44 ± 3.58	− 0.18 ± 0.34	0.586	− 0.857; 0.488			
WATT	EG1	127 ± 30.55	167 ± 34.40	40 ± 2.36**	< 0.001	35.29; 44.71	98.33	< 0.001	0.73
	EG2	125 ± 35.36	162 ± 40.26	37 ± 2.36**	< 0.001	32.29; 41.71			
	CG	117 ± 32.05	115 ± 29.76	− 2 ± 2,36	0.4	− 6.71; 2.71			

Table 3. Effect of combined training and endurance training on metabolic biomarkers, and physical fitness. CT: Total Cholesterol; HDL: High Density Lipoprotein; LDL: Low Density Lipoprotein; TG: Triglycerides; RA: right arm; LA: left arm; 1RM: Maximum Repetition; UL: Upper Limb; LL: Lower Limb; MPV: mean propulsive velocity; VO2p: Peak oxygen consumption. *Significantly different from CG value at the $p < 0.05$ level. **Significantly different from CG value at the $p < 0.01$ level. #Significantly different from other EG $p < 0.05$ level. ##Significantly different from other EG value at the $p < 0.01$ level.

myokines promotes lipolysis and fatty acid oxidation, and induces the darkening of white adipose tissue[43,44]. It is important to note that the participants who performed the concurrent training obtained greater reductions in abdominal perimeter than the participants who performed the endurance training. These results may be due to the fact that strength training favours visceral fat loss by promoting metabolic adaptations in the abdominal subcutaneous adipose tissue, with a significant increase in lipolysis in this area both during and after the training[45,46].

Glucose values in both experimental groups were significantly reduced after the intervention versus the CG. This improvement could be due to the fact that exercise is able to improve insulin sensitivity starting from the first training session, as well as overall glucose homeostasis[47]. Exercise can increase glucose-6-phosphate levels

accompanying the increase in GLUT4, hexokinase, and glycogen synthase activity, leading to an increase in glucose tolerance and a decrease in blood glucose levels[34,47,48].

With respect to the physical condition variables, the participants in both experimental groups showed improvements in both their strength and cardiorespiratory capacity. With regard to strength gains, these were due to the fact that training, regardless of the modality, is able to provoke structural (peripheral) and neural (central) physiological adaptations, given that in all the exercises, muscle action is required to overcome resistance[21,22]. It is important to note that the concurrent training group obtained greater improvements in all the tests than the endurance training group. These results may be due to the specificity of the strength training, which provoked greater adaptations of the central nervous system thanks to a greater recruitment of motor units, their better synchronisation, and the frequency of the stimulus, as already shown in much of the literature[49–52].

Finally, the cardiorespiratory capacity also improved significantly after completion of the exercise programmes in both groups. Exercise promotes adaptations in skeletal muscle such as increased mitochondrial biogenesis and capillary density, thereby improving the ability to transport and use oxygen to generate energy[53–55]. Numerous studies have attributed a key role to peroxisome proliferator-activated receptor gamma coactivator 1α (PGC-1α) in these cardiovascular exercise-induced muscle adaptations[53,55–57]. Although there is a controversy in the literature that concurrent training may interfere with the adaptations induced by the different metabolic pathways, AMPK was activated by endurance training and m-TOR was activated by strength training. However, in this present study, it can be observed that the participants who performed the combined training showed greater improvements in VO_2peak than the participants who performed the endurance training. These results of concurrent training could be justified by the large adaptive reserve of sedentary subjects to any training programme. Previous work has shown that when a previously sedentary subject begins a concurrent training programme, the response to the two exercise modalities is positive and additive, promoting a generic adaptation in the absence of a true specificity of the training effect[58]. Another important factor to consider is the low degree of effort involved in strength training, which would explain why the possible interference would also be low, resulting in greater responses with respect to the maintenance of MHC IIX fibres[59], which could be translated into an improved ability to transport and use oxygen, an increased ability to apply force and a significant improvement in physical fitness.

