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Morrison, BN, George, K, Kreiter, E, Dixon, D, Rebello, L, Massarotto, RJ and Cote, AT (2023) Effects of endurance exercise training on left ventricular structure in healthy adults: a systematic review and metaanalysis. European Journal of Preventive Cardiology. 30 (9). pp. 772-793.

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Effects of endurance exercise training on left ventricular structure in healthy adults: a systematic review and meta-analysis

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Received 15 August 2022; revised 24 January 2023; accepted 26 January 2023; online publish-ahead-of-print 31 January 2023

See the editorial comment for this article 'Endurance training: what is the expected left ventricle remodelling?', by F. Bandera, https://doi. org/10.1093/eurjpc/zwad109.

Aims	To determine the impact of endurance training (ET) interventions on left ventricular (LV) chamber size, wall thickness, and mass in healthy adults.
Methods and results	Electronic databases including CINAHL, MEDLINE, PsycINFO, SPORTDiscus, Cochrane library, and EBM Reviews were searched up to 4 January 2022. Criteria for inclusion were healthy females and/or males (>18 years), ET intervention for \geq 2 weeks, and studies reporting pre- and post-training LV structural parameters. A random-effects meta-analysis with heterogeneity, publication bias, and sensitivity analysis was used to determine the effects of ET on LV mass (LVM) and diastolic measures of interventricular septum thickness (IVSd), posterior wall thickness (PVVTd), and LV diameter (LVDd). Meta-regression was performed on mediating factors (age, sex, training protocols) to assess their effects on LV structure. Eighty-two studies met inclusion criteria ($n = 1908$; 19–82 years, 33% female). There was a significant increase in LVM, PWTd, IVSd, and LVDd following ET [standardized mean difference (SMD) = 0.444, 95% confidence interval (CI): 0.361, 0.527; $P < 0.001$; SMD = 0.234, 95% CI: 0.159, 0.309; $P < 0.001$; SMD = 0.237, 95% CI: 0.159, 0.316; $P < 0.001$; SMD = 0.249, 95% CI:0.173, 0.324; $P < 0.001$, respectively]. Trained status, training type, and age were the only mediating factors for change in LVM, where previously trained, mixed-type training, young (18–35 years), and middle-aged (36–55 years) individuals had the greatest change compared with untrained, interval-type training, and older individuals (>55 years). A significant increase in wall thickness was observed in males, with a similar augmentation of LVDd in males and females. Trained individuals elicited an increase in PWTd and LVDd.
Conclusion	Left ventricular structure is significantly increased following ET. Males, young and trained individuals, and ET interventions involving mixed training regimes elicit the greatest changes in LV structure.
Lay summary	 Heart structure significantly increases the following endurance training (ET) ≥2 weeks. Changes in heart structure were most prominent in males, who are young (18–35 years), already trained, and following concurrent continuous and interval training. Changes in heart size were not shown in older individuals (>55 years) compared with young and middle-aged individuals. While both males and females similarly increase their cavity size and heart mass, sex differences were revealed for wall thickness where significant increases were seen in males but not females.
Keywords	Endurance exercise training • Left ventricle • Athletes • Sex differences

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Introduction

Participation in regular endurance training (ET) is associated with structural and functional cardiac adaptations that, in turn, improve cardiorespiratory fitness needed for higher peak oxygen uptake required for enhancing athletic performance.^{1,2} These structural adaptations include increases in left ventricular (LV) chamber size, wall thickness, and mass (LVM) and require careful consideration when differentiating between normal physiological adaptation and potential pathology.¹ Previous cross-sectional literature has demonstrated that endurancetrained individuals have an increased LVM compared with age- and sexmatched controls,³⁻⁸ but that these physiological cardiac adaptations can be mediated by gender, training volume, and sport type.^{5,6,8,9} Evidence suggests that male athletes,^{5,8} those with greater training volume,^{5,8} and those that participate in high dynamic-low static sports and high dynamic-high static sports have the largest LVM.^{6,10} Cross-sectional data are, however, limited by selection bias and cannot determine the cause-and-effect relationship between ET and cardiac phenotype. This requires intervention-based, longitudinal training studies. There is a growing evidence-base available suggesting that longitudinal training studies can lead to cardiac adaptation, at least qualitatively similar to that observed in cross-sectional, athlete-control studies. For example, a 1-year intensive ET programme in sedentary individuals resulted in a significant increase in LVM, approaching similar levels to that seen in elite endurance-trained athletes.²

Although research has demonstrated increases in LV chamber size, wall thickness, and mass in response to ET, these changes have been highly variable, study-to-study, and there has been limited systematic evaluation of potential factors that may mediate the cardiac structure ET response. Confounding factors such as age, sex, ET history (untrained or previously trained), modality of ET (i.e. running, cycling, rowing, swimming, or combination of more than one modality), or type of training programme (continuous, interval, or mixture of both types) require further study and the complexity and breadth of potential confounders lends itself to a systematic review and meta-analysis. Therefore, the aim of the current systematic review was to determine the impact of prospective ET interventions on LV structure in healthy adults. The secondary purpose was to assess how variation in potential confounders may mediate change in LVM. We hypothesized that LV structure would be significantly greater following ET, with males, younger, trained individuals, and ET interventions involving high dynamic-high static modalities eliciting greater changes in LVM and other structural variables.

Methods

The review is reported in accordance with the PERSiST (implementing PRISMA in Exercise, Rehabilitation, Sport medicine and SporTs science) consensus statement.¹¹ This review is registered with Prospero (CRD42017072090).

Eligibility criteria

Studies included had to meet the following inclusion criteria: (i) ET interventions in healthy men and women ≥ 18 years; (ii) LV structural parameters reported prior to and after an ET intervention; and (iii) ≥ 2 weeks in duration. Cross-sectional studies comparing training methods across sporting disciplines and observational longitudinal studies, including multi-day races, were excluded, as were conference abstracts, editorial, and review papers. Studies that included clinical populations were excluded; however, if there was a healthy control population that underwent ET, the control population results were included. Individually or in any combination, ET that included running, aerobics, cycling, swimming, rowing, soccer, or other ET modality of at least moderate intensity were excluded. Interventions that reported an element of strength training within their moderate or higher

intensity ET intervention were included. There were no restrictions on the setting in which the ET were performed (i.e. classes, supervised individual, or group training). Furthermore, exercise could not be combined with pharmacological interventions. In the event the same study had multiple publications, the report that included the greatest sample size of the eligible outcome measures was included. In studies that assessed more than two time-points during the intervention, the pre-training and last training block measurements were included in the analysis.^{3,12–22} In instances where studies only broadly discussed the training phases (i.e. pre-season training, competitive season, maintenance phases), and did not prospectively prescribe the training programme, they were excluded as observational studies.

Search strategy

The systematic search was conducted by a librarian (E.K.) who had expertise in systematic reviews and verified by a senior librarian (D.D.). The databases searched included CINAHL, MEDLINE, PsycINFO, SPORTDiscus, Cochrane (Database of Systematic Reviews, Clinical Answers, Central Register of Controlled Trials, Methodology Register), and EBM Reviews (Health Technology Assessment, NHS Economic Evaluation Database, ACP Journal Club, Database of Abstracts of Reviews of Effects). These databases were last searched on 4 January 2022 and yielded 3481 results. The search strategy combined the two concepts of intervention and outcome, investigating the impact of ET (intervention) on LV structure (outcome). Keyword searches, with the phrase and truncation indications, were performed in the Title and Abstract fields. Subject headings were employed where available. See Supplementary material online, Table S1 for the full list of keywords and subject headings used in each database, according to their interface (EBSCO or Ovid). The English-language filter was the only limiter applied to the search results; results were not limited according to date or publication type.

Selection process

A total of 3481 articles were identified through database searching with an additional 13 articles identified through reference lists and hand searching. The articles were imported into a reference management software (Endnote X9) where duplicates were removed. The remaining 1631 results were imported into a systematic review management software (COVIDENCE, Melbourne, Australia) for screening so that investigators could work independently. Two reviewers (N.S., A.R.) reviewed all study titles and abstracts and excluded studies according to the pre-specified criteria with a unanimous result required to exclude a study (*Figure 1*). Two investigators (A.T.C., B.N.M.) reviewed the full-text articles and assessed them according to the search criteria for inclusion. Disagreement in any of the stages was resolved by consensus between the two reviewers and a third reviewer (K.G.) if consensus could not be reached.

Data extraction

One investigator (B.N.M.) extracted data using a standardized data extraction form agreed upon by three reviewers (A.T.C., K.G., B.N.M.). A second investigator (L.R.) reviewed the data for accuracy, and any inconsistencies were resolved by discussion between these investigators, and a third investigator (A.T.C.) solved any disagreements. General study information (authors, publication year, sample size), participant information (age, sex), imaging modality (echocardiography, echo; cardiac magnetic resonance imaging, CMR), LV structural parameters (interventricular septum thickness in end-diastole, IVSd; posterior wall thickness in end-diastole, PWTd; LV enddiastolic diameter, LVDd), and LV functional parameters [(VO_{2max}, enddiastolic volume, EDV; end-systolic volume, ESV; and stroke volume, SV), ET intervention features: trained status, modality (running/aerobics, cycling, swimming, rowing, soccer, or any combination of these), type of training, inclusion of strength training, duration of the study (weeks), frequency of training (days/week), time per session (h); total weekly hours] were extracted from included studies. Participants' trained status were classified as untrained (individuals who had not previously exercised regularly, on an organized basis or competed in previous competitions) and trained (individuals who followed a regular training programme or previously competed, including those who were at the beginning an ET programme (i.e. college matriculation, training for a marathon) and athletes who went through a period of detraining prior to the ET intervention). The type of training included: continuous (CONT) training defined as ET that performed with a

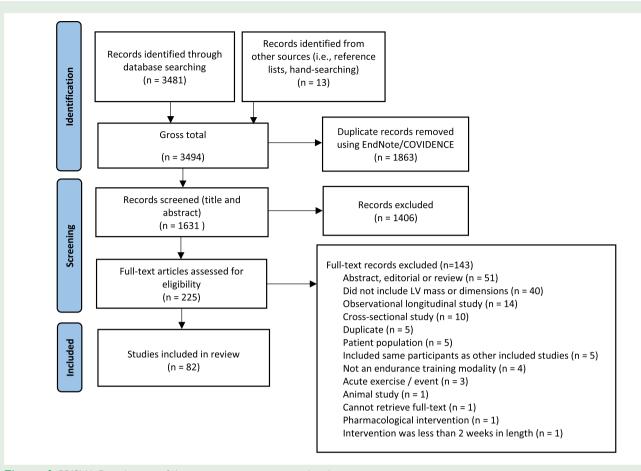


Figure 1 PRISMA flow diagram of the systematic process in article selection.

continuous intensity throughout that did not involve rest periods, *interval* (*INT*) training that included alternating bouts of high intensity with rest periods, and *mixed* (*MIX*) training that included a combination of these, either within the same session or during separate training sessions. Studies assessing more than one independent group were extracted as individual interventions for the analyses. Where full-text articles could not be found, or if data were unavailable from tables or the results section, the authors of the study in question were contacted by email. If the authors could not be contacted, the study was excluded. In instances where the training details were not reported, these studies were left out of the respective sub-analysis.

Data synthesis and analysis Meta-analysis

The raw data extracted from the studies were transformed into effect sizes and were calculated as standardized mean differences (SMD) between preand post-training values using sample size and paired *P*-values with a meta-analysis software, using a random-effects model (Comprehensive Meta-Analysis V3). This model was selected due to different imaging techniques used to assess functional and structural variables as well as differences in the estimation equations to derive LVM across the studies. Absolute values for all variables of interest were the preferred value for the meta-analysis. Indexed values were used if absolute values or body surface area (BSA, pre- and post-measurement) were not reported. Since the model calculates the difference between pre- and post-values, the inclusion of the indexed values in this manner was justified. In cases where exact *P*-values were not reported as 0.05, 0.01, and 0.001, respectively, and when reported as non-significant or *P* > 0.05, the values were reported as 0.999. An overall meta-analysis was conducted for each of the LV structural outcomes (LVM, LVDd, IVSd, PVVTd) and additional meta-analyses were performed independently for each moderator variable to investigate their effect on LV structures. The planned moderators to be assessed were sex, age group [young (18–35 years), middle-aged (36–55 years), or older (>55 years)], training status, type of training, and mode of training. A meta-regression was conducted to ascertain if any effect moderator variable influenced the SMD in LV structures.

Heterogeneity among studies was assessed using l^2 statistics (the percentage of total variation between studies due to heterogeneity rather than by chance) and classified as low, moderate, and high at <50, 51–75, and >75%, respectively.²³ Relative influence of each study on the SMD was assessed by omitting one study at a time for sensitivity analysis ('one study removed analysis'). Publication bias was investigated by funnel plots for a visual inspection of asymmetry and statistically assessed using Egger's test and the trim-and-fill method.^{24,25} The National Heart, Lung, and Blood Institute (NHLBI) quality assessment tool for pre-post studies with no control group to assess for potential flaws in study methods including sources of bias, sampling, cofounding variables, study power, and other relevant factors.²⁶ Each study was judged as 'good', 'fair', or 'poor' quality based on ratings from 11 items included in the tool. The 12th item was not included in this assessment as it pertained to group-level interventions (e.g. a whole hospital, a community) which was not relevant in the current review. Globally, a good study had the least risk of bias and was considered valid. A fair study is prone to some bias, but insufficient to invalidate its findings, varying in its strengths and weaknesses. A poor-quality study has a high risk of bias and is considered invalid. If a study was rated 'poor', it was removed from the analysis to determine its influence on the SMD. If the removal of the poor-rated study did not change the overall outcome of the

SMD when the study was removed, the study remained in the analysis. The quality assessment was performed by two reviewers (B.N.M. and R.J.M.), with a third reviewer (A.T.C.) involved in cases of uncertainty.

Descriptive analysis

The pre- and post-values for structural and functional values were reported as estimated pooled means and were calculated using a weighted sample dependent upon the sample size of each study [pooled average = $((n_1 \times mean_1) + (n_2 \times mean_2)...(n_k \times mean_k))$ /sum of all samples] and pooled standard deviations were calculated as:

$$s_{\text{pooled}} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \dots + (n_k - 1)s_k^2}{n_1 + n_2 + \dots + n_k - k}}$$

When the SD was not reported, it was estimated from the standard error of the mean, 95% confidence interval (CI), or IQR as suggested in the Cochrane handbook.²⁷ In situations where provided measures were not able to be converted to SD, they were excluded from the pooled means table and the sample size and number of studies were adapted accordingly. In instances where the relative VO_{2max} (mL/kg/min) was not provided, it was estimated by dividing the group absolute mean VO_2 (L/min) by the group mean body weight (L/min/kg × 1000). In studies where the SV was not reported, it was calculated using the following equation SV = LVEDV -LVESV. Per cent change was reported in consideration of different measurement techniques and modalities and calculated as ((post - pre)/pre) × 100 for all LV structural variables (LVM, IVSd, PWTd, LVDd) and their mediating factors (i.e. sex, age group, training status, type of training, mode of training). Independent samples t-test or one-way ANOVA was used to determine differences between groups with the Tukey post hoc analysis. The Pearson correlation was used to establish associations between training status and protocols with changes in LVM. Statistical significance was considered statistically significant at a P-value of <0.05. Statistical analyses were performed using SPSS software Version 27.0 (IBM Corp., Armonk, NY, USA).

Results

Study selection and characteristics

The PRISMA flow diagram (Figure 1) illustrates the process of article selection, removal, and inclusion. Eighty-two studies satisfied the inclusion criteria (n = 1908; 19–82 years, 33% female).^{3,12–22,28–97} Baseline characteristics for the included studies are reported in Table 1. There were 19 studies that included more than one population. Specifically, 8 studies reported more than one type^{16,43,44,51,53,62,65} or mode³¹ of ET intervention and 11 studies reported more than one population type (i.e. sex, ^{19,60,63} age,⁶⁹ trained status, ^{14,21,50,54} menopause status,⁴¹ genotype 30) for a total of 105 analyses. Of these studies, 15 were randomized to either the ET or control group. 28,31,36,37,48,51,53,63,66,67,76,77,89,96 Left ventricular structural characteristics were assessed before and after ET using echo or CMR. Table 2 summarizes the ET interventions. The average duration (range) of the ET interventions was 16.3 weeks (2-52 weeks), 4 sessions per week (1-8), and 4.8 h per week (0.2-32.5), with the majority of ET sessions between 30 and 60 min in duration. There were 11 studies that reported an element of strength training within their ET intervention.^{18,32,39,57,61,72,73,75,78,91,93} Trained individuals engaged in a significantly greater number of hours per week compared with untrained individuals $(14.3 \pm 8.8 \text{ vs. } 3.1 \pm 2.2;$ P < 0.001, respectively), with similar length of ET programs (18.9 ± 11.9 vs. 15.9 ± 12.3 weeks; P=0.378). Table 3 summarizes pooled means and % change for before and after ET intervention for all structural and functional parameters in untrained and trained individuals. Figure 2A–E illustrates the per cent change for all LV structural variables and their mediating factors.

Overall ET had a high tolerability, with three participants reporting the training to be burdensome and 19 reporting musculoskeletal injuries out of 10 studies. No studies reported major adverse outcomes; however, there were four cardiac abnormalities identified (i.e. three dysrhythmias and one left bundle branch block) in two studies. There were 127 (7%) dropouts amongst all studies, although 48 studies did not report adherence.

Effect of endurance training on left ventricular structure

Meta-analysis

The results of all meta-analyses including the overall SMD for LV structures and their independent moderators, heterogeneity, and publication bias are reported in Supplementary material online, S2-S5. The meta-analyses revealed a significant increase in all LV structures (LVM: SMD = 0.444; P < 0.001, IVSd: SMD = 0.237; P < 0.001, PWTd: SMD = 0.234; P < 0.001, LVDd: SMD = 0.249; P < 0.001) (see Supplementary material online, S9–S11), with the greatest increase in LVM (Figure 3). Left ventricular mass and LVDd increased in both males and females (LVM: SMD = 0.498; P < 0.001 and SMD = 0.280; P = 0.004; LVDd: SMD = 0.216; P < 0.001 and SMD = 0.245; P = 0.003, respectively), whereas PWTd and IVSd only increased in males. Egger's test revealed publication bias for LVM (P = 0.001) and LVDd (P =0.013). Using the Trim and Fill method in those with publication bias, the SMD decreased slightly for LVM (0.368, 95% CI: 0.279, 0.458) and LVDd (0.188, 95% CI: 0.107, 0.269). The heterogeneity was low to moderate in all studies. None of the studies had high (>75%) heterogeneity. Each of the included studies were of good (n = 33), fair (n = 47), and poor (n = 2) quality as indicated by the NHLBI quality assessment and agreed upon by both reviewers. The removal of the two studies with 'poor' quality did not elicit a significant change in the SMD for LV structural parameters; therefore, these studies remained in the analyses. Sensitivity analyses using the one study removed protocol revealed that the omission of any single study showed no change in the overall statistical significance, indicating that the presented results are statistically robust.

