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High-intensity interval training on body composition, functional capacity and biochemical markers in healthy young versus older people

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ABSTRACT

Background: The aim of the following study was to identify the effects of a 12-week high-intensity interval training (HIIT) program on the modification of parameters of body composition, functional capacity as well as lipid and glucose homeostasis markers in healthy young people versus older adults.
Design: Experimental trial.
Methods: Healthy young (YNG, 21 ± 1 years, BMI 26.01 ± 2.64 $kg{\cdot}m^{-2}$, n = 10) and older (OLD, 66 ± 5 years, BMI 27.43 ± 3.11 $kg{\cdot}m^{-2}$, n = 10) males were subjected to 12 weeks of HIIT. Prior to and immediately after the HIIT program, dual-energy X-ray absorptiometry, dominant leg strength one-repetition maximum (1-RM), maximal oxygen uptake (VO_{2max}) and physical performance tests were performed. Blood samples were also taken.
Results: Flexibility ($P = 0.000$), static balance ($P = 0.004$), timed up and go test (TUG) ($P = 0.015$), short physical performance battery (SPPB) ($P = 0.005$), dominant leg strength 1-RM ($P = 0.012$), and VO_{2max} ($P = 0.000$) were better in YNG versus OLD. HIIT improved the % whole-body fat mass ($P = 0.031$), leg lean mass ($P = 0.047$), dominant leg strength 1-RM ($P = 0.025$), VO_{2max} ($P = 0.000$), fasting cholesterol ($P = 0.017$) and fasting glucose ($P = 0.006$). TUG was improved by the training only in the OLD group ($P = 0.016$), but insulin ($P = 0.002$) and the homeostasis model assessment - insulin sensitivity (HOMA-IS) ($P = 0.000$) decreased only in the YNG group. HOMA-IS was correlated positive with BMI ($R = 0.474$, $P = 0.035$) and with whole-body fat mass ($R = 0.517$, $P = 0.019$).
Conclusions: HIIT for 12 weeks improves parameters of body composition, functional capacity and fasting serum lipid and glucose homeostasis markers in healthy young and older participants. Young people are shown as benefiting more.

1. Introduction

Aging process is characterized by changes in body composition, being the decrease in skeletal muscle mass the main feature. This is part of the phenomenon called “sarcopenia” (Rosenberg, 1997). Its prevalence is ~25% around 70 years of age and increases to 40% at 80 years (Thompson, 2009). Multiple factors have been related to the etiology of sarcopenia, including skeletal muscle fiber atrophy, physical inactivity, high levels of pro-inflammatory cytokines, increased free radical production, decrease in the antioxidant defense system, malnutrition and low release of anabolic hormones (Giovannini et al., 2008). In addition, in older adults the skeletal muscle presents anabolic resistance, i.e., the anabolic response is attenuated to amino acids and/or resistance training (Churchward-Venne et al., 2014; Morton et al., 2018).

The strategies that are used to mitigate skeletal muscle atrophy due to aging include oral supplements, electrostimulation, mechanical loads and/or physical exercise (Dirks et al., 2015; Magne et al., 2013;

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Marzuca-Nassr et al., 2017; Wall and van Loon, 2013; Chodzko-Zajko et al., 2009; Mora and Valencia, 2018). The variables to consider in the volume of physical exercise applied are training intensity (work per time unit), duration (time per session) and frequency (sessions per week) (MacInnis and Gibala, 2017). High-intensity interval training (HIIT) is one of the various types of physical exercise and is characterized as short periods of high-intensity exercise accompanied by rest at intervals repeated over time (Mancilla et al., 2014; Robinson et al., 2017).

At the moment, great emphasis is being placed on the effects of HIIT on aging at the aerobic or muscle level separately. However, studies in animal and human models suggest that HIIT could be of comprehensive benefit (body composition, physical performance, oxidative stress and inflammation markers) to fighting the changes produced by aging (Robinson et al., 2017; Li et al., 2018).

It has been shown that HIIT as cardiometabolic exercise has benefits in young people and older adults on body weight, regulation of physiological parameters like blood pressure, increase in VO_{2max}, and reductions in glucose levels and triglycerides (Mancilla et al., 2014; Robinson et al., 2017; Grace et al., 2018; Herbert et al., 2017; Osawa et al., 2014; Sculthorpe et al., 2017). At muscle level, HIIT increases the cross-sectional area of quadriceps in healthy middle-aged adults (20–48 years of age) (Osawa et al., 2014) and diabetic middle-aged adults (45.4 ± 7.2) (Boudou et al., 2003). In this regard, there is evidence that HIIT produces an increase in *in vivo* myofibrillar and sarcoplasmic fractional synthetic rate in older adults (Bell et al., 2015), improves insulin resistance (Hwang et al., 2016), increases IGF-1 (Herbert et al., 2017) and increases fat-free mass and lower limb muscle power (Sculthorpe et al., 2017).

In light of all this information, the aim of the following study was to identify the effects of a 12-week HIIT program on the modification of parameters of body composition, functional capacity as well as fasting serum lipid and glucose homeostasis markers in healthy young people versus older adults.

2. Methods

2.1. Participants

Ten young people (YNG; age, 21 ± 1 years and weight, 76.59 ± 10.58 kg; body mass index [BMI], 26.01 ± 2.64 $kg{\cdot}m^{-2}$) and ten older adults (OLD; age, 66 ± 5 years; weight, 78.53 ± 11.59 kg; BMI, 27.43 ± 3.11 $kg{\cdot}m^{-2}$) completed the following study (Fig. 1). This research is part of a wider project that seeks to determine the effect of HIIT on several health parameters between young people and older adults and was approved by the Scientific Ethics Committee of the Universidad de La Frontera (Minutes No. 069_18, Folio 025_18, 2018) in accordance with the Declaration of Helsinki. One week before the study, the participants completed a routine medical screening and general health questionnaire to ensure their suitability to take part in the study. Inclusion criteria were: males between 18–35 and 55–75 years of age; sedentary (do not perform physical activity more than twice a week); BMI between 18.5 and 30 $kg{\cdot}m^{-2}$. The exclusion criteria were: recent surgery (within 3 months prior to the study); use of anticoagulants; musculoskeletal or orthopedic injuries; type 2 diabetes mellitus (determined by fasting blood glucose > 100 mg/dL or HbA1c-values > 6.5%); uncontrolled high blood pressure; use of nutritional supplementation (leucine, glutamine, casein, whey-protein, fatty acids and creatine); smoker; any family history of thrombosis; and/or severe cardiac problems. All the subjects were informed of the nature and possible risks of the experimental procedures prior to obtaining their informed consent in writing. During screening, participants were made familiar with the dominant leg strength one-repetition maximum (1-RM) and dominant grip strength 1-RM.

