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ASTHMA OUTCOMES



Effects of high intensity interval training and sprint interval training in patients with asthma: a systematic review

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ABSTRACT

Objective: The aim of this study is to review the effects of high-intensity interval training (HIIT)/sprint interval training (SIT) on asthma symptoms, cardiorespiratory functions, and other variables among asthmatic patients.

Data sources: Randomized controlled trials published between January 2000 and January 2021 were searched in PubMed/MEDLINE, Web of Science, and Cochrane Library databases.

Study selections: Following pre-specified inclusion criteria, this review included 7 randomized controlled studies that compare HIIT/SIT as an intervention with any other intervention and/or control group.

Results: Of the included studies only four reported the chronic phase effects of the HIIT/SIT protocols. HIIT and SIT protocols applied in studies differ. HIIT improved forced expiratory volume in 1 s (FEV₁) in the acute phase and maximal oxygen consumption (VO_{2max}) in the chronic phase in the asthmatic patients ($p < 0.05$).

Conclusion: To our knowledge, our systematic review is the first study evaluating the effects of HIIT/SIT protocols on asthma patients. HIIT/SIT protocols have beneficial effects on asthma patients. In order to better understand the results of these training procedures, studies that will be designed with high methodology are needed.

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KEYWORDS

Exercise; acute; chronic; FEV₁; VO_{2max}

Introduction

Asthma is a complex and multifactorial disorder. It can be classified as early onset (childhood), late onset (adulthood), obesity-related, neutrophilic, or exercise-induced bronchoconstriction (1). Airway inflammation, decreased control of airway tone, and increased reactivity could be the underlying mechanism of asthma (2). It leads to learning difficulties, decreased physical activity level, decreased quality of life, and heavy burden (3,4). Therefore, prevention and treatment of asthma are important and physical training is an effective method to reduce symptoms, healthcare use and medication use (5,6).

Regular aerobic activity is recommended to patients with asthma, especially for cardiovascular fitness, improvement in maximal oxygen consumption, peak expiratory flow, asthma control, and increase of

asthma-related quality of life (7,8). It can decrease airway inflammation and disease exacerbation (6). Furthermore, exercising regularly can improve symptom perception and mood (9). In short, regular aerobic activity can improve both physical and psychological health.

High-intensity interval training (HIIT) is a type of aerobic exercise that includes alternating short bursts of high-intensity exercise ($\geq 85\%$ maximum heart rate, $\geq 80\%$ maximal oxygen consumption, or $\geq 80\%$ heart rate reserve) and decreased-intensity recovery periods of ≤ 5 min in duration (10). Sprint interval training (SIT) is a type of HIIT that includes supramaximal activities. The pace reaches and exceeds the maximal oxygen consumption (VO_{2max}) (11). They both are becoming increasingly popular especially for their improvements in cardiorespiratory fitness, cardiovascular function, anthropometric variables, exercise

capacity, muscular system and function, and decreasing the severity of anxiety/depression (12–15).

Currently, interval training is also getting popular among patients with pulmonary conditions (16). Its superiority stems from having a refractory period during the exercise, which gives the respiratory system extra time for better adaptation without triggering asthma symptoms (17). Although the relationship between asthma and the effects of HIIT/SIT were studied in the literature, there was not one comparing the results of these aforementioned studies. We hypothesized that HIIT exercises have a greater impact than other conventional approaches in asthmatic patients. Therefore, the present study aimed to review the effects of HIIT/SIT on asthma symptoms, cardiorespiratory functions, and other variables among asthmatic patients.

Methods

Study selection criteria

The determined PICOS search strategy (Participants, Interventions, Comparison, Outcome, and Study Design) criteria for our study were:

1. Participants: Diagnosed with asthma;
 - a. diagnosed with asthma by a physician or,
 - b. have at least 1 positive diagnostic test demonstrating variable airflow obstruction: a mannitol test/methacholine test/reversibility test.
3. Interventions: HIIT and/or SIT as an intervention at least in one group according their protocols.
4. Comparison: Any other intervention and/or control group (asthmatic and/or healthy subjects).
5. Outcome: Anthropometric parameters, lung function, cardiovascular variables, cardiorespiratory fitness, EIBS/asthma symptoms and control, quality of life.
6. Study design: Randomized controlled studies and randomized crossover studies.

Case reports, meta-analysis, narrative and systematic review, and manuscripts that were written in languages other than English were excluded.

