Received: 22 November 2023 | Revised: 10 April 2024 | Accepted: 23 June 2024

DOI: 10.1002/ejsc.12163

REVIEW

EJSS Official ECSS Journal Open Access WILEY

10-20-30 exercise training improves fitness and health

Jens Bangsbo

The August Krogh Section for Human Physiology, Department of Nutrition, Exercise and Sports, University of Copenhagen, Copenhagen, Denmark

Correspondence
Jens Bangsbo, The August Krogh Section for Human Physiology, Department of Nutrition, Exercise and Sports, University of Copenhagen, Universitetsparken 13, Copenhagen DK-2100, Denmark.
Email: jbangsbo@nexs.ku.dk

Abstract

Intense interval exercise training has been shown to improve performance and health of untrained and trained people. However, due to the exercise intensity causing high-perceived exertion, the participants often do not wish to continue the training. The 10-20-30 training concept consists of low intensity for 30 s, 20 s at a moderate pace, and then 10 s with high intensity either running or cycling. A 10-20-30 training session consist of two to four 5-min blocks. The 10-20-30 training improved fitness and performance as well as lowered blood pressure and body fat of both untrained and trained individuals even with a significant reduction in the training volume. Similarly, hypertensive, diabetic, and asthmatic patients lowered body fat, improved fitness, and performance during a 10-20-30-training intervention period. In addition, hypertensive patients reduced systolic and diastolic blood pressure markedly with the 10-20-30 training twice a week for 8 weeks. Diabetic patients lowered long-term blood sugar (HbA_{1c}), which did not occur with moderate-intensity exercise training. Furthermore, asthmatic patients improved their control of asthma and asthma-related quality of life with the 10-20-30 training. The adherence for the patient groups was high (>80%), and no adverse events were reported. Thus, the 10-20-30 training seems to be time efficient and feasible for untrained and trained individuals as well as patients and may be used in the prevention and treatment of noncommunicable diseases.

KEYWORDS
asthma, blood pressure, diabetes, high intensity training, hypertension

Highlights

What is already known?

- Aerobic moderate-intensity exercise training has been shown to improve fitness and health of untrained individuals.
- Intense exercise training has been shown to benefit some patient groups, but many patients are struggling with the training due to the strenuous effort experienced during training.
- Untrained individuals and patients have difficulties to find time and motivation to do physical activities.

What are the findings?

- The 10-20-30 training is a new training modality, which has greater benefits than aerobic moderate-intensity training, and is a more time-efficient way to improve performance and health even in trained people.
- The 10-20-30 training reduces blood pressure and body fat in untrained and already trained people even with lowered training volume.
- The 10-20-30 training is feasible for hypertensive, diabetic, and asthmatic patients, who with the 10-20-30 training are reducing blood pressure, improve long-term blood sugar management, and lower symptoms of asthma, respectively.

1 | INTRODUCTION

There are many types of interval trainings with the exercise intensity ranging from low to maximal with exercise and rest periods of various durations. It may be the aerobic high-intensity training, which mainly targets the aerobic system, for example, 4-min intervals at an intensity close to that eliciting maximum oxygen uptake separated by 1-min rest periods (Helgerud et al., 2007; Weston et al., 2014) or speed endurance training, which primarily stimulates the anaerobic systems, for example, exercise periods of a duration of 30 s with almost maximal intensity separated by rest periods of a duration of 3 min (Bangsbo, 2015; Bangsbo et al., 2009; Esfarjani & Laursen, 2007; Iaia et al., 2008). Both training modalities have been shown to improve maximum oxygen uptake and performance of already trained individuals and athletes (Hostrup & Bangsbo, 2017; Hostrup et al., 2021). High-intensity training has also been shown to be effective for patients with cardiometabolic diseases (Weston et al., 2014). However, the training requires a high perceived effort, which sometimes restricts people from completing the training.

Interval training can also be carried out with changes in the intensity during the work periods with both the aerobic and anaerobic systems being highly stimulated. One such interval form is the so-called *fartlek*, where the participants change running speed in an irregular way. For example, one study examined the effect of varying the intensity continuously for total durations of 1 min 10 s, 2 min 30 s, 4 min, and 6 min, and this training was superior to other interval training forms (Nupp, 1970). Some 10 years ago, the 10-20-30 training method was developed, where exercise intensity (i.e., running speed or loading/pedaling frequency on a bike) is changed in a systematic manner (Gunnarsson & Bangsbo, 2012). It is performed as low intensity for 30 s, followed by 20 s at a moderate pace, and then 10 s with high intensity. It is repeated five times and such 5-min periods (blocks) are conducted 2–4 times, separated by a 1–4-min rest period. Since the original study (Gunnarsson & Bangsbo, 2012), a significant number of studies have been conducted investigating the effect of the 10-20-30 training on performance and health using both running and cycling exercise interventions. Various groups have been investigated, such as patients, untrained individuals, trained individuals, and athletes, where the 10-20-30 training for the two latter groups represented intensified training, and in most cases, the training volume was reduced.

This narrative review covers the effect of the 10-20-30 training on performance and health for untrained and trained individuals as well as patient groups such as hypertensive, diabetic, and asthmatic patients. It should be emphasized that there is a limited number of studies for each category, and further studies are needed to confirm the conclusions.

2 | METHOD

The aim of this narrative review is to provide a focused overview of the existing knowledge on the effect of the 10-20-30 training on untrained, trained, and patient groups. Four online databases (PubMed, Web of Science, Google Scholar, and MEDLINE) were used to find peer-reviewed research published up until March 2024. Searches only included studies published in English.

2.1 | Characteristics of the 10-20-30 training

When conducting the 10-20-30 training as running the participants jog for 30 s, run at their normal speed (speed they can maintain during a long run) for 20 s, and then sprint for 10 s. Figure 1 shows an example of the running velocity and heart rate (HR) for a recreational runner during a 10-20-30-training session consisting of three 5-min periods. HR for the runner was higher than 90% of maximal HR after a couple of minutes in each of the 5-min blocks. Generally, mean and peak HR during the 10-20-30 training has been observed to be 85% and 96% of maximal HR, respectively, with the time spent over 90% of maximal HR being 11 min for three 5-min blocks, which did not occur when the runners were doing their typical training (Gunnarsson & Bangsbo, 2012). When doing the 10-20-30 training on a cycle ergometer the participant's cycle at a low load frequency of 60–80 revolutions per min for 30 s, the load is then increased and the frequency is maintained for 20 s, followed by the maximal frequency maintaining the external load for 10 s, which is then reduced immediately after the 10 s. In all studies (except in one study–please see below), the running velocity or cycle intensity in the 10-s exercise periods was self-selected, but the subjects were guided to put maximal effort into these periods.

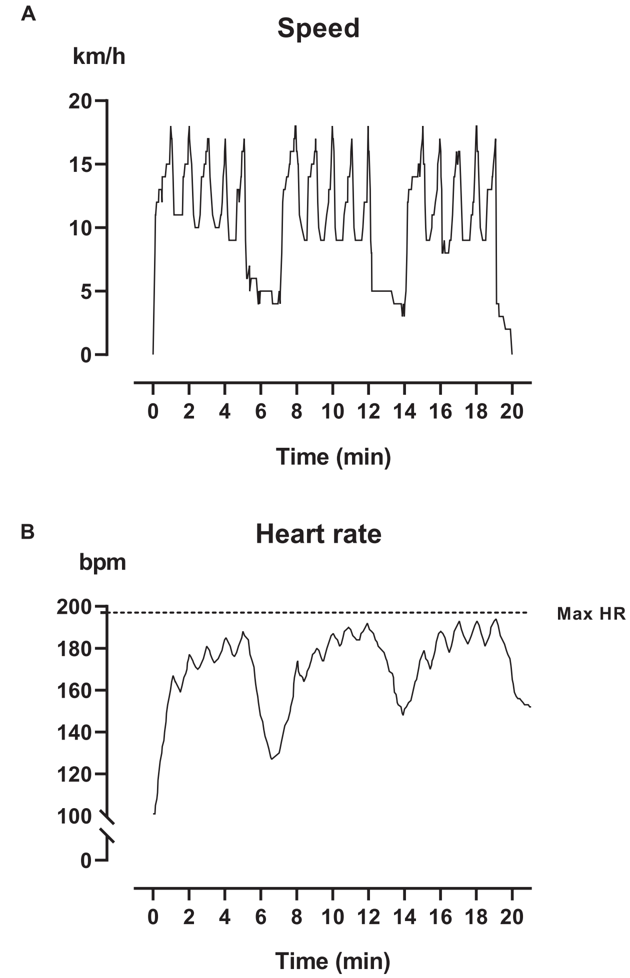

FIGURE 1 Running speed and heart rate for a runner during a 10-20-30-training session.