2.2. Study design

Participants underwent 12 weeks of HIIT on a stationary bicycle. In two separate tests (test 1, PRE and test 2, POST), 48 h before the first session and 48 h after the last training session, a whole-body dual energy x-ray absorptiometry (DEXA) scan and a blood sample were taken between 8:00 and 10:00 a.m. in a fasting state. After eating a standardized breakfast, an anthropometric assessment, a dominant leg strength 1-RM and a physical performance testsa evaluation were performed. Twelve hours later on this day, aerobic capacity was evaluated by calorimetry. Two days before every test day, the participants could not drink alcohol or perform intense physical activity.

2.3. Body composition

Body composition was assessed using dual-energy X-ray absorptiometry or DEXA (Lunar General Electric iDEXA, General Electric Medical Systems, Madison, WI, USA). To evaluate muscle mass, the parameter of lean mass was considered, indicated by segments (lower extremities) and total. Parameters such as fat mass and bone mass density were also recorded.

Weight was recorded on a SECA® platform scale (Madison, WI, USA) with a graduation of 0.1 kg and height was measured to an accuracy of 0.5 cm using a stadiometer coupled to the scale, with subjects barefoot. Waist circumference was measured on exhalation at the midpoint between the lowest rib and the iliac crest on the right half of the body with a SECA® retractable metric measuring tape with a graduation of centimeters (Madison, WI, USA). In relation to the dominant leg volume, the method and anthropometric formula proposed by Jones & Pearson was used (Jones and Pearson, 1969).

2.4. Functional capacity

Functional capacity included the evaluation of flexibility, balance, muscle strength and aerobic capacity (Marzuca-Nassr et al., 2020). The evaluation of these variables is detailed below.

2.4.1. Flexibility and balance

Upper extremity flexibility was assessed using the dominant back scratch test and the lower extremity using the dominant seated reach test following the recommendations of Rikli and Jones (1999).

Static balance was evaluated through the dominant unipedal stance test (Eladio Mancilla et al., 2015) (with a maximum of 60 s as a limit) and dynamic balance through the Timed Up and Go test (TUG) (Podsiadlo and Richardson, 1991). In addition, the total score of the short physical performance battery (SPPB) was included (from 0 points with severe limitations to 12 points with normal physical performance) (Guralnik et al., 1995).

2.4.2. Muscle strength

Maximal muscle strength was assessed in the dominant arm and leg. Grip strength for maximal strength of the upper extremity was evaluated with the JAMAR® hand dynamometer and knee extension for maximal strength of the lower extremity with a load cell (Load Cell - 500 lb.; S beam Load Cell; Sensortronics, USA). For the upper extremity, participants were seated in a chair with arms and their dominant arm was placed with an elbow flexion at 90° angle. Three hand grip repetitions were performed and the maximum value was taken (1-RM). For the lower extremity, participants were seated in a chair and their dominant leg was placed at a knee flexion angle of 90°. Three repetitions of knee extensions were performed and the maximum value was taken (1-RM).

2.4.3. Aerobic capacity

Aerobic capacity was evaluated on a cycle ergometer (Lode Corival Groeningen®, Netherlands) and with a gas analyzer (Ultima CPX