This study has some limitations that should be taken into account for future research, such as the total intervention time, possibly with longer periods of time more significant results could have been obtained in some of the variables. Another point to consider is the lack of a strength group in which the intensity and volume were not quantified through the speed of execution, but in the traditional way, through the percentage of 1RM and a determined number of repetitions. This would have allowed us to know the effects of the different training programs on blood pressure levels and to continue advancing in the improvement of cardiovascular health. Finally, another limitation was the daily intake of the participants, the diet could have been controlled by making a daily dietary record. Despite the limitations, this would be the first study conducted in an adult population with hypertension, in which the intensity and volume of strength training had been programmed through the velocity of execution, which allowed individualising the work stimulus for each participant with the greatest possible precision, something unknown to date in this population group. In addition, this quantification of the training load allowed the degree of fatigue reached by the participants to be similar throughout the intervention period. This study will provide new insights into the scientific community's multicomponent impact on adults with hypertension. This is the first study to apply a strength-speed training protocol based on training in this population. It also compares it with aerobic training. Controlling this variable is vital for injury prevention[28,29], and the present study shows improvements in hemodynamic parameters, demonstrating reduced fatigue. This improves training control, enhances safety, and reduces the risk of injury.

The findings of the present study indicate that following a strength training programme, based on an individual load-velocity ratio assessment, combined with endurance training at a frequency of 2 days per week for 12 weeks, produces improvements in metabolic and blood biomarkers, body composition, and physical fitness of adults with hypertension, with these adaptations being superior to those produced by endurance training alone, even though the latter showed improvements, but to a lesser extent.

Methods

Study design

A randomised control trial was conducted. A simple randomization method with the software Microsoft Excel (version 2016) was used to distribute subjects into the Experimental Group 1 (EG1) ($n=25$), Experimental Group 2 (EG2) ($n=25$), and Control Group (CG) ($n=25$). Based on blood pressure, a randomised sequence was generated. The group assignment was blinded to the examiner and staff who performed the statistical analysis. The trial design was recorded (22/06/2023) in ClinicalTrial.gov (Code: NCT05914870) and followed the Consolidated Standards of Reporting Trials (CONSORT) guidelines and the Template for Intervention Description and Replication (TIDIER) checklist.

This randomized control trial obtained the approval by the Research Ethics Committee of the Universidad Católica de Murcia (CE062107), in accordance with the Declaration of Helsinki. The Informed Consent document was signed by all participants prior to the start of the study.

Participants

The study included 75 volunteers, 36 women and 39 men (54.45 ± 6.72 years). Figure 1 shows a flowchart representing the Consolidated Standards of Reporting Trials.

The inclusion criteria were: (a) adults with diagnosed hypertension and with follow-up by their primary care physician; (b) being within the age range of 40–65 years old and (c) not having exercised during the last year. The exclusion criteria were: (a) subjects with osteoarticular or musculoskeletal problems that could interfere with