Search strategy

The determined keywords were “asthma” and (“high-intensity interval training” or “high-intensity

interval training” or “high intensity interval training” or “high-intensity interval trainings” or “interval training, high-intensity” or “interval trainings, high-intensity” or “training, high-intensity interval” or “trainings, high-intensity interval” or “high-intensity intermittent exercise” or “exercise, high-intensity intermittent” or “exercises, high-intensity intermittent” or “high-intensity intermittent exercises” or “sprint interval training” or “sprint interval trainings” or “interval training” or “interval exercise” or “intermittent exercise” or “high intensity interval exercise” or “high intensity exercise” or “high intensity training” or “high intensity intermittent exercises” or “high-intensity exercise”). These keywords were searched in the following electronic databases: PubMed/MEDLINE, Web of Science, and Cochrane Library. Each study published between January 2000 and January 2021 was manually examined and grouped using the selection criteria determined by the authors.

Data extraction and quality assessment

This systematic review was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (18) and registered to Prospero (The review number is: *blinded peer review*). In the beginning, the potentially relevant articles were selected due to their titles and abstracts. Then, the full texts of articles were screened and checked to meet the inclusion criteria by five authors (ÇG, GE, HE, KS, GKA), independently. By using Mendeley, duplicates were excluded. Any disagreements between reviewers about data extraction or quality assessment were resolved by consensus.

The methodological quality of the studies was assessed with the PEDro (Physiotherapy Evidence Database) scale (19). The PEDro scale has sufficient reliability for use in systematic reviews of RCTs of physical therapy. This scale, which consists of 11 items, scores between 0 and 10 points and higher scores show the higher quality of the study. Articles with a score ≥ 6 are considered to be of higher quality, and those with scores 4–5 are considered fair.

Risk of bias assessed by Cochrane risk-of-bias tool for randomized trials (20), which included random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other sources of bias headlines.

Results

The initial search identified 66 articles. Twenty-one of those were excluded due to duplicate publication. Thirty-seven articles were excluded after reading the title and abstract. Eight remaining articles were considered potentially relevant and were read as full text. After reading the full text, an article which was published by the same author was excluded because the participants and results were similar to another article included in the study. Eventually, seven articles were included in the study. Figure 1 provides a study inclusion flowchart. In addition, the list of excluded studies was provided as an Appendix with their reasons.

Quality of the studies

Quality analysis of the studies included in the systematic review are presented in Table 1. Two of the studies had high quality (20,21) and five of the studies had fair quality (23–27) according to the PEDro score.

Figures 2 and 3 list the summary of each aspect examined in the study risk of bias. The only one study was determined to have a low risk of biased (22). The headline with the lowest risk of bias was incomplete outcome data also with the highest risk

of bias were blinding of participants, personnel and, outcome assessment in the studies.

Characteristics of the studies

The characteristics of the included 7 studies are summarized in Table 2. According to the inclusion criteria of the studies, the selected patients have any phenotype of asthma. In three studies, participants were specified to have EIBC (22,23,26). The stage of asthma was not clear in one of the studies (22). Three studies stated the stage of asthma between mild to severe (20,24,25). Three of the studies worked with adolescents (20,24,26) and four of them worked with adults (21–23,25). Three of the studies worked on the acute response of HIIT/SIT (22,23,25), while in the other studies, the duration of intervention was two to six months (20,21,24,26).

Outcome measurements of the studies

Spirometry, VO_{2max} , heart rate, adequacy of asthma control, quality of life, cardiorespiratory fitness, physical activity level, and blood analysis were assessed in the studies. Details about the outcome measures for each study is shown in Table 2.