Moderator analysis

Several moderator variables influenced the SMD of the LV structures. The meta-regression bubble plots are reported in Supplementary material online S6-S8. LVM: There was a significant association between age group and LVM (P = 0.0408), with young and middle-aged individuals (B = 0.2836, P = 0.0185; B = 0.3444, P = 0.0256, respectively)conferring the greatest change in LVM compared with older individuals. Trained individuals conferred a greater change in LVM (B = 0.2778, P =0.0110) than untrained and mixed training (B = 0.2976, P = 0.0335) elicited the greatest increase in LVM compared with continuous- and interval-type raining. IVSd: Sex influenced the SMD of IVSd, with males demonstrating the greatest change in IVSd compared with females (B =0.2981, P = 0.0053). Training status also demonstrated a significant association, with those that were trained (B = 0.2362, P = 0.0261) conferring a greater change than untrained individuals. PWTd: There was a significant association between sex and SMD of PWTd, with males conferring the greatest change in PWTd (B = 0.1954, P = 0.0443). There was also a significant association between trained status (P = 0.0010), training type (P = 0.0492), and mode of exercise (P = 0.0046) on SMD of PWTd. Those that were trained (B = 0.3162, P = 0.0010) had a greater change compared with those that were untrained, mixed, and continuous training regimes elicited the greatest change (B =0.2650, P=0.0263; B=0.2404, P=0.0215, respectively) compared with interval training, and swimming, rowing, and running (B = 1.4014), P = 0.0093; B = 0.3084, P = 0.0340; B = 0.2831, P = 0.0022, respectively) conferred the greatest change compared with cycling. LVDd: Those that were trained (B = 0.2344, P = 0.0328) conferred a greater increase compared with the untrained. Of the training types, only those that

Study (author, year)	n	Control (n)	Female (%)	Age [mean ± SD or (range)]	Population	VO _{2max} [mL/ min/kg) (mean ± SD or (range)]	Imaging modality (dimensions included)
Untrained							
Adams_1981 ²⁸	22	9 ^a	0	22 (18–25)	College students (no endurance training > 3 months in last 5 years)	48.6 ± 6.0	Echo (IVSd, PWTd, LVDd)
Aksakai_2013 ²⁹	34	n/a	0	22 ± 2	No history of prior exercise exposure	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Alves_2009_1, 2, 3, 4 ³⁰	83	n/a	0	27 ± 1	Brazilian policeman	47–50	Echo (LVM, IVSd, PWTd, LVDd)
Andersen_2010_A ³¹	18	10 ^a	100	37 ± 8^{b}	Sedentary (no physical training for at least 2 years)	35.5 ± 5.9	Echo (IVSd, PWTd, LVDd)
Andersen 2010_B ⁴	19	10 ^a	100	37 ± 8^{b}	Sedentary (no physical training for at least 2 years)	32.5 ± 4.6	Echo (IVSd, PWTd, LVDd)
Arbab-Zadeh_2014 ³	12	n/a	42	29±6	Untrained (< 30 min/day, < 3×/week regularly using either dynamic or static exercise)	40.3 ± 5.5	CMR (LVM)
Bates_2013 ^{c33}	10	n/a	40	39 <u>+</u> 12	Untrained	27.6 ± 6.3	CMR (LVM)
Boone_2014 ³⁵	9	n/a	0	27 ± 3	Moderately active (< 3×/week of any training)	53	Echo (LVM, IVSd, LVDd)
Camargo_2008 ³⁶	6	7 ^a	0	29 ± 4	Healthy (no regular physical training in previous year, 35–42 VO _{2peak} (mL/ min/kg)	38.1 ± 2	CMR (LVM)
Cornelissen_2011 ³⁷	16	n/a	44	59 (55–71) ^b	Sedentary	21.8 ± 0.8	CMR (LVM)
Cox_1986 ³⁸	11	5 ^a	55	23±1	Sedentary, inactive (no formal training for at least 3 months prior)	40.8 ± 2.1	Echo (LVM, IVSd, PWTd, LVDd)
Dart_1992 ¹²	10	n/a	50	20–30	Sedentary	38	Echo (LVM, IVSd, PWTd, LVDd)
DeMaria_1978 ⁴⁰	24	n/a	46	26	Sacramento Police Academy	35.5 ± 1.7	Echo (LVM, IVSd, PWTd, LVDd)
Egelund_2017_1 ⁴¹	36	n/a	100	49±2	Late pre-menopausal, sedentary (<2 h of physical training/week during previous 2 years, <40 VO ₂ (mL/min/kg)	30.1 ± 4.4	Echo (LVM, IVSd, PWVTd, LVDd)
Egelund_2017_2 ⁴¹	37	n/a	100	53±3	Early post-menopausal, sedentary (<2 h of physical training/week during previous 2 years, < 40 VO ₂ (mLl/min/ kg)	30.4 ± 3.3	Echo (LVM, IVSd, PWVTd, LVDd)
Ehsani_1991 ¹³	10	n/a	0	64±3	Sedentary	29.6 <u>±</u> 4.1	Echo (LVM, PWTd, LVDd)
Esfandiari_2014_A ⁴³	8	n/a	0	25 ± 3	Untrained (<2 h of <6 METs)	39.5 ± 7.1	Echo (LVM, IVSd, PWTd, LVDd)
Esfandiari_2014_B ⁴³	8	n/a	0	26±5	Untrained (<2 h of <6 METs)	39.9 ± 5.9	Echo (LVM, IVSd, PWTd, LVDd)
Eskelinen_2016_A ⁴⁴	14	n/a	0	47 <u>+</u> 9	Untrained (< 2×/week, no active training background, < 40 VO ₂ (mL/min/kg)	34.7 ± 4.1	CMR (LVM)
Eskelinen_2016_B ⁴⁴	14	n/a	0	48 ± 10	Untrained (< 2×/week, no active training background, < 40 VO ₂ (mL•/min•/kg)	33.7 ± 3.9	CMR (LVM)
Fujimoto_2010 ⁴⁷	9	n/a	33	71 ± 3	Sedentary (\leq 30 min, 3×/week)	22.8 ± 3.4	CMR (LVM)
Fujimoto_2013 ⁴⁶		13 ^a	71	67 ± 6	Sedentary (\leq 30 min, 3×/week)	23.0 ± 4.7	CMR (LVM)
Grace_2018_1 ¹⁴		n/a	0	62 ± 5	Sedentary (no participation in formal exercise training)	28.3	Echo (LVM, IVSd, PWVTd, LVDd)

Table 1 Continued

Study (author, year)	n	Control (n)	Female (%)	Age [mean ± SD or (range)]	Population	VO _{2max} [mL/ min/kg) (mean ± SD or (range)]	Imaging modality (dimensions included)
Haykowsky_2005 ⁴⁸	8	8 ^a	100	66±3	No regular participation in aerobic or strength training	22	Echo (LVM, IVSd, PWTd, LVDd)
Hedman_2017 ⁴⁹	21	21ª	100	34±7	No regular participation in aerobic training within last year	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Hickson_1982_1, 2 ⁵⁰	15	n/a	40	29 ± 5	Moderately active in recreational sports, but no training in last 6 months	39.6–45.2	Echo (LVM, IVSd, PWTd, LVDd)
Holloway_2018 ¹⁵	12	9 ^a	0	21 ± 2	Healthy	42.5	Echo (IVSd, PWTd)
Huang_2019_1 ⁵¹	18	9 ^a	0	22 ± 1	Sedentary (exercise <1/week, < 20 min)	20.4 ± 1.4	Echo (LVM, IVSd, LVDd)
Huang_2019_2 ⁵¹	18	9 ^a	0	22 ± 0	Sedentary (exercise <1/week, < 20 min)	21.0 ± 1.0	Echo (LVM, IVSd, LVDd)
Hulke_2012_1 ⁵²	42	n/a	100	20 ± 2	Healthy (DNR physical activity criteria)	37.4 ± 3.3	Echo (LVM, IVSd, PWTd, LVDd)
Hulke_2012_2 ⁵²	43	n/a	0	20 ± 1	Healthy (DNR physical activity criteria)	45.1 ± 5.9	Echo (LVM, IVSd, PWTd, LVDd)
Hulke_2012_A ¹⁶	14	12	DNR	20 ± 1	Healthy (DNR physical activity criteria)	34.1 ± 6.1	Echo (LVM, IVSd, PVVTd, LVDd)
Hulke _2012_B ¹⁶		12	DNR	20 ± 1	Healthy (DNR physical activity criteria)	33.3 ± 8.5	Echo (LVM, IVSd, PWTd, LVDd)
Hwang_2016_1 ⁵³		14 ^a	67	65 <u>+</u> 1	Sedentary	23.1 ± 0.7	Echo (LVM, IVSd, PWTd, LVDd)
Hwang_2016_2 ⁵³		14 ^a	50	66 ± 2	Sedentary	25.9 ± 1.9	Echo (LVM, IVSd, PWTd, LVDd)
Kanakis_1982_1,2 ⁵⁴		n/a	58	23 (19–32)	Moderately active in recreational sports	35.9–42.5	Echo (IVSd, PWTd, LVDd)
Kiflom_2022 ⁵⁵	20	n/a	0	19–23	No regular participation in exercise training	n/a	Echo (IVSd, PWTd, LVDd)
Kivisto_2006 ⁵⁶		n/a	71	43 (23–58)	Sedentary	n/a	CMR (LVM)
Krzeminski_1989 ¹⁷		n/a	0	21±8	No active participation in sports	46.3 ± 4.3	Echo (PWTd, LVDo
Landry_1985 ⁵⁹		n/a	60	25 ± 4	Sedentary (never trained)	37	Echo (LVM, IVSd, PVVTd, LVDd)
Lane_2014_1 ⁶⁰		n/a	0	24 ± 1	Sedentary (<30 min, < 1/week)	38	Echo (LVM)
Lane_2014_2 ⁵⁹ Lusiani_1986 ⁶¹		n/a 9ª	100 0	24 ± 1 20 ± 7	Sedentary (<30 min, < 1/week) Prior to beginning training program	30 DNR	Echo (LVM) Echo (LVM, IVSd, PWTd, LVDd)
Mahdiabadi_2013_A ⁶²	10	n/a	0	21 ± 2	Non-athletic	DNR	Echo (IVSd, PWTd, LVDd)
Mahdiabadi_2013_B ⁶²	10	n/a	0	21 ± 1	Non-athletic	DNR	Echo (IVSd, PWTd, LVDd)
Marsh_1983 ⁶⁴	12	12	100	28 ± 4	Running on unorganized basis <6 months - 4 years	46.4 ± 3.6	Echo (LVM, IVSd, PVVTd, LVDd)
Marsh_2021_1 ⁶³	46	COC	100	24±5	Untrained (< 150 min/week of organized exercise)	DNR	CMR (LVM)
Marsh_2021_2 ⁶³		COC	0	28 ± 6	Untrained (< 150 min/week of organized exercise)	DNR	CMR (LVM)
Masoomeh_2012 ⁹⁷	10		100	25±4	Non-athletic (no previous regular exercise training)	DNR	Echo (LVM, IVSd, PWVTd, LVDd)
Matsuo_2014_A ⁶⁵	14	n/a	0	26 ± 7	Sedentary (no participation in regular activities for 1 year)	43.9 ± 6.7	CMR (LVM)

Continued

Study (author, year)	n	Control (n)	Female (%)	Age [mean ± SD or (range)]	Population	VO _{2max} [mL/ min/kg) (mean ± SD or (range)]	Imaging modality (dimensions included)
Matsuo_2014_B ⁶⁵	14	n/a	0	27±6	Sedentary (no participation in regular activities for 1 year)	41.9 ± 5.6	CMR (LVM)
Matsuo_2014_C ⁶⁵	14	n/a	0	26 ± 6	Sedentary (no participation in regular activities for 1 year)	42.0 ± 6.8	CMR (LVM)
Morrison_1986 ⁶⁶	17	8	100	52 ± 4	Untrained	27.3 ± 4.6	Echo (IVSd, PWTd, LVDd)
O'Driscoll_2018 ⁶⁷	40	COC	0	21 ± 2	Inactive/sedentary (<2.5 MET-h/week,> 8 h/day sitting time)	43.2 ± 5.2	Echo (LVM, IVSd, PWTd, LVDd)
Park_2003 ⁶⁸	8	n/a	100	63 ± 2	Sedentary	21.6 ± 2.6	Echo (LVDd)
Perrault_1982_1 ⁶⁹	11	n/a	0	19±1	DNR	DNR	Echo (IVSd, PWTd, LVDd)
Perrault_1982_2 ⁶⁹	13	n/a	0	40 ± 3	DNR	DNR	Echo (IVSd, PWTd, LVDd)
Pickering_1997 ⁷⁰	10	n/a	60	62 ± 2	Sedentary	25.0 ± 3.2	Echo (IVSd, PWTd, LVDd)
Rahimi_2018_1 ⁷¹	10	n/a	100	32±7	Non-athlete (no specific exercise activities)	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Rodrigues_2006 ⁷²	23	n/a	0	31 ± 4	Sedentary	39±5	Echo (LVM, IVSd, PWTd, LVDd)
Rojek_2015 ⁷³	21	0	24	33±6	Starting to prepare for triathlon competition	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Rubal_1987_1 ¹⁹	10	n/a	100	19–31	No participation in regular programme of physical conditioning	38±8	Echo (LVM, IVSd, PWTd, LVDd)
Rubal_1987_2 ¹⁹	10	n/a	0	19–30	No participation in regular programme of physical conditioning	42 ± 7	Echo (LVM, IVSd, PWTd, LVDd)
Saadatnia_2016 ⁹⁶	12	10 ^a	0	23 ± 3	Untrained (currently no regular exercise), non-athlete	37.6	Echo (LVM, IVSd)
Sagiv_1989 ⁷⁴	20	n/a	0	67 <u>±</u> 4	Physically active in supervised aerobic programme for > 1 year, 3×/week	29.9	Echo (IVSd, PWTd)
Sayevand_2015 ⁷⁶	10	10 ^a	100	23 ± 1	No regular training in the previous year	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Scharf_2015 ⁷⁷	42	n/a	0	44 ± 5	Sedentary (<3 h/week of physical training)	DNR	CMR (LVM)
Shapiro_1983 ²⁰	15	15	0	26	No recent participation in sport	48.6 ± 4.0	Echo (LVM, IVSd, PWTd, LVDd)
Skattebo_2020 ⁷⁹	12	n/a	42	29±6	Untrained (≤ 1 exercise training session/ week during previous year)	44.5	Echo (LVM, IVSd, PWTd, LVDd)
Slordahl_2004 ⁸⁰	12	n/a	100	22 ± 1	Sedentary (no formal training programme <3 months prior to the study)	42.6 ± 2.9	Echo (LVM, IVSd, PWTd, LVDd)
Soto_2008 ⁸¹	12	n/a	50	69±6	Sedentary (≤30 min/day, <2 days/week)	23 ± 3	Echo (LVM)
Spence_2011 ⁸²	10	n/a	0	27 ± 1	<3 h/week of structured activity	45.8 ± 1.6	CMR (LVM, IVSd, PWTd, LVDd)
Spina_1992 ⁸⁴	17	n/a	41	27 <u>±</u> 16	Sedentary (no regular exercise for 6 months prior to study)	40.9	Echo (LVDd)
Spina_1997 ⁸⁶	8	n/a	0	66 ± 5	Sedentary (no regular exercise for 6 months prior to study)	28.7	Echo (LVM, IVSd, PWTd, LVDd)
Spina_2000 ⁸⁵	10	n/a	100	54 <u>±</u> 3	Sedentary (<2×/month of regular physical activity)	22.0 ± 0.5	Echo (LVM, IVSd, PWTd, LVDd)

Table 1 Continued

Study (author, year)	n	Control (n)	Female (%)	Age [mean ± SD or (range)]	Population	VO _{2max} [mL/ min/kg) (mean ± SD or (range)]	Imaging modality (dimensions included)
Spina_2004 ⁸³	22	14 ^a	50	82±4	Sedentary	17±3	Echo (LVM, IVSd, PWTd, LVDd)
Vance_2014 ⁸⁷	19	22 ^a	0	22–37	Untrained (<2 h/week of aerobic training prior to enrolment,<50 mL/kg/min)	37.1 ± 7.1	Echo (LVM, IVSd, PWTd, LVDd)
Vanhees_1992 ⁸⁸	27	n/a	0	38 ± 2	Sedentary (<1 h/week of sport activities)	n/a	Echo (LVM, IVSd, PWTd, LVDd)
Wieling_1981_1 ²¹	9	17 ^d	0	20 ± 2	Freshmen (active in high school sports, but no daily training programme)	58 ± 8	Echo (IVSd, PWTd, LVDd)
Windecker_2002 ⁹²	8	n/a	0	36±5	Healthy (DNR prior physical activity levels)	46±6	Echo (LVM, IVSd, PWTd, LVDd)
Wolfe_1979 ²²	12	10 ^a	0	37	No engagement in regular exercise for at least 5 years prior	42.4 ± 2.4	Echo (LVM, IVSd, PWTd, LVDd)
Wolfe_1992 ⁹³	7	4 ^a	100	19±2	Sedentary (no previous participation in endurance-type sport)	41.3 ± 3.3	Echo (LVM, IVSd, PWTd, LVDd)
Younis_1987 ⁹⁴	19	n/a	0	19	Non-athlete, active	53±6	Echo (LVM, IVSd, PWTd, LVDd)
Trained							
Baggish_2009 ^{e32}	38	n/a	50	20 ± 1	University students participating in official competitive athletics	DNR	Echo (LVM, IVSd, PW/Td)
3onaduce_1998 ³⁴	15	15 ^d	0	21 ± 4	High level bicyclists competing in Italian amateur national teams for >3 years	62±4	Echo (LVM, IVSd, PWTd, LVDd)
D'Ascenzi_2015 ³⁹	91	n/a	0	23±6	Professional athletes (soccer, basketball, volleyball) competing in national or international level	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Ehansi_1978 ⁴²	8	n/a	13	17–19	University swim team (no regular exercise for 2–7 months before the beginning of training)	51.8 ± 2.0	Echo (LVM, PWTd, LVDd)
Fagard_1983 ⁴⁵	12	12 ^d	0	24 <u>+</u> 1	Belgian cyclists (professional and amateur)	60.9 ± 1.5	Echo (IVSd, PWTd, LVDd)
Grace_2018_2 ¹⁴	17	n/a	0	61±5	Masters athletes (national competitors, in triathlon, athletics, sprint cycling, racquet sports)	40.4	Echo (LVM, IVSd, PWTd, LVDd)
Kleinnibbelink_2021_1 ⁵⁷	19	n/a	0	26 ± 4	Elite (Olympic) rowers	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Kleinnibbelink_2021_2 ⁵⁷	8	n/a	100	27 ± 2	Elite (Olympic) rowers	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Lamont_1980 ⁵⁸	11	n/a	100	21 ± 4	University swim team	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Naylor_2005 ¹⁸	22	12 ^ª	23	20 ± 3	Elite rowers	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Rahimi_2018_2 ⁷¹	10	n/a	100	31 <u>+</u> 9	Athlete (>5×/week, 2 h)	DNR	Echo (LVM)
Sareban_2018 ⁷⁵	15	n/a	0	20 ± 3	National or international level rowers	67±6	Echo (LVM, LVDd)
Shah_2018 ⁷⁸	9	n/a	0	19 <u>+</u> 1	Newly matriculated, recruited members of varsity rowing	39.2	Echo (LVM, IVSd, PWTd, LVDd)
Venckunas_2006 ⁸⁹	12	11 ^a	0	25 <u>+</u> 7	Distance runners	DNR	Echo (LVM, IVSd, PWTd, LVDd)
Wasfy_2018 ⁹⁰	8	4 ^d	0	DNR	Newly matriculated, recruited members of varsity rowing	DNR	Echo (LVM)

Continued

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Table 1 Continued

Study (author, year)	n	Control (n)	Female (%)	Age [mean ± SD or (range)]	Population	VO _{2max} [mL/ min/kg) (mean ± SD or (range)]	Imaging modality (dimensions included)
Wasfy_2019 ⁹¹	17	n/a	47	19±0	Collegiate swimmers	DNR	Echo (LVM, LVDd)
Wieling_1981_2 ²¹	14	17 ^d	0	22 ± 6	Senior oarsmen (completed at least 1 rowing season)	62.1 ± 7.6	Echo (IVSd, PVVTd, LVDd)
Zilinski_2015 ⁹⁵	45	n/a	0	48 <u>+</u> 7	Recreational athletes	44.6 ± 5.2	Echo (LVM, PWTd)

Articles assessing independent training groups were evaluated as individual studies and were distinguished by letters (A, B, C, D); articles assessing independent population groups were evaluated as individual studies and were distinguished by number (1, 2, 3, 4).COC, cross-over control study; CMR, cardiac magnetic resonance imaging; DNR, did not report; Echo, echocardiography.

^aUnderwent pre- and post-measurement.

^bOnly reported age as a group.

^cControl group in a clinical study that underwent intervention.

^dPre-measurement only.