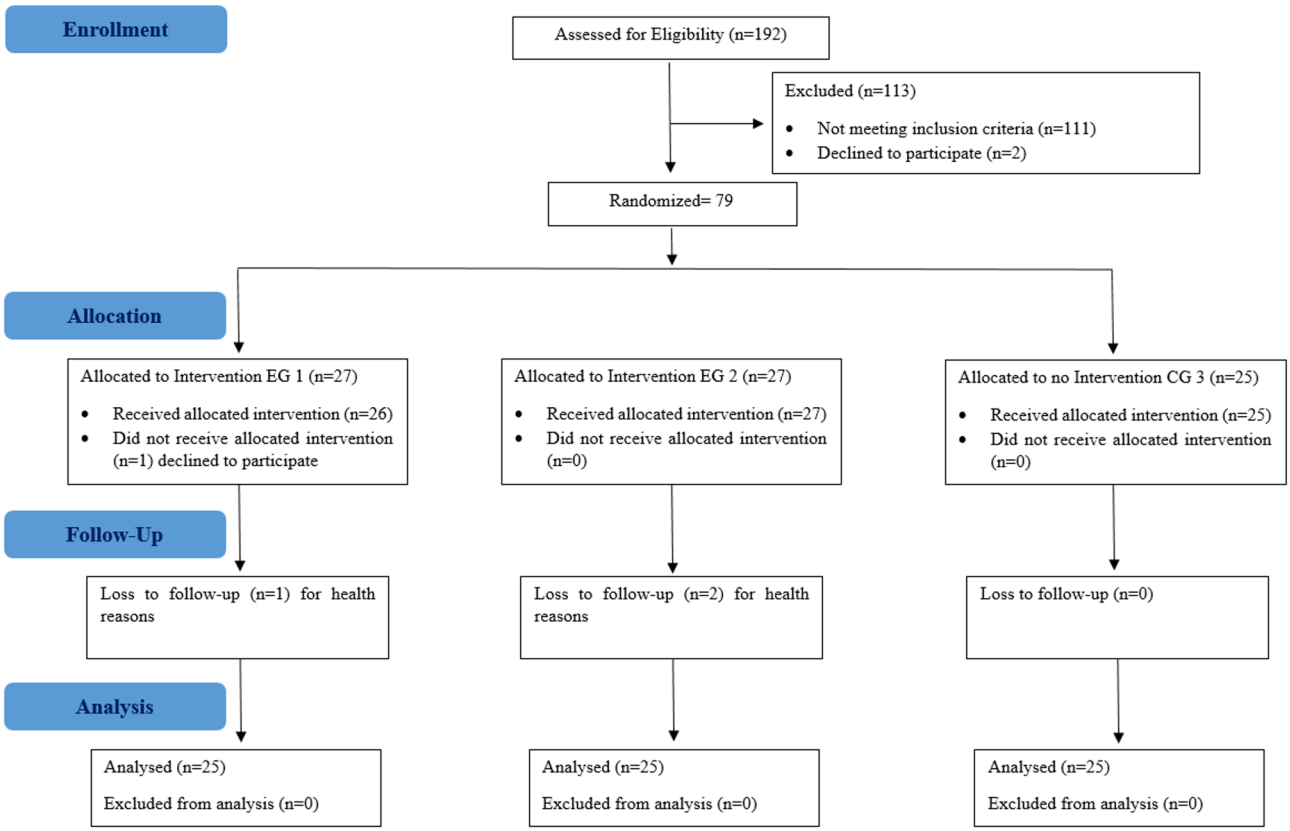

Fig. 1. Consolidated standards of reporting trials flow diagram.

the performance of daily activities; (b) acute or chronic disease that could compromise the subject's autonomy and functional independence; or (c) neurological problems. The participants were instructed not to modify their lifestyle: eating habits and physical activity. The sample size and power calculations were performed using Rstudio 3.15.0 software. The significance level was set at $\alpha = 0.05$ and the power to 95% ($1\text{-}\beta = 0.95$). The standard deviation was used according to the standard deviation for blood pressure from previous studies[60]. A total of 10 mmHg in SBP and 5 mmHg in DBP were set as a minimum clinically significant change[61]. Considering a dropout rate of up to 9.57%[62], 27 participants in each group needed to be enrolled. The final sample provided a power of 95% if found between and within a variance of 4.9 mmHg of SBP and 3.39 mmHg in DBP.

Assessment

Two researches conducted all pre-post intervention measurements under the same conditions. Two weeks before the initial evaluations, all participants were informed of the prerequisites for each of the tests.

Two assessment sessions were necessary, 48–72 h apart from one another. The assessments were carried out in a laboratory with a standardised temperature of 24 °C. The measurements were taken in the morning, between 8:00 and 13:00 h from Monday to Saturday. Height was measured with a SECA 217 stadiometer (SECA, Germany). The Body Composition Analysis was performed with the Body Composition Analyser InBody 770 through the measurement method DSM-BIA (Bioelectric Impedance Multifrequency and Direct Segmental)[63,64]. Prior to the assessment, the participant was informed that they should come to the appointment fasting or at least 3 h after the last meal; 30 min before the assessment, they should not have ingested any liquids; they should not have been to the toilet; they should not have drunk alcohol 48 h before; and they should not wear any metal elements in contact with the skin (rings, bracelets or watches). For the measurement the participant completely cleaned his hands and feet completely with the InBody tissue and stood in front of the equipment; they climbed onto the InBody stepping barefoot on the foot plates and holding the hand electrodes, with arms outstretched without touching the sides of the body and without being allowed to speak or move until the end of the test.

Waist circumference was measured according to the ISAK protocol[65] with a non-elastic tape measure (SECA 200; SECA). The participant stood with their feet together, arms crossed over the chest and relaxed abdomen; the measurement was taken at the narrowest point of the waist at the end of a normal exhalation.

Haemodynamic parameters were assessed using the BPBIO-750 sphygmomanometer, clinically validated according to the ESH protocol[66]. The measurement was performed on the left arm, supported and relaxed on the blood pressure monitor, with the cuff at the level of the heart. Three measurements were taken within 3 min of each other. The mean values of the measurements were taken as a reference[67].