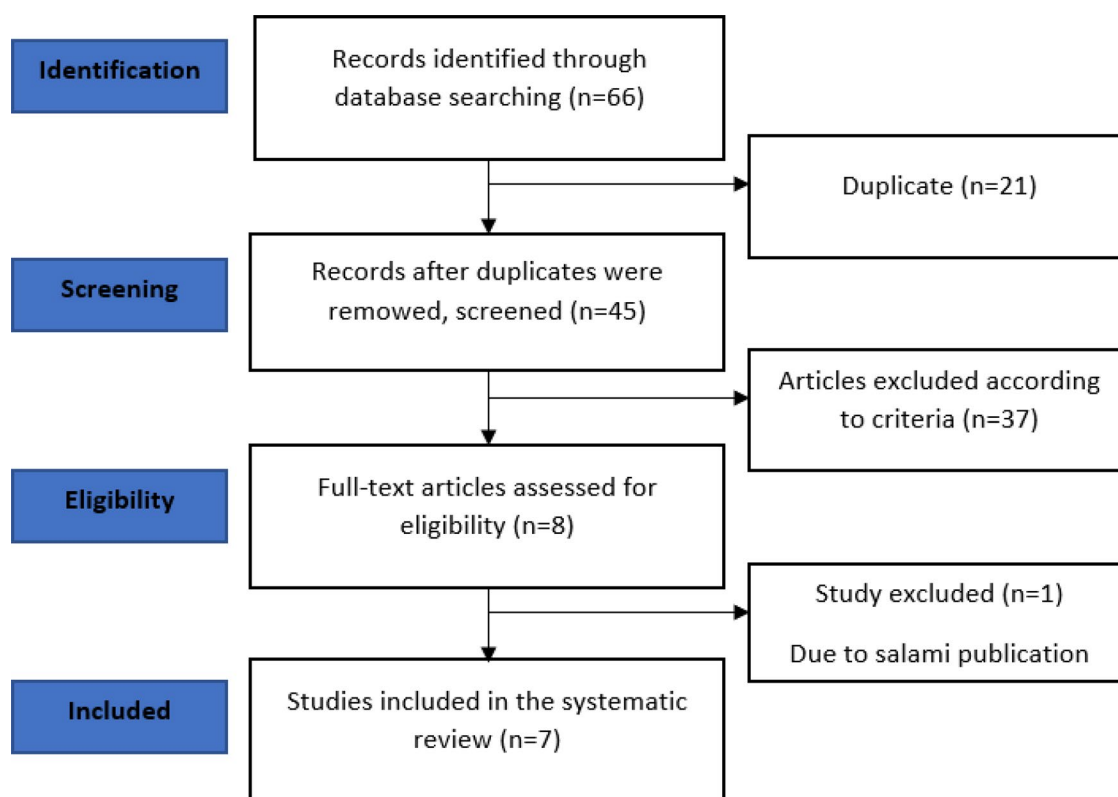


Figure 1. Flow chart of the systematic review inclusion.

Table 1. Quality analysis of the studies with PEDro scale.

Studies	Eligibility	Random allocation	Concealed allocation	Baseline similarity	Subject blinding	Therapist blinding	Assessor blinding	<15% Dropouts	Intention to-treat analysis	Between-group difference reported	Point estimate, variability reported	Total
Winn et al. (21)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Toennesen et al. (22)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	7
Good et al. (23)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	5
Good et al. (24)	Y	Y	N	Y	N	N	N	N	Y	Y	Y	5
McNarry et al. (25)	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5
O'Neill et al. (26)	Y	N	N	Y	N	N	N	N	Y	Y	N	4
Sidiropoulou et al. (27)	Y	N	N	Y	N	N	N	N	Y	Y	N	4

PEDro: physiotherapy evidence database (www.pedro.org). Y: yes; N: no.

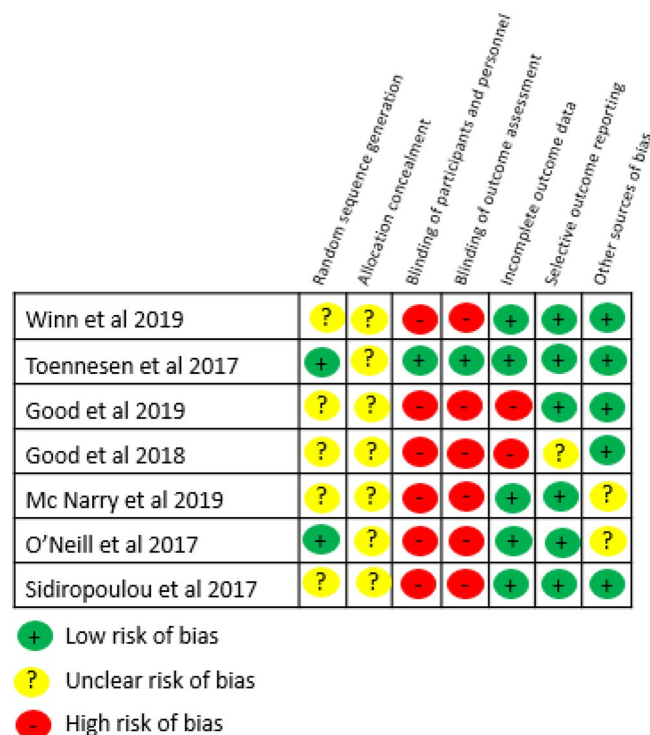


Figure 2. Bias assessment for randomized trials using the Cochrane risk of bias tool criteria.