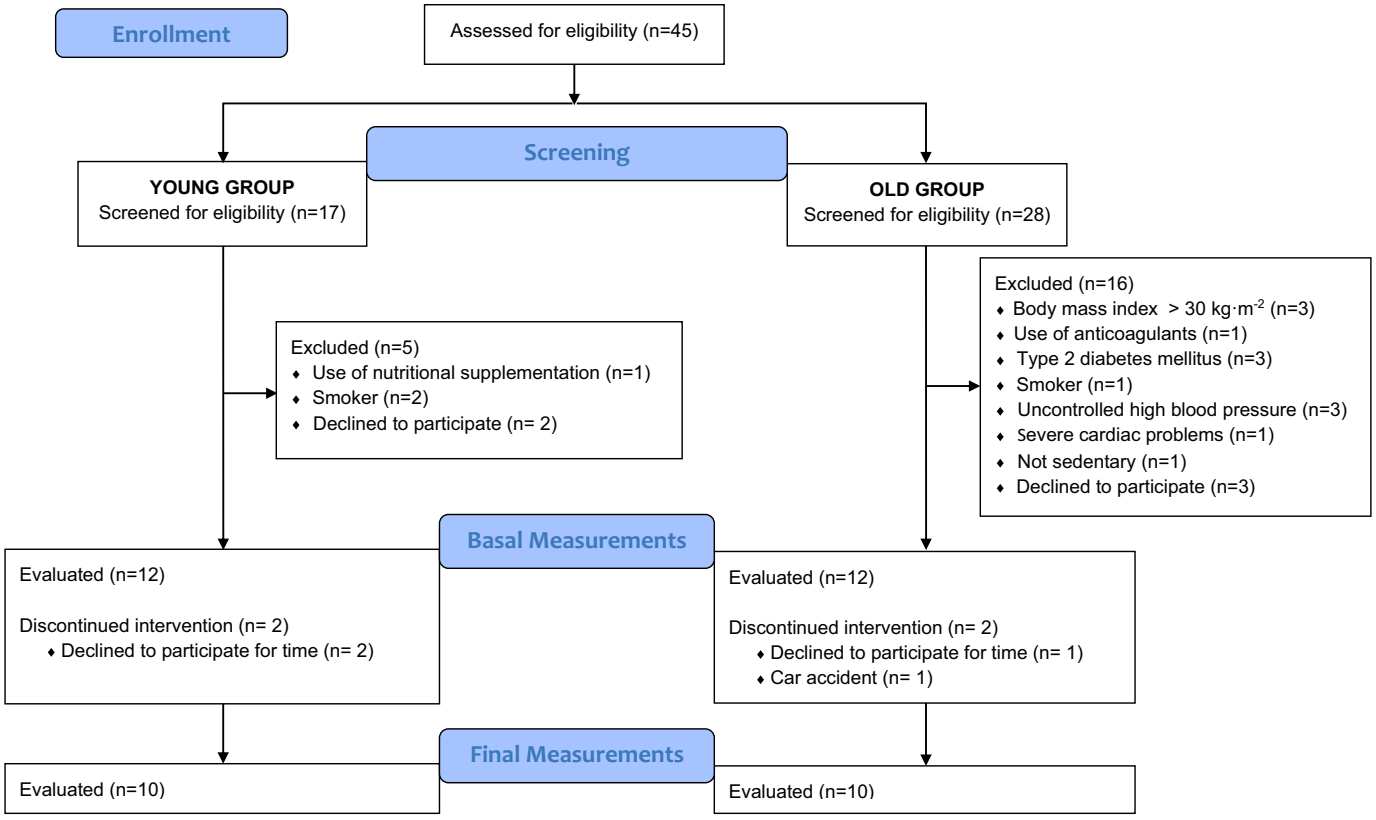

Fig. 1. Flow diagram of the participants of the study.

Medgraphics, Minnesota®, USA) previously calibrated for reference volume and gases. Maximal aerobic capacity (VO_{2max}) with continuous monitoring of heart rate (Polar, Finland) was determined using the modified Astrand test (Mancilla et al., 2014).

2.5. Biochemical markers

Blood samples were taken after 12 h of fasting from cubital fossa anterior of the participants elbow without anticoagulant to obtain serum in 6 mL tubes. Then, the samples were centrifuged at 2500 rpm × 15 min. The serum was distributed in microtubes and stored in a freezer at −80 °C for later analysis. The lipid and glucose profile was determined by enzymatic-colorimetric methods using an automatic photometer (Metrolab 2300 plus, Wiener lab, Argentina). Insulin was evaluated by ELISA using the Human Insulin ELISA Kit (Catalog # KAQ1251, Invitrogen, Thermo Fisher Scientific Inc., Waltham, MA, USA) following the manufacturer's recommendations. All inter- and intra-assay CVs were below 9%, when using normal controls, and pathological controls. The homeostasis model assessment - insulin sensitivity (HOMA-IS) calculation was done to assess insulin sensitivity using the following formula: fasting insulin concentration, mU/mL × fasting glucose, mg/dL/405, published by Matthews et al. (1985).

2.6. High-intensity interval training

HIIT was done for 3 times a week for 12 weeks using a stationary bicycle (Oxford®, BE2700). HIIT was performed at an intensity which elicited 90% peak heart rate during the VO_{2max} test, followed by 2 min of inactive rest repeated 10 times. Participants had personalized supervision and heart rate was checked at the beginning and end of each series in each session (Mancilla et al., 2014).

2.7. Statistics

All data are expressed as mean ± standard deviation (SD). Baseline characteristics between groups were compared by means of an independent samples *t*-test. Pre- versus post-intervention data were analyzed using a repeated-measures ANOVA with time (PRE versus POST) as the within-subject factor and group (YNG versus OLD) as the between-subjects factor. In the case of a significant interaction, paired *t*-tests were performed to determine time effects within groups and independent *t*-tests for group differences in the PRE- and POST-intervention values. In the case that paired *t*-tests were less than $P < 0.05$ level, the effect size was estimated using Cohen's d and represented as d. An effect size < 0.2 indicates no effect, 0.2–0.49 indicates small effect, 0.5–0.79 indicates medium effect, and ≥0.8 indicates large effect (Cohen, 1988). Correlations were also made with Pearson's test. All calculations were performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Participants

Basal characteristics of the participants are in Table 1. During the study, 4 participants were lost: 2 young people and 2 older adults (see Fig. 1).

3.2. Body composition

The differences between PRE and POST in body composition of the participants that completed the intervention program are in Table 2 (YNG and OLD, both n = 10). Before and after beginning the intervention, there was a difference between YNG and OLD in BMD mean femoral neck (group effect, $P = 0.035$). Interaction effect was observed in leg volume ($P = 0.037$). No differences were noted in the remaining

Table 1
Participants' characteristics.

	YNG (n = 10)	OLD (n = 10)	*P* value
Age (years)	21 ± 1	66 ± 5	0.007
Weight (kg)	76.59 ± 10.58	78.53 ± 11.59	0.995
Height (m)	1.71 ± 0,06	1.68 ± 0.06	0.906
BMI ($kg{\cdot}m^{-2}$)	26.01 ± 2.64	27.43 ± 3.11	0.611
Waist circumference (cm)	89.17 ± 9.16	99.12 ± 9.82	0.031
HR ($b{\cdot}min^{-1}$)	72.90 ± 12.63	70.05 ± 10.24	0.299
SBP (mm Hg)	125.30 ± 5.10	129.30 ± 9.08	0.058
DBP (mm Hg)	78.40 ± 6.26	80.90 ± 8.25	0.364

YNG: young group; OLD: older group; BMI: body mass index; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure. Values represent means ± SD. * Different from YNG at the $P < 0.05$ level; ** Different from YNG at the $P < 0.01$ level.

parameters ($P \geq 0.05$).

In the intra-group analysis after 12 weeks of HIIT, changes were observed in % whole-body fat mass (time effect, $P = 0.031$, −4.32%, d = 0.714 in YNG and −1.81%, d = 0.332 in OLD, Supplemental Table 1) with a decrease in both groups and leg lean mass (time effect, $P = 0.047$, 4.14%, d = 0.630 in YNG and 1.69%, d = 0.500 in OLD) with an increase in both groups.

3.3. Functional capacity

With respect to flexibility (Table 3), OLD had a lower value than YNG in the dominant back scratch test (group effect, $P = 0.000$). In dominant seated reach test, no differences were observed (time effect, $P = 0.805$; interaction effect, $P = 0.979$; group effect, $P = 0.523$).

OLD group presented worse results in dominant unipedal stance test, TUG and SPPB (group effect, $P = 0.004$, $P = 0.015$ and $P = 0.005$, respectively) compared to YNG group. Interaction effect was observed in TUG ($P = 0.011$) showing an improvement in OLD group after the 12-week intervention with HIIT ($P = 0.016$, d = 1.040).