Blood samples were taken by puncturing the cubital vein. The samples were stored in sterile blood tubes in refrigerated conditions (4–8° degrees Celsius (C)) for no longer than 4 h and then sent to testing according

to standardized procedures. Blood glucose was measured using an ultraviolet assay with hexokinase; total cholesterol (TC), high density lipoprotein (HD), and low-density lipoprotein (LDL) were measured using a homogeneous enzymatic colorimetric test, and triglycerides (TG) were measured using enzymatic assay (Cobas 8000 C702, Roche, Mannheim, Germany).

The manual grip force was measured with the Baseline manual hydraulic dynamometer. For the measurement, the participants had to remain seated on the chair with their back against it, feet on the floor, right elbow flexed at 90º, and the wrist in a neutral position. Then, they had to grip the dynamometer with their thumb upwards; once in the correct position, the subject squeezed the grip as tightly as possible for 3 s. The highest peak strength (kilograms (kg)) recorded between the two attempts was considered for analysis[68].

The assessment of lower and upper body strength was carried out through the velocity of execution in the concentric action by means of the Velowin optoelectronic encoder (Velowin v.1.7.232, Instruments and Sports Technology; Murcia, Spain)[24,25]. In addition, the velocity of execution allowed for high precision programming of training intensity and volume. Two tests per body region were carried out, one of progressive loads, to estime 1RM and determine the training load, and the other of loss of velocity in the set (VL%), to establish the number of repetitions, on a Multipower BH TR machine, and the exercises performed were the squat and the bench press[24,25,69]. For reasons of standardization and safety, the concentric phase of each exercise was performed at the maximum possible velocity and the eccentric phase at a slow and controlled velocity, between 3 and 4 s in duration. The squat and bench press tests were performed in different sessions and their order was randomised. All participants performed 2–3 pre-test repetitions in the same evaluation session, they were instructed to move the barbell at the maximum possible speed in the concentric phase and in a slow and controlled manner in the eccentric phase.

For the progressive load test with the squat exercise, the participant stood with knees and hips extended, legs approximately shoulder-width apart and the Multipower bar resting on the upper back. The subject performed the parallel squat downwards in a continuous motion until reaching 80–90° of knee flexion, touching the reference bench, and immediately climbed back up to the starting position at the maximum possible velocity keeping the feet in contact with the ground (without jumping), although the heels could be lifted slightly[70,71]. The initial external load for the squat exercise was set at 15 kg for women and progressively increased individually with 5 kg, 2.5 kg and 1.25 kg discs. For men, it was set at 25 kg and progressively increased individually with 10 kg, 5 kg and 2.5 kg discs. Both, males and females executed the exercise until reaching a mean propulsive velocity (MPV) between 0.76 –0.68 $m{\cdot}s^{-1}$, which corresponds to 75%-80% 1 repetition maximum (1RM) in this exercise. In the test, 5 sets were performed, in the first set the participant performed 3 reps with a very light load which allowed them to move the bar at a lower velocity of 1.28 $m{\cdot}s^{-1}$ (less than 40% 1RM); in the second set, they performed 3 reps with a light load that allowed them to move the bar between 1.28 and 1.21 $m{\cdot}s^{-1}$ (40%-45% 1RM); In the third set, he performed 3 reps with a medium load that allowed him to move the barbell between 1.14 and 1.00 $m{\cdot}s^{-1}$ (50%-60% 1RM); In the fourth set, they performed 2 reps with a medium-high load that allowed them to move the barbell between 0.92 –0.84 $m{\cdot}s^{-1}$ (65%-70% 1RM); and in the fifth set he performed 1 rep with a high load that allowed them to shift the bar between 0.76 and 0.68 $m{\cdot}s^{-1}$ (75%-80% 1RM). The velocity loss (VL) test was performed 24 h after the progressive load test. For this test, a medium workload was defined, the participant was allowed to move the barbell to 0.99 ± 0.02 $m{\cdot}s^{-1}$, assuming 60% of 1RM, and a low VL magnitude of 10% was set for the squat exercise. The test ended when the subject reached the prescribed VL% limit, regardless of the number of repetitions performed in the set[70,72,73]. For the progressive load test with the bench press exercise, the participant was positioned lying on a horizontal bench with feet resting on the back bar of the Multipower to avoid lumbar arching; hands were placed on the non-slip area of the bar 5–7 cm wider than shoulder width apart. The position of the bench was adjusted so that the bar was aligned with the chest line of each participant. During execution, the eccentric phase of each repetition was performed with controlled speed until the bar was 1–2 cm above the chest, they stopped for 1s, to minimise the contribution of the stretch-shortening cycle, and then pushed the bar at maximum velocity. The initial external load for bench press exercise was set at 10 kg for women and progressively increased individually with 5 kg, 2.5 kg and 1.25 kg discs. For men, it was set at 20 kg and progressively increased individually with 10 kg, 5 kg and 2.5 kg discs. Both, males and females executed the exercise until reaching an MPV between 0.55 and 0.47 $m{\cdot}s^{-1}$, which corresponds to 75%-80% 1RM in this exercise. For the test, 5 sets were performed, in the first set the participant performed 3 reps with a very light load which allowed them to move the bar at a lower speed of 1.13 $m{\cdot}s^{-1}$ (less than 40% 1RM); in the second set, they performed 3 reps with a light load that allowed them to move the bar between 1.13 and 1.04 $m{\cdot}s^{-1}$ (40%-45% 1RM); In the third set, they performed 3 reps with a medium load that allowed him to move the barbell between 0.95 –0.87 $m{\cdot}s^{-1}$ (50%-60% 1RM); In the fourth set, they performed 2 reps with a medium-high load that allowed them to move the barbell between 0.70 –0.62 $m{\cdot}s^{-1}$ (65%-70% 1RM); and in the fifth set they performed 1 rep with a high load that allowed him to shift the bar between 0.55 and 0.47 $m{\cdot}s^{-1}$ (75%-80% 1RM). The velocity loss test was performed 24 h after the progressive load test. For this test, a medium workload was defined, which allowed the participant to move the barbell to 0.97 ± 0.03 $m{\cdot}s^{-1}$, assuming 50% 1RM, and a low velocity loss magnitude of 15% was set. The test ended when the subject reached the prescribed VL% limit, regardless of the number of repetitions performed in the set[24,72,74].