^eOnly included group with parents who did not have hypertension.

participated in a mixed training regime elicited an increase in SMD of LVDd (B = 0.3459, P = 0.0053). Furthermore, only those that participated in swimming and rowing conferred an increase in SMD of LVDd (B = 0.6527, P = 0.0056; 0.3839, P = 0.0198, respectively) compared with running.

Impact of training protocol and status on left ventricular structural change

The length of the ET intervention was not associated with an increase in LVM when all studies from 2 to 52 weeks were evaluated together (r = 0.103; P = 0.349). The dose-response association between the length of the training programme and LVM between sexes are presented in Figure 4A and B. In the males, there was a significant positive association between the length of study and change in LVM (r =0.424; P < 0.005), whereas in females, there was not (r = 0.264; P =0.274). In the studies that reported VO_{2max} , all reported an increase in VO_{2max} except for one group of elite rowers.⁷⁵ The mean per cent change for VO_{2max} was higher in the untrained (N=69) vs. the trained (N = 8) group (14.7 \pm 7.6 and 8.6 \pm 5.3; P = 0.014, respectively); however, the mean per cent change for LVM was higher in the trained (N = 15) vs. untrained (N = 71) group (19.7 ± 11.7 and 9.9 \pm 10.1; P = 0.007, respectively). Additionally, pre-intervention VO_{2max} and LVM (N=63) were positively associated with the change in LVM (r = 0.285, P = 0.024).

Discussion

This systematic review and meta-analysis synthesized data from 82 studies and 1908 participants examining the impact of ET intervention on LV structure in healthy men and women. The main findings were: (i) all LV structures increased in response to ET; (ii) LVM increased in young and middle-aged individuals but not in older individuals; (iii) a significant increase in wall thickness was observed in males, whereas an increase in LVM and LVDd was similarly augmented in males and females; (iv) trained status was associated with a greater increase in all LV structural parameters compared with untrained; (v) type of training influenced the adaption of LVM, PWTd, and LVDd with mixed-type training eliciting the greatest change; and (vi) mode of training conferred an increase in PWTd and LVDd with rowing and swimming eliciting the greatest increase (*Figure 5*). These findings in the context of influencing factors are discussed below.

Age

Ageing is associated with numerous cardiac changes, such as an increase in wall thickness and a decline in ventricular contractility.^{3,98,99} Additionally, LVM and LVM index increases naturally with age in both males and females.¹⁰⁰ It is accepted that intense and long-lasting ET increases wall thickness beyond age-associated norms with a concomitant increase in cavity size in younger individuals; however, these changes have not been consistently observed in older individuals initiating an ET programme.^{47,98} In a study comparing the impact of 6 months of unsupervised training on cardiac structure in younger (mean age 29 ± 4) and older (mean age 46 ± 7) individuals preparing for a marathon, both groups demonstrated a similar increase in LVM; however. the younger group also saw an increase in LV cavity size.⁹⁸ Another study reported that in sedentary seniors (71 ± 3) compared with Masters athletes (68 ± 3), the sedentary seniors' baseline LVM was significantly less than the Masters athletes'.⁴⁷ After 1 year of progressive training, the sedentary seniors' LVM increased closer to the LVM of the Masters athletes; however, they did not see a change in their mass-volume ratio. $^{\rm 47}$ A potential reason for this could be that long and intense programmes required to elicit such changes are cautiously initiated in the previously inactive older population due to the concern of causing a musculoskeletal injury or an adverse cardiac event. However, it would be important to determine if high intensity and longer types of ET could elicit positive remodelling in these older age groups, safely to prevent age-associated cardiac structural and functional changes such as LV hypertrophy and LV stiffening.⁹⁹ In order to prevent the age-related, cross-linked advanced glycation end products in the vascular and LV walls and to elicit change in the number and volume of cardiac myocytes, exercise training needs to start early, and if started later in life, may be too late.¹⁰¹ Secondly, sedentary adults may need a longer period of time to see improvements in cardiac structure and function compared with their younger counterparts.¹⁰¹ In the present study, the average length of study in the older group was 24.1 ± 18.7 (6–52) weeks and the average hours of ET per week was 2.5 ± 1.3 h. Further research examining the age ET needs to be undertaken to attenuate age-related decline in cardiac structure and function and thereby cardiac risk as well as determining age-appropriate training programmes.

Sex differences

Many of the mechanisms that contribute to cardiac sex differences are unclear, including the magnitude and temporal sequence of cardiac