3 | MAXIMUM OXYGEN UPTAKE AND PERFORMANCE

The original 10-20-30 training study included 12 male and 6 female recreational runners aged between 22 and 44 years with more than two years of running experience (Table 1) (Gunnarsson & Bangsbo, 2012). Before the study, the runners were training 2–4 times a week with a total distance of approximately 30 km at a running speed of about 11.5 km/h. For seven weeks, the participants completed the 10-20-30 training 3 times per week consisting of three 5-min blocks for the first 4 weeks and four 5-min bouts the last 3 weeks. The total volume was 13 km in the first weeks and 16 km in the following weeks, that is, a reduction in training volume of 57% and 47%, respectively. $\dot{V}O_{2max}$ was 4% higher after the 10-20-30 training period (Figure 2A). In addition, 1500-m and 5000-m run time improved by 23 and 49 s, respectively (Figure 2B). A control group continuing the normal training had no change in $\dot{V}O_{2max}$ and performance. In another study, recreational male and female runners with an average age of 33 years conducted three to four 5-min blocks of 10-20-30 training for eight weeks with a reduction in total distance from 15 to 11 km per week (Faelli et al., 2019). They increased $\dot{V}O_{2max}$ (10%) and improved performance in a 1000-m run with the 10-20-30 training intervention (Figure 2). Furthermore, 160 recreational runners with a mean age of 49 years doing the 10-20–30 training (3-4 5-min blocks) twice and one prolonged run a week for 8 weeks increased performance in a 5-km run by 38 s and $\dot{V}O_{2max}$, measured in a subgroup of participants was 3% higher (Gliemann et al., 2015). No changes were observed in a control group.

In a study, two groups of runners performed the 10-20-30 training for 6 weeks with one group only doing 80% of maximal effort during the 10-s intervals and the other group with maximal effort. Both groups improved $\dot{V}O_{2max}$ (6.4% and 7.5%, respectively) and 5-km performance (3.0% and 2.3%) to a similar extent (Skovgaard et al., 2024). This suggests that the improvements associated with the 10-20-30 training can be achieved even when not performing maximally in the 10-s intervals. However, it is important to note that, only the group performing the 10-20-30 training with maximal effort had an increase in muscle oxidative enzymes.

Improvements in $\dot{V}O_{2max}$ and performance have also been observed when the 10-20-30 training was conducted using cycling (Gunnarsson, Ehlers, Fiorenza, et al., 2020). Thus, a group of untrained men, with a mean age of 59 years, doing the 10-20-30 cycle training (2–3 5-min blocks) twice a week for six weeks had an 8% increase in $\dot{V}O_{2max}$ (37.0 vs. 34.3 ml·kg^{-1}·min^{-1}) and 17% increase in performance measured as time to exhaustion during an incremental cycle test.

3.1 | Comparison of 10-20-30 training with other types of intense interval training

The effect of 10-20-30 training has been compared to other types of interval training. In a study by Faelli and colleagues, recreational runners conducted either the 10-20-30 training (3–4 5-min blocks) twice a week or the 30–30 training consisting of 30 s at a running speed corresponding to 90%–100% of maximal aerobic speed followed by 30 s at a low speed for 20–30 min (Faelli et al., 2019). The weekly training volume was significant lower in the 10-20-30 training group compared to the 30–30 training group (11.6 vs. 15.1 km), with the 10-20-30 training group having lower subjective perception of effort. The groups improved 1-km run performance and $\dot{V}O_{2max}$ to a similar extent.

For a group of soccer players, the 10-20-30 training was compared with speed training consisting of 6 s maximal effort followed by 54 s of rest during the season, with a 20% decrease in training volume in both groups (Hostrup et al., 2019). The 10-20-30 training group improved (18%) repeated high-speed running performance measured determined by conducting the Yo-Yo intermittent recovery test level 1 (Bangsbo et al., 2009), whereas the speed

TABLE 1 Subjects characteristics and effect of the 10-20-30 training in studies with healthy untrained and trained (A) and patient (B) groups.

	Subject characteristics						Intervention	
Study	Activity level	Age (years)	Gender (M/F)	Body composition	Training intervention	Measurements	Pre	Post
A. Untrained and trained								
Faelli et al., 2019#	Recreational Runners	32.5 ± 3.1	M, $n = 11$	BMI (kg/m^2): 23.2 ± 0.9	**8 weeks** Wk 1–5: 3 × 5 min of 10-20-30 2 min rest 2/wk Wk 6–8: 4 × 5 min of 10-20-30 2 min rest 2/wk Wk 1–8: Continuous running for 40 min at 60% MAS - 1/wk	VO_{2max} (ml/kg/min) Body mass (kg) Lean mass (kg) Fat mass (%)	43.0 ± 2.9 69.8 ± 2.8 55.3 ± 2.5 17.7 ± 2.9	44.5 ± 1.2* 69.7 ± 2.8 58.0 ± 2.3** 13.4 ± 2.6***
Gliemann et al., 2015#	Recreational Runners	49.0 ± 1.0 45.0 ± 2.0	M, $n = 58$ F, $n = 74$ M, $n = 11$ F, $n = 2$	Body mass (kg): 73.7 ± 1.1 BMI (kg/m^2): 24.7 ± 1.0	**8 weeks** 3–4 × 5 min of 10-20-30 2 min rest 2/wk Continuous running at 75%–85% of HRmax–1/wk	VO_{2max} (ml/kg/min) 5-km (min:s) Systolic BP (mmHg) Diastolic BP (mmHg) Resting HR (bpm)	52.1 ± 1.7 21:23 ± 00:48 132.3 ± 1.3 81.0 ± 0.8 58.1 ± 0.8	53.5 ± 1.8* 21:15 ± 00:47 130.5 ± 1.4* 80.0 ± 0.9 59.0 ± 0.8
Gunnarsson and Bangsbo, 2012#	Moderately Trained	33.8 ± 1.6	M, $n = 7$ F, $n = 3$	Body mass (kg): 75.2 ± 3.5 Height (cm): 178.8 ± 2.1	**7 weeks** Wk 1–4: 3 × 5 min of 10-20-30 2 min rest 3/wk Wk 5–7: 4 × 5 min of 10-20-30 2 min rest 3/wk	VO_{2max} (ml/kg/min) 1500-m (min) 5-km (min) Systolic BP (mmHg) Diastolic BP (mmHg) Resting HR (bpm)	51.6 ± 1.9 6.2 ± 0.3 23.1 ± 1.1 127 ± 4 75 ± 3 53 ± 3	53.8 ± 2.3* 5.8 ± 0.2* 22.3 ± 0.9* 122 ± 3* 76 ± 3 55 ± 3
Gunnarsson et al., 2020	Sedentary	57.9 ± 10	M, $n = 12$	BMI (kg/m^2): 23.5 ± 1.8	**6 weeks** Wk 1–2: 2 × 5 min of 10-20-30 3 min rest 3/wk Wk 3–6: 3 × 5 min of 10-20-30 3 min rest 3/wk	VO_{2max} (ml/kg/min) Body mass (kg) Fat mass (%) BMD (g/cm^2) Systolic BP (mmHg) Diastolic BP (mmHg)	34.3 ± 3.3 86.9 ± 12.7 33.1 ± 4.0 1.3 ± 0.1 128 ± 9 78 ± 7	37.0 ± 4.3* 85.6 ± 12.6* 31.7 ± 4.2* 1.3 ± 0.1 119 ± 14* 78 ± 7

(Continues)

TABLE 1 (Continued)

Study	Subject characteristics: Activity level	Age (years)	Gender (M/F)	Body composition	Training intervention	Measurements	Intervention: Pre	Post
Hostrup et al., 2019	Football players	22.8 ± 2.2	M, $n = 12$	BMI (kg/m^2): 23.5 ± 1.8	**10 weeks** Wk 1–4: 2 × 5 min of 10-20-30 4 min rest 3/wk Wk 5-10: 3 × 5 min of 10-20-30 4 min rest 3/wk	YYIR1 (m) 30-M sprint (s) T-test sprint (s)	1853 ± 362 4.3 ± 0.1 9.3 ± 0.2	2183 ± 401** 4.3 ± 0.1 9.3 ± 0.1
B. Patients								
Baasch-Skytte et al., 2020	Sedentary Type 2 diabetes	61.0 ± 6.2	M, $n = 23$	BMI (kg/m^2): 30.6 ± 5.4	**10 weeks** 3 × 5 min of 10-20-30 2 min rest 3/wk	VO_{2max} (ml/kg/min) Body mass (kg) Fat mass (%) HbA1c (%)	26.9 ± 2.2 101.9 ± 22.8 33.2 ± 6.8 7.5 ± 1.6	28.7 ± 1.4** 101.0 ± 22.6 32.0 ± 0.5*** 7.0 ± 0.3***
Ehlers et al., 2020	Sedentary Essential hypertension	62.1 ± 6.9	M, $n = 14$	BMI (kg/m^2): 28.0 ± 3.1	**6 weeks** Wk 1–2: 2 × 5 min of 10-20-30 3 min rest 2/wk Wk 3–6: 3 × 5 min of 10-20-30 3 min rest 2/wk	VO_{2max} (ml/min) Body mass (kg) Systolic BP (mmHg) Diastolic BP (mmHg) Resting HR (bpm)	2860 ± 485 85.5 ± 7.7 136 ± 12 83 ± 8 61.0 ± 9.1	2871 ± 490 84.1 ± 7.9* 135 ± 12 79 ± 6.3* 59.3 ± 11.2
Gliemann et al., 2015#	Recreational runners Essential hypertension	47 ± 2.0	M, $n = 14$ F, $n = 16$	Body mass (kg): 75.5 ± 2.4	**8 weeks** 3–4 x 5 min of 10-20-30 2 min rest 2/wk Continuous running at 75%–85% of HRmax - 1/wk	Body mass (kg) Systolic BP (mmHg) Diastolic BP (mmHg) Resting HR (bpm)	75.5 ± 2.4 151.6 ± 2.6 91.7 ± 1.8 63.5 ± 1.9	74.5 ± 2.5* 147.0 ± 2.8* 88.8 ± 2.2* 62.7 ± 1.8
Gunnarsson et al., 2020	Sedentary Essential hypertension	59.5 ± 9.7	M, $n = 10$	BMI (kg/m^2): 29.2 ± 4.0	**6 weeks** Wk 1–2: 2 × 5 min of 10-20-30 3 min rest 3/wk Wk 3–6:	VO_{2max} (ml/kg/min) Body mass (kg) Fat mass (%) BMD (g/cm2) Systolic BP (mmHg) Diastolic BP (mmHg)	32.9 ± 4.9 91.7 ± 11.5 33.1 ± 3.6 1.4 ± 0.1 153 ± 11 86 ± 10	33.9 ± 5.5* 91.2 ± 12.2 31.4 ± 4.4* 1.4 ± 0.1 142 ± 10 81 ± 9