With respect to muscle strength, no differences were observed in dominant grip strength 1-RM (time effect, $P = 0.521$; interaction effect, $P = 0.165$; group effect, $P = 0.220$), but there were differences in dominant leg strength 1-RM. In this, there was a difference in group effect ($P = 0.012$) between YNG and OLD, with OLD group showing less muscle strength in the lower extremity. Twelve weeks of HIIT managed to increase dominant leg strength 1-RM in both groups (time effect, $P = 0.025$), with the increase being greater in OLD group (YNG ~6%, d = 0.457 vs OLD ~11%, d = 0.634).

The 12-week HIIT intervention program was effective at increasing VO_{2max} in both groups (time effect, $P = 0.000$), with a greater increase in the OLD group (YNG ~26%, d = 1.659 vs OLD ~40%, d = 2.030). However, there was an inter-group difference between YNG and OLD (group effect, $P = 0.000$).

3.4. Metabolic parameters

PRE concentrations of fasting total cholesterol, HDL, LDL and triglycerides did not present differences between YNG and OLD groups (Table 4). After the intervention (POST) a reduction was observed only in cholesterol in both groups (time effect, $P = 0.017$, d = 0.865 in YNG and d = 0.338 in OLD).

3.5. Glucose homeostasis

Table 4 shows PRE and POST fasting glucose values, noting a decrease in both groups (time effect, $P = 0.006$), with the improvement in POST fasting glucose level being equivalent to ~14% in YNG (d = 1.353) and ~ 5% in OLD (d = 0.259). Fasting insulin value did not differ between groups and were observed differences in time and interaction effects ($P = 0.005$ and $P = 0.001$, respectively) with a decrease in the levels after HIIT program in YNG group ($P = 0.002$, d = 1.427).

HOMA-IS was determined with fasting glucose and fasting insulin levels. HOMA-IS only reduced in the YNG group (~54%, $P = 0.000$, d = 2.921). Finally, HOMA-IS was correlated positive with BMI (R = 0.474, $P = 0.035$) and with whole-body fat mass (R = 0.517, $P = 0.019$) (Table 5).

4. Discussion

The aim of the following study was to identify the effects of a 12-week HIIT program on the modification of parameters of body composition, functional capacity, fasting serum lipid and glucose homeostasis markers in healthy young people versus older adults. Our findings show that, after 12 weeks of HIIT on a bicycle, there were a decrease in % whole-body fat mass and an increase in leg lean mass, dominant leg strength 1-RM and VO_{2max} in both groups (with the beneficial effects being greater in the older adults in these last two variables). In addition, dynamic balance (TUG) improved only in the older adults. In the blood markers, fasting cholesterol and glucose fell in both groups, but not fasting insulin (and thus the HOMA-IS), which only decreased in the YNG group. Finally, HOMA-IS was correlated positive with BMI and with whole-body fat mass. HIIT model was used effectively by showing an increase in VO_{2max}. Then, HIIT can also be used as an effective strategy to improve VO_{2max} in both healthy younger and older people, as was demonstrated by others (StØren et al., 2017;

Table 2
Body composition before and after 12 weeks of HIIT.

	YNG (n = 10)		OLD (n = 10)		Within-subjects effects		Between-subjects effects
	PRE	POST	PRE	POST	TIME	TIME * GROUP	GROUP
Waist circumference (cm)	89.17 ± 9. 16	90.10 ± 13.03	99.12 ± 9.82	98.74 ± 9.95	0.834	0.618	0.056
Whole-BMD ($g{\cdot}cm^{-1}$)	1.032 ± 0.140	1.028 ± 0.147	0.990 ± 0.153	0.988 ± 0.145	0.403	0.778	0.536
BMD mean femoral neck ($g{\cdot}cm^{-1}$)	1.046 ± 0.151	1.037 ± 0.156	0.898 ± 0.133#	0.895 ± 0.126#	0.176	0.562	**0.035**
Whole-body fat mass (%)	30.11 ± 5.84	28.81 ± 5.78*	32.56 ± 7.81	31.97 ± 6.84	**0.031**	0.390	0.352
Whole-body fat mass (kg)	22.34 ± 7.32	21.43 ± 7.11	24.81 ± 7.69	24.58 ± 7.19	0.271	0.298	0.416
Android fat mass (kg)	2.11 ± 0.91	2.00 ± 0.79	2.72 ± 0.92	2.68 ± 0.93	0.151	0.485	0.117
Leg fat mass (kg)	7.70 ± 2.61	7.32 ± 2.48	6.42 ± 1.93	6.45 ± 1.94	0.123	0.076	0.300
Whole-body lean mass (kg)	54.73 ± 14.03	51.57 ± 4.12	50.00 ± 6.60	50.97 ± 6.16	0.596	0.325	0.425
Leg lean mass (kg)	16.91 ± 2.14	17.61 ± 2.27*	15.89 ± 2.06	16.16 ± 1.74	**0.047**	0.271	0.182
Leg volume (cm^3)	18,134.85 ± 2368.77	17,421.97 ± 1927.64	16,391.82 ± 2244.45#	16,938.62 ± 2524.880	0.770	**0.037**	0.271

HIIT: high-intensity interval training; YNG: young group; OLD: older group; PRE: pre-intervention; POS: post-intervention; BMD: bone mass density. Values represent means ± SD; * Different from pre-intervention values at the $P < 0.05$ level; # Different inter group at the $P < 0.05$ level. Bold numbers at the $P < 0.05$ level.

Table 3
Functional capacity before and after 12 weeks of HIIT.