11 RUN 85% HR _{Ms} DNR 12 RUN 11-2/17 RF (Borg scale) 1 volume 13 RUN R1 between VT - HR signty above RCP DNR 16 RUN 82% HR _{Ms} DNR 16 SOCCER Football session DNR 16 CYCLE, or 5 training zones (base pace - intervals) 1 duration 16 CYCLE 70-80% VO _{max} and RPE Reasses VO _{max} at 8 wh. 17 12-14 (Borg scale) THR Reasses VO _{max} at 8 wh. 10 WiK DN, 56% HR DNR 11 RUN 70% MHL DNR 12 HR, RUN 70% MHL DNR 13 BUN 70% MHL DNR 14 BUN 70% MHL DNR 10 WiK DN, 66% HR DNR 11 RUN 70% MHL DNR 12 RUN 70% MHL DNR 13 BUN THR DNR 14 DNR DNR DNR 14 DNR DNR DNR 14 DNR DNR DNR 14 DNR DNR DNR 11 DNN DNR DNR </th <th>Image: Number of the stand service of the serv</th> <th>Study (author, year)</th> <th>Length of study (weeks)</th> <th>Modality</th> <th>Intensity</th> <th>Progressive training</th> <th>Type of training</th> <th>Frequency (days/week)</th> <th>Time per session, min</th> <th>Total hours (h/ week)</th>	Image: Number of the stand service of the serv	Study (author, year)	Length of study (weeks)	Modality	Intensity	Progressive training	Type of training	Frequency (days/week)	Time per session, min	Total hours (h/ week)
11 RJN ⁴ 855 H _{Rus} DNR 28 RUN H1 +>217 RFE (Borg scale) 1 volume 28 RUN Reseven VT - HR slightly above RCP DNR 20 RUN Reseven VT - HR slightly above RCP DNR 21 RUN Football session DNR 22 RUN The Reveen VT - HR slightly above RCP DNR 23 RUN CCLE 70-90% VO _{Javas} and RPE DNR 24 Hitestity profits from DNR RWS 26 CYCLE 4 Intensity profits from DNR 27 RUN 703 MHS DNR Nork adjusted to achieve 27 RUN 703 MHS DNR Nork adjusted to achieve 28 CYCLE 85-90% VO _{Javas} (cycle ergometer) - 100% VO _{Java} (S V _{VI} and S V _S) Nork adjusted to achieve 27 RUN TCLE 736 M _R me Nork adjusted to achieve 29 VO _{Line} (cycle ergometer) - 100% VO _{Javas} (S V 11 V/veek ThR Nork adjusted to achieve 21 RUN <	11 RUN* BSS HR DNR COUT 5 12 RUN HEANENT - HR slighty above RCP DNR COUT 23 16 RUN REANENT - HR slighty above RCP DNR COUT 23 16 RUN REANENT - HR slighty above RCP DNR COUT 23 16 RUN CCLE 5 training session DNR COUT 23 16 CCLE 7 training Internoty Internoty MX 23 17 - CCLE 1-1-4 (Borg stell) NNR CONT 3 17 - CCLE 1-1-4 (Borg stell) NNR CONT 3 17 - CCLE 4 NNR NNR CONT 3 17 NNR NNR NNR NNR CONT 3 17 - CNLE or STP - NNR NNR CONT 3 18 - CNLE or STP NNR NNR CONT 3 19 - CNLE	Untrained								
26 RUN 11 -2.17 RF (Borg scale) 1 volume 12 RUN 11 -2.17 RF (Borg scale) 1 volume 16 RUN CYCLE, or 5 raning zones (base pace - intervals) 1 (arration 23<	26 RUN 11 — -2^{17} RFE (Berg stale) Toolme COUT DNR COUT D 16 RUN R5 berner VT – HR supprotect DNR COUT 3 16 RUN CYCLE or SUN CYCLE of SUN CYCLE of SUN CYCLE Framing sores (base pace – intervals) Tothen MX 2-3 16 CYCLE 70 80% VO _{2max} and RFE Reasses VO _{2max} at 8 ws. COUT 3 17 CYCLE 70 80% VO _{2max} and RFE Reasses VO _{2max} at 8 ws. COUT 3 17 CYCLE 70 80% VO _{2max} and RFE DNR MX 3 3 17 RUN 050 HIR Not adjusted to addres MX 3 3 18 RUN KUN 65 HR SN VO _{2max} at 8 ws. COUT 3 10 WLK RUN 65 HR NN NN MX 3 10 WLK RUN 65 HR SN VO _{2max} at 8 ws. COUT 3 11 RUN 70 % VO _{2max} at 8 ws. COUT 3 11 <	Adams_1981 ²⁸	11	RUN ^a	85% HR _{max}	DNR	CONT	5	50	4.2
12 RUN HR between VT \rightarrow HR signtly above RCP DNR 16 SOCCER Football session DNR 16 SOCCER Football session DNR 22 RUN. CYCLE or 5 training zones (base pace – intervals) T duration 16 CYCLE 70–80% VO _{2mus} and RPE Reasses VO _{2mus} at 8 w/s. 20 CYCLE 70–80% VO _{2mus} and RPE Reasses VO _{2mus} at 8 w/s. 21 CYCLE 70% VAIts. DNR 20 CYCLE 70% MHR DNR 20 No 30% VAIts. DNR 21 RUN 70% HR DNR 21 RUN 70% HR DNR 21 RUN 70% HR. DNR 22 RUN. CYCLE 60–96% VO _{2mus} (sycle ergometer) – 100% VO _{2mus} (sy requested to maintain 23 RUN. CYCLE 60–96% VO _{2mus} DNR 24 CYCLE 70% HR. DNR 25 RUN. CYCLE 60–96% VO _{2mus} Tork digree to maintain 26 CYCLE<	12 RUN Influence IVT - HR algebry above RCP DNR COUT 2-3 16 RUN CYCLE, or SMM 52% MHR DNR MN 7 2-3 17 SMM CYCLE 57% MHR DNR MN 2-3 16 SCCLE Fraining zones (tase pace - interval) 1 1 1 2-3 17 CCLE Attraining zones (tase pace - interval) 1 1 1 2-3 17 CCLE Attraining zones (tase pace - interval) NR 2-3 3 17 HCLE 4 interval) NR 3 3 17 NLN CCLE NR NR NR 3 17 NLN S NR NR NR 3 18 NLN NR NR NR 3 19 VLN NR NR 3 10 NLN NR NR 3 11 RUN NR NR<	Aksakai_2013 ²⁹	26	RUN	11 →≥17 RPE (Borg scale)	↑ volume	CONT	DNR	60240	DNR
16 RUN 22% MHR DNR 16 SOCCER Forbial sesion DNR 16 SOCCER Forbial sesion DNR 16 CYCLE 71-400 Straining zones (base pace - intervals) 1 duration 16 CYCLE 70-400% VO.Dms and RFE Reasers VO.Dms at 8 Ws, work adjusted to achieve 17 12-14 (Borg scale) 17-14 (Borg scale) THR 10 VVK.R.UN. 6.00 r30% Watthms Work adjusted to achieve 11 NUN CYCLE 70% WOR adjusted to achieve THR 10 WK.R.UN. 70% HR DNR 11 R.UN.CYCLE 70% WOL adjusted to achieve 11 R.UN.CYCLE 70% VO.Dms at 8 Ws, work adjusted to achieve 11 R.UN.CYCLE 70% VO.Dms (5 × 111 WiveeK 11 R.UN.CYCLE 60% HR.M. 70% HR.M. 12 CYCLE 70% VO.Dms (5 × 111 WiveeK 13 R.UN.CYCLE 60% HR.M. 70% HR.M. 14 CYCLE 70% VO.Dms (5 × 111 W	16 RUN S2% MHR DNR CONT 2-3 17 SOCCER Football seasion DNN MX 2-3 17 RUN, CYCLE or 5 training zones (base pace – internals) DNR MX 2-3 17 RUN, CYCLE or 5 training zones (base pace – internals) DNR MX 2-3 17 CYCLE or 70-80% VO _{2max} and PRE Reases VO _{2max} at 8 wks. CONT 3-46 17 CYCLE or STIP 70-80% VO _{2max} and PRE DNR MX 2-3 17 RUN 706 w130% watth-second DNR MX 2-3 17 RUN 700 w130% watth-second DNR 2-3 3-6 17 RUN 700 w130% watth-second DNR 7-11 7-7 7-7	Alves 2009_1,2,3,4 ³⁰	12	RUN	HR between $VT \rightarrow HR$ slightly above RCP	DNR	CONT	ſ	60	m
16 SOCCER Football session DNR 52 RUN, CYCLE, or 5 training zones (base pace - intervals) 1 duration 16 CYCLE 70.80% VO. _{2mex} and RPE Reassess VO. _{2mex} at 8 wks. 12–14 (Borg scale) 1.2–14 (Borg scale) 1 duration 12–14 (Borg scale) THR Reassess VO. _{2mex} at 8 wks. 12 VIN, CYCLE 4 intensity profiles from NR 12 NUN, CYCLE 85-90% VO. _{2mex} and RPE Reassess VO. _{2mex} at 8 wks. 12 RUN 50% MR DNR 12 NUN, CYCLE 85-90% VO. _{2mex} (cycle ergometer) - 100% VO. _{2mex} at 8 wks. 10 WLK, RUN 66% HRR DNR 11 RUN, CYCLE 85-90% VO. _{2mex} (cycle ergometer) - 100% VO. _{2mex} (s 7 111 W/week 11 RUN 70% VO. _{2mex} (ED) YOR adjusted to maintain 12 CYCLE 60-96% VO. _{2mex} (ED) YOR adjusted to maintain 13 CYCLE 70% VO. _{2mex} (ED) YOR adjusted to maintain 14 RUN 70% VO. _{2mex} (ED) YOR adjusted to maintain <	16 SOCCER Football sestion DNR C/I M/X M/X M/X M/X 2-3 16 CVCLE, or SWM Tuning zones (base pace - intervals) Zon-BOX VD_mus and RFE Zon-BOX VD_mus and RFE Zon-BOX VD_mus and RFE Reasers VD_mus at 8 wds, ZoN ZoN Zon-BOX VD_mus and RFE Zon-BOX VD_mus at 8 wds, ZoN ZoN <td>Andersen_ 2010_A³¹</td> <td>16</td> <td>RUN</td> <td>82% MHR</td> <td>DNR</td> <td>CONT</td> <td>2–3</td> <td>60</td> <td>2.5^c</td>	Andersen_ 2010_A ³¹	16	RUN	82% MHR	DNR	CONT	2–3	60	2.5 ^c
52 RUN, CYCLE, or SWM 5 training zones (base pace – intervals) † duration 16 CYCLE 70-80% VC _{2xxx} and RFE Reassess (VC _{2xxx} and RFE 12–14 (Borg scale) nintensity 12 WUN, CYCLE, or 7 12 4 CYCLE 4 intensity profiles from 12 NUN, RUN, 6% HR Reassess (VC _{2xxx} and RFE 12 8 0 to 130% Wattshaw DNR 10 WLK, RUN, 6% HR DNR 7 RUN, CYCLE 6.50 to 130% Wattshaw DNR 7 RUN, CYCLE 8 90 to 130% Wattshaw DNR 7 RUN, CYCLE 6.0 to 130% Wattshaw DNR 0 7 RUN, CYCLE 70% VC _{2xxx} DNR 7 RUN, CYCLE 70% VC _{2xxx} DNR 7 RUN, CYCLE 60-96% VC _{2xxx} CYCLE 8 CYCLE 60-96% VC _{2xxx} CYCLE 9 CYCLE 60-96% VC _{2xxx} THK 11 RUN 70% HR _{max} THK 12 CYCLE 60-96% VC _{2xxx} CYCLE 13 CYCLE 60-96% VC _{2xxx} THK 14 RUN 70% HR _{max} THK 12	52RUN CTCLE orStraing zones (base pace - intendity)IduationMIX $3-6$ 16CYCLE $7-60\%$ Voltana and RPERassess Voltana, at 8 wks.COVT316CYCLE $7-60\%$ Voltana and RPERassess Voltana, at 8 wks.COVT317 $1-2+14$ (805 value) $1-14$ (805 value)DNRMX3518CYCLE $1-14$ (805 value)DNRMX3519KUN70% MHRDNRDNRCOVT310WLK, RUN70% MHRDNRDNRCOVT311RUN70% MHRDNRDNRCOVT311RUN70% MHRDNRCOVT312CYCLE of STP5 min intervalis)DNRDNRCOVT313RUN70% MRNork adjusted to maintainCOVT314RUN70% MR.Nork adjusted to maintainCOVT315RUN70% MR.Nork adjusted to maintainCOVT316CYCLE60-96% Voltana70% MR.70% MR.317RUN70% MR.70% MR.70% MR.318RUNCYCLE9-100% Voltana70% MR.70% MR.317RUN70% MR.70% MR.70% MR.318RUN70% MR.70% MR.70% MR.319CYCLE9-100% Voltana70% MR.70% MR.310CYCLE9-100% Voltana70% MR.70	Andersen_2010_B ³¹	16	SOCCER	Football session	DNR	XIM	2–3	60	2.5 ^c
SWM Intensity 16 CYCLE 70–90% VO _{Invas} and RPE Reassess VO _{Invas} at 8 Ws. 12–14 (Borg scale) 12–14 (Borg scale) work adjusted to achieve THR 12 RUN 70-90% VO _{Invas} and RPE Reassess VO _{Invas} at 8 Ws. 12 RUN 70% NHR DNR 10 WLK, RUN. 6.6% HRR DNR 11 RUN 70% NHR DNR 12 RUN 70% NHR DNR 13 NULK, RUN. 6.6% HRR DNR 10 WLK, RUN. 6.6% HRR DNR 11 RUN 70% VO _{Invas} DNR 12 CYCLE 70% VO _{Invas} DNR 11 RUN 70% HRms. DNR 12 CYCLE 60-96% VO _{Invas} DNR 11 RUN 70% NV Mork adjusted to maintain 7 RUN, CYCLE 60-96% VO _{Invas} DNR 11 RUN 70% NRms. DNR 12 CYCLE 60-96% VO _{Invas} DNR 13 RUN, CYCLE 60-96% VO _{Invas} DNR 14 RUN 70% NRms DNR 15 RUN, CYCLE 60-96% VO _{Invas} DNR 16 </td <td>NVM Filteristy Interesty Entersity CVCLE 70-80% VO_mus and RPE Reastess VO_mus at 8 Ms. CONT 3 6 CYCLE 12-14 (Rorg sciel) DNR MX CONT 3 12 Horesty profile from DNR DNR MX 35 3 12 RUN 706 Horesty profile from DNR MX 35 3 12 RUN 706 MR DNR DNR MX 35 12 RUN 706 MR DNR DNR 20 3 13 CCICLE or SOW Som Kuttmans DNR DNR 3 14 CVCLE 70% VOmma (ED) Vork adjusted to maintain CONT 3 15 RUN 70% VOmma (ED) Vork adjusted to maintain CONT 3 16 CYCLE 60-90% VOmma (ED) Vork adjusted to maintain CONT 3 17 RUN 70% VOmma (ED) Vork adjusted to maintain CONT 3 18</td> <td>Arbab-Zadeh_2014³</td> <td>52</td> <td>RUN, CYCLE, or</td> <td>5 training zones (base pace – intervals)</td> <td>↑ duration</td> <td>XIX</td> <td>3–6</td> <td>30–180</td> <td>80</td>	NVM Filteristy Interesty Entersity CVCLE 70-80% VO_mus and RPE Reastess VO_mus at 8 Ms. CONT 3 6 CYCLE 12-14 (Rorg sciel) DNR MX CONT 3 12 Horesty profile from DNR DNR MX 35 3 12 RUN 706 Horesty profile from DNR MX 35 3 12 RUN 706 MR DNR DNR MX 35 12 RUN 706 MR DNR DNR 20 3 13 CCICLE or SOW Som Kuttmans DNR DNR 3 14 CVCLE 70% VOmma (ED) Vork adjusted to maintain CONT 3 15 RUN 70% VOmma (ED) Vork adjusted to maintain CONT 3 16 CYCLE 60-90% VOmma (ED) Vork adjusted to maintain CONT 3 17 RUN 70% VOmma (ED) Vork adjusted to maintain CONT 3 18	Arbab-Zadeh_2014 ³	52	RUN, CYCLE, or	5 training zones (base pace – intervals)	↑ duration	XIX	3–6	30–180	80
16 CYCLE 70–80% VO_max, and RPE Reassess VO_max, at 8 ws. work adjusted to achieve THR 6 CYCLE 4 intensity profiles from 50 to 130% Watts.max Reassess VO_max, at 8 ws. work adjusted to achieve THR 10 WLK, RUN. 6/8 HR DNR 7 RUN. CYCLE 85–90% VO_max, 6/8 / HR DNR 7 RUN. CYCLE 85–90% VO_max, 6/8 / HR DNR 7 RUN. CYCLE 85–90% VO_max, 6/8 / HR DNR 70% WLS, RUN. 6/8 / HR DNR CYCLE or STEP 7 RUN. CYCLE 85–90% VO_max, 6/8 / HR DNR 7 RUN. CYCLE 85–90% VO_max, 6/8 / HR DNR 7 RUN. CYCLE 85–90% VO_max, 7/1 / Wreek T/8 / HR 7 RUN. CYCLE 60–100% VO_max, 7/1 / Work 4// HR T/8 / HR 7 CYCLE 60–100% VO_max, 7/1 / HR T/8 / HR T/8 / HR 2 CYCLE 60–100% VO_max T/8 / HR T/8 / HR 2 CYCLE 60–96% VO_max T/8 / HR T/8 / HR 2 CYCLE 60–96% V	16 CYCLE 70–80% VO _{mus} and RPE Reassess VO _{mus} at 8 w/s. CONT 3 6 T2–14 (Borg scale) NM NM NM 35 12–14 (Borg scale) NM NM NM 35 12 NUN VCLE 4 intensity profile from NM 35 12 NUN VCLE 6 % HR NM 35 10 WVK, RUN 05 % HR NM 35 11 NUN CYCLE 85–90% VO _{pauk} (cycle ergometer) - 100% VO _{pauk} (5 × 111 W/weik MM 4 11 RUN 70% VO _{pauk} (move adjusted to maintain CONT 3 12 CYCLE, O'S WO _{pauk} (CD) 70% VO _{pauk} (move adjusted to maintain CONT 4 12 RUN 70% VO _{pauk} (move adjusted to maintain CONT 3 12 CYCLE 60–90% VO _{pauk} (move adjusted to maintain CONT 4 13 CYCLE 70% VO _{pauk} (move adjusted to maintain CONT 3 13 CYCLE 60–90% VO _{pauk} (move adjusted to maintain <			SWIM		↑ intensity				
12-14 (Borg scale) vork adjusted to achieve THR 6 CYCLE 4 intensity profiles from 5 to 130% Wattsmas DNR 12 RUN 70% MHR DNR 10 WLK, RUN, 66% HRR DNR 7 RUN, CYCLE 85-90% VO _{2nask} (cycle ergometer) – 100% VO _{2nask} (5 × 111 W/week 5 min intervals) 1 RUN, CYCLE 85-90% VO _{2nask} Nork adjusted to maintain 1 RUN, CYCLE 60-96% VO _{2nask} Nork adjusted to maintain 12 CYCLE 70% HR _{max} 70% HR _{max} 13 RUN, CYCLE 60-96% VO _{2nask} Nork adjusted to maintain 12 CYCLE 60-96% VO _{2nask} 100% VO _{2nask} 13 CYCLE 60-90% VO _{2nask} 100% VO _{2nask} 14 RUN, CYCLE 69-96% VO _{2nask} 100% VO _{2nask} 12 CYCLE 69-96% VO _{2nask} 100% VO _{2nask} 13 CYCLE 69-96% VO _{2nask} 100% VO _{2nask} 14 RUN 70% HR _{max} 100% VO _{2nask} 14 RUN 70% HR _{max} 100% VO _{2nask} 14 RUN 70% VO _{2nask} 100% VO _{2nask} 15 CYCLE 60% Pole 100% VO _{2nask} 16 S 100% VO _{2nask}	12-14 (Borg scale) vork adjusted to achieve THR 6 CYCLE 1/1-41 (Borg scale) NMR 35 10 VUX, RUN, 6% HR DNR MY 35 10 VUX, RUN, 6% HR DNR MY 35 10 VUX, RUN, 6% HR DNR COUL 3 11 VUX, RUN, 6% HR DNR COUL 3 11 VUX, RUN, 6% HR DNR COUL 3 12 CYCLE 70% VO _{2max} DNR COUL 4 11 RUN 70% VO _{2max} DNR COUL 4 12 CYCLE 65 VO _{2max} DNR MY 5 12 RUN, CYCLE 60-96% VO _{2max} TOW VO _{2max} MY 5 13 CYCLE 60-96% VO _{2max} TOW VO _{2max} MY 5 14 RUN 70% VO _{2max} TOW VO _{2max} MY 5 14 RUN 70% VO _{2max} TOW VO	Bates_2013 ^{c33}	16	CYCLE	70–80% VO $_{2max}$ and RPE	Reassess VO _{2max} at 8 wks,	CONT	ſ	30	1.5
6 CYCLE 4 intensity profiles from 5 to 130% Watthmas DNR 12 RUN 70% MHR DNR 10 WLK, RUN, 6.6% HRR DNR 10 WLK, RUN, 6.6% HRR DNR 7 RUN, CYCLE 85-90% VO _{2pesk} (cycle ergometer) - 100% VO _{2max} (5 × 111 W/week 5 min intervals) 7 RUN, CYCLE 85-90% VO _{2max} (cycle ergometer) - 100% VO _{2max} (5 × 111 W/week 70% VO _{2max} (5 × 7 × 7 × 111 W/week 11 RUN 70% MR _{max} (ED) Work adjusted to maintain 2 CYCLE 60-96% VO _{2max} (ED) Work adjusted to maintain 11 RUN 70% MR _{max} (ED) Work adjusted to maintain 2 CYCLE 60-96% VO _{2max} 100% VO _{2max} 2 CYCLE 95-100% VO _{2max} 100% VO _{2max}	THR THR THR 35 12 KUN 70% WHR DNR MX 35 12 KUN 70% WHR DNR COUT 3 12 KUN 70% WHR DNR COUT 3 13 WK, RUN, 66% HR DNR COUT 3 14 CYCLE or STEP MK MN COUT 3 17 RUN CYCLE 70% VD _{max} MY 6 3 11 RUN 70% HR _{max} MY 6 3 12 CYCLE 70% VD _{max} MY 6 3 12 CYCLE 70% HR _{max} MY 6 3 13 CYCLE 60-96% VD _{max} MY 7				12–14 (Borg scale)	work adjusted to achieve				
6 CYCLE 4 intensity profiles from DNR 30 to 130% Watts _{max} $30 to 130% Wattsmax DNR 10 WLK, RUN, 66% HR DNR 7 RUN, CYCLE 70% Watsajusted to maintain 70% VO2max 11 RUN 70% HRmax (ED) 70% VO2max 12 CYCLE 60-100% VO2max Vork adjusted to maintain 70% VC2max TO% HRmax TO% HRmax 12 CYCLE 60-100% VO2max TO% Mork adjusted to maintain 12 CYCLE 60-96% VO2max TO% VO2max 13 RUN, CYCLE 60-100% VO2max TO% Mork adjusted to maintain 14 RUN TO% HRmax TO% VO2max 12 CYCLE 95-100% VO2max TO% Mork adjusted to maintain 13 CYCLE 60-96% VO2max TO% Mork adjusted to maintain 14 RUN TO% CYCLE $	6 CYCLE 4 intensity profiles from DNR MX 35 12 RUN 700 v1305 Watthans DNR COVIT 3 10 WLK, RUN, 668 HRR DNR COVIT 3 10 WLK, RUN, 668 HRR DNR COVIT 3 11 RUN, CYCLE 658 HRR DNR COVIT 3 11 RUN, CYCLE 659 KNO _{2max} DNR COVIT 4 5 <min intervals)<="" td=""> Vork adjusted to maintain COVIT 3 3 11 RUN 705 VO_{2max} Tot Vork adjusted to maintain COVIT 4 12 CYCLE 60-1056 VO_{2max} Tot Vork adjusted to maintain COVIT 4 13 CYCLE 60-1056 VO_{2max} Tot Vork adjusted to maintain COVIT 3 14 RUN 705 HR_{max} Tot Vork adjusted to maintain COVIT 3 12 CYCLE 60-1056 VO_{2max} Tot VO_{2max} stepplement with MX 5 12</min>					THR				
12 NUL 70% MHR DNR 10 WLK, RUN, 6% HR DNR 7 CCLE, or STEP B5-90% VO _{2peak} (cycle ergometer) - 100% VO _{2max} (5× 11 W/week 7 RUN, CYCLE 85-90% VO _{2peak} (cycle ergometer) - 100% VO _{2max} (5× 11 W/week 7 RUN, CYCLE 70% VO _{2max} Work adjusted to maintain 11 RUN 70% HR _{max} Work adjusted to maintain 70% VO _{2max} 70% VO _{2max} YOM adjusted to maintain 12 CYCLE 60-96% VO _{2max} Work adjusted to maintain 22 RUN, CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 23 RUN, CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 24 CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 25 RUN, CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 26 CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 27 CYCLE 60-100% VO _{2max} PO _{2max} every 3 months 28 RUN 70-100% VO _{2max} PO _{2max} every 3 months	10NUK, RUN, WK, RUN, 658, HR000 DD0 wrk, RUN, 658, HR000 DD00000037WUK, RUN, CYCLE or STEP668, HRDNRCOUT37RUN, CYCLE85-90% VO2 _{pask} (sycle ergometer) - 100% VO2 _{max} (5 × 111 W/weekMK64CYCLE70% VO2 _{max} Work adjusted to maintainCOUT311RUN70% HR _{max} Work adjusted to maintainCOUT312CYCLE60-96% VO2 _{max} 70% VO2 _{max} MK312CYCLE60-96% VO2 _{max} 100% VO2 _{max} MK312CYCLE60-96% VO2 _{max} 100% VO2 _{max} MK32CYCLE60-96% VO2 _{max} 100% VO2 _{max} MK32CYCLE60-90% VO2 _{max} 100% VO2 _{max} MK32CYCLE60-90% VO2 _{max} 100% VO2 _{max} MK32CYCLE60-90% VO2 _{max} 100% VO2 _{max} MK32CYCLE95-100% VO2 _{max} 100% VO2 _{max} MK32CYCLE95-00% VO2 _{max} 100% VO2 _{max} MK32CYCLE95% VO2 _{max} 100% VO2 _{max} 100% VO2 _{max} 100%3 <td>Boone_2014³⁵</td> <td>6</td> <td>CYCLE</td> <td>4 intensity profiles from</td> <td>DNR</td> <td>XIX</td> <td>3.5</td> <td>60</td> <td>3.5^c</td>	Boone_2014 ³⁵	6	CYCLE	4 intensity profiles from	DNR	XIX	3.5	60	3.5 ^c
12 RUN 70% MHR DNR DNR 10 WLK, RUN, 66% HRR DNR DNR 7 CYCLE or STEP 5 min intervals) Work adjusted to maintain 7 RUN, CYCLE 85–90% VO _{2nexk} (cycle ergometer) – 100% VO _{2nexk} Work adjusted to maintain 7 RUN, CYCLE 85–90% VO _{2nexk} (cycle ergometer) – 100% VO _{2nexk} Work adjusted to maintain 11 RUN 70% HR _{max} DNR Work adjusted to maintain 12 CYCLE 60–100% VO _{2nexk} TO% MR _{max} PNOrk adjusted to maintain 22 CYCLE 60–100% VO _{2nexk} PNOR adjusted to maintain PO _{2nexk} 23 RUN, CYCLE 60–100% VO _{2nexk} PO _{2nexk} PO _{2nexk} 23 CYCLE 65% VO _{2nexk} PO _{2nexk} PO _{2nexk} 24 TOK 70% HR _{max} PO _{2nexk} PO _{2nexk} 25 RUN, CYCLE 60–100% VO _{2nexk} PO _{2nexk} PO _{2nexk} 26 CYCLE 95–100% VO _{2nexk} PO _{2nexk} PO _{2nexk} 27 <t< td=""><td>12 RUN 70% MHR DNR CONT 3 7 WLK, RUN, 66% HRR DNR CONT 3 7 RUN, CCLE, or STEP MK 66% HRR MK 6 4 CrCLE, or STEP MK, KUN, 65% HR MK 6 4 CrCLE $35-90\%$ VO_{prasi} (cycle ergometer) - 100% VO_{prasi} (s/s 111 Wweek MK 6 5 min intervals) MK adjusted to maintain CONT 3 10 CVCLE 70% VO_{prasi} (S/s 111 Wweek MK 6 5 min intervals) MK 6 70% VO_{prasi} 70% VO_{prasi} 11 RUN 70% HR_{max} MK 6 70% VO_{prasi} 70% NOrt 6 2 CYCLE 60-100\% VO_{prasi} 1 10% HR_{max} MK 5 2 CYCLE 60-100\% VO_{prasi} 1 10% HR_{max} MK 5 2 CYCLE 60-100\% VO_{prasi} 1 10% HR_{max} 1 1</td><td></td><td></td><td></td><td>VICION AVAILSmax</td><td></td><td></td><td></td><td></td><td></td></t<>	12 RUN 70% MHR DNR CONT 3 7 WLK, RUN, 66% HRR DNR CONT 3 7 RUN, CCLE, or STEP MK 66% HRR MK 6 4 CrCLE, or STEP MK , KUN, 65% HR MK 6 4 CrCLE $35-90\%$ VO _{prasi} (cycle ergometer) - 100% VO _{prasi} (s/s 111 Wweek MK 6 5 min intervals) MK adjusted to maintain CONT 3 10 CVCLE 70% VO _{prasi} (S/s 111 Wweek MK 6 5 min intervals) MK 6 70% VO _{prasi} 70% VO _{prasi} 11 RUN 70% HR _{max} MK 6 70% VO _{prasi} 70% NOrt 6 2 CYCLE 60-100\% VO _{prasi} 1 10% HR _{max} MK 5 2 CYCLE 60-100\% VO _{prasi} 1 10% HR _{max} MK 5 2 CYCLE 60-100\% VO _{prasi} 1 10% HR _{max} 1 1				VICION AVAILSmax					
10WLK, RUN,6.8, HRDNR7CYCLE or STEP $CYCLE or STEP$ S -90% VO2 _{peak} (cycle ergometer) - 100% VO2 _{max} (5 × 111 W/week7RUN, CYCLE $85-90\%$ VO2 _{peak} (cycle ergometer) - 100% VO2 _{max} (5 × 111 W/week11RUN70% VO2 _{max} 70% VO2 _{max} (70% SO2 _{max} 12CYCLE $60-96\%$ VO2 _{max} 70% VO2 _{max} 12CYCLE $60-96\%$ VO2 _{max} 70% PR _{max} 12CYCLE $60-90\%$ VO2 _{max} 100% Proceed2CYCLE $60-100\%$ VO2 _{max} 100% Proceed2CYCLE 60% Real100% Proceed2CYCLE 50% RPO100%12CYCLE 50% RPO100%12CYCLE 50% RPO100%	10 WLK, RUN, CCLE, or STEP 68, HR DNR COLI 3 7 RUN, CYCLE 85-90% VO _{2nux} (sycle ergometer) - 100% VO _{2nux} (sy cl quisted to maintain 5 min intervals) MK 6 4 CYCLE 85-90% VO _{2nux} 5 min intervals) Work adjusted to maintain 70% VO _{2nux} MK 6 11 RUN 70% HR _{mux} Work adjusted to maintain 70% VO _{2nux} CNIT 3 12 CYCLE 60-96% VO _{2nux} 1 ritensity MK 3 12 CYCLE 60-96% VO _{2nux} 1 ritensity MK 3 12 CYCLE 60-100% VO _{2nux} 1 ritensity MK 3 12 CYCLE 60-96% VO _{2nux} 1 ritensity MK 3 13 CYCLE 60-96% VO _{2nux} 1 ritensity MK 3 12 CYCLE 60-100% VO _{2nux} 1 ritensity MK 3 13 CYCLE 60-96% VO _{2nux} 1 ritensity MK 5 14 MK 1 ritensity MK 3 <	Camargo_2008 ³⁶	12	RUN	70% MHR	DNR	CONT	m	35	1.5
CYCLE or STEP 7 RUN, CYCLE 85-90% VO _{2peak} (cycle ergometer) - 100% VO _{2max} (5 × 111 W/week 6 TOK 70% VO _{2max} (S) 11 RUN 70% VO _{2max} (ED) 70% VO _{2max} (ED) 70% VO _{2max} (ED) 70% VO _{2max} (ED) <t< td=""><td>7CYCLE or STEP RUN, CYCLEMXK</td><td>Cornelissen_2011³⁷</td><td>10</td><td>WLK, RUN,</td><td>66% HRR</td><td>DNR</td><td>CONT</td><td>٣</td><td>60</td><td>с</td></t<>	7CYCLE or STEP RUN, CYCLEMX K	Cornelissen_2011 ³⁷	10	WLK, RUN,	66% HRR	DNR	CONT	٣	60	с
7 RUN, CYCLE 85-90% VO _{2nask} (cycle ergometer) - 100% VO _{2nask} (5 × 11 W/week 5 min intervals) Vork adjusted to maintain 11 RUN 70% VO _{2nask} 12 CYCLE 70% VO _{2nask} 13 CYCLE 60-96% VO _{2nask} 14 RUN, CYCLE 60-96% VO _{2nask} 15 CYCLE 60-96% VO _{2nask} 12 CYCLE 60-96% VO _{2nask} 13 CYCLE 60-96% VO _{2nask} 14 RUN, CYCLE 60-100% VO _{2nask} 15 CYCLE 60-100% VO _{2nask} 16 CYCLE 60-100% VO _{2nask} 17 Prose very 3 months 100-2nask very 3 months 18 NUN, CYCLE 60-96% VO _{2nask} 19 CYCLE 65% VO _{2nask} 10 Nusk verkload 100-2nask verkload 11 Prose verkload 100-2nask verkload 11 Nusk verkload 100-2nask verkload 11 Nusk verkload 100-2nask verkload 11 Nusk verkload 11 11 Nusk verkload 11 11 Nusk verkload 11 12 CYCLE 65% VO _{2nask} 13 NUN 14 100-2nask </td <td>7RUN, CYCLEB5-90% VO2nexis (orde ergometer) - 100% VO2nexis (5 × 111 W/week)MX685min intervals)York adjusted to maintainCONT31RUN70% VO2nexis70% VO2nexis70% VO2nexis41RUN70% HRaus (ED)70% VO2nexis70% VO2nexis412CYCLE60-96% VO2nexis170% HRaus70% HRaus62CYCLE60-100% VO2nexis170% HRaus70% HRaus72CYCLE60-100% VO2nexis170% HRaus70% HRaus72CYCLE95-100% VO2nexis170% HRaus70% HRaus72CYCLE95-100% VO2nexis170% HRaus772CYCLE95-100% VO2nexis170% HRaus732CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140732CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95014095-1032CYCLE50% PRO1401403312140140140341250% PRO140140312CY</td> <td></td> <td></td> <td>CYCLE, or STEF</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	7RUN, CYCLEB5-90% VO2nexis (orde ergometer) - 100% VO2nexis (5 × 111 W/week)MX685min intervals)York adjusted to maintainCONT31RUN70% VO2nexis70% VO2nexis70% VO2nexis41RUN70% HRaus (ED)70% VO2nexis70% VO2nexis412CYCLE60-96% VO2nexis170% HRaus70% HRaus62CYCLE60-100% VO2nexis170% HRaus70% HRaus72CYCLE60-100% VO2nexis170% HRaus70% HRaus72CYCLE95-100% VO2nexis170% HRaus70% HRaus72CYCLE95-100% VO2nexis170% HRaus772CYCLE95-100% VO2nexis170% HRaus732CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140732CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95-100% VO2nexis140332CYCLE95014095-1032CYCLE50% PRO1401403312140140140341250% PRO140140312CY			CYCLE, or STEF						
5 min intervals) 5 min intervals) 11 CVCLE 70% VO _{2max} 11 RUN 70% VO _{2max} 12 CYCLE 60–96% VO _{2max} 13 CYCLE 60–96% VO _{2max} 14 RUN 70% HR _{max} 12 CYCLE 60–100% VO _{2max} 12 CYCLE 60–100% VO _{2max} 13 CYCLE 60–100% VO _{2max} 14 NUN, CYCLE 60–100% VO _{2max} 1 Intervals 1 13 CYCLE 60–100% VO _{2max} 14 NUN, CYCLE 60–100% VO _{2max} 1 NUN, CYCLE 60–100% VO _{2max} 1 Proves every 3 months 1 14 NUN, CYCLE 60–100% VO _{2max} 2 CYCLE 95–100% VO _{2max} 3 14 14 4 1 5 RUN 70–80% HR _{max} 5 RUN <td< td=""><td>1$1$</td><td>Cox_1986³⁸</td><td>7</td><td>RUN, CYCLE</td><td>85–90% VO$_{\rm 2peak}$ (cycle ergometer) – 100% VO$_{\rm 2max}$ (5 ×</td><td>↑11 W/week</td><td>XIM</td><td>6</td><td>40</td><td>4</td></td<>	1 1	Cox_1986 ³⁸	7	RUN, CYCLE	85–90% VO $_{\rm 2peak}$ (cycle ergometer) – 100% VO $_{\rm 2max}$ (5 ×	↑11 W/week	XIM	6	40	4
4CYCLE70% VO2maxWork adjusted to maintain 70% VO2max11RUN70% HRmax (ED)70% VO2max12CYCLE $60-96\%$ VO2maxWork adjusted to maintain 70% HRmax12CYCLE $60-96\%$ VO2maxProperty adjusted to maintain 70% HRmax12CYCLE $60-96\%$ VO2maxProperty adjusted to maintain 70% HRmax12CYCLE $60-96\%$ VO2maxProperty adjusted to maintain 70% HRmax2CYCLE $60-96\%$ VO2max 1 intensity2CYCLE $95-100\%$ VO2max 1 intensity2CYCLE 55% VO2max 1 intensity2CYCLE 65% VO2max 1 intensity2CYCLE 65% VO2max 1 intensity2CYCLE 65% VO2max 1 intensity2CYCLE 60% peak workload 1 intensity + duration +12CYCLE 50% PPO 1 intensity + duration +	4CYCLE70% VO2muxCONT311RUN70% VO2mux70% O2muxCONT412RUN70% HRms70% VO2mux70% VO2mux412CYCLE60-96% VO2mux70% HRms70% NO2mux412CYCLE60-96% VO2mux100% HRms70% NO2mux412CYCLE60-100% VO2mux100% HRms70% NO2mux32CYCLE60-100% VO2mux100% HRms70% NOT32CYCLE95-100% VO2mux100mux100mux32CYCLE65% VO2mux100mux100mux32CYCLE65% VO2mux100mux100mux32CYCLE65% VO2mux100mux100mux32CYCLE60% pesk workdoad100mux100mux35RUN70% SPO100mux100mux36CYCLE50% PODNR100mux312CYCLE50% PODNR100mux312CYCLE50% PODNR100mux36CYCLE50% PODNR100mux37100mux100mux100mux100mux38CYCLE50% PODNR100mux39CYCLE50% PODNR100mux313CYCLE50% PODNR100mux313CYCLE50% PODNR100mux314CYCLE				5 min intervals)					
11 RUN 70% VO _{2max} 12 CYCLE 60–96% VO _{2max} Work adjusted to maintain 12 CYCLE 60–96% VO _{2max} Work adjusted to maintain 12 CYCLE 60–96% VO _{2max} Tintensity 12 CYCLE 60–96% VO _{2max} Tintensity 12 CYCLE 60–100% VO _{2max} Tintensity 13 CYCLE 60–100% VO _{2max} Tintensity 2 CYCLE 95–100% VO _{2max} Tintensity 2 CYCLE 96/200 Tintensity 3 Intensity 10 Intensity 4 N 70–80% HR _{max} Tintensity	11RUN $70\% H\Omega_{max}$ $70\% NO_{max}$ $70\% NO_{max}$ 4 12CYCLE $60-96\% VO_{max}$ $70\% H\Omega_{max}$ $70\% H\Omega_{max}$ 4 12CYCLE $60-96\% VO_{max}$ $70\% H\Omega_{max}$ $10\% H\Omega_{max}$ 3 2CYCLE $60-96\% VO_{max}$ $10\% NO_{max}$ $10\% N\Omega_{max}$ 3 2CYCLE $65-100\% VO_{max}$ $10\% NO_{max}$ $10\% N\Omega_{max}$ 3 2CYCLE $95-100\% VO_{max}$ $10\% NO_{max}$ $10\% N\Omega_{max}$ 3 2CYCLE $55\% VO_{max}$ $10\% NO_{max}$ $10\% N\Omega_{max}$ 3 2CYCLE $60\% pax workoad11\% N\Omega_{max}10\% N\Omega_{max}32CYCLE60\% pax workoad11\% N\Omega_{max}310\% N\Omega_{max}32CYCLE10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}32CYCLE10\% N\Omega_{max}10\% N\Omega_{max}332CYCLE10\% N\Omega_{max}10\% N\Omega_{max}332CYCLE10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}32CYCLE10\% N\Omega_{max}10\% N\Omega_{max}310\% N\Omega_{max}312CYCLE5\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}12CYCLE5\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}1310\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{max}10\% N\Omega_{m$	Dart_1992 ¹²	4	CYCLE	70% VO _{2max}	Work adjusted to maintain	CONT	с	30	1.5
11RUN70% HR Mmx (ED)Work adjusted to maintain 70% HR 70% HR 	11RUN 70% HR _{max} (ED)Work adjusted to maintainCONT412CYCLE $60-96\%$ VO _{2max} 70% HR _{max} MX312CYCLE $60-96\%$ VO _{2max} 1 intensityMX312CYCLE $60-100\%$ VO _{2max} 1 VO _{2max} + supplement withMX32CYCLE $95-100\%$ VO _{2max} 1 VO _{2max} + supplement withMX32CYCLE $95-100\%$ VO _{2max} 1 fintensityMT32CYCLE $95-100\%$ VO _{2max} 1 fintensisNT32CYCLE 65% VO _{2max} 1 fintensisNT32CYCLE 60% peak workload 1 fintensisNT32CYCLE 60% peak workload 1 fintensisNT32CYCLE 60% peak workload 1 fintensis 1 fintensis 1 fintensis5RUN 10 duration 10 furation 10 fintensis 3 fintensis5RUN 10 duration 10 furation 10 fintensis 10 fintensis6CYCLE 50% PPODNR 10 furation 1 fintensis12CYCLE 50% PN 10 furation 10 fintensis 10 fintensis6CYCLE 50% PN 10 furation 10 fintensis 10 fintensis7 10 furation 10 furation 10 fintensis 10 fintensis 10 fintensis8CYCLE 50% PN 10 furation 10 fintensis 10 fintensis <td< td=""><td></td><td></td><td></td><td></td><td>70% VO_{2max}</td><td></td><td></td><td></td><td></td></td<>					70% VO _{2max}				
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12 CYCLE 60-96% VO _{2max} 1 intensity 52 RUN, CYCLE 60-100% VO _{2max} 1 vO _{2max} + supplement with 52 RUN, CYCLE 60-100% VO _{2max} 1 vO _{2max} + supplement with 2 CYCLE 95-100% VO _{2max} 1 vO _{2max} + supplement with 2 CYCLE 95-100% VO _{2max} 1 mervals + re-measure 2 CYCLE 65% VO _{2max} 1 #intervals 2 CYCLE 65% VO _{2max} 1 #intervals 2 CYCLE Maximal effort 1 #intervals 2 CYCLE Maximal effort 1 #intervals 2 CYCLE Maximal effort 1 #intervals 5 RUN Relow VT (~75-85 HR _{max}) - VT threshold (~85-90% 1 mersity + duration + 1 HR _{max}) + intervals (5-10 beats below HR _{max}) 1 mersity + duration + 6 CYCLE 50% PPO 1 mersity + duration + 12 CYCLE 50% PPO DNR	12CYCLE $60-96\% VO_{2max}$ intensityMX352RUN, CYCLE $60-100\% VO_{2max}$ $1 \cdot VO_{2max} + supplement with$ MX52CYCLE $60-100\% VO_{2max}$ $1 \cdot VO_{2max} + supplement with$ MX52CYCLE $95-100\% VO_{2max}$ $1 \cdot VO_{2max} + supplement with$ MX32CYCLE $95-100\% VO_{2max}$ $1 \cdot VO_{2max} + supplement with$ MX32CYCLE $95-100\% VO_{2max}$ $1 \cdot WO_{2max} + supplement with$ MT32CYCLE $65\% VO_{2max}$ $1 \cdot WO_{2max} + supplement with$ MT32CYCLE $65\% VO_{2max}$ $1 \cdot WO_{2max} + supplement with$ MT32CYCLE $65\% VO_{2max}$ $1 \cdot WO_{2max} + supplement with$ MT32CYCLE $05\% ped workload1 \cdot WO_{2max} + supplement withMT32CYCLE05\% peO1 \cdot WO_{2max} + supplement withMT331 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with32CYCLE95 \cdot WO_{2max} + Supplement with1 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with3 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supplement with3 \cdot WO_{2max} + supplement with1 \cdot WO_{2max} + supple$					70% HR _{max}				
52RUN, CYCLE $60-100\% \text{ VO}_{2max}$ 1 VO_{2max} + supplement with intervals + re-measure VO_{2max} every 3 months2CYCLE $95-100\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $95-100\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $95-100\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $65\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $65\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $65\% \text{ VO}_{2max}$ 1 #intervals 2CYCLE $60\% \text{ peak workload}$ 1 #intervals 52RUNBelow VT (~75-85 HR _{max}) - VT threshold (~85-90\% 1 #intervals 52RUN70-80% HR _{max}) 1 threshold 6CYCLE $50\% \text{ PO}$ 1 threshold 7CYCLE $50\% \text{ PO}$ 1 threshold 12CYCLE $50\% \text{ PO}$ 1 threshold 12CYCLE $60-80\% \text{ HRR}$ 1 threshold	52RUN.CYCLE60-100% VO2max \uparrow VO2max+ supplement withMIX52CYCLE95-100% VO2max \downarrow WO2max+ supplement withMIX32CYCLE95-100% VO2max \uparrow mervals + re-masure \downarrow WO2max+ supplement withMIX32CYCLE95-100% VO2max \uparrow mitervals \uparrow mitervals \lvert mitervals<	Egelund_2017_1,2 ⁴¹	12	CYCLE	60–96% VO _{2max}	↑ intensity	MIX	S	50	2.5
 ¹³ 2 CYCLE 95-100% VO_{2max} intervals + re-measure ¹³ 2 CYCLE 95-100% VO_{2max} VO_{2max} every 3 months ¹⁴ 2 CYCLE 65% VO_{2max} ¹ 4 duration ¹⁴ 2 CYCLE 65% VO_{2max} ¹⁴ 1 duration ¹⁴ 2 CYCLE 65% PO ¹⁴ 1 duration 	 intervals + re-measure 2 CYCLE 95-100% VO_{2max} 2 CYCLE 95-100% VO_{2max} 2 CYCLE 95-100% VO_{2max} 2 CYCLE 65% VO_{2max} 4 2 CYCLE 65% VO_{2max} 5 CYCLE 60% peak workload 7 #intervals 8 CYCLE 50% PRO 7 #intervals 7 #	Ehsani_1991 ¹³	52	RUN, CYCLE	60–100% VO _{2max}	$\uparrow VO_{2max}$ + supplement with		5	60	5
 ⁴³ 2 CYCLE 95-100% VO_{2max} every 3 months ⁴⁴ 2 CYCLE 65% VO_{2max} ⁴⁵ 2 CYCLE 65% VO_{2max} ⁴⁶ 2 CYCLE 65% VO_{2max} ⁴⁶ 2 CYCLE 60% peak workload ⁴⁷ 1 mitervals ⁴⁷ 2 CYCLE 60% peak workload ⁴⁸ 1 mitervals ⁴⁸ 2 CYCLE 60% peak workload ⁴⁸ 1 mitervals ⁴⁸ 2 CYCLE 60% peak workload ⁴⁸ 2 CYCLE 60% peak workload ⁴⁸ 1 mitervals ⁴⁸ 2 CYCLE 60% peak workload ⁴⁸ 1 mitervals ⁴⁸ 2 CYCLE 60% peak workload ⁴⁸ 1 mitervals 	 ¹³ 2 CYCLE 95-100% VO_{2max} every 3 months ¹⁴ 1 #intervals ¹⁴ 2 CYCLE 65% VO_{2max} ¹⁴ 1 #intervals ¹⁴ 1 #interv					intervals + re-measure				
1 2 CYCLE 95-100% VO _{2max} 1 #intervals 1 2 CYCLE 65% VO _{2max} 1 #intervals 1 2 CYCLE 60% peak workload 1 #intervals 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 intervals 52 RUN 70-80% HR _{max}) 1 intervals 1 intervals 52 RUN 70-80% HR _{max} 1 furation 1 intervals 6 CYCLE 50% PPO 1 frequency 1 furation 12 CYCLE 50% PPO DNR 1 duration	10 2 $CYCLE$ $95-100\% VO_{2max}$ $1 \pm intervals$ INT 3 10 2 $CYCLE$ $65\% VO_{2max}$ $1 \pm intervals$ INT 3 10 2 $CYCLE$ $65\% VO_{2max}$ $1 \pm intervals$ INT 3 10 2 $CYCLE$ $65\% VO_{2max}$ $1 \pm intervals$ INT 3 10 2 $CYCLE$ 60% peak workload $1 \pm intervals$ INT 3 52 RUN $Below VT (~75-85 HR_{max}) - VT threshold (~85-90\%intervalsINT352RUNRow VT (~75-85 HR_{max}) - VT threshold (~85-90\%intervalsINT36CYCLE60\% PRIR_{max}I \pm intervalsI \pm intervals36CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervals312CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervals12CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervals12CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervals12CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervals12CYCLE50\% PRI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervalsI \pm intervals<$					VO _{2max} every 3 months				
13 2 CYCLE 65% VO _{2max} 1duration 14 2 CYCLE Maximal effort 1 #intervals 1 2 CYCLE 60% peak workload 1 #intervals 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 furation 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 intervals 52 RUN 70-80% HR _{max}) + intervals (5-10 beats below HR _{max}) 1 intervals 6 CYCLE 50% PRO 1 frequency 7 6 CYCLE 50% PRO 1 frequency 8 12 CYCLE 60-80% HRR 1 duration	32CYCLE $6\% VO_{2msK}$ IdurationCONT342CYCLEMaximal effort \uparrow #intervals $ M'TT00000000000000000000000000000000000$	Esfandiari_2014_A ⁴³	2	CYCLE	95–100% VO _{2max}	↑ #intervals	INT	S	20 [€]	1 ^c
Intervals Image: Cycle Maximal effort 1 # intervals 2 CYCLE 60% peak workload 1 duration 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 duration 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 intervals 52 RUN 70-80% HR _{max}) + intervals (5-10 beats below HR _{max}) intervals 52 RUN 70-80% HR _{max} 1 duration 6 CYCLE 50% PPO 1 duration 7 CYCLE 60-80% HRR 1 duration	1 2 CYCLE Maximal effort 1 #intervals INT 3 2 CYCLE 60% peak workload 1 mation CONT 3 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 mation CONT 3 52 RUN Delow VT (~75-85 HR _{max}) – VT threshold (~85-90% 1 mation CONT 3 52 RUN 70-80% HR _{max} 1 matrixis + duration + MIX 5 6 CYCLE 50% PRO 1 matrixis 1 matrixis 3-4 12 CYCLE 50% PRO DNR INT 1 8 12 CYCLE 50% PRO DNR 1 matrixis	Esfandiari_2014_B ⁴³	2	CYCLE	65% VO _{2max}	↑duration	CONT	e	105 ^c	5.25 ^c
 2 CYCLE 60% peak workload 52 RUN Below VT (~75-85 HR_{max}) – VT threshold (~85-90% 1 intensity + duration + HR_{max}) + intervals (5-10 beats below HR_{max}) intervals 52 RUN 70-80% HR_{max} 6 CYCLE 50% PPO 7 frequency 7 frequency 7 duration 	4 2 CYCLE 60% peak workload fduration CONT 3 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% ñintensity + duration + MIX 5 52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% ñintensity + duration + MIX 5 52 RUN 70-80% HR _{max} intervals 7 1 6 CYCLE 50% PRO 1 7 3 8 12 CYCLE 50% PRO DNR INT 1	Eskelinen_2016_A ⁴⁴	2	CYCLE	Maximal effort	↑ #intervals	INT	m	18.5 ^c	~
52 RUN Below VT (~75-85 HR _{max}) – VT threshold (~85-90% Tintensity + duration + RNmax) HR _{max}) + intervals (5-10 beats below HR _{max}) intervals 52 RUN 70-80% HR _{max} 1 duration 6 CYCLE 50% PPO NR 12 CYCLE 60-80% HRR 1 duration	52 RUN Below VT (~75–85 HR _{max}) – VT threshold (~85–90% Tintensity + duration + MX 5 ^r 52 RUN TR _{max}) + intervals (5–10 beats below HR _{max}) intervals mtervals 5 ^r 52 RUN 70–80% HR _{max}) intervals intervals 7 ^r 6 CYCLE 50% PPO 1 1 1 1 CYCLE 50% PPO DNR INT 1 8 12 CYCLE 50% PPO DNR INT 1	Eskelinen_2016_B ⁴⁴	2	CYCLE	60% peak workload	† duration	CONT	e	50 ^c	2.5 ^c
HR _{max}) + intervals (5–10 beats below HR _{max}) intervals 52 RUN 70–80% HR _{max} † duration 6 CYCLE 50% PPO DNR 12 CYCLE 60–80% HRR † duration	FRmax) + intervals (5-10 beats below HR _{max}) intervals 52 RUN 70-80% HR _{max}) 1duration CONT 3-4 6 CYCLE 50% PPO 1frequency 1 1 12 CYCLE 60-80% HRR 1 duration CONT 3	Fujimoto_2010 ⁴⁷	52	RUN	Below VT (\sim 75–85 HR _{max}) – VT threshold (\sim 85–90%	<pre>fintensity + duration +</pre>	XIM	5°	2560	
52 RUN 70-80% HR _{max} 1 duration 6 CYCLE 50% PPO DNR 8 12 CYCLE 60-80% HRR 1 duration	52 RUN 70-80% HR _{max} †duration CONT 3-4 6 CYCLE 50% PPO 1 frequency 1 frequency 1 8 12 CYCLE 60-80% HRR 1 duration CONT 3				HR_{max}) + intervals (5–10 beats below HR_{max})	intervals				
6 CYCLE 50% PPO DNR 20 Automotion for the constraint of the constr	6 CYCLE 50% PPO DNR INT 1 12 CYCLE 60-80% HRR 1 duration CONT 3	Fujimoto_2013 ⁴⁶	52	RUN	70–80% HR _{max}	† duration	CONT	3-4	25-40	2.3
6 CYCLE 50% PPO DNR 12 CYCLE 60–80% HRR † duration	6 CYCLE 50% PPO DNR INT 1 12 CYCLE 60-80% HRR 1 duration CONT 3					↑ frequency				
12 CYCLE 60–80% HRR	12 CYCLE 60–80% HRR 1 duration CONT 3	Grace_2018_1,2 ¹⁴	6	CYCLE	50% PPO	DNR	INT	. 	18	0.3
		Haykowsky_2005 ⁴⁸	12	CYCLE	60-80% HRR	↑ duration	CONT	m	15-42.5	2.1