TABLE 1 (Continued)

Study	Subject characteristics: Activity level	Age (years)	Gender (M/F)	Body composition	Training intervention	Measurements	Intervention: Pre	Post
					3 × 5 min of 10-20-30			
					3 min rest			
					3/wk			
Toennesen et al.,	Untrained	39.4 ± 12.5	M, $n = 16$	BMI (kg/m^2):	**8 weeks**	**Exercise**		
2018	Asthma patients		F, $n = 13$	24.9 ± 2.5	Wk 1–2:	VO_{2max} (ml/kg/min)	38.4 ± 8.9	(+3.1 ± 3.6**)
					2 × 5 min of 10-20-30	Body mass (kg)	76.4 ± 9.8	(−1.1 ± 2.2**)
					2 min rest	Fat mass (%)	22.3 ± 6.9	(−1.4 ± 2.0**)
					3/wk	ACQ (score)	1.7 ± 0.6	1.0 ± 0.8**
					Wk 3–5:	AQLQ (score)	5.7 ± 0.6	6.2 ± 0.5**
					3 × 5 min of 10-20-30	FEV1 (%pred)	84.9 ± 12.6	84.5 ± 13.1
					2 min rest	FVC (%pred)	93.1 ± 10.4	94.0 ± 10.3
					3/wk			
		43.7 ± 13.9	M, $n = 7$	BMI (kg/m^2):	Wk 6–8:	**Exercise + diet**		
			F, $n = 23$	26.1 ± 2.5	4 × 5 min of 10-20-30	VO_{2max} (ml/kg/min)	31.5 ± 6.2	(+5.3 ± 2.5**)
					2 min rest	Body mass (kg)	75.8 ± 10.5	(−3.1 ± 2.2**)
					3/wk	Fat mass (%)	27.6 ± 6.0	(−3.9 ± 1.7**)
						ACQ (score)	1.9 ± 0.7	1.0 ± 0.7***
						AQLQ (score)	5.2 ± 0.8	6.2 ± 0.7***
						FEV1 (%pred)	82.6 ± 15.2	84.5 ± 16.2
						FVC (%pred)	94.3 ± 15.3	96.8 ± 14.0***

Note: Means ± SD are given, except for “#” which are means ± SE. ( ): Change with intervention.

Abbreviations: M, Male; F, Female; MAS, maximal aerobic speed; HR, heart rate; HRmax, maximum heart rate; BP, blood pressure; YYIR-1, YoYo intermittent recovery test 1; BMD, bone mineral density; ACQ, Asthma Control Questionnaire; AQLQ, Asthma-Related Quality-of-Life Questionnaire; FEV1, forced expiratory volume; and FVC, forced vital capacity.

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$ different from baseline.

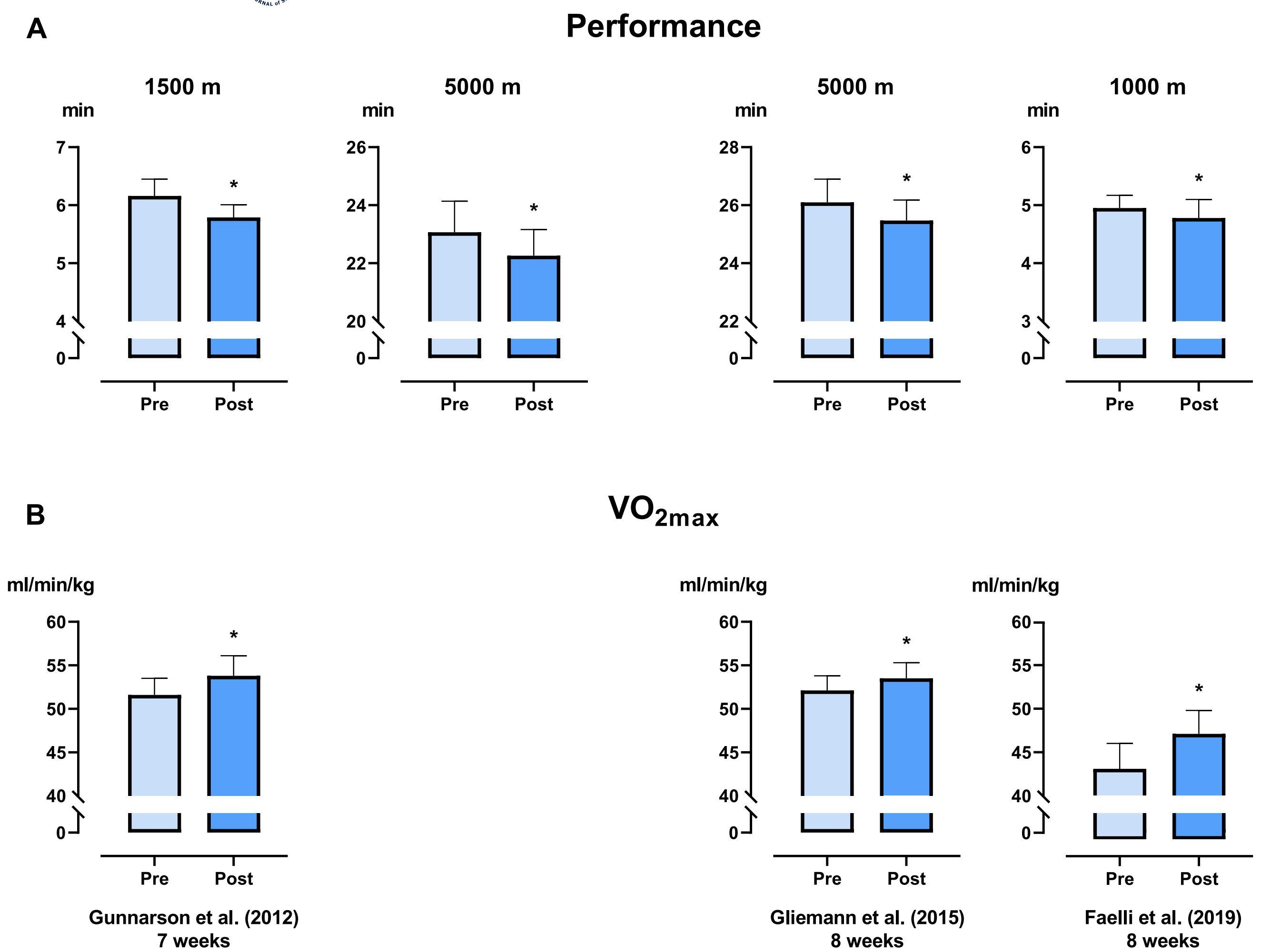

FIGURE 2 $VO_{2\text{-max}}$ (A) and performance (B) in groups of recreational runners, before (pre, light blue bars), and after (post, dark blue bars) a period of the 10-20-30 training. Data from Gunnarsson and Bangsbo (2012), Faelli et al. (2019), and Gliemann et al. (2015). Data are presented as mean ± SD. *Post different ($p < 0.05$) from Pre.

training group had no improvement, but increased sprint performance by 0.5%. Only the 10-20-30 training group had higher abundance of muscle Na^+,K^+-ATPase subunits α_2 and β after compared to before the intervention. Such changes are commonly found in studies of speed endurance training, where the exercise time with maximal effort is significant longer (>20 s), and the changes have been associated with improved K^+ handling during and in recovery from intense exercise as well as enhanced performance (Bangsbo et al., 2009; Gunnarsson et al., 2013; Hostrup & Bangsbo, 2017; Hostrup et al., 2021; Iaia et al., 2008; Mohr et al., 2007).

The 10-20-30 training also increased muscle content of oxidative enzymes, such as pyruvate dehydrogenase (PDH)-E1α and the fatty acid beta-oxidation enzyme, hydroxyacyl-CoA dehydrogenase trifunctional multienzyme complex subunit alpha (HADHA), as well as the content of mitochondrial electron transport chain (ETC) complexes, with the 10-20-30 training being superior to the speed training in upregulating content of PDH-E1α and HADHA. Similarly, a group of trained people doing six 30-s sprints during 60 min of moderate-intensity cycling performed three times a week for 8 weeks had superior improvement in muscle cytochrome C oxidase IV and citrate synthase (CS) compared to a group doing only moderate-intensity cycling (Gunnarsson et al., 2019). On the other hand, when well-trained did speed endurance training, that is, intense exercise periods lasting 20–40 s separated by 2–3-min rest periods, no increases in muscle oxidative enzymes were observed (Christensen et al., 2015; Gunnarsson et al., 2013). Thus, it may be that the high aerobic component in the 10-20-30 training, reflected by the high heart rates, compared to speed endurance training, has caused the adaptations in the muscle oxidative enzymes.