	YNG (n = 10)		OLD (n = 10)		Within-subjects effects		Between-subjects effects
	PRE	POST	PRE	POST	TIME	TIME * GROUP	GROUP
Dominant back scratch test (cm)	2.41 ± 4.03	2.46 ± 5.06	−9.79 ± 7.41$^{\#\#\#}$	−15.88 ± 12.00$^{\#\#\#}$	0.116	0.110	**0.000**
Dominant seated reach test (cm)	−2.89 ± 9.38	−2.42 ± 11.59	−5.75 ± 11.93	−5.37 ± 9.56	0.805	0.979	0.523
Dominant unipedal stance test (seg)	60.00 ± 0.0	60.00 ± 0.0	36.27 ± 22.59$^{\#\#}$	42.57 ± 19.00$^{\#\#}$	0.161	0.161	**0.004**
TUG (seg)	5.92 ± 0.70	6.11 ± 0.70	7.56 ± 1.46$^{\#\#}$	6.72 ± 1.00**	0.087	**0.011**	**0.015**
SPPB (points)	12.00 ± 0.0	12.00 ± 0.0	11.10 ± 1.10$^{\#\#}$	11.80 ± 0.42$^{\#\#}$	0.094	0.094	**0.005**
Dominant grip strength 1-RM (kg)	42.53 ± 9.49	43.00 ± 9.43	38.67 ± 7.36	37.42 ± 7.01	0.521	0.165	0.220
Dominant leg strength 1-RM (kg)	61.90 ± 17.15	65.67 ± 17.09*	43.39 ± 11.65$^{\#}$	48.16 ± 12.72$^{\#}$*	**0.025**	0.778	**0.012**
VO_{2max} (ml/kg/min)	29.87 ± 6.60	37.74 ± 6.79***	16.65 ± 4.55$^{\#\#\#}$	23.39 ± 3.63$^{\#\#\#}$***	**0.000**	0.548	**0.000**

HIIT: high intensity interval training; YNG: young group; OLD: older group; PRE: pre-intervention; POS: post-intervention; TUG: timed up go; SPPB: Short Physical Performance Battery; 1-RM: one maximum repetition; VO_{2max}: maximal oxygen consumption. Values represent means ± SD; different from pre-intervention values at the: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ levels; different inter group at the $^{\#}P < 0.05$, $^{\#\#}P < 0.01$, $^{\#\#\#}P < 0.001$ levels. Bold numbers at the $P < 0.05$ level.

Table 4
Fasting biochemical markers before and after 12 weeks of HIIT.

	YNG (n = 10)		OLD (n = 10)		Within-subjects effects		Between-subjects effects
	PRE	POST	PRE	POST	TIME	TIME * GROUP	GROUP
Cholesterol (mg/dL)	165.70 ± 38.92	145.50 ± 33.86*	186.00 ± 24.95	178.10 ± 26.10*	***0.017***	0.264	0.057
HDL (mg/dL)	47.30 ± 18.67	48.00 ± 12.25	54.40 ± 15.36	49.80 ± 21.14	0.649	0.537	0.498
LDL (mg/dL)	101.00 ± 33.52	81.60 ± 24.55	110.60 ± 31.29	106.80 ± 41.48	0.065	0.202	0.219
Triglycerides (mg/dL)	86.60 ± 54.66	79.10 ± 36.40	103.20 ± 44.70	107.80 ± 58.85	0.782	0.256	0.306
Glucose (mg/dL)	99.30 ± 7.26	85.90 ± 7.28**	96.10 ± 17.78	91.40 ± 9.06**	**0.006**	0.154	0.781
Insulin (μU/mL)	15.32 ± 5.67	7.96 ± 3.55**	11.52 ± 5.36	12.24 ± 6.54	**0.005**	**0.001**	0.914
HOMA-IS	3.70 ± 1.18	1.69 ± 0.78***	2.60 ± 1.07	2.74 ± 1.43	**0.000**	**0.000**	0.961

All markers were determined in fasting blood samples. HIIT: high-intensity interval training; YNG: young group; OLD: older group; PRE: pre-intervention; POS: post-intervention; HDL: high density lipoprotein; LDL: low density lipoprotein; HOMA-IS: homeostatic model assessment – insulin sensitivity. Values represent means ± SD; different from pre-intervention values at the *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ levels. Bold numbers at the $P < 0.05$ level.

Table 5
Relationship between HOMA-insulin sensitivity and body composition or maximal oxygen consumption test before and after 12 weeks of HIIT.

HOMA-IS	YNG		OLD		Total	
Correlation	R	*P*	R	*P*	R	*P*
BMI ($kg{\cdot}m^{-2}$)	0.344	0.331	0.485	0.156	0.517*	**0.019**
Whole-body fat mass (%)	0.609	0.062	0.196	0.587	0.415	0.069
Whole-body fat mass (kg)	0.589	0.073	0.310	0.383	0.474*	**0.035**
Leg fat mass (kg)	0.434	0.210	−0.053	0.885	0.356	0.123
Android fat mass (kg)	0.354	0.316	−0.129	0.723	0.300	0.199
Whole-body lean mass (kg)	−0.397	0.256	0.292	0.412	0.040	0.868
Leg lean mass (kg)	−0.317	0.373	−0.335	0.344	−0.182	0.443
VO_{2max} (ml/kg/min)	−0.481	0.159	−0.202	0.576	0.077	0.746

HIIT: high-intensity interval training; HOMA-IS: homeostasis model assessment - insulin sensitivity; YNG: young group; OLD: older group; BMI: body mass index; $VO_{2\ max}$: maximal oxygen consumption; R, Pearson correlation; correlation is significant at the level *: $P < 0.05$ (bilateral). Bold numbers at the $P < 0.05$ level.

Østerås et al., 2005) and by the present study.

In aging, there is less skeletal muscle mass, which translates to a greater loss of type II fibers, which have the characteristics of fast contraction and glycolytic metabolism (Whyte et al., 2010). On the other hand, it is known that skeletal muscle recruitment depends on the intensity of the exercise; therefore, with HIIT (high intensity and short duration), greater benefits will be gained in terms of type II/glycolytic fibers/fast contraction, which are most affected by aging (Verdijk et al., 2014). In addition, cellular responses are associated with loss/gain of skeletal muscle mass in normal and pathological conditions. However, it has been established that the anabolic resistance of skeletal muscle in older adults prevents them from achieving favorable responses as young people with the same stimulus (Wall et al., 2015).