Burkly clutter, year) Lengton in the process of the proces of the proce	Longention towerselyModelinyIntensityConcerts training landTypeRepresents training landRepresents training lan									
12 CICLE Attenuting Increases in traditione and colutions and colutins and colutins and colutins and colutions and colutio	1CrCLEArrenting intereases in restance and acdance untiplated. DNRCOVI211 $UNLCCEUONLCCEUONNVO_{2mak} be and of exercise seasionI intensity in each VO_{2mak}MC6CTCLE00NVO_{2mak} be and of exercise seasionI intensity in each VO_{2mak}MC26CTCLE00NVO_{2mak} be and of exercise seasionI intensity in each VO_{2mak}MC26CTCLE00NVO_{2mak}00NVO_{2mak}M_{10} meter of training loadCONT21UNN50NVO_{2mak}00NVRO_{2mak}00NVRO_{2mak}00NVRO_{2mak}00NVRO_{2mak}00NVRO_{2mak}1UNN50NVO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRO_{2mak}00NRO_{2mak}2UNN50NRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRO_{2mak}00NRO_{2mak}2RUN00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}2RUN00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}2RUN00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}300NRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}00NRRO_{2mak}400NRO_{2mak}00NRRO_{2mak}$	Study (author, year)	Length of study (weeks)	Modality	Intensity	Progressive training	Type of training	Frequency (days/week)		Total hours (h/ week)
0 10 KUN CYCLE Up to 100% VO _{2nue} by end of exercise session Tirrensity to reach VO _{2nue} MX 6 6 CYCLE 95% VO _{2nue} 95% VO _{2nue} Adjustment of training load MT 5 6 CYCLE 95% VO _{2nue} 66% VO _{2nue} 66% VO _{2nue} 74% 5 1 6 CYCLE 95% VO _{2nue} Adjustment of training load MT 5 1 RUN 535% HR _{mue} (gepredicted) DNR CONT 8 2 RUN 735% HR _{mue} 955 HR _{mue} DNR CONT 8 1 RUN 735% HR _{mue} 955 HR _{mue} DNR CONT 8 1 RUN 735 HR _{mue} 955 HR _{mue} DNR CONT 8 2 RUN 735 HR _{mue} 955 HR _{mue} DNR CONT 8 3 RUN COLE 50-75% HR _{mue} DNR CONT 8 4 RUN COLE 50-75% HR _{mue} DNR CONT 8 <td>III IN CYCLE Up to 100% VO_{2num} by and deterrate association of the control o</td> <td>Hedman_2017⁴⁹</td> <td>12</td> <td>CYCLE</td> <td>Alternating increases in resistance and cadence until peal effort achieved</td> <td>DNR</td> <td>CONT</td> <td>з</td> <td>45–60</td> <td>e</td>	III IN CYCLE Up to 100% VO _{2num} by and deterrate association of the control o	Hedman_2017 ⁴⁹	12	CYCLE	Alternating increases in resistance and cadence until peal effort achieved	DNR	CONT	з	45–60	e
6 CCLE 96% VO _{2nus} Adjustment of training load INT 3 6 CCLE 86% VO _{2nus} 60% VO _{2nus} Adjustment of training load ICNT 5 1 6 CVLE 86% VO _{2nus} Adjustment of training load ICNT 5 2 RUN 395% HR _{us} (gepredicted) DNR CONT 6 2 RUN 395% HR _{us} (gepredicted) DNR CONT 6 2 RUN 95% HR _{us} (gepredicted) DNR CONT 6 3 SKIPPIG. 95% HR _{us} (gepredicted) DNR CONT 6 3 RUN CYCLE 50-75% HR _{us} DNR CONT 6 4 RUN CYCLE 50-75% HR _{us} DNR CNT 7 8 RUN CYCLE 50-75% HR _{us} DNR CNT 7 1 RUN CYCLE 50-75% HR _{us} DNR CNT 2 8 CYCLE 60-55% HR _{us} DNR <	6CrCLE96% VOl_musAdjustment of training loadIVI36CYCLE86% VOl_mus66% VOl_musAdjustment of training loadIVI56CVCLE86% VOl_mus75% HTm. (geprendicted)DNRCOVT810RUN57% HTm. (geprendicted)DNRCOVT820RUN74% HTM. (geprendicted)DNRIVI411RUN74% HTM. (geprendicted)DNRCOVT812RUN74% HTM. (geprendicted)DNRCOVT813ROW*75% HTM. (geprendicted)DNRCOVT814RUN75% HTM. (geprendicted)DNRCOVT815RUN75% HTM. (geprendicted)DNRCOVT816RUN75% HTM. (geprendicted)DNRCOVT817RUNCOCLE60-75% HTM. (geprendicted)DNRCOVT818RUNDNRDNRCOVT8819CCCE60-75% HTM. (geprendicted)DNRCOVT810RUNDNRDNRDNRCOVT811RUNDNRRUNDNRCOVT811RUNDNRRUNDNRCOVT811RUNDNRRUNDNRCOVT811RUNDNRRUNDNRCOVT811RUNDNRRUNDNRCOVT811RUN <t< td=""><td>Hickson_1982_1,2⁵⁰</td><td>10</td><td>RUN, CYCLE</td><td>Up to 100% VO_{2max} by end of exercise session</td><td>↑ intensity to reach VO_{2max}</td><td>XIM</td><td>9</td><td>30-45</td><td>4</td></t<>	Hickson_1982_1,2 ⁵⁰	10	RUN, CYCLE	Up to 100% VO _{2max} by end of exercise session	↑ intensity to reach VO _{2max}	XIM	9	30-45	4
6 CYCLE 60% VO _{2nue} 7 7 7 1 2 CYCLE 50% VO _{2nue} DNR DNR COUT 3 1 RUN CYCLE 50% VO _{2nue} 1 1 1 1 1 CYCLE 50% VO _{2nue} 1 1 <t< td=""><td>6 CYCLE 60% $V_{0,men}^{1,men}$ 60% V_{0,me</td><td>Holloway_2018¹⁵</td><td>9</td><td>CYCLE</td><td>90% VO_{2max}</td><td>Adjustment of training load</td><td>INT</td><td>ſ</td><td>13–15</td><td>0.7^c</td></t<>	6 CYCLE 60% $V_{0,men}^{1,men}$ 60% V_{0,me	Holloway_2018 ¹⁵	9	CYCLE	90% VO _{2max}	Adjustment of training load	INT	ſ	13–15	0.7 ^c
6 CYCLE 80% VO _{2nuc} Adjustment of training load IVT 5 16 RUN Somewhat hard (RF scale) DNR CONT 8 20 RUN SSM Runa, (Reperdicted) DNR CONT 8 20 RUN 74% KH ma, (Reperdicted) DNR CONT 8 20 RUN 74% KH ma, (Reperdicted) DNR CONT 8 20 RUN CCLE 75% KH ma, (Reperdicted) DNR CONT 4 21 RUN CCLE 75% KH ma, (Reperdicted) DNR CONT 4 21 RUN CCLE 75% KH ma, (Reperdicted) DNR CONT 4 23 MALL games DNR DNR CONT 4 24 RUN 75% KH ma, (Reperdicted) DNR CONT 4 24 MALL games DNR DNR CONT 4 25 CYCLE 50-95% KH ma, (Reperdicted) DNR CONT 4 26 RUN DNR	6CYCLE80% VO_mer80% VO_merAdjustment of training loadINT516RUN5 onewhat load (80 POlone)DNRCONT820RUN5 onewhat load (88 Pordicide)DNRCONT820RUN74% H m_{max} (88 Pordicide)DNRCONT820RUN74% H m_{max} DNRCONT821RUN70% H m_{max} DNRCONT822RUN70% H m_{max} DNRCONT823RUN60-75% HRDNRDNRCONT824RUN20% H m_{max} DNRCONT825RUN60-75% HRDNRDNRCONT826RUN70% H m_{max} DNRCONT327CCCLE60-75% HRDNRCONT828CCCLE60-75% HRDNRCONT329RUNDNRDNRNRNR320RUNDNRDNRNRNR320RUN00% H m_{max} DNRNRNT320RUN05.90% H m_{max} DNRNRNT321RUN00% H m_{max} DNRNRNT321RUN00% H m_{max} DNRNRNT322RUN05.90% H m_{max} DNRNRNT323RUN00% H m_{max} DNRNRNT3 <t< td=""><td>Huang_2019_1⁵¹</td><td>9</td><td>CYCLE</td><td>60% VO_{2max}</td><td>Adjustment of training load</td><td>CONT</td><td>5</td><td>30</td><td>2.5</td></t<>	Huang_2019_1 ⁵¹	9	CYCLE	60% VO _{2max}	Adjustment of training load	CONT	5	30	2.5
16 RUN Somewhat hand (RFE scale) DNR CONT 8 200 RUN 59.5 HR _{ma} (ge-predicted) DNR CONT 8 8 ROW ⁶ 95.5 HR _{ma} (ge-predicted) DNR CONT 8 11 RUN CrCLE 50.75 KH _{ma} (ge-predicted) DNR CONT 8 8 ROW ⁶ 95.5 HH _{ma} (ge-predicted) DNR CONT 4 11 RUN CrCLE 50.75 KH _{ma} DNR CONT 4 8 ROM ⁶ 60-35 KH _{ma} DNR CONT 4 12 CYCLE 50-75 KV ₂ ma DNR CONT 4 13 CYCLE 50-75 KV ₂ ma DNR CONT 4 14 RNIN CYCLE 50-75 KV ₂ ma DNR CONT 3 14 RNIN DNR DNR DNR CONT 4 5 15 RNIN DNR DNR DNR DNR CONT 3 16	16 RUN Somewhat hand (RFE scale) DNR CONT 8 20 RUN 935 H $_{max}$ (gepredicted) DNR CONT 8 20 RUN 935 H $_{max}$ (gepredicted) DNR CONT 8 21 ROW ⁺ 955 H $_{max}$ (gepredicted) DNR CONT 8 21 ROW ⁺ 955 H $_{max}$ DNR CONT 4 21 ROW ⁺ 955 H $_{max}$ DNR CONT 4 21 ROW ⁺ 955 H $_{max}$ DNR CONT 4 21 CYCLE 50-735 H $_{max}$ DNR CONT 4 21 CYCLE 50-735 H $_{max}$ DNR CONT 4 22 CYCLE 50-735 H $_{max}$ DNR DNR CONT 4 21 CYCLE 50-735 H $_{max}$ DNR DNR CONT 4 23 CYCLE 50-735 H $_{max}$ DNR DNR CONT 4 24 RUN	Huang_2019_2 ⁵¹	6	CYCLE	80% VO _{2max}	Adjustment of training load	INT	5	30	2.5
		Hulke_2012_1,2 ⁵²	16	RUN	Somewhat hard (RPE scale)	DNR	CONT	8	09	8
	20 RUN 74% Hm., (gerredicted) DNR CONT 8 8 ROW ¹ 90% HR, min. DNR CONT 4 1 2 RUN 75% HR, min. DNR CONT 4 1 RUN 75% HR, min. DNR CONT 4 1 RUN 75% HR, min. DNR CONT 4 1 RUN 75% HR, min. DNR CONT 4 8 RUN 60-35% HR, min. DNR CONT 3 1 CCLE 50-75% HR, min. DNR CONT 4 1 RUN CCLE 60-35% HR, min. DNR CONT 3 2 CCLE 60-35% HR, min. DNR DNR CONT 3 8 RUN DNR DNR DNR DNR CONT 3 8 RUN DNR DNR DNR DNR DNR DNR DNR 1 RUN	Hulke_2012_A ¹⁶	20	RUN	59.5% HR _{max} (age-predicted)	DNR	CONT	8	25–30	4
8 ROW ⁶ 90% HP _{mai} DNR INT 4 1 8 ROW ⁶ 70% HP _{mai} DNR CONT 3 1 12 ROM ⁶ 50% HP _{mai} DNR CONT 3 1 RALL games CONT 60-73% HR _{mai} DNR CONT 3 1 CYCLE 60-73% HR _{mai} Timensity CONT 3 1 CYCLE 50-73% HR _{mai} Timensity CONT 3 20 CYCLE 50-73% HR _{mai} Timensity CONT 3 20 CYCLE 50-73% HR _{mai} Timensity CONT 3 21 CYCLE 50-73% HR _{mai} Timensity CONT 3 21 RUN 70% HR _{mai} Timensity CONT 3 23 RUN 70% HR _{mai} Timensity CONT 3 24 RUN 70% HR _{mai} Timensity CONT 3 24 RUN 70% HR _{mai}	8 ROW^2 $90R$ R_{main}^{446} DNR INT 4 1 8 ROW^2 $70S$ R_{main}^{446} DNR INT 4 1 8 ROW^2 $70S$ R_{main}^{446} DNR $CONT$ 4 1 ROL $50-75S$ VR_{main}^{46} DNR $CONT$ 4 8 ROL $60-75S$ VR_{main}^{46} $Intensity$ $CONT$ 3 1 $CCLE$ $50-75S$ VR_{main}^{46} $Intensity$ $CONT$ 3 2 $CCLE$ $50-75S$ VR_{main}^{46} $Intensity$ $CONT$ 3 2 $CCLE$ $50-75S$ VR_{main}^{46} $Intensity$ $CONT$ 3 RON DR RUN DR RUN TI RON RON S RON RON RON RON RON RON S RON RON RON RON RON RON S RON RON	Hulke_2012_B ¹⁶	20	RUN	74.9% HR _{max} (age-predicted)	DNR	CONT	8	25–30	4
8 ROW ⁶ 70% HR _{pat} DN COUT 4 12 RUN CYCLE 50-75% HHR DN COUT 3 8 MLL games COUL 60-75% HR _{mat} DN COUT 3 11 CYCLE 50-75% HR _{mat} 1 intensity COUT 3 12 CYCLE 50-75% HR _{mat} 1 intensity COUT 3 13 CYCLE 50-75% HR _{mat} 1 intensity COUT 3 20 CYCLE 60-95% HR _{mat} DNR 1 intensity COUT 3 20 CYCLE on ELLor 60-95% HR _{mat} DNR MIX 3 8 RUN 70% HR _{mat} DNR MIX 3 11<	8 ROW ⁶ 70% HR _{mati} DNR CONT 4 12 Surprox. 8 NUX. CYCLE 50-75% HHR DNR CONT 3 8 NUX. CYCLE 60-75% HHR 70% HR _{mati} Tintensity CONT 3 13 CYCLE 60-75% HR _{mati} Tintensity CONT 3 13 CYCLE 50-75% VC _{2mati} Tintensity CONT 3 13 CYCLE 50-75% VC _{2mati} Tintensity CONT 3 13 CYCLE 50-75% VC _{2mati} DNR MIN 3 14 RUN DNR MIN CONT 3 11 RUN DNR DNR MIN 3 11 RUN 70% HR _{mati} DNR MIN 3 11 RUN 70% HR _{mati} DNR MIN 3 11 RUN 70% HR _{mati} DNR MIN 3 12 RUN 70% HR _{mati} DNR	Hwang_2016_1 ⁵³	8	ROW ^b	90% HR _{peak}	DNR	INT	4	25	1.7 ^c
12 RUN, CYCLE 50-75% MHR DNR CONT 3 BALL games B. BALL games 1 intensity CONT 3 12 CYCLE 60-75% MR. _{max} 1 intensity CONT 3 13 CYCLE 50-75% VO. _{max} 1 intensity CONT 3 13 CYCLE 50-75% VO. _{max} 1 intensity CONT 3 13 CYCLE 50-95% HR. _{max} DNR MN 3 11 KUN NN DNR MN 3 11 RUN 70% HR. _{max} DNR MN 3 11 RUN 70% HR. _{max} DNR MN 3 11 RUN 70% HR. _{max} DNR MN 3 12 RUN 70% HR. _{max} DNR MN 3 13 MU 1 duration MN 3 3 14 RUN 70% HR. _{max} DNR MN 3 14	12RUN, CYCLE50-75% MHDNDNCONT3 $BALL gamesBALL gamesBALL games1 intensityCONT3-412CYCLE60-75\% HR, max1 intensityCONT3-413CYCLE60-75\% VD, max1 intensityCONT3-413CYCLE60-95\% HR, max1 intensityCONT3-414NUNDNDNRDNRMM38RUN70% HR, maxDNRDNRMM395RUN70% HR, maxDNRDNRMM396RUN70% HR, maxDNRDNRMM397RUN70% HR, maxDNRDNRMM398RUN70% HR, maxDNRDNRMM398RUN70% HR, maxDNRDNRMM398RUN70% HR, maxDNRMM398RUN70% HR, maxDNRMM398RUN70% HR, maxDNRMM398RUN70% HR, maxDNRMM399RUN70% HR, maxDNRMM398RUN70% HR, maxDNRMM398RUN70% HR, maxDNRMM399CYCLE6-90% HR, maxMM3398CYCLE50% VD, maxMMMM399CYCLE50% VD, maxMMMM$	Hwang_2016_2 ⁵³	8	ROW ^b	70% HR _{peak}	DNR	CONT	4	32	2.1 ^c
SkiPhNG, BALL games SkiPhNG, BALL games 12 CYCLE 60-75% HR _{max} 1 intensity COVI 3-4 13 CYCLE 50-75% VO _{2max} 1 intensity COVI 3-4 13 CYCLE 50-75% VO _{2max} 1 intensity COVI 3-4 20 CYCLE 60-85% HR _{max} 1 intensity COVI 3-5 20 CYCLE 60-85% HR _{max} DNR COVI 3-5 20 CYCLE 60-85% HR _{max} DNR MX 3 8 RUN 70% HR _{max} DNR MX 3 8 RUN 70% HR _{max} DNR MX 3 9 RUN 70% HR _{max} DNR MX 3 11 RUN 70% HR _{max} DNR MX 3 12 RUN 70% HR _{max} DNR MX 3 13 HUN 70% HR _{max} DNR MX 3 14 RUN 70% HR _{max}	SurPrind: Bull.games 12 CYCLE 60-35% HR.ms. 1 intensity COVT 3-4 13 CYCLE 50-75% VO.ms. 1 intensity COVT 3-5 20 CYCLE 50-90% HR.ms. DNR MN 3-5 8 RUN 70% HR.ms. DNR MN 3-5 91 RUN 70% HR.ms. DNR MN 3-5 11 RUN 70% HR.ms. DNR MN 3-7 DNR RUN 70% HR.ms. DN	Kiflom_2022 ⁵⁵	12	RUN, CYCLE,	50–75% MHR	DNR	CONT	٣	60–80	3.5°
12 CYCLE 60-75% HR _{max} 1 intensity CONT 3-4 1 CYCLE 50-75% VO _{2max} 1 intensity CONT 3 2 CYCLE 50-75% VO _{2max} 1 intensity CONT 3 2 CYCLE 50-75% VO _{2max} DNR CONT 3 2 CYCLE 50-75% VO _{2max} DNR CONT 3 8 CYCLE 50-90% HR _{max} DNR CONT 3 8 RUN 70% HR _{max} DNR MR 3 8 RUN 70% HR _{max} DNR NT 3 1 RUN 70% HR _{max} DNR NT 5 1 RUN 70% HR _{max} MR NT 5 1 RUN	12 CYCLE 60-75% HR _{max} 1 intensity COVT 3-4 13 CYCLE 50-75% VO _{2max} 1 intensity COVT 3 20 CYCLE of ELL or 60-90% HR _{max} 1 intensity COVT 3 20 CYCLE of ELL or 60-90% HR _{max} DNR COVT 3 4 I RUN 70% HR _{max} DNR COVT 3 5 RUN 70% HR _{max} DNR DNR COVT 3 6 RUN 70% HR _{max} DNR DNR DNR 3 7 RUN 70% HR _{max} DNR DNR DN 3 6 RUN 70% HR _{max} DNR DNR DN 3 7 RUN 70% HR _{max} DNR DNR DN 3 7 RUN 70% HR _{max} DNR DNR DN 3 9 RUN 70% HR _{max} DNR DNR DN 3 12 RUN 70% HR _{max} Munton 10 MU 5 13 HINENSIN COVI DNR 1 1 14 MUN 70% HR _{max} MU 1 1 14			SKIPPING, BALL games						
13 CYCLE 50-75% VO _{Inst} 1 duration 20 CYCLE 60-35% HR 1 intensity CONT $4 - 5$ 20 CYCLE or ELL or >60-35% HR 1 intensity CONT $4 - 5$ 8 CYCLE or ELL or >60-35% HR DNR CONT $3 - 5$ 11 RUN DNR DNR CONT $3 - 5$ 8 RUN 70% HR _{mak} DNR DNR CONT $3 - 5$ 11 RUN 70% HR _{mak} DNR DNR DNR $3 - 5$ 11 RUN 70% HR _{mak} DNR DNR $3 - 5$ $3 - 5$ 12 RUN 70% HR _{mak} DNR DNR $3 - 5$ $3 - 5$ 12 RUN 70% HR _{mak} DNR DNR $3 - 5$ $3 - 5$ 13 HUN 70% HR _{mak} DNR DNR $3 - 5$ $3 - 5$ 14 RUN 70% HR _{mak} DNR DNR $3 - 5$ $3 - 5$ 14 RUN 70% HR _{mak} DNR DNR $3 - 5$ $3 -$	13 CYCLE 50-73% VO _{2nuc} 1 duration 20 CYCLE of ELL or 60-93% HRass 1 intensity CONT 3 8 CYCLE of ELL or 60-90% HR _{max} DNR CONT 3 8 RUN 70% HR _{max} DNR M 3 95 RUN 70% HR _{max} DNR M 3 11 RUN 70% HR _{max} DNR M 3 95 RUN 70% HR _{max} DNR M 3 11 RUN 70% HR _{max} DNR N 3 12 RUN 70% HR _{max} DNR N 3 12 RUN 70% HR _{max} 1 nutensity CONT 3 12 RUN 70% HR _{max} 1 nutensity M 3 13 HUN 70% HR _{max} 1 nutensity 1 nutensity 3 14 RUN 70% HR _{max} 1 nutensity 1 nutensity 3 14 RUN 70% HR _{max} 1 nutensity 1 nutensity 3 12 R	Kivisto_2006 ⁵⁶	12	CYCLE	60–75% HR _{max}	↑ intensity	CONT	3-4	30	1.75 ^c
13 CYCLE 50-75% VO _{2nnet} 1 intensity CONT 3 20 CYCLE of ELL or 560-90% HR _{max} 0.85% HR 1 intensity CONT 4-5 8 CYCLE of ELL or 560-90% HR _{max} DNR CNT 3 1 RUN NR DNR DNR CONT 3 8 RUN 70% HR _{max} DNR DNR NIT 3 9 RUN 70% HR _{max} DNR NIT 3 9 RUN 70% HR _{max} DNR NIT 3 1 RUN 70% HR _{max} DNR NIT 3 1 RUN 70% HR _{max} DNR NIT 55 2 NUN 70% HR _{max} 1 1 1 1 1 1 HUN 70% HR _{max} DNR NIT 55 1 2 Repeat examinations when 1 1 1 1 1 1 RUN, CYCLE <td>13CYCLE$50-75\% VO_{nux}$1 intensityCONT320CYCLE or ELL or$60-85\%$ HR1 intensityCONT$4-5$20CYCLE or ELL or$60-85\%$ HR1 intensityCONT3RUNNUNNUN0 RUN0 NR0 NR$3$$1RUN70\%$ HR_{max}0 NR0 NR$3$$8^{45}RUN70\%$ HR_{max}0 NR0 NR$3$$8^{45}RUN70\%$ HR_{max}0 NR0 NR$3$$1RUN70\%$ HR_{max}0 NR0 NR0 NI1RUN70% HR_{max}0 NR0 NR0 NI1RUN70% HR_{max}0 NR0 NR0 NI1RUN70% HR_{max}0 NI0 NI$5$$1RUN70\%$ HR_{max}0 NI0 NI$0$$1RUN70\%$ HR_{max}0 NI0 NI$0$$1RUN0$ NI0 NI0 NI$0$$1RUN0$ NI0 NI0 NI$0$$1RUN0$ NI0 NI0 NI$0$$1RUN0$ NI0 NI<td></td><td></td><td></td><td></td><td>† duration</td><td></td><td></td><td></td><td></td></td>	13CYCLE $50-75\% VO_{nux}$ 1 intensityCONT320CYCLE or ELL or $60-85\%$ HR 1 intensityCONT $4-5$ 20CYCLE or ELL or $60-85\%$ HR 1 intensityCONT 3 RUNNUNNUN 0 RUN 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 3 8^{45} RUN 70% HR _{max} 0 NR 0 NR 3 8^{45} RUN 70% HR _{max} 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 3 1 RUN 70% HR _{max} 0 NR 0 NR 0 NI 1 RUN 70% HR _{max} 0 NR 0 NR 0 NI 1 RUN 70% HR _{max} 0 NR 0 NR 0 NI 1 RUN 70% HR _{max} 0 NI 0 NI 5 1 RUN 70% HR _{max} 0 NI 0 NI 0 1 RUN 70% HR _{max} 0 NI 0 NI 0 1 RUN 0 NI 0 NI 0 NI 0 1 RUN 0 NI 0 NI 0 NI 0 1 RUN 0 NI 0 NI 0 NI 0 1 RUN 0 NI 0 NI <td></td> <td></td> <td></td> <td></td> <td>† duration</td> <td></td> <td></td> <td></td> <td></td>					† duration				
20 CYCLE 60-90% HR 1 intensity COVI< 4-5 8 CYCLE or ELL or 560-90% HR _{max} DNR COVI 3 11 RUN DNR DNR MIX 3 8 RUN 70% HR _{max} DNR MIX 3 8 RUN 70% HR _{max} DNR MIX 3 9.4 RUN 70% HR _{max} DNR MIX 3 9.4 RUN 70% HR _{max} DNR MIX 3 9.4 RUN 70% HR _{max} DNR MIX 3 1 RUN 70% HR _{max} DNR MIX 5 DNR RUN 70% HR _{max} MIR 1 1 1 RUN 70% HR _{max} 1 1 1 1 1 1 RUN, CYCLE 60-90% HR _{max} 1 1 1 1 1 1 1 RUN, CYCLE 60-90% HR _{max} 1 1	20 CYCLE 60-85% HR 1 intensity CONT 4-5 8 CYCLE or ELL or RUN >60-90% HR _{max} DNR CONT 3 1 RUN NN NN NN NN 3 8 RUN 70% HR _{max} DNR NN 3 9 8 RUN 70% HR _{max} DNR NN 3 9 8 RUN 70% HR _{max} DNR NN 3 0 RUN 70% HR _{max} DNR NN 3 3 1 RUN 70% HR _{max} DNR NN 3 3 1 HUN 70% HR _{max} DNR NN 3 3 1 HUN 70% HR _{max} MN 7 1 4 3 1 HUN 70% HR _{max} 1 4 4 3 3 1 RUN 7 4 1 4 3 3 1	Krzeminski_1989 ¹⁷	13	CYCLE	50–75% VO _{2max}	↑ intensity	CONT	٣	30	1.5
8 CYCLE or ELL or >60-90% HR _{max} DNR CONT 3 RUN NN DNR DNR MIX 3 11 RUN DNR DNR MIX 3 8 RUN T/0% HR _{max} DNR DNR MIX 3 91 RUN 70% HR _{max} DNR DNR MIX 3 91 RUN 70% HR _{max} DNR DNR MIX 3 91 RUN 70% HR _{max} DNR DNR MIX 3 10 RUN 70% HR _{max} DNR DNR MIX 3 11 RUN 70% HR _{max} DNR MIX 5 11 RUN 70% HR _{max} MIX 5 MIX 5 12 RUN, CYCLE 60-90% HR _{max} MIX 5 MIX 5 13 Recetuation of workload MIY 5 MIX 5 14 Mas per equation 60-65	8 CYCLE or ELL or RUN 560-90% HR _{max} DNR CONT 3 11 RUN 70% HR _{max} DNR MY 3 8 RUN 70% HR _{max} DNR MR 3 9.0 RUN 70% HR _{max} DNR MY 3 9.1 RUN 70% HR _{max} DNR MR 3 9.1 RUN 70% HR _{max} DNR MY 3 DNR RUN 70% HR _{max} DNR MR 3 10 RUN 70% HR _{max} Threesity CONT 3 11 RUN 70% HR _{max} Threesity CNT 5 12 RUN, CYCLE 60-90% HR _{max} Haration MY 3 13 Hunstein Topeat examinations when Haration 3 14 MUN, CYCLE 60-90% HR _{max} MX 3 13 Hunstein Haration MI 3 14 Hunstein Haration MI 3 15 RUN, CYCLE 60-90% HR _{max} MI 3 14 Haration MI 1 1 15 RUN, CYCLE 50-90% VO _{2max} MI 1 <td>Landry_1985⁵⁹</td> <td>20</td> <td>CYCLE</td> <td>60–85% HRR</td> <td>↑ intensity</td> <td>CONT</td> <td>45</td> <td>40-45</td> <td>3.4</td>	Landry_1985 ⁵⁹	20	CYCLE	60–85% HRR	↑ intensity	CONT	45	40-45	3.4
RUN 11 RUN DNR MY 3 8 RUN 70% HR _{max} DNR MY 3 8 RUN 70% HR _{max} DNR NT 3 95 8 RUN 70% HR _{max} DNR NT 3 1 Aun 65-80% HR _{max} DNR NT 3 1 Aun 70% HR _{max} DNR NT 3 1 Aun 70% HR _{max} DNR NT 3 1 Aun 70% HR _{max} CONT 3 3 1 Aunation Aunation Aunation Aunation 3 1 Aunation Aunation Aunation 3 3 1 Aunation Aunation Aunation 3 3 1 Aunation Aunation Aunation 3 3 1 Bundo Aunation Aunation Aunation 3 3 1	And Bun MN MN MN MN M	Lane_2014_1,2 ⁶⁰	œ	CYCLE or ELL or	>60-90% HR _{max}	DNR	CONT	٣	30-60	2.25 ^c
	11 RUN DNR MN MX 3 8* RUN 70% HR _{max} DNR CONT 3 8* RUN 70% HR _{max} DNR NT 3 9* RUN 70% HR _{max} DNR NT 3 9* RUN 70% HR _{max} DNR NT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 10 RUN 70% HR _{max} 1 intensity 1 1 11 RUN 70% HR _{max} 1 intensity 1 1 12 RUN.CYCLE 60-90% HR _{max} 1 intensity 1 1 18 CYCLE 50-90% VO _{2max} 1 was per equation 1 1 18 CYCLE 60-65% VO _{2max} 1 was per equation 1 1			RUN						
4 ⁴ 8 RUN 70% HR _{max} DNR CONT 3 8 ⁴ 8 RUN 70% HR _{max} DNR NT 3 8 RUN 65-80% HR _{max} 1/max 0/max 0/max 3 DNR RUN 70% HR _{max} 1/max 1/max 0/max 5 DNR RUN 70% HR _{max} 1/max 1/max 5 DNR RUN 70% HR _{max} 1/max 7 DNR RUN 70% HR _{max} 1/max 7 DNR RUN 7/max 1/max 7 Image of angle form 30 matro of a form 30 1/max 3 Image of angle form 30 matro of a form 30 1/max 3 R CVCLE 1/max 1/max 3	4 ⁶ 8 RUN 70% HR _{max} DNR CONT 3 8 ⁹ 8 RUN 70% HR _{max} DNR RUT 3 8 RUN 65-80% HR _{max} 1 intensity CONT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 DNR RUN 70% HR _{max} 1 intensity CONT 3 IDN RUN 70% HR _{max} 1 intensity CONT 3 IDN RUN 70% HR _{max} 1 intensity CONT 3 IDN RUN 70% HR _{max} 1 intensity MT 3 IDN RUN, CYCLE 60-90% HR _{max} 1 distance changed from 30 MT 3 IDN Repeat examinations when mecocycle (%) pin MT 5 (M) as per equation 5 IDN CVCLE 60-65% VO _{2max} (M) as per equation CONT 5 (M)	Lusiani_1986 ⁶¹	11	RUN	DNR	DNR	XIM	٣	DNR	DNR
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DNR RUN 70% HR _{max} 1 distance CONT 5.5 12 RUN, CYCLE 60-90% HR _{max} Repeat examinations when mileage changed from 30 and 50 miles from baseline 1 12 RUN, CYCLE 60-90% HR _{max} Periodized progressive MX 3 13 RUN, CYCLE 120% VO _{2max} Recalculation of workload MT 5 14 So-90% VO _{2max} Recalculation of workload NT 5 15 CYCLE 50-90% VO _{2max} Recalculation of workload NT 5 15 CYCLE 50-90% VO _{2max} Recalculation of workload NT 5 16 CYCLE 50-90% VO _{2max} (W) as per equation 1 5 16 CYCLE 60-65% VO _{2max} (W) as per equation 1 5	DNR RUN 70% HR _{max} † distance CONT 5.5 12 RUN, CYCLE 60–90% HR _{max} Repat examinations when mileage changed from 30 and 50 miles from baseline MY 3 13 RUN, CYCLE 60–90% HR _{max} Periodized progressive MY 3 8 CYCLE 120% VO _{2max} Recalculation of workload INT 5 8 CYCLE 50–90% VO _{2max} Recalculation of workload INT 5 8 CYCLE 60–65% VO _{2max} (W) as per equation 7 5					↑ duration				
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8 CYCLE 120% VO _{2max} Necalulation of workload INI 5 8 CYCLE 50–90% VO _{2max} (W) as per equation 5 8 CYCLE 50–90% VO _{2max} Recalculation of workload INT 5 8 CYCLE 60–65% VO _{2max} (W) as per equation 5 (W) as per equation 5	8 CYCLE 120% VO _{2max} Recalculation of workload INI 5 8 CYCLE 50–90% VO _{2max} (W) as per equation 5 8 CYCLE 50–90% VO _{2max} (W) as per equation 5 8 CYCLE 60–65% VO _{2max} (W) as per equation 5 8 CYCLE 60–65% VO _{2max} (M) as per equation 5	59. 1000	c			macrocycle (×3) plan	ŀ			0
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8 CTCLE 50-90% VO _{2max} Recalculation of workload INI 5 (W) as per equation 5 8 CYCLE 60-65% VO _{2max} CONT 5	8 CTCLE 50-90% VO _{2max} Recalculation of workload INI 5 8 CYCLE 60-65% VO _{2max} (W) as per equation CONT 5	292	c			(W) as per equation	Ē	L	0	L
8 CYCLE 60–65% VO _{2max} (VV) as per equation CONT 5	8 CYCLE 60–65% VO _{2nax} (W) as per equation CONT 5	Matsuo_2014_6	α	CYCLE	50-90% VO _{2max}	Kecalculation of workload		Q	8	<u>.</u>
8 CTCLE 60-65% VO2nax	8 CTCLE 60-65% VO2max		c			(W) as per equation	H A O O	L	Ļ	
		Matsuo_2014_C	α	CICLE	60-63% VO2max		CON	n	64	c/.c