4 | BLOOD PRESSURE AND BODY COMPOSITION

The recreational runners in the original study had a reduction in systolic blood pressure from 127 to 122 mmHg measured at rest during the 7-week 10-20-30-training period, with no change in diastolic blood pressure (Table 1) (Gunnarsson & Bangsbo, 2012). Similarly, when 160 recreational runners did the 10-20-30 training for 8 weeks, systolic blood pressure was significantly lowered from 132 to 130 mmHg (Gliemann et al., 2015).

The 10-20-30 training can also lead to changes in body composition. Thus, when a group of recreational runners performed the 10-20-30 training twice per week in conjunction with one prolonged run per week for 8 weeks, with a reduction in training volume per week from about 15 to 12 km, body fat mass was reduced by 3.0 kg (Table 1) (Faelli et al., 2019). In addition, lean body mass increased by 2.7 kg. Similarly, a group of middle-aged not previously trained men lost 1.6 kg of fat with 6 weeks of the 10-20-30 cycle training with a non-significant gain in lean body mass of 0.2 kg (Gunnarsson, Ehlers, Fiorenza, et al., 2020) (Table 1).

5 | EFFECT OF THE 10-20-30 TRAINING IN HYPERTENSIVE INDIVIDUALS

Hypertension is associated with impairments in cardiovascular structure and function and is a well-established risk factor for developing cardiovascular diseases (Lopes et al., 2021; Williams et al., 2018). More than 30% of the adult population worldwide has hypertension and has been attributed as one of the main causes of cardiovascular diseases (Forouzanfar et al., 2017; Williams et al., 2018). Notably, regular physical activity can lower blood pressure and decrease the risk of health complications (Alpsoy, 2020; Lopes et al., 2021).

In the study by Gliemann et al., 2015, 30 of the 160 recreational runners were hypertensive, and they significantly lowered systolic blood pressure from 152 to 147 mmHg and diastolic blood pressure from 92 to 89 mmHg after the 8 weeks with the 10-20-30 training (Gliemann et al., 2015).

In another study, individuals aged 55–65 years with hypertension and age-matched normotensive controls carried out six weeks of the 10-20-30 training on cycle ergometers (Gunnarsson, Ehlers, Fiorenza, et al., 2020). For the first two weeks, two 5-min bouts per training session twice a week and the following four weeks three 5-min bouts per training session three times a week. The participants completed 98% of the training sessions. HR during the training sessions was similar in the two groups with about 60% of the time spent between 80% and 90% of maximum HR and 13% above 90% of maximum HR.

In the hypertensive group, systolic and diastolic blood pressure decreased by 9 and 5 mmHg, respectively, with the 10-20-30 training intervention, and the normotensive group had a decrease in systolic and diastolic blood pressure (5 and 3 mmHg, respectively).

The cause of the lowered blood pressure with the 10-20-30 training may be modulation in the activity of the autonomic nervous system, neurohumoral adaptations, as well as a reduction in systemic vascular resistance (Cornelissen & Fagard, 2005; Pedersen & Saltin, 2006). Thus, it was shown that six weeks of the 10-20-30 training lowered resting muscle sympathetic nerve activity in both a hypertensive and a normotensive group (Ehlers et al., 2020). In addition, the response to infusion of the endothelium-independent vasodilators sodium nitroprusside (SNP) on leg vascular conductance was normalized with training in the hypertensive subjects, demonstrating that six weeks of the 10-20-30 training reversed the blunted smooth muscle cell vasodilator responsiveness associated with essential hypertension. Thus, it is likely that the improved smooth muscle cell vasodilator responsiveness contributed to the reduction in blood pressure. Specifically, improvements in the nitric oxide and prostaglandin systems have been related to reduced blood pressure in subjects with essential hypertension after a period of the high-intensity cycle ergometer training (Hellsten et al., 2012; Nyberg et al., 2012). In support, a group of hypertensive post-menopausal women reversed a blunted nitric oxide response after playing floorball twice a week for 10 weeks (Gunnarsson, Ehlers, Baasch-Skytte, et al., 2020). Changes in arteriolar vessels may also have caused the lowering of the blood pressure after the 10-20-30 training period, as it has been observed that arteriolar stiffness decreases with high-intensity exercise training (Cocks et al., 2013).

Performance during an incremental cycle test increased by 7% and 12% with the 10-20-30 training in the hypertensive group and the normotensive group, respectively. Similarly, $\dot{V}O_{2max}$ improved by 3% and 8%, respectively.

Fat mass decreased with the six weeks of the 10-20-30 training from 29.5 to 27.9 kg in the hypertensive group and from 27.7 to 26.1 kg in the normotensive group. Similarly, fat percentage decreased from 33.1% to 31.4% and 33.1% to 31.7%, respectively. In addition, visceral fat was significantly lowered in both groups (0.2 and 0.1 kg, respectively), whereas fat free mass increased only in the hypertensive group (59.1 to 60.1 kg).

Taken together, the 10-20-30 training has positive effects on blood pressure, fitness, and body composition of individuals with hypertension. The lowering in blood pressure in these studies is of clinical relevance, as a decrease of 10 mmHg in systolic blood pressure is associated with ~40% lower risk of stroke death and ~30% lower risk of death from ischemic heart disease (Lewington et al., 2002).

6 | EFFECT OF THE 10-20-30 TRAINING IN DIABETIC PATIENTS

Diabetes is one of the most common chronic diseases worldwide with more than 400 million diagnosed individuals, and it is estimated that more than 600 million individuals will have diabetes by 2045 (Ogurtsova et al., 2017). Most individuals have (~90%) type 2 diabetes (T2D), which is characterized by lowered insulin sensitivity and reduced glucose tolerance. It typically arises from a sedentary lifestyle, poor diet, and/or genetic susceptibility (Colberg et al., 2016; Stanford & Goodyear, 2014). Exercise is effective in improving glycemic control in persons with T2D and should be considered a cornerstone in the first line of treatment (Colberg et al., 2016).

The effect of the 10-20-30 training on T2D patients has been studied. The T2D patients in a randomized design conducted a 10-week cycle intervention program with either the 10-20-30 training or moderate-intensity training (Baasch-Skytte et al., 2020). The time when the patients were diagnosed with type 2 diabetes ranged from 6 months to 10 years. Both groups trained three times a week. The 10-20-30 training consisted of 3–4 blocks per session and the moderate-intensity training group performed 50 min continuous cycling per session, according to the official exercise recommendations for T2D patients. Thus, the total time of training per week was 45–60 and 150 min, respectively, with the mean HR being significant higher during the 10-20-30 training.

All the T2D patients in the study had blood HbA_{1c} values higher than 7% before the training intervention. After 10 weeks, the 10-20-30 training group had a ~0.5% point reduction in HbA_{1c}, whereas no change was observed in the group doing moderate-intensity training (Figure 3). In agreement, meta-analyses have shown that 10–26 weeks of moderate-intensity training did not lower HbA_{1c} in T2D patients (Kelley & Kelley, 2007; Mann et al., 2014). Furthermore, a review reported that only six out of 14 studies had positive changes in glycemic control after a period of high-intensity training (Wormgoor et al., 2017). The 10-20-30 training was equally effective in lowering HbA_{1c} compared to these six studies which all used longer and more intense exercise periods (Banitalebi et al., 2019; Madsen et al., 2015; Mitranun et al., 2014; Stoa et al., 2017).

Fat mass was reduced from 35.3 to 33.9 kg, with a corresponding decrease in fat percentage of 4% in the T2D patients conducting the 10-20-30 training with similar changes in the T2D group doing the moderate-intensity work (Baasch-Skytte et al., 2020). In addition, visceral fat mass was lowered, but only in the 10-20-30 training group. These changes are likely of clinical importance, as a reduction in total fat mass enhances insulin sensitivity (Buemann et al., 2005) and reduction in visceral fat mass is associated with a lowered risk of cardiovascular diseases (Bjorntorp, 1988; Raji et al., 2001).

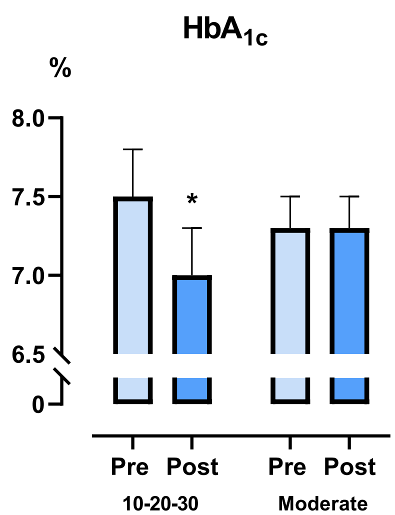

FIGURE 3 HbA_{1c} in male type 2 diabetic patients, before (pre, light blue bars) and after (post, dark blue bars) 10 weeks of either the 10-20-30 training (10-20-30), or moderate-intensity continuous training. Data from Baasch-Skytte et al. (2020). Data are presented as mean ± SD. *Post different ($p < 0.05$) from Pre.