Cardiorespiratory capacity was assessed using a maximal effort test on the IC7 high-precision cycloergometer with a direct WattRate power meter and an exact magnetic resistance of 300 degrees. The steps lasted 2 min and the pedalling cadence was 70-80ppm. In the first 2 min, the subject pedalled at 50w, after which the load was increased by 25w every 2 min; the test ended when the participants voluntarily decided to stop due to fatigue that prevented them from continuing with the test[75]. The test lasted between 10 and 15 min. The maximum working power was determined as the last 2 min step that the subject was able to complete without interruption, and the ACSM formula was used for the estimation of VO_2max[76]. The following formula was used: VO_2max = (1.8 * workload (kg.m.min-1))/body weight (kg) + 3.5 + 3.5 (where one watt = 6.12 kg.m.min-1). For intensity control

Set	Load	Repetitions	1RM	Squat exercise speed	Bench press speed
1	Very light	3	< 40%	< 1.28 m·s^{-1}	< 1.13 m·s^{-1}
2	Light	3	40%-45%	1.28–1.21 m·s^{-}	1.13–1.04 m·s^{-1}
3	Medium	3	50%-60%	1.14–1.00 m·s^{-1}	0.95 –0.87 m·s^{-1}
4	Medium-high	2	65%-70%	0.92 –0.84 m·s^{-1}	0.70 –0.62 m·s^{-1}
5	High	1	75%-80%	0.76–0.68 m·s^{-1}	0.55–0.47 m·s^{-1}

Table 4. Description of the 5-set protocol.

the heart rate (HR) was monitored at all times using the MyZone MZ-3 Heart Rate Monitor[77]. To address the potential limitations of this method of HR monitoring, we simultaneously recorded the subjective perception of exertion (RPE)[78,79] every 10 min during the session, and monitored and recorded the training in watts at all times with the WattRate direct measurement potentiometer[80] via a computer installed in the cycloergometer, helping participants to achieve the prescribed work intensity for each training protocol. In addition, blood pressure and oxygen saturation were monitored during the stress test.

Procedure

The intervention period lasted 12 weeks, 2 days/week, with the sessions lasting 60 min each.