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Study (author, year)	Length of study (weeks)	Modality	Intensity	Progressive training	Type of training	Frequency (days/week)	Time per session, min	Total hours (h/ week)
				Remeasurement of VO ₂ every	,			
				2 weeks				
Morrison_1986 ⁶⁶	35	RUN	65–75% HRR	\uparrow intensity to maintain HR	CONT	с	40	2
O'Driscoll_2018 ⁶⁷	2	CYCLE	100% effort	N/A	INT	3	5.5	0.3
Park_2003 ⁶⁸	36	RUN, CYCLE	50-60% HRR	Reperform ET and adjust	CONT	3	60	e
				intensity				
Perrault_1982_1 ⁶⁹	20	RUN	80% HR _{max} (ED)	Adjustment of training load to	CONT	e	30	1.5
				maintain intensity				
Perrault_1982_2 ⁶⁹	20	CYCLE	80% HR _{max} (ED)	Adjustment of training load to	CONT	3	30	1.5
				maintain intensity				
Pickering_1997 ⁷⁰	16	CYCLE	50% VO $_{2max}$ – HR @ lactate threshold	↑ intensity	MIX	c	20–55	2.75 ^c
				↑ duration				
Rahimi_2018_1 ⁷¹	12	SWIM (water	60–80% HR _{max}	↑ intensity	CONT	£	30–60	2 ^c
		aerobics)		↑ duration				
Rodrigues_2006 ⁷²	26	RUN	HR_{AT} – HR 10% lower than RCP – HR @ RCP	↑ intensity	CONT	£	40-45	2.25
Rojek_2015 ⁷³	52	RUN, CYCLE,	DNR	DNR	DNR	J	> 90	11.2 ^c
		SWIM						
Rubal_1987_1,2 ¹⁹	10	RUN	>70% HR _{max}	DNR	CONT	3.5	> 30	2 ^c
Saadatnia_2016 ⁹⁶	10	RUN	Maximal effort	↑ #intervals	INT	ſ	8–16	0.2 ^c
Sagiv_1989 ⁷⁴	12	RUN	70% VO _{2max}	Adjustment of training load to	CONT	e	30	1.5
				maintain intensity				
Sayevand_2015 ⁷⁶	4	CYCLE	80% VO _{2max}	Adjustment of training power	, INT	£	40	2
				output				
Scharf_201577	16	RUN	65–90% HR _{max}	↑ frequency	MIX	2-4	DNR	DNR
Shapiro_1983 ²⁰	6	RUN	DNR	DNR	CONT	5	15–30	1.8 ^c
Skattebo_2020 ⁷⁹	10	CYCLE	70–90% HR _{peak}	↑ #intervals	MIX	٣	36–60	0.8 ^c
Slordahl_2004 ⁸⁰	8	RUN	50–95% HR _{max}	DNR	INT	e	25	1.25 ^c
Soto_2008 ⁸¹	44	RUN, CYCLE	60–100% VO _{2max}	Re-measure VO ₂ every 3	XIX	45	60	4.5 ^c
				months				
Spence_2011 ⁸²	24	RUN	Individualized (based on VO _{2peak} and time trial performances) periodized programme. included 3	Variations in intensity, volume MIX	MX	£	60	£
			phases [preparatory phase (low-moderate intensity),					
			specific phase (hill running, short intervals),					
			reduced)]					
								Continued