Only the 10-20-30 training group had an increase in fat free mass (0.6 kg). It may in part explain the lower HbA1c, as the skeletal muscle is recognized as the primary site of insulin-mediated glucose disposal (DeFronzo et al., 1985). The plasma catecholamine concentrations were higher during the 10-20-30 training sessions compared to the moderate-intensity training, which may be one of the explanations for the lower visceral fat mass with the 10-20-30 training, as epinephrine has been shown to induce lipid mobilization post-exercise, albeit in subcutaneous adipose tissue (de Glisezinski et al., 2009).

Performance during an incremental test was 17% and 20% better after the intervention in the 10-20-30 and the moderate-intensity training T2D group, respectively (Baasch-Skytte et al., 2020). Similarly, $\dot{V}O_{2max}$ increased by 7% and 8%, respectively, which likely contributed to the improved exercise capacity.

Only the 10-20-30 training T2D group increased the expression of superoxide dismutase 2 (SOD2), suggesting a training-induced enhancement in mitochondrial antioxidant protection (Baasch-Skytte et al., 2021). The maximal activity of muscle CS was also elevated with the 10-20-30 training, which indicates that the training-induced increase in SOD2 may be due to higher mitochondrial content, as CS activity is a marker of mitochondrial content (Larsen et al., 2012). It is further supported by increases in muscle ETC complex II, III, IV, and V. These changes are critically important, as men with T2D have been reported to have lower oxidative enzyme activity (He et al., 2001), mitochondrial respiration (Phielix et al., 2010), and antioxiative defense (Pan et al., 2010; Ramakrishna & Jailkhani, 2008) than non-diabetes counterparts, suggesting a lower ATP production capacity in T2D patients.

Expression of muscle Na^+/K^+ $\alpha 1$ was higher after the 10-20-30 training intervention (Baasch-Skytte et al., 2021), which may in part explain the improved exercise performance in the T2D patients, as an association has been observed in other studies (Iaia et al., 2011). The training also elevated the content of muscle Kir6.2 channel and monocarboxylate transporter 1 (MCT1) (Baasch-Skytte et al., 2021). Notably, MCT1 is highly expressed in oxidative muscle fibers (Wilson et al., 1998), suggesting that the training intervention increased the H^+ handling proteins primarily in the oxidative muscle fibers, which may also have contributed to the better performance.

Taken together, the 10-20-30 training had a significant number of positive effects for T2D patients, such as improved $\dot{V}O_{2max}$ and performance as well as reduced fat mass, and in some essential aspects, such as elevated fat free mass, higher muscle oxidative enzymes, and abundance of ion transporters as well as lowered blood HbA_{1c}, superior to moderate-intensity training. Particularly, the ~0.5% point fall in HbA_{1c} with the 10-20-30 training intervention is of clinical relevance for T2D patients, as a reduction in HbA_{1c} by 1% point reduces the risk of microvascular complications and death by about 25% and 21%, respectively (Stratton et al., 2000). In addition, the diabetic patients are 19% and 43% less likely to suffer from cataracts and amputation, respectively, due to peripheral vascular disease.

7 | EFFECT OF THE 10-20-30 TRAINING IN ASTHMA PATIENTS

Asthma is a chronic respiratory condition characterized by airway inflammation and hyperactivity. Asthma prevalence is steadily rising. In 1980 in United States, 6.8 million people were living with asthma, and in 2010, the number was 25.7 million (Akinbami et al., 2012; Moorman et al., 2012). Exercise training and nutrition may have the potential to improve asthma control and lung function (Alwarith et al., 2020; Hansen et al., 2020).

The effect of the 10-20-30 training on asthma patients has been explored. Thus, in a study, female and male asthma patients, aged 18–65 years, participated in an 8-week intervention period divided into a training group, a diet group, a training and diet group, and a control group which maintained usual physical activity levels and diet (Table 1) (Toennesen, Meteran, et al., 2018). The training groups conducted the 10-20-30 training indoors on cycle ergometers 3 times a week. The participants completed two 5-min intervals the first two weeks, three 5-min intervals the next three weeks, and four 5-min intervals the last three weeks. Patients took two puffs of their regular short acting beta-2 agonist 10–15 min prior to the training and during the training sessions, if necessary to prevent bronchoconstriction. The patients were able to maintain the high intensity during the training sessions without getting asthma symptoms, which could not be relieved with 1–2 puffs of beta-2 agonist or a short pause (1–2 min) from training. The time spent between 90% and 100% of maximum HR during training increased from 6 min during the first 2 weeks to 11 min during the last 3 weeks. The training groups completed 90% of the training sessions. The patients in the two diet groups prepared their own food with a high protein content (25%–30%) and carbohydrates (<55%) with low glycemic index, including a minimum of 300 g of vegetables.

Both 10-20-30 training groups and the diet group improved their control of asthma, and all four groups improved asthma-related quality of life with the training/diet group having the greatest improvement (Figure 4).

The 10-20-30 training group and the 10-20-30 training/diet group reduced fat mass during the intervention period by 1.4 and 3.9 kg, respectively, whereas the control group had no change in fat mass (Toennesen, Meteran, et al., 2018). The weight loss may explain part of the improvements in asthma control and quality of life; as a study by Scott et al. (2013) found that, a 5%–10% reduction in body mass in obese patients with asthma was associated with improvements in asthma control and quality of life (Scott et al., 2013).

$\dot{V}O_{2max}$ increased by 8% from 38.4 to 41.5 ml·kg^{-1}·min^{-1} in the 10-20-30 training group and by 17% from 31.5 to 36.8 ml·kg^{-1}·min^{-1} in the 10-20-30 training/diet group, whereas the diet and control group did not have any change.

Thus, in asthma patients, the 10-20-30 training, with or without a specific diet, does lower fat mass, increase $\dot{V}O_{2max}$, and control of asthma.

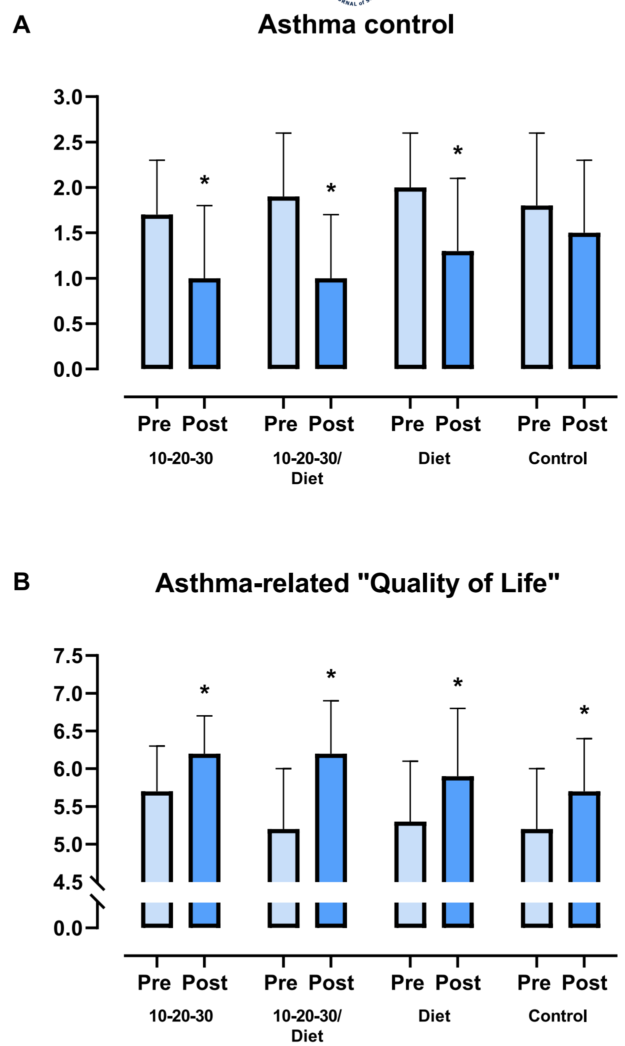

FIGURE 4 Control of asthma (arbitrary values-lower value better control; A) and asthma-related quality of life (arbitrary values-higher value better quality, B) for asthma patients before (pre, light blue bars) and after (post, dark blue bars) an 8-week period with the 10-20-30 training (10-20-30), the 10-20-30 training and diet intervention (10-20-30/Diet), diet intervention (Diet), and no intervention (Control). Data from Toennesen, Meteran, et al. (2018). Data are presented as mean ± SD. *Post different ($p < 0.001$) from Pre.

8 | SYNOPSIS

Together, the studies showed that the 10-20-30 training was effective in enhancing $\dot{V}O_{2max}$ and performance even in trained subjects, despite a marked reduction in training volume. Furthermore, the 10-20-30 training led to increases in muscle ion transport proteins and oxidative enzymes. The 10-20-30 training also lowered blood pressure and fat mass as well as increased lean body mass. Thus, having positive effects on health also beneficial for already trained people.