In relation to glucose concentrations and insulin sensitivity, previous studies have reported inconsistent results on the effect of HIIT between young people and older adults (Robinson et al., 2017; Whyte et al., 2010; Larsen et al., 2015; Søgaard et al., 2018). Lower insulin sensitivity in older adults may also be due to obesity and physical inactivity more than to the aging process (Lalia et al., 2016; Poehlman et al., 2000; Karakelides et al., 2010). This has been associated using negative correlations between android fat mass with insulin sensitivity after HIIT (Søgaard et al., 2018; Kelley et al., 2000). Recently, Hayes et al. reported that 12 weeks of training (6 weeks of aerobic preconditioning added to 6 weeks of HIIT) produced small improvements in fasting insulin, glucose and HOMA-IS in sedentary older people compared to master athletes (Hayes et al., 2020). In our results, we observed that HIIT for 12 weeks decreased glucose in both groups (time factor), but insulin and HOMA-IS only decreased in young people. The differences between the results obtained in the sedentary older people from the two studies may be due to the different protocols used and the difference in the basal body composition from the sedentary older participants between the studies (BMI 29.5 ± 4.5, % whole-body fat mass 24 ± 17 versus BMI 27.43 ± 3.11, % whole-body fat mass 32.56 ± 7.81). This last point (BMI and % fat mass), strongly influences the variation of glucose homeostasis markers. Future studies on humans are needed to clarify these differences.

Despite the benefits recorded in muscle function after the intervention with HIIT on a bicycle in a young population (Weston et al., 2014; Martinez-Valdes et al., 2017), the magnitude of such effects in older adults remains unknown. This is mainly due to the complexity of the comparisons between the multiple HIIT protocols used and the use of hybrid interventions that combine different exercise modalities with interval training, which has ultimately generated heterogeneity in the results (Tavoian et al., 2019).

Among the multiple interventions that have applied HIIT for muscle

adaptation in older adults, Buckinx et al. reported that HIIT performed on an elliptical for 6 weeks only induces improvements in the functionality of the lower extremities (TUG, $P < 0.05$), with no changes in muscle mass regardless of the amount of protein consumption (Buckinx et al., 2019). This contrasts with the results obtained in the present study, where there were improvements in TUG (~11%), leg lean mass (~2%) and dominant leg strength 1-RM (~11%). Such a discrepancy could be justified by the differences between the protocols and time used in the two studies.

In relation to the increase in muscle strength, several studies have also demonstrated improvements in the dominant leg (Sculthorpe et al., 2017; Hurst et al., 2019; Adamson et al., 2014); however, this essentially involves concurrent interventions that combine muscle resistance and aerobic training. In the same way, Jiménez-García et al., after 12 weeks of HIIT or Moderate-intensity interval training (MIIT) in older people at risk of falls, reported improvements in balance, gait, TUG and reduced fear of falls. Such effects are not completely comparable to ours, due to differences in the characteristics of the participants (risk of falls) and the HIIT modality used by these researchers (suspension training) (Jiménez-García et al., 2019).

HIIT reveals greater mRNA expression, mainly in mitochondrial oxidative capacity, compared to other types of exercise such as aerobics or combined types (Robinson et al., 2017). At molecular level, HIIT increases the release of calcium into the muscle, requiring a great ATP exchange rate, leading to a greater use of carbohydrates as energy. This carries with it a large accumulation of metabolites, ions and free radicals, which will increase muscle protein signaling pathways such as Ca2+/calmodulin-dependent protein kinase II (CaMKII) and AMP-activated protein kinase (AMPK). The increase in these proteins will cause greater gene expression of PGC-1α, leading to an increase in mitochondrial protein synthesis (MacInnis and Gibala, 2017). In aging there is a reduction in mitochondrial capacity in the muscle, and it has been shown that HIIT, through the previously mentioned molecular mechanisms, can augment the gene expression of mitochondrial markers regardless of age (Robinson et al., 2017).

Part of these findings were observed in the present study, where 12 weeks of HIIT on a bicycle were beneficial, not only in isolation in some systemic parameters but also as a complete strategy, noting changes in body composition, functional capacity and fasting serum lipid and glucose markers in young people and older adults. We believe that our results are due to developing exercise at high-intensity and high-frequency (3 sessions per week) in 12 weeks, unlike other authors who, performing exercise at low-frequency (1 session per week) did not find differences, for example, in functional capacity (static balance) (Sculthorpe et al., 2017). In the same line, we believe that by working HIIT on a cycle ergometer we have favored the skeletal muscle mass gain and the increase of strength in the legs and with this the improvement in physical performance as observed in TUG (that reflects the performance of the legs).

Among the limitations of this study, we can mention that these results cannot be extrapolated to older women; the study was performed in a very limited number of individuals; a larger greater sample is required to generalize the results to the wider population without pathologies. Moreover, in light of the diversity of HIIT protocols applied to improve morphofunctional parameters in older adults, it is difficult to compare or standardize these results, and there is still a lack of evidence that identifies the most effective dose and modality of HIIT that can be applied to the wider population.

5. Conclusions

We conclude that the strategy of 12 weeks of HIIT on a bicycle is beneficial to improving parameters of body composition, functional capacity and fasting serum lipid, and glucose homeostasis markers. After the intervention, % whole-body fat mass decreased and leg lean mass, dominant 1-RM leg strength and VO_{2max} increased in both groups. In addition, TUG improved only in the older adults. In the blood markers, fasting cholesterol and glucose fell in both groups, but not the insulin (and consequently the HOMA-IS), which fell only in the young people. Finally, HOMA-IS was correlated moderately and positive with BMI and whole-body fat mass.

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CRediT authorship contribution statement

- **Gabriel Nasri Marzuca-Nassr**: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Supervision; Validation; Visualization; Writing - original draft; Writing - review & editing.
- **Macarena Artigas-Arias**: Investigation; Formal analysis; Methodology; Writing - original draft.
- **María Angélica Olea**: Investigation; Methodology.
- **Yuri SanMartín-Calísto**: Investigation; Methodology.
- **Nolberto Huard**: Investigation; Methodology.
- **Fernanda Durán-Vejar**: Investigation; Methodology.
- **Francisca Beltrán-Fuentes**: Investigation; Methodology.
- **Aris Muñoz-Fernández**: Investigation; Methodology.
- **Andrea Alegría-Molina**: Investigation; Methodology.
- **Jorge Sapunar**: Investigation, Visualization, Writing - review & editing.
- **Luis A. Salazar**: Funding acquisition, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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References

Adamson, S.B., Lorimer, R., Cobley, J.N., Babraj, J.A., 2014. Extremely short-duration high-intensity training substantially improves the physical function and self-reported health status of elderly adults. J. Am. Geriatr. Soc. 62 (7), 1380–1381.