Study (author, year)	Length of study (weeks)	Modality	Intensity	Progressive training	Type of training	Frequency (days/week)	Time per session, min	Total hours (h/ week)
Spina_1992 ⁸⁴	12	RUN and CYCLE	50–95% VO _{2max}	Re-measure VO ₂ every 3	MIX	6	40-45	4.25 ^c
				weeks				
				1 pace and power				
Spina_1997 ⁸⁶	36	RUN, CYCLE	60–95% VO _{2max}	Re-measure VO ₂ every 3	XIX	5	60	5
				months and adjust intensity				
Spina_2000 ⁸⁵	48	RUN, CYCLE	60–95% VO _{2max}	Re-measure VO ₂ every 3	XIX	5	60	5
				months and adjust intensity				
Spina_2004 ⁸³	12	run, cycle, Row	65–90% VO _{2max}	DNR	XIX	m	1060	3°
Vance_2014 ⁸⁷	16	RUN	Half-marathon training	DNR	DNR	DNR	DNR	DNR
Vanhees_1992 ⁸⁸	16	RUN, CYCLE	70% HRR	Encouraged to improve	CONT	e	60	e
				performance				
Wieling_1981_1 ²¹	30	Non-specific	Non-specific endurance, interval training, rowing training	\Box	XIX	DNR	DNR	9c
Windecker_2002 ⁹²	22	RUN or CYCLE	80% VO _{2peak}	DNR	CONT	54	≥60	4≤
Wolfe_1979 ²²	26	RUN ^a	60–80% HR _{max}	↑ intensity	CONT	4	10–30	2 ^c
				1 duration				
Wolfe_1992 ⁹³	11	RUN	80–85% HR _{max}	↑ frequency	CONT	3–5	20-45	2.2 ^c
				↑ duration				
Younis_1987 ⁹⁴	26	SWIM, RUN, T/F, basic sports, ball	≥70% HR _{max}	DNR	CONT	DNR	≥2	12
		games						
Trained								
Baggish_2009 ^{d32}	13	ROW	DNR (college training plan followed)	DNR (college training plan	CONT	DNR (college	60–180	11.1 ^c
				followed)		training		
						plan followed)		
Bonaduce_1998 ³⁴	20	CYCLE, AER	DNR (followed training plan)	DNR (followed training plan)	CONT	7	180	21
D'Ascenzi_2015 ³⁹	18	SOC, VB, BB	Low training period (high volume/low intensity and	DNR (followed training plan)	XIX	DNR	DNR	12–20
5			sprinting); peak training (70–95% ${\sf HR}_{\sf max}$)					
Ehansi_1978 ⁴²	6	SWIM	DNR (followed swim team training plan)	DNR	DNR	6	180	12
Fagard_1983 ⁴⁵	DNR	CYCLE	DNR (followed competitive cycling training plan)	DNR	DNR	DNR	DNR	DNR
Kleinnibbelink_2021_1,2 ⁵⁷	7 36	ROW	DNR (followed elite rowing training programme	DNR	XIX	DNR	DNR	24–35
			consisted of high intensity and endurance)					
								Continued