All the studies with patient groups found that $\dot{V}O_{2max}$ increased with the 10-20-30 training with more than 3 ml·kg^{-1}·min^{-1}, which is of clinical relevance since $\dot{V}o_{2max}$ is a strong predictor for all-cause mortality (Kodama et al., 2009), and each 1 ml·kg^{-1}·min^{-1} increase in $\dot{V}o_{2max}$ has been shown to be associated with a ~9% reduction in relative risk in all-cause mortality (Laukkanen et al., 2016) and a 45-day increase in longevity (Clausen et al., 2018). In addition, the work capacity of the patients was improved. The 10-20-30 training for the various patient groups also reduced total fat and visceral fat mass, which are expected to significantly reduce the risk of developing metabolic diseases. Particularly, the key challenge of each patient group was reduced with the 10-20-30 training intervention such as lowered blood HbA_{1c} in the T2D patients, reduced blood pressure in the hypertensive subjects, and better asthma control for the asthmatic patients. Thus, the 10-20-30 training was efficient and beneficial for these patients groups; at the same time, the patients were adherent to the training. However, a limited number of studies within the various target groups have been conducted, and more research needs to be carried out in order to confirm the conclusions.

9 | PERSPECTIVES

Often it can be challenging for sedentary people and patients to get to exercise (Thomas et al., 2004). Lack of time has been reported as one of the most cited barriers for not engaging in physical exercise among patients (Trost et al., 2002). In the 10-20-30 training, studies compliance for the untrained and patient training groups was >80%, which is higher than observed with other training interventions (Lunt et al., 2014; Revdal et al., 2016; Shepherd et al., 2015). In addition, the 10-20-30 training is easy to conduct in a nonclinical setting, and the brevity of the sprints is manageable for the patients (Toennesen, Soerensen, et al., 2018). No adverse events were observed with the training intervention in either 10-20-30 training groups. Thus, the 10-20-30 training appears to be feasible, at the least for the groups studied, and time efficient to improve health. Nevertheless, precautions should always be taken when intense exercise is performed, and if an individual feels pain or gets dizzy, the training should be stopped immediately.

ACKNOWLEDGMENT

The subjects and researchers in the original studies are acknowledged for their effort. The original studies conducted in our laboratory were supported by the Danish Ministry of Culture, Nordeafonden, Trygfonden, and Novo Nordisk Fonden.

CONFLICT OF INTEREST STATEMENT

Jens Bangsbo is the author of a book, which provides practical guidelines of how to conduct the 10-20-30 training.

ORCID

Jens Bangsbo https://orcid.org/0000-0003-1305-9274

REFERENCES

Akinbami, L. J., J. E. Moorman, C. Bailey, H. S. Zahran, M. King, C. A. Johnson, and X. Liu. 2012. *Trends in Asthma Prevalence, Health Care Use, and Mortality in the United States, 2001-2010*, Vol. 94, 1–8. NCHS Data Brief.

Alpsoy, S. 2020. "Exercise and Hypertension." *Advances in Experimental Medicine & Biology* 1228: 153–67. https://doi.org/10.1007/978-981-15-1792-1_10.

Alwarith, J., H. Kahleova, L. Crosby, A. Brooks, L. Brandon, S. M. Levin, and N. D. Barnard. 2020. "The Role of Nutrition in Asthma Prevention and Treatment." *Nutrition Reviews* 78(11): 928–38. https://doi.org/10.1093/nutrit/nuaa005.

Baasch-Skytte, T., T. P. Gunnarsson, M. Fiorenza, and J. Bangsbo. 2021. "Skeletal Muscle Proteins Important for Work Capacity Are Altered with Type 2 Diabetes - Effect of 10-20-30 Training." *Physics Reports* 9(1): e14681. https://doi.org/10.14814/phy2.14681.

Baasch-Skytte, T., C. T. Lemgart, M. H. Oehlenschlager, P. E. Petersen, M. Hostrup, J. Bangsbo, and T. P. Gunnarsson. 2020. "Efficacy of 10-20-30 Training versus Moderate-Intensity Continuous Training on HbA1c, Body Composition and Maximum Oxygen Uptake in Male Patients with Type 2 Diabetes: A Randomized Controlled Trial." *Diabetes, Obesity and Metabolism* 22(5): 767–78. https://doi.org/10.1111/dom.13953.

Bangsbo, J. 2015. "Performance in Sports--With Specific Emphasis on the Effect of Intensified Training." *Scandinavian Journal of Medicine & Science in Sports* 25(Suppl 4): 88–99. https://doi.org/10.1111/sms.12605.

Bangsbo, J., T. P. Gunnarsson, J. Wendell, L. Nybo, and M. Thomassen. 2009. "Reduced Volume and Increased Training Intensity Elevate Muscle Na+-K+ Pump Alpha2-Subunit Expression as Well as Short- and Long-Term Work Capacity in Humans." *Journal of Applied Physiology* 107(6): 1771–80. https://doi.org/10.1152/japplphysiol.00358.2009.

Banitalebi, E., A. Kazemi, M. Faramarzi, S. Nasiri, and M. M. Haghighi. 2019. "Effects of Sprint Interval or Combined Aerobic and Resistance Training on Myokines in Overweight Women with Type 2 Diabetes: A Randomized Controlled Trial." *Life Sciences* 217: 101–9. https://doi.org/10.1016/j.lfs.2018.11.062.

Bjorntorp, P. 1988. "Are Regional Metabolic Differences of Adipose Tissue Responsible for Different Risks of Obesity?" *Hormone and Metabolic Research Supplement Series* 19: 23–5.

Buemann, B., T. I. Sorensen, O. Pedersen, E. Black, C. Holst, S. Toubro, A. Astrup, J. J. Holst, C. Rasmussen, and A. Astrup. 2005. "Lower-body Fat Mass as an Independent Marker of Insulin Sensitivity--the Role of Adiponectin." *International Journal of Obesity* 29(6): 624–31. https://doi.org/10.1038/sj.ijo.0802929.

Christensen, P. M., T. P. Gunnarsson, M. Thomassen, D. P. Wilkerson, J. J. Nielsen, and J. Bangsbo. 2015. "Unchanged Content of Oxidative Enzymes in Fast-Twitch Muscle Fibers and VO2 Kinetics after Intensified Training in Trained Cyclists." *Physics Reports* 3(7): e12428. https://doi.org/10.14814/phy2.12428.

Clausen, J. S. R., J. L. Marott, A. Holtermann, F. Gyntelberg, and M. T. Jensen. 2018. "Midlife Cardiorespiratory Fitness and the Long-Term Risk of Mortality: 46 Years of Follow-Up." *Journal of the American College of Cardiology* 72(9): 987–95. https://doi.org/10.1016/j.jacc.2018.06.045.

Cocks, M., C. S. Shaw, S. O. Shepherd, J. P. Fisher, A. M. Ranasinghe, T. A. Barker, Kevin D. Tipton, Anton J. M. Wagenmakers, and A. J. Wagenmakers. 2013. "Sprint Interval and Endurance Training Are Equally Effective in Increasing Muscle Microvascular Density and eNOS Content in Sedentary Males." *Journal of Physiology* 591(3): 641–56. https://doi.org/10.1113/jphysiol.2012.239566.

Colberg, S. R., R. J. Sigal, J. E. Yardley, M. C. Riddell, D. W. Dunstan, P. C. Dempsey, Edward S. Horton, Kristin Castorino, Deborah F. Tate, and D. F. Tate. 2016. "Physical Activity/Exercise and Diabetes: A Position

Statement of the American Diabetes Association." *Diabetes Care* 39(11): 2065–79. https://doi.org/10.2337/dc16-1728.

Cornelissen, V. A., and R. H. Fagard. 2005. "Effects of Endurance Training on Blood Pressure, Blood Pressure-Regulating Mechanisms, and Cardiovascular Risk Factors." *Hypertension* 46(4): 667–75. https://doi.org/10.1161/01.HYP.0000184225.05629.51.

DeFronzo, R. A., R. Gunnarsson, O. Bjorkman, M. Olsson, and J. Wahren. 1985. "Effects of Insulin on Peripheral and Splanchnic Glucose Metabolism in Noninsulin-dependent (Type II) Diabetes Mellitus." *Journal of Clinical Investigation* 76(1): 149–55. https://doi.org/10.1172/JCI111938.

de Glisezinski, I., D. Larrouy, M. Bajzova, K. Koppo, J. Polak, M. Berlan, J. Bulow, et al. 2009. "Adrenaline but Not Noradrenaline Is a Determinant of Exercise-Induced Lipid Mobilization in Human Subcutaneous Adipose Tissue." *Journal of Physiology* 587(Pt 13): 3393–404. https://doi.org/10.1113/jphysiol.2009.168906.

Ehlers, T. S., Y. Sverrisdottir, J. Bangsbo, and T. P. Gunnarsson. 2020. "High-Intensity Interval Training Decreases Muscle Sympathetic Nerve Activity in Men with Essential Hypertension and in Normotensive Controls." *Frontiers in Neuroscience* 14: 841. https://doi.org/10.3389/fnins.2020.00841.

Esfarjani, F., and P. B. Laursen. 2007. "Manipulating High-Intensity Interval Training: Effects on VO2max, the Lactate Threshold and 3000 M Running Performance in Moderately Trained Males." *Journal of Science and Medicine in Sport* 10(1): 27–35. https://doi.org/10.1016/j.jsams.2006.05.014.

Faelli, E., V. Ferrando, A. Bisio, M. Ferrando, A. Torre, M. Panasci, and P. Ruggeri. 2019. "Effects of Two High-Intensity Interval Training Concepts in Recreational Runners." *Int J Sports Med* 40(10): 639–44. https://doi.org/10.1055/a-0964-0155.