EG1 performed strength training, based on an individual load-velocity ratio assessment, combined with endurance training. The first phase was a warmup of 5 min of Nordic walking on an elliptical bike, joint mobility exercises, and dynamic stretching; and 2 sets of squat and bench press with a light weight. The main phase consisted of 20 min of strength work with a selection of 2 exercises: squat (60% 1RM) and bench press (50% 1RM). For both exercises, 3 sets were performed, with a 3 min rest between sets and the number of repetitions individualised for each participant by the initial speed loss test; the average number of repetitions performed for the squat exercise was 8 repetitions and for the bench press exercise 7 repetitions (Table 4).

The initial absolute loads corresponding to 50% of 1RM in bench press and 60% of 1RM in squat were not modified throughout the intervention period, nor were the number of repetitions set for each participant. Regarding the selection of volume for each of the exercises used, and following a minimum stimulus criterion, we considered the scientific literature regarding the control of this variable by means of the loss of velocity in the sets (VL%), as a more precise way of establishing the degree of effort[24,72,81]. In this way, it was determined that the same loss of velocity in the sets allows for a similar degree of effort or fatigue to be reached between subjects who performed a training protocol with the same relative intensity, although they performed different numbers of repetitions[69,74]. The analysis of the studies already carried out allowed establishing a VL of 25–30% in squat and 35–40% in bench press, as moderate-high degrees of effort beyond which the degree of fatigue begins to have important repercussions at a metabolic and mechanical level, causing a significant reduction in physical capacity and performance[24,69,74]. In strength training, speed losses in the series of less than 20–30% in exercises such as squats or bench presses are associated with better physical fitness results. A speed loss in the set between 10 and 20% is sufficient to achieve significant physical condotion benefits, while losses greater than 30% are closer to muscle failure, which may not be optimal for a health improvement goal. To guarantee the use of a low training volume, for the intensity rates proposed in the present study, VL% was set at 10% for the squat exercise and 15% for the bench press in order to ensure improvements in physical condition and reduce potencial risks, given that the study population is sedentary.

In the last 20 min of the main phase, the participants performed continuous endurance training on a cycloergometer. The training intensity was programmed using the Heart Rate Reserve (HRR) using Karvonen's formula (HRR = HRmax - HRrest); once the HRR was known, the prescribed intensity percentage was calculated (% HR= (HRR × % intensity) + HRrest)[82]. As this was a sedentary population, and the exercise tolerance of each subject was unknown, a moderate intensity range was prescribed for the entire intervention, between 55% and 70% of their heart rate reserve (HRR), in order to achieve the metabolic adaptations already described in the scientific literature[83]. Finally, the post-training phase included 10 min of cool down and static stretching.

As this was a sedentary population, and the exercise tolerance of each subject was unknown, a moderate intensity range was prescribed for the entire intervention, between 55% and 70% of their heart rate reserve (HRR), in order to achieve the metabolic adaptations already described in the scientific literature.

EG2 performed continuous endurance training. The warm-up was the same as EG1 except for the squat and bench press sets. In the main phase, they performed 40 min of continuous endurance training on a cycloergometer, taking into account the same protocol as in EG1. The post-workout phase was the same as EG1.

Statistical analysis

The Kolmogorov–Smirnov test and Mauchly's W-test were used to evaluate the normality and the sphericity of the data. The mean and standard deviation were calculated from the quantitative variables, and frequency and percentage were used for the qualitative variables. A two-way ANOVA analysis of variance with repeated measurements and Bonferroni's correction were used to compare the changes from the baseline between groups, evaluation time interaction, and evaluation time. To protect against a Type I error, Bonferroni's correction was used to achieve a $p = 0.005$ for statistical significance. The effect size was calculated using partial eta-squared (η2p) for analysis of variance, and was defined as small: ES ≥ 0.10; moderate: ES ≥ 0.30, large: ES ≥ 1.2; or very large: ES ≥ 2.0; an error of $p \leq 0.05$ is established[84]. All analyses were based on intention-to-treat with an error of $p < 0.05$. The statistical analysis was performed using the statistical package SPSS 24.0 for Windows.

Data availability

Data will be available upon request to the corresponding author.

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I.L.-R. and N.G.-G: conceived and designed the experiments; I.L.-R., F.L.R.-P., M.D.M., J.R.H.-E. and N.G.-G.: performed the experiments; I.L.-R. and N.G.-G: analysed the data, I.L.-R. and N.G.-G: wrote the manuscript; I.L.-R., F.L.R.-P., M.D.M., J.R.H.-E. and N.G.-G.: proofed the manuscript. All authors have proofed the article.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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