Bell, K.E., Séguin, C., Parise, G., Baker, S.K., Phillips, S.M., 2015. Day-to-day changes in muscle protein synthesis in recovery from resistance, aerobic, and high-intensity interval exercise in older men. Med. Sci. 1024–1029.

Boudou, P., Sobngwi, E., Mauvais-Jarvis, F., Vexiau, P., Gautier, J.F., 2003. Absence of exercise-induced variations in adiponectin levels despite decreased abdominal adiposity and improved insulin sensitivity in type 2 diabetic men. Eur. J. Endocrinol. 149 (5), 421–424 Nov.

Buckinx, F., Gaudreau, P., Marcangeli, V., Boutros, G.E.H., Dulac, M.C., Morais, J.A., et al., 2019. Muscle adaptation in response to a high-intensity interval training in obese older adults: effect of daily protein intake distribution. Aging Clin. Exp. Res. 31 (6), 863–874 Jun 1.

Chodzko-Zajko, W.J., Proctor, D.N., Fiatarone Singh, M.A., Minson, C.T., Nigg, C.R., Salem, G.J., et al., 2009. Exercise and physical activity for older adults. Med. Sci. Sports Exerc., vol. 41, 1510–1530.

Churchward-Venne, T.A., Breen, L., Phillips, S.M., 2014. Alterations in human muscle protein metabolism with aging: protein and exercise as countermeasures to offset sarcopenia. In: BioFactors. vol. 40. Wiley-Blackwell, pp. 199–205.

Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences, 2nd. erlbaum,

Hillsdale, NJ.
Dirks, M.L., Hansen, D., Van Assche, A., Dendale, P., Van Loon, L.J.C., 2015. Neuromuscular electrical stimulation prevents muscle wasting in critically ill comatose patients. Clin. Sci. 128 (6), 357–365.
Eladio Mancilla, S., José Valenzuela, H., Máximo, Escobar C., 2015. Timed up and go right and left unipodal stance results in chilean older people with different degrees of disability. Rev. Med. Chil. 143 (1), 39–46 Jan 1.
Giovannini, S., Marzetti, E., Borst, S.E., Leeuwenburgh, C., 2008. Modulation of GH/IGF-1 axis: potential strategies to counteract sarcopenia in older adults. Mech. Ageing Dev. 129 (10), 593–601 Oct 13.
Grace, F., Herbert, P., Elliott, A.D., Richards, J., Beaumont, A., Sculthorpe, N.F., 2018. High intensity interval training (HIIT) improves resting blood pressure, metabolic (MET) capacity and heart rate reserve without compromising cardiac function in sedentary aging men. Exp. Gerontol. 109, 75–81 Aug 1.
Guralnik, J.M., Ferrucci, L., Simonsick, E.M., Salive, M.E., Wallace, R.B., 1995. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. N. Engl. J. Med. 332 (9), 556–562 Mar 2.
Hayes, L.D., Herbert, P., Sculthorpe, N., Grace, F., 2020. High intensity interval training (HIIT) produces small improvements in fasting glucose, insulin, and insulin resistance in sedentary older men but not masters athletes. Exp. Gerontol. 140 Oct 15.
Herbert, P., Hayes, L.D., Sculthorpe, N., Grace, F.M., 2017. High-intensity interval training (HIIT) increases insulin-like growth factor-I (IGF-I) in sedentary aging men but not masters' athletes: an observational study. Aging Male 20 (1), 54–59 Jan 2.
Hurst, C., Weston, K.L., Weston, M., 2019. The effect of 12 weeks of combined upper- and lower-body high-intensity interval training on muscular and cardiorespiratory fitness in older adults. Aging Clin. Exp. Res. 31 (5), 661–671.
Hwang, C.L., Yoo, J.K., Kim, H.K., Hwang, M.H., Handberg, E.M., Petersen, J.W., et al., 2016. Novel all-extremity high-intensity interval training improves aerobic fitness, cardiac function and insulin resistance in healthy older adults. Exp. Gerontol. 82, 112–119 Sep 1.
Jiménez-García, J.D., Hita-Contreras, F., de la Torre-Cruz, M., Fábrega-Cuadros, R., Aibar-Almazán, A., Cruz-Díaz, D., et al., 2019. Risk of falls in healthy older adults: benefits of high-intensity interval training using lower body suspension exercises. J. Aging Phys. Act. 27 (3), 325–333.
Jones, P.R., Pearson, J., 1969. Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. J. Physiol. 204 (2), 63P–66P Oct 1.
Karakelides, H., Irving, B.A., Short, K.R., O'Brien, P., Sreekumaran Nair, K., 2010. Age, obesity, and sex effects on insulin sensitivity and skeletal muscle mitochondrial function. Diabetes 59 (1), 89–97 Jan.
Kelley, D.E., Thaete, F.L., Troost, F., Huwe, T., Goodpaster, B.H., 2000 May. Subdivisions of subcutaneous abdominal adipose tissue and insulin resistance. Am. J. Physiol. Endocrinol. Metab. 278 (5), 41–45.
Lalia, A.Z., Dasari, S., Johnson, M.L., Robinson, M.M., Konopka, A.R., DIstelmaier, K., et al., 2016. Predictors of whole-body insulin sensitivity across ages and adiposity in adult humans. J. Clin. Endocrinol. Metab. 101 (2), 626–634 Feb 1.
Larsen, S., Danielsen, J.H., Søndergård, S.D., Søgaard, D., Vigelsoe, A., Dybboe, R., et al., 2015. The effect of high-intensity training on mitochondrial fat oxidation in skeletal muscle and subcutaneous adipose tissue. Scand. J. Med. Sci. Sport 25 (1), e59–e69 Feb 1.
Li, F.H., Sun, L., Zhu, M., Li, T., Gao, H.E., Wu, D.S., et al., 2018. Beneficial alterations in body composition, physical performance, oxidative stress, inflammatory markers, and adipocytokines induced by long-term high-intensity interval training in an aged rat model. Exp. Gerontol. 113, 150–162 Nov 1.
MacInnis, M.J., Gibala, M.J., 2017. Physiological adaptations to interval training and the role of exercise intensity. J. Physiol. 595, 2915–2930 Blackwell Publishing Ltd.
Magne, H., Savary-Auzeloux, I., Rémond, D., Dardevet, D., 2013. Nutritional strategies to counteract muscle atrophy caused by disuse and to improve recovery. Nutr. Res. Rev. 26 (2), 149–165.
Mancilla, R., Torres, P., Álvarez, C., Schifferli, I., Sapunar, J., Bustos, E.D., 2014. Ejercicio físico interválico de alta intensidad mejora el control glicémico y la capacidad aeróbica en pacientes con intolerancia a la glucosa. Rev. Med. Chil. 142 (1), 34–39.
Martinez-Valdes, E., Falla, D., Negro, F., Mayer, F., Farina, D., 2017. Differential motor unit changes after endurance or high-intensity interval training. Med. Sci. Sports Exerc. 49 (6), 1126–1136.
Marzuca-Nassr, G.N., Droguett-Cervela, R.A., Córdova-Sáez, M.P., Ibarra-Fuentealba, I.A., Donoso, W., López-Suárez, A., et al., 2017. Acute Electrical Stimulation Modifies Cross-sectional Area and Desmin Protein in the Skeletal Muscle of Old Rats Submitted to Hindlimb Suspension. Indian J. Physiol. Pharmacol. 61 (3), 219–231.
Marzuca-Nassr, G.N., SanMartín-Calísto, Y., Guerra-Vega, P., Artigas-Arias, M., Alegría, A., Curi, R., 2020. Skeletal muscle aging atrophy: assessment and exercise-based treatment. Adv. Exp. Med. Biol. 1260, 123–158.
Matthews, D.R., Hosker, J.P., Rudenski, A.S., Naylor, B.A., Treacher, D.F., Turner, R.C., 1985. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28 (7), 412–419 Jul.
Mora, J.C., Valencia, W.M., 2018. Exercise and older adults. In: Clinics in Geriatric Medicine. vol. 34. W.B. Saunders, pp. 145–162.
Morton, R.W., Traylor, D.A., Weijs, P.J.M., Phillips, S.M., 2018. Defining anabolic resistance: Implications for delivery of clinical care nutrition. In: Current Opinion in Critical Care. vol. 24. Lippincott Williams and Wilkins, pp. 124–130.
Osawa, Y., Tabata, S., Katsukawa, F., Ishida, H., Oguma, Y., Kawai, T., et al., 2014. Effects of 16-week high-intensity interval training using upper and lower body ergometers on aerobic fitness and morphological changes in healthy men: a preliminary study. Open Access J. Sport Med. 5, 257 Nov.
Østerås, H., Hoff, J., Helgerud, J., 2005. Effects of high-intensity endurance training on maximal oxygen consumption in healthy elderly people. J. Appl. Gerontol. 24 (5), 377–387 Nov 29.
Podsiadlo, D., Richardson, S., 1991 Feb 1. The timed "up & go": a test of basic functional mobility for frail elderly persons. J. Am. Geriatr. Soc. 39 (2), 142–148.
Poehlman, E.T., Dvorak, R.V., Denino, W.F., Brochu, M., Ades, P.A., 2000. Effects of resistance training and endurance training on insulin sensitivity in nonobese, young women: a controlled randomized trial. J. Clin. Endocrinol. Metab. 85.
Rikli, R.E., Jones, C.J., 1999. Functional fitness normative scores for community-residing older adults, ages 60-94. J. Aging Phys. Act. 7 (2), 162–181 Apr 1.
Robinson, M.M., Dasari, S., Konopka, A.R., Johnson, M.L., Manjunatha, S., Esponda, R.R., et al., 2017. Enhanced protein translation underlies improved metabolic and physical adaptations to different exercise training modes in young and old humans. Cell Metab. 25 (3), 581–592 Mar 7.
Rosenberg, I.H., 1997. Symposium: sarcopenia: diagnosis and mechanisms sarcopenia: origins and clinical relevance. J. Nutr. 127 (5), 990S–991S.
Sculthorpe, N.F., Herbert, P., Grace, F., 2017. One session of high-intensity interval training (HIIT) every 5 days, improves muscle power but not static balance in lifelong sedentary ageing men. A randomized controlled trial. Med (United States) 96 (6).
Søgaard, D., Lund, M.T., Scheuer, C.M., Dehlbaek, M.S., Dideriksen, S.G., Abildskov, C.V., et al., 2018. High-intensity interval training improves insulin sensitivity in older individuals. Acta Physiol. 222 (4), e13009 (Apr 1).
StØren, Ø., Helgerud, J., SÆbØ, M., StØa, E.M., Bratland-Sanda, S., Unhjem, R.J., et al., 2017 Jan 1. The effect of age on the V-O2max response to high-intensity interval training. Med. Sci. Sports Exerc. 49 (1), 78–85.
Tavoian, D., Russ, D.W., Law, T.D., Simon, J.E., Chase, P.J., Guseman, E.H., et al., 2019. A randomized clinical trial comparing three different exercise strategies for optimizing aerobic capacity and skeletal muscle performance in older adults: protocol for the DART Study. Front. Med. 6, 236 Oct 22.
Thompson, L.D.V., 2009. Age-related muscle dysfunction. Exp. Gerontol. 44 (1–2), 106–111 Jan.
Verdijk, L.B., Snijders, T., Drost, M., Delhaas, T., Kadi, F., van Loon, L.J., 2014. Satellite cells in human skeletal muscle; from birth to old age. Age 36 (2), 545–547.
Wall, B.T., van Loon, L.J., 2013. Nutritional strategies to attenuate muscle disuse atrophy. Nutr. Rev. 71 (4), 195–208 Apr.
Wall, B.T., Gorissen, S.H., Pennings, B., Koopman, R., Groen, B.B., Verdijk, L.B., et al., 2015. Aging Is Accompanied by a Blunted Muscle Protein Synthetic Response to Protein Ingestion. Plos One 10 (11).
Weston, M., Taylor, K.L., Batterham, A.M., Hopkins, W.G., 2014. Effects of low-volume high-intensity interval training (HIT) on fitness in adults: a meta-analysis of controlled and non-controlled trials. In: Sports Medicine. vol. 44. Springer International Publishing, pp. 1005–1017.
Whyte, L.J., Gill, J.M.R., Cathcart, A.J., 2010. Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. Metabolism 59 (10), 1421–1428 Oct.