Forouzanfar, M. H., P. Liu, G. A. Roth, M. Ng, S. Biryukov, L. Marczak, C. J. Murray, et al. 2017. "Global Burden of Hypertension and Systolic Blood Pressure of at Least 110 to 115 Mm Hg, 1990-2015." *JAMA* 317(2): 165–82. https://doi.org/10.1001/jama.2016.19043.

Gliemann, L., T. P. Gunnarsson, Y. Hellsten, and J. Bangsbo. 2015. "10-20-30 Training Increases Performance and Lowers Blood Pressure and VEGF in Runners." *Scandinavian Journal of Medicine & Science in Sports* 25(5): e479–89. https://doi.org/10.1111/sms.12356.

Gunnarsson, T. P., and J. Bangsbo. 2012. "The 10-20-30 Training Concept Improves Performance and Health Profile in Moderately Trained Runners." *Journal of Applied Physiology* 113(1): 16–24. https://doi.org/10.1152/japplphysiol.00334.2012.

Gunnarsson, T. P., N. Brandt, M. Fiorenza, M. Hostrup, H. Pilegaard, and J. Bangsbo. 2019. "Inclusion of Sprints in Moderate Intensity Continuous Training Leads to Muscle Oxidative Adaptations in Trained Individuals." *Physics Reports* 7(4): e13976. https://doi.org/10.14814/phy2.13976.

Gunnarsson, T. P., P. M. Christensen, M. Thomassen, L. R. Nielsen, and J. Bangsbo. 2013. "Effect of Intensified Training on Muscle Ion Kinetics, Fatigue Development, and Repeated Short-Term Performance in Endurance-Trained Cyclists." *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 305(7): R811–21. https://doi.org/10.1152/ajpregu.00467.2012.

Gunnarsson, T. P., T. S. Ehlers, T. Baasch-Skytte, A. P. Lund, A. Tamariz-Ellemann, L. Gliemann, J. Bangsbo, and Jens Bangsbo. 2020. "Hypertension Is Associated with Blunted NO-Mediated Leg Vasodilator Responsiveness that Is Reversed by High-Intensity Training in Postmenopausal Women." *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 319(6): R712–23. https://doi.org/10.1152/ajpregu.00170.2020.

Gunnarsson, T. P., T. S. Ehlers, M. Fiorenza, M. Nyberg, and J. Bangsbo. 2020. "Essential Hypertension Is Associated with Blunted Smooth Muscle Cell Vasodilator Responsiveness and Is Reversed by 10-20-30 Training in Men." *American Journal of Physiology - Cell Physiology* 318(6): C1252–63. https://doi.org/10.1152/ajpcell.00047.2020.

Hansen, E. S. H., A. Pitzner-Fabricius, L. L. Toennesen, H. K. Rasmusen, M. Hostrup, Y. Hellsten, M. Henriksen, and Marius Henriksen. 2020. "Effect of Aerobic Exercise Training on Asthma in Adults: a Systematic Review and Meta-Analysis." *European Respiratory Journal* 56(1): 2000146. https://doi.org/10.1183/13993003.00146-2020.

He, J., S. Watkins, and D. E. Kelley. 2001. "Skeletal Muscle Lipid Content and Oxidative Enzyme Activity in Relation to Muscle Fiber Type in Type 2 Diabetes and Obesity." *Diabetes* 50(4): 817–23. https://doi.org/10.2337/diabetes.50.4.817.

Helgerud, J., K. Hoydal, E. Wang, T. Karlsen, P. Berg, M. Bjerkaas, J. Hoff, et al. 2007. "Aerobic High-Intensity Intervals Improve VO2max More Than Moderate Training." *Medicine & Science in Sports & Exercise* 39(4): 665–71. https://doi.org/10.1249/mss.0b013e3180304570.

Hellsten, Y., L. Jensen, P. Thaning, M. Nyberg, and S. Mortensen. 2012. "Impaired Formation of Vasodilators in Peripheral Tissue in Essential Hypertension Is Normalized by Exercise Training: Role of Adenosine and Prostacyclin." *Journal of Hypertension* 30(10): 2007–14. https://doi.org/10.1097/HJH.0b013e328356dd57.

Hostrup, M., and J. Bangsbo. 2017. "Limitations in Intense Exercise Performance of Athletes - Effect of Speed Endurance Training on Ion Handling and Fatigue Development." *Journal of Physiology* 595(9): 2897–913. https://doi.org/10.1113/JP273218.

Hostrup, M., S. P. Cairns, and J. Bangsbo. 2021. "Muscle Ionic Shifts during Exercise: Implications for Fatigue and Exercise Performance." *Comprehensive Physiology* 11(3): 1895–959. https://doi.org/10.1002/cphy.c190024.

Hostrup, M., T. P. Gunnarsson, M. Fiorenza, K. Morch, J. Onslev, K. M. Pedersen, and J. Bangsbo. 2019. "In-season Adaptations to Intense Intermittent Training and Sprint Interval Training in Sub-elite Football Players." *Scandinavian Journal of Medicine & Science in Sports* 29(5): 669–77. https://doi.org/10.1111/sms.13395.

Iaia, F. M., J. Perez-Gomez, M. Thomassen, N. B. Nordsborg, Y. Hellsten, and J. Bangsbo. 2011. "Relationship between Performance at Different Exercise Intensities and Skeletal Muscle Characteristics." *Journal of Applied Physiology* 110(6): 1555–63. https://doi.org/10.1152/japplphysiol.00420.2010.

Iaia, F. M., M. Thomassen, H. Kolding, T. Gunnarsson, J. Wendell, T. Rostgaard, J. Bangsbo, et al. 2008. "Reduced Volume but Increased Training Intensity Elevates Muscle Na+-K+ Pump Alpha1-Subunit and NHE1 Expression as Well as Short-Term Work Capacity in Humans." *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 294(3): R966–74. https://doi.org/10.1152/ajpregu.00666.2007.

Kelley, G. A., and K. S. Kelley. 2007. "Effects of Aerobic Exercise on Lipids and Lipoproteins in Adults with Type 2 Diabetes: a Meta-Analysis of Randomized-Controlled Trials." *Public Health* 121(9): 643–55. https://doi.org/10.1016/j.puhe.2007.02.014.

Kodama, S., K. Saito, S. Tanaka, M. Maki, Y. Yachi, M. Asumi, and H. Sone. 2009. "Cardiorespiratory Fitness as a Quantitative Predictor of All-Cause Mortality and Cardiovascular Events in Healthy Men and Women: a Meta-Analysis." *JAMA* 301(19): 2024–35. https://doi.org/10.1001/jama.2009.681.

Larsen, S., J. Nielsen, C. N. Hansen, L. B. Nielsen, F. Wibrand, N. Stride, Henrik Daa Schroder, et al. 2012. "Biomarkers of Mitochondrial Content in Skeletal Muscle of Healthy Young Human Subjects." *Journal of Physiology* 590(14): 3349–60. https://doi.org/10.1113/jphysiol.2012.230185.

Laukkanen, J. A., F. Zaccardi, H. Khan, S. Kurl, S. Y. Jae, and R. Rauramaa. 2016. "Long-term Change in Cardiorespiratory Fitness and All-Cause Mortality: A Population-Based Follow-Up Study." *Mayo Clinic Proceedings* 91(9): 1183–8. https://doi.org/10.1016/j.mayocp.2016.05.014.

Lewington, S., R. Clarke, N. Qizilbash, R. Peto, R. Collins, and C. Prospective Studies. 2002. "Age-specific Relevance of Usual Blood

Pressure to Vascular Mortality: a Meta-Analysis of Individual Data for One Million Adults in 61 Prospective Studies." *Lancet* 360(9349): 1903–13. https://doi.org/10.1016/s0140-6736(02)11911-8.

Lopes, S., V. Afreixo, M. Teixeira, C. Garcia, C. Leitao, M. Gouveia, Daniela Figueiredo, et al. 2021. "Exercise Training Reduces Arterial Stiffness in Adults with Hypertension: a Systematic Review and Meta-Analysis." *Journal of Hypertension* 39(2): 214–22. https://doi.org/10.1097/HJH.0000000000002619.

Lunt, H., N. Draper, H. C. Marshall, F. J. Logan, M. J. Hamlin, J. P. Shearman, C. M. Frampton, Nicholas E. Kimber, Gavin Blackwell, and Christopher M. A. Frampton. 2014. "High Intensity Interval Training in a Real World Setting: a Randomized Controlled Feasibility Study in Overweight Inactive Adults, Measuring Change in Maximal Oxygen Uptake." *PLoS One* 9(1): e83256. https://doi.org/10.1371/journal.pone.0083256.

Madsen, S. M., A. C. Thorup, K. Overgaard, and P. B. Jeppesen. 2015. "High Intensity Interval Training Improves Glycaemic Control and Pancreatic Beta Cell Function of Type 2 Diabetes Patients." *PLoS One* 10(8): e0133286. https://doi.org/10.1371/journal.pone.0133286.

Mann, S., C. Beedie, S. Balducci, S. Zanuso, J. Allgrove, F. Bertiato, and A. Jimenez. 2014. "Changes in Insulin Sensitivity in Response to Different Modalities of Exercise: a Review of the Evidence." *Diabetes Metab Res Rev* 30(4): 257–68. https://doi.org/10.1002/dmrr.2488.