Study (author, year) Length of Modality study (weeks)	Length of study (weeks)	Modality	Intensity	Progressive training	Type of training	Frequency (days/week)	Time per session, min	Total hours (h/ week)
Lamont_1980 ⁵⁸	13	SWIM	DNR (followed swim training programme)	DNR	×Ψ	5	180–240	16
Naylor_2005 ¹⁸	26	ROW, AER	80–90% HR _{max}	DNR (followed rowing	CONT	6-7	270	29.3
				training programme				
Rahimi_2018_2 ⁷¹	12	SWIM (water	60–80% HR _{max}	↑ intensity	CONT	c	30-60	2 ^c
		aerobics)		↑ duration				
Sareban_2018 <mark>75</mark>	11	ROW, RUN,	DNR (followed preparatory training period for elite	DNR	DNR	DNR	DNR	11.8 ^c
		CYCLE, SWIM	athletes)					
Shah_2018 ⁷⁸	13	ROW	DNR (collegiate rowing training programme)	DNR	CONT	5-6	60–180	11.9 ^c
Venckunas_2006 ⁸⁹	52	RUN	Increased training volume \sim 50% (20–125) in first 2	↑ volume	CONT	DNR	~ 120	DNR
			months and then continued at this training volume for	L				
			remaining 10 months, participated in no more than					
			once every 2 months, allowed to alternate mileage of	f				
			sessions as desired					
Wasfy_2018 ⁹⁰	12	ROW	DNR (collegiate rowing training programme)	DNR	DNR	DNR	DNR	13
Wasfy_2019 ⁹¹	13	SWIM	DNR (followed collegiate training programme)	DNR	CONT	7	60–180	16.3
Wieling_1981_2 ²¹	30	ROW	DNR (followed collegiate rowing training programme)	DNR	XIX	DNR	DNR	12 ^c
Zilinski_2015 ⁹⁵	18	RUN	DNR (followed marathon training programme)	↑ distance	CONT	4–5	DNR	4

^aBicycle ergometer substituted if injury or indement weather. ^bArm/leg non-weight-bearing ergometer. ^cMean if hours or frequency reported as range, and when mean hours reported for entire study population.

Endurance training and left ventricular structure

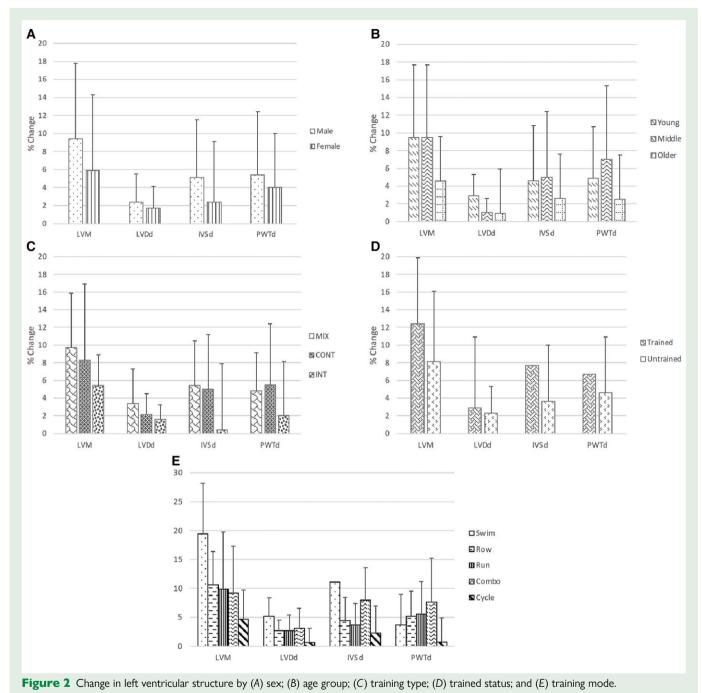
LV parameter (units)	Descriptives (N analyses; N participants)	Pre-intervention (mean \pm SD)	Post-intervention (mean \pm SD)	% change±SD (range)
Untrained				
LV structure				
LVM (g)	57; 1035	139.7 <u>+</u> 25.6	149.4 <u>+</u> 27.0	7.7 ± 7.3 (-4.6 to 32.1)
LVMi (g/m ²)	39; 824	77.7 ± 12.6	83.8 ± 14.0	8.3 ± 8.3 (-5.13 to 31.7)
IVSd (mm)	65; 1144	9.0 ± 1.4	9.3 ± 1.2	3.6 ± 6.3 (-19.5 to 20.3)
PWTd (mm)	63; 1139	8.8 ± 1.1	9.2 ± 1.1	4.6 ± 6.3 (-5.7 to 28.9)
LVDd (mm)	64; 1125	47.9 <u>+</u> 1.9	48.8 ± 1.8	2.0 ± 2.8 (-6.1 to 13.2)
LV function				
VO _{2max} (mL/min/kg)	61; 1017	37.9 <u>+</u> 4.5	44.1 <u>+</u> 4.5	15.0 ± 7.6 (0.4 to 33.8)
VO _{2max} (L/min)	7; 132	2.4 ± 2.4	2.6 ± 2.5	12.2 ± 4.4 (8.8 to 21.5)
End-diastolic volume (mL)	33; 546	125.5 <u>+</u> 18.0	131.6 ± 42.8	5.5 ± 5.3 (-1.3 to 21.7)
End-systolic volume (mL)	31; 524	49.2 ± 9.4	50.0 ± 8.8	1.2 ± 7.3 (-17.5 to 14.4)
Stroke volume (mL)	40; 702	76.3 ± 12.4	82.7 ± 12.4	9.0 ± 9.8 (-7.2 to 33.5)
Trained				
LV structure				
LVM (g)	10; 229	196 ± 43.8	217.7 ± 50.8	11.2 ± 5.5 (3.8–19.5)
LVMi (g/m ²)	13; 281	111.2 ± 17.7	124.4 <u>+</u> 18.7	11.5 ± 7.7 (-0.9 to 29.4)
IVSd (mm)	11; 240	10.0 ± 1.6	10.8 ± 2.5	7.6 ± 4.7 (1.1 to 18.2)
PWTd (mm)	13; 293	9.7 ± 1.1	10.4 ± 1.1	6.3 ± 5.8 (-2.0 to 20.0)
LVDd (mm)	13; 270	52.1 ± 2.1	53.3 ± 2.0	$2.6 \pm 2.9 \ (-1.16 \text{ to } 8.8)$
LV function				
VO _{2max} (mL/min/kg)	7; 118	53.5 ± 3. 8	57.3 ± 4.9	8.9 ± 5.7 (0 to 15.5)
VO _{2max} (L/min)	1; 17	3.2 ± 0.6	3.5 ± 0.5	7.8
End-diastolic volume (mL)	6; 167	133 <u>+</u> 29.4	142.2 ± 30.3	7.5 ± 10.2 (-8.5 to 21.4)
End-systolic volume (mL)	5; 159	55.6 ± 16.0	60.4 ± 15.4	$6.9 \pm 9.6 \ (-6.9 \text{ to } 18.5)$
Stroke volume (mL)	4; 61	89.4 ± 17.0	92.5 <u>+</u> 18.0	3.1 ± 9.3 (-9.6 to 12.1)

 Table 3
 Pooled means for left ventricular structure and function

changes in response to ET. In the present study, both males and females demonstrated a significant increase in LVM; however, the SMD was greater in males than females. This is in-fitting with other reports where LVM was shown to increase in both males and females.¹⁰² Additionally, a positive correlation was observed between the length of the study programme and change in LVM in males, but not in females. Few studies have explored cardiac adaptation over time between the sexes. One study investigated sex differences in cardiac structure every 3 months over 1 year of an intensive ET intervention.¹⁰³ They found that both sexes demonstrated an increase in LVM (scaled to fat-free mass); however, the females demonstrated the greatest increase in LVM within the first 3 months of a 12-month training programme, compared with the males where LVM progressively increased throughout the entire 12 months, with the greatest increase in the first 6 months.¹⁰³ Additionally, they found that with an increasing exercise stimulus, LVM was markedly augmented in males, whereas in females, it was attenuated. Analysis of PWTd, IVSd, and LVDd revealed that only PWTd and IVSd significantly increased in males, whereas LVDd was similarly augmented in both males and females. Previous research in athletes demonstrates that when females LVDd is indexed for BSA, they exhibit a higher cavity size. When involved in dynamic sports, females predominately exhibit eccentric LV hypertrophy, whereas a significant proportion of males in dynamic sports demonstrate concentric LV remodelling.¹⁰⁴ Some potential mechanisms contributing to these sex differences are that males have a higher circulating concentration of testosterone and a higher density of myocardial testosterone receptors.¹⁰⁵ Additionally, a higher exercise-related systolic blood pressure in males may play a role in the development of LV hypertrophy.¹⁰⁶

Training status

Early studies comparing athletes to inactive individuals demonstrated that exercise leads to increased wall thickness, LVM, and LV cavity size.^{4,7,107} In the present analysis, this was supported by an increase in all LV structural parameters in both the untrained and trained groups. However, the trained group had a greater increase compared with the untrained group, suggesting that prior training and/or cardiorespiratory fitness is an important factor in cardiac adaptation. It can be speculated that previously trained individuals would have less capacity to increase their LVM due to already having a well-adapted heart. Possible explanations for this could be that athletes train at a higher overall volume of exercise eliciting a greater response, have a superior genetic endowment, and have a greater capacity to push their bodies to their limits.¹⁰⁷ Another factor could be the use of prohibited substances: however, this was not reported in any of the studies. Our data support the suggestion that a greater number of training hours per week may stimulate enhanced cardiac adaption. Additionally, a higher baseline VO_{2max} was significantly correlated with greater changes in LVM, and the post-intervention VO_{2max} in the untrained group was less than that of the baseline VO_{2max} seen in the trained group. Thus, these findings may also represent

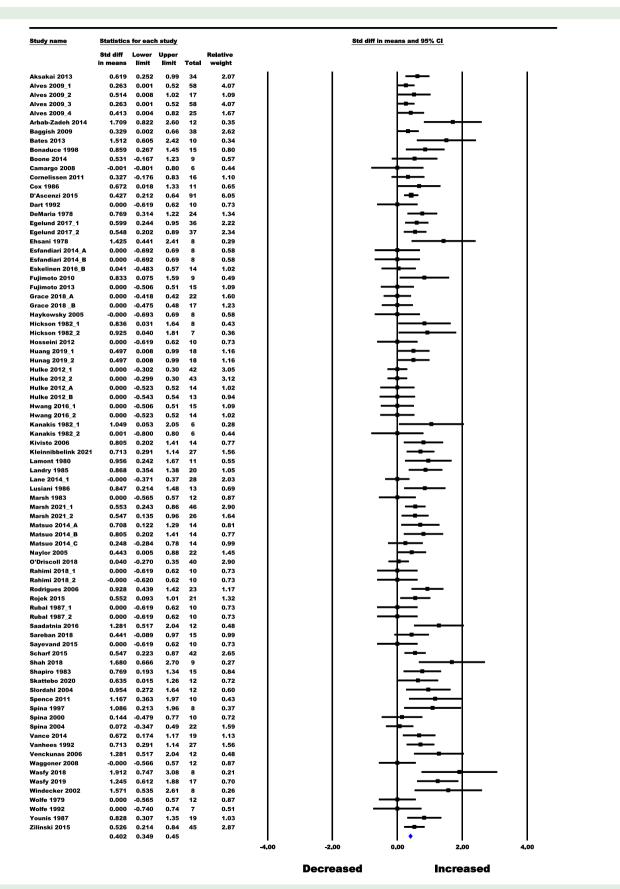


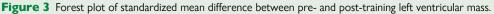
in part a genetic component driving the enhanced adaptions seen in trained individuals.

Type of training

The type of training programme may influence the magnitude of cardiac remodelling. Previous research suggests that interval training involving shorter intervals and rest periods primarily improves the oxidative capacity of peripheral muscles, whereas continuous and aerobic interval training involving longer intervals targets central adaptations such as cardiac function.^{65,108} Previous studies have shown continuous and aerobic interval training is characterized by both an increase in LVDd and LV wall thickness, and consequently LVM.^{10,65} Increases in LVM have been

observed in short/sprint interval training and can occur with submaximal heart rates to allow optimal CA²⁺ cycling,¹⁰⁸ increased training volumes, high baseline cardiorespiratory fitness, and longer duration programmes (i.e. >3 months).^{56,65,82} In the present meta-analysis, mixed-type training elicited the greatest increase in LVM, PVVTd, and LVDd, compared with interval- and continuous-type training. It is possible that changes in these structural parameters were not seen in interval-type training as they are often shorter duration as a time-efficient method to improve VO_{2max}, and, therefore, the length of study and training volume were not sufficient to induce these cardiac structural changes. Additionally, the present analysis did not report sprint and aerobic interval training separately; therefore, we were not able to determine cardiac structural changes specific to these two interval training types.





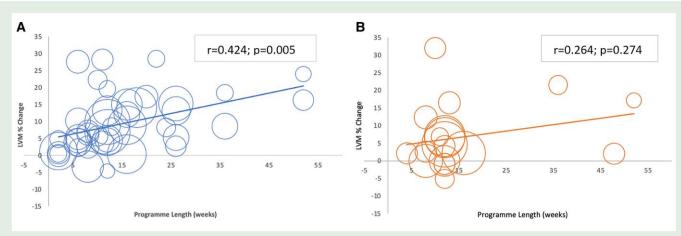
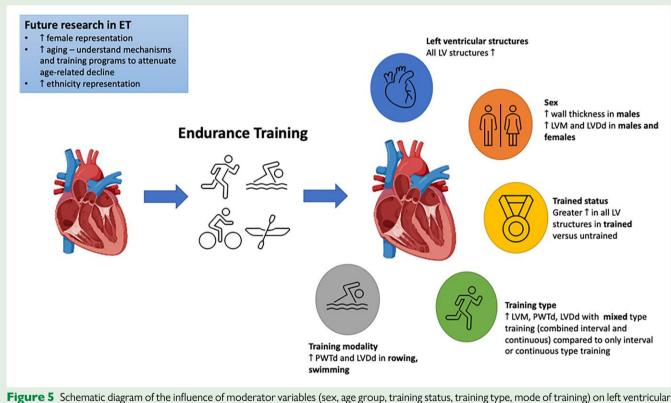


Figure 4 Dose–response association between the length of training programme and left ventricular mass in (A) males and (B) females.



Mode of training

Left ventricular structural changes are influenced by the degree of static and dynamic components involved in the sport modality.¹⁰⁹ We found all modes of exercise increased LVM; however, the mode of exercise influenced the adaptation of PWTd and LVDd with swimming and rowing eliciting the greatest increase and cycling conferring the smallest change. Modalities that combine both dynamic and static components (i.e. rowing) require increases in cardiac output, heart rate, SV, systolic blood pressure, and mean arterial pressure, thereby generating the greatest changes in cavity dimensions and LV wall thickness.¹⁰⁹ Conversely, studies that are predominately dynamic (i.e. running) have lower afterload, and therefore will observe smaller LV structural changes.¹⁰⁹ Although there were only three studies that included swimming as the training stimulus, all elicited a significant increase in LVM, PWTd, and LVDd.^{42,58,91} Swimming is a unique sport, due to the physiological response of being immersed in water, and less gravitational forces being exerted on the swimmer.¹¹⁰ The horizontal position of swimming aids venous return, which is increased with the kicking of the legs. There is a concomitant increase in preload, increasing SV, and cardiac output which can generate an increase in both wall thickness and

LVDd.¹¹⁰ In studies that have compared swimming to other sporting disciplines, the results are unequivocal;^{4,111-116} however, when age and BSA are accounted for, swimming is associated with greater cardiac dimensions.^{115,116} Although there is a small sample size of swimmers in this analysis, the present findings confirm previous reports. Interestingly, cycling elicited the smallest changes across LV structures, which does not conform to previous literature where cyclists have been shown to elicit the greatest increases in LVM compared with other sport types.^{10,116–118} In the present analysis the majority (93%) of the studies utilising cycling as their training modality were in previously sedentary individuals, therefore, the disparity seen in this study compared to other studies that investigated the impact of cycling on LVM is likely due to the other studies including elite male and female cyclists.^{116,117} The stimulus in the cycling studies included in the present analysis was likely not intense or long enough to elicit large increases in LVM compared with that observed in previous studies.

Limitations

The present analysis has some limitations. First, it is important to note that these results pertain to healthy populations, and may not translate to clinical populations. Secondly, the impact of ethnicity could not be determined as only four studies reported ethnicity. Thirdly, while we compared the impact of ET in males and females from individual studies, there were very few within-study sex comparisons. Our overall female sample size was much smaller than that of males, and the Egger's test for publication bias was significant in males, warranting further studies exploring sex differences. Fourthly, a possible confounding factor seen in the trained group was that several of these studies reported strength training as part of their training programme for their specific sports which may have impacted LV structural parameters seen in this group. We are unable to isolate the impact of this additional strength training on cardiac adaptations within an ET intervention;, however, a previous meta-analysis of cross-sectional studies reported no significant difference in LV structural parameters between athletes that are combined endurance-trained and strength-trained compared with those that are only endurance-trained.¹⁰ Fifthly, we found cycling interventions elicited the smallest change in LVM, contrary to previous cross-sectional studies where cyclists demonstrated greater LVM compared with other sports. This observation may be due to most cycling studies included in this meta-analysis were conducted with untrained participants, therefore may not represent the competitive cyclist response to an ET. Sixthly, swimming elicited the greatest increase in LVM; however there were only three studies and a very small sample size within each one; therefore, these results need to be interpreted with caution and confirmed in additional studies. Lastly, there was inconsistent reporting between studies with respect to whether they indexed for BSA, fat-free mass, or allometric scaling; therefore, we could not determine how the LV adaptations would be altered when indexed following changes in body mass or composition.

Conclusion

From this review, we confirm our hypothesis that LV structure is significantly increased following ET. Males, younger, trained individuals and ET interventions involving mixed training regimes elicit the greatest changes in LVM and other LV structural variables. Understanding these mediating factors during ET is important in developing effective training programmes and can help delineate between physiological adaptations to ET and potential pathology.

Authors' contributions

B.N.M. contributed to the design, screening, data extraction, and analysis, and wrote this review. K.G. contributed to design, data analysis,

Supplementary material

Supplementary material is available at European Journal of Preventive Cardiology.

Acknowledgements

We would like to thank Natalie Szakun and Andrew Roberts for their assistance with the article screening process.

Funding

A.T.C. was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC, Discovery Grant 2018-06848) and the Canada Research Chairs Program (CRC) Program (950-231915). B.N.M. was supported through A.T.C.s CRC program.

Conflict of interest: None declared.

Data availability

The data sets generated from the review are available from the corresponding author upon reasonable requests.

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