Mitranun, W., C. Deerochanawong, H. Tanaka, and D. Suksom. 2014. "Continuous vs Interval Training on Glycemic Control and Macro- and Microvascular Reactivity in Type 2 Diabetic Patients." *Scandinavian Journal of Medicine & Science in Sports* 24(2): e69–76. https://doi.org/10.1111/sms.12112.

Mohr, M., P. Krustrup, J. J. Nielsen, L. Nybo, M. K. Rasmussen, C. Juel, and J. Bangsbo. 2007. "Effect of Two Different Intense Training Regimens on Skeletal Muscle Ion Transport Proteins and Fatigue Development." *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 292(4): R1594–602. https://doi.org/10.1152/ajpregu.00251.2006.

Moorman, J. E., L. J. Akinbami, C. M. Bailey, H. S. Zahran, M. E. King, C. A. Johnson, and X. Liu. 2012. "National Surveillance of Asthma: United States, 2001-2010." *Vital Health Stat* 3(35): 1–58.

Nupp, W. F. 1970. "The Relative Effectiveness of Four Cardio-Respiratory Conditioning Programs." *The Journal of Sports Medicine and Physical Fitness* 10(2): 84–9.

Nyberg, M., L. G. Jensen, P. Thaning, Y. Hellsten, and S. P. Mortensen. 2012. "Role of Nitric Oxide and Prostanoids in the Regulation of Leg Blood Flow and Blood Pressure in Humans with Essential Hypertension: Effect of High-Intensity Aerobic Training." *Journal of Physiology* 590(6): 1481–94. https://doi.org/10.1113/jphysiol.2011.225136.

Ogurtsova, K., J. D. da Rocha Fernandes, Y. Huang, U. Linnenkamp, L. Guariguata, N. H. Cho, L. E. Makaroff, J. e. Shaw, and L. e. Makaroff. 2017. "IDF Diabetes Atlas: Global Estimates for the Prevalence of Diabetes for 2015 and 2040." *Diabetes Research and Clinical Practice* 128: 40–50. https://doi.org/10.1016/j.diabres.2017.03.024.

Pan, H. Z., L. Zhang, M. Y. Guo, H. Sui, H. Li, W. H. Wu, D. Chang, M.-hua Liang, and Dong Chang. 2010. "The Oxidative Stress Status in Diabetes Mellitus and Diabetic Nephropathy." *Acta Diabetologica* 47(Suppl 1): 71–6. https://doi.org/10.1007/s00592-009-0128-1.

Pedersen, B. K., and B. Saltin. 2006. "Evidence for Prescribing Exercise as Therapy in Chronic Disease." *Scandinavian Journal of Medicine & Science in Sports* 16(Suppl 1): 3–63. https://doi.org/10.1111/j.1600-0838.2006.00520.x.

Phielix, E., R. Meex, E. Moonen-Kornips, M. K. Hesselink, and P. Schrauwen. 2010. "Exercise Training Increases Mitochondrial Content and Ex Vivo Mitochondrial Function Similarly in Patients with Type 2 Diabetes and in Control Individuals." *Diabetologia* 53(8): 1714–21. https://doi.org/10.1007/s00125-010-1764-2.

Raji, A., E. W. Seely, R. A. Arky, and D. C. Simonson. 2001. "Body Fat Distribution and Insulin Resistance in Healthy Asian Indians and Caucasians." *Journal of Clinical Endocrinology & Metabolism* 86(11): 5366–71. https://doi.org/10.1210/jcem.86.11.7992.

Ramakrishna, V., and R. Jailkhani. 2008. "Oxidative Stress in Non-insulin-dependent Diabetes Mellitus (NIDDM) Patients." *Acta Diabetologica* 45(1): 41–6. https://doi.org/10.1007/s00592-007-0018-3.

Revdal, A., S. M. Hollekim-Strand, and C. B. Ingul. 2016. "Can Time Efficient Exercise Improve Cardiometabolic Risk Factors in Type 2 Diabetes? A Pilot Study." *Journal of Sports Science and Medicine* 15(2): 308–13.

Scott, H. A., P. G. Gibson, M. L. Garg, J. J. Pretto, P. J. Morgan, R. Callister, and L. G. Wood. 2013. "Dietary Restriction and Exercise Improve Airway Inflammation and Clinical Outcomes in Overweight and Obese Asthma: a Randomized Trial." *Clinical and Experimental Allergy* 43(1): 36–49. https://doi.org/10.1111/cea.12004.

Shepherd, S. O., O. J. Wilson, A. S. Taylor, C. Thogersen-Ntoumani, A. M. Adlan, A. J. Wagenmakers, and C. S. Shaw. 2015. "Low-Volume High-Intensity Interval Training in a Gym Setting Improves Cardio-Metabolic and Psychological Health." *PLoS One* 10(9): e0139056. https://doi.org/10.1371/journal.pone.0139056.

Skovgaard, C., D. Christiansen, A. Martinez-Rodriguez, and J. Bangsbo. 2024. "Similar Improvements in 5-km Performance and Maximal Oxygen Uptake with Submaximal and Maximal 10-20-30 Training in Runners, but Increase in Muscle Oxidative Phosphorylation Occur Only with Maximal Effort Training." *Scandinavian Journal of Medicine & Science in Sports* 34(1): e14493. https://doi.org/10.1111/sms.14493.

Stanford, K. I., and L. J. Goodyear. 2014. "Exercise and Type 2 Diabetes: Molecular Mechanisms Regulating Glucose Uptake in Skeletal Muscle." *Advances in Physiology Education* 38(4): 308–14. https://doi.org/10.1152/advan.00080.2014.

Stoa, E. M., S. Meling, L. K. Nyhus, S. Glenn, K. M. Mangerud, J. Helgerud, O. Storen, and Øyvind Støren. 2017. "High-intensity Aerobic Interval Training Improves Aerobic Fitness and HbA1c Among Persons Diagnosed with Type 2 Diabetes." *European Journal of Applied Physiology* 117(3): 455–67. https://doi.org/10.1007/s00421-017-3540-1.

Stratton, I. M., A. I. Adler, H. A. Neil, D. R. Matthews, S. E. Manley, C. A. Cull, and R. R. Holman. 2000. "Association of Glycaemia with Macrovascular and Microvascular Complications of Type 2 Diabetes (UKPDS 35): Prospective Observational Study." *BMJ* 321(7258): 405–12. https://doi.org/10.1136/bmj.321.7258.405.

Thomas, N., E. Alder, and G. P. Leese. 2004. "Barriers to Physical Activity in Patients with Diabetes." *Postgraduate Medical Journal* 80(943): 287–91. https://doi.org/10.1136/pgmj.2003.010553.

Toennesen, L. L., H. Meteran, M. Hostrup, N. R. Wium Geiker, C. B. Jensen, C. Porsbjerg, V. Backer, J. Bangsbo, D. Parker, and V. Backer. 2018. "Effects of Exercise and Diet in Nonobese Asthma Patients-A Randomized Controlled Trial." *Journal of Allergy and Clinical Immunology: In Practice* 6(3): 803–11. https://doi.org/10.1016/j.jaip.2017.09.028.

Toennesen, L. L., E. D. Soerensen, M. Hostrup, C. Porsbjerg, J. Bangsbo, and V. Backer. 2018. "Feasibility of High-Intensity Training in Asthma." *Eur Clin Respir J* 5(1): 1468714. https://doi.org/10.1080/20018525.2018.1468714.

Trost, S. G., N. Owen, A. E. Bauman, J. F. Sallis, and W. Brown. 2002. "Correlates of Adults' Participation in Physical Activity: Review and Update." *Medicine & Science in Sports & Exercise* 34(12): 1996–2001. https://doi.org/10.1097/00005768-200212000-00020.

Weston, K. S., U. Wisloff, and J. S. Coombes. 2014. "High-intensity Interval Training in Patients with Lifestyle-Induced Cardiometabolic Disease: a Systematic Review and Meta-Analysis." *British Journal of Sports Medicine* 48(16): 1227–34. https://doi.org/10.1136/bjsports-2013-092576.

Williams, B., G. Mancia, W. Spiering, E. Agabiti Rosei, M. Azizi, M. Burnier, E. S. C. S. D. Group, et al. 2018. "2018 ESC/ESH Guidelines for the

Management of Arterial Hypertension." *European Heart Journal* 39(33): 3021–104. https://doi.org/10.1093/eurheartj/ehy339.

Wilson, M. C., V. N. Jackson, C. Heddle, N. T. Price, H. Pilegaard, C. Juel, A. P. Halestrap, Ian Montgomery, Otto F. Hutter, and Andrew P. Halestrap. 1998. "Lactic Acid Efflux from White Skeletal Muscle Is Catalyzed by the Monocarboxylate Transporter Isoform MCT3." *Journal of Biological Chemistry* 273(26): 15920–6. https://doi.org/10.1074/jbc.273.26.15920.

Wormgoor, S. G., L. C. Dalleck, C. Zinn, and N. K. Harris. 2017. "Effects of High-Intensity Interval Training on People Living with Type 2 Diabetes: A Narrative Review." *Canadian Journal of Diabetes* 41(5): 536–47. https://doi.org/10.1016/j.jcjd.2016.12.004.