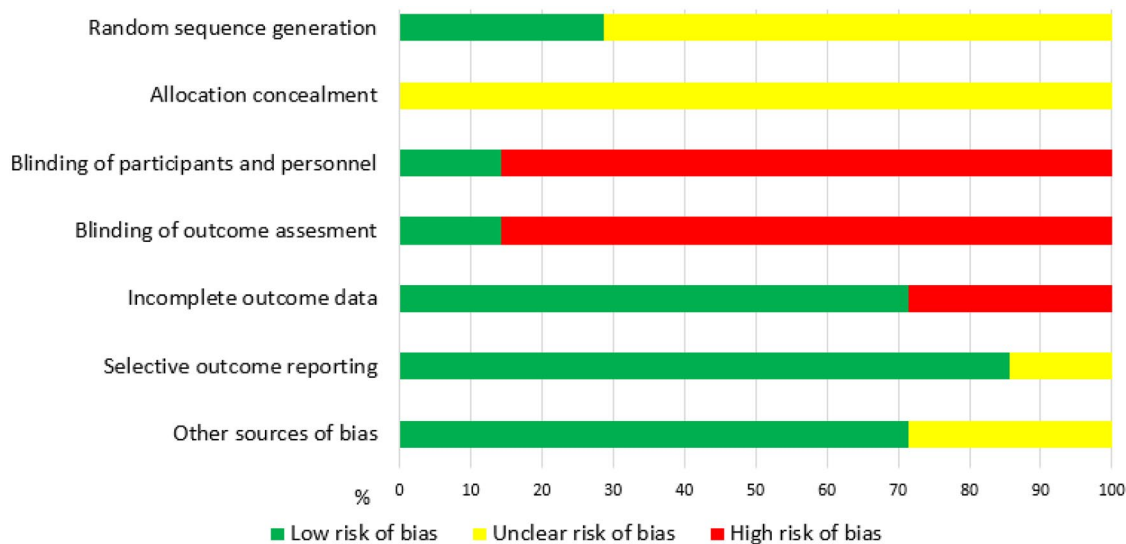


Figure 3. Risk of bias summary across all included randomized trials.

Characteristics of the HIIT/SIT programs

The HIIT protocols in the studies were varied and described with different parameters. While Sidiropoulou et al. (27) determined the loading intensity by using the “(Maximum Heart Rate (MHR) – Resting Heart Rate (RHR)) $\times$ 0.8 + RHR” formula, for each individual; O’Neil et al. (26) followed 90% peak power output (PPO) for 1 min and 10% PPO for 1 min and repeated 10 times. Toennesen et al. (22) applied the “30–20–10” concept on indoor spinning bikes by following less than 30%, less than 60%, and

more than 90% of VO_{2max} , respectively, during 5 $\times$ 1-min intervals. Two of the studies (21,25) performed circuits and game-based activities designed to elicit a heart rate of >90% MHR, derived from the incremental ramp exercise test, with a 1:1 exercise to rest ratio.

The applied SIT protocols were the same in two studies (23,24) which included 30, 20, 10 and 5 s sprints at 0.075 kg/kg of body weight separated by 4.5 min of active recovery with unloaded cycling at 40–60 revolutions per minute (RPM).

Table 2. Characteristics of included studies.

Authors	Patients	Stage of asthma	Intervention group(s) parameters	Intervention duration and frequency	Control group(s) parameters	Outcome measures	I/C patients, n	I/C patient age, years; mean $\pm$ SD
Winn et al. (21)	Willing students from 5 different schools, healthy and asthmatic adolescents who are stable and had not a severe attack of asthma owing to exercise	Moderate to severe asthma	Asthma intervention: Mixture of circuits and game-based activities designed to elicit a heart rate (HR) of $>90\%$ HRmax, with a 1:1 exercise to rest ratio Healthy intervention: healthy adolescents doing the same intervention program	6 months, 3 times in a week (30-min sessions)	Asthma controls: Asthmatic adolescents engaged in their usual day-to-day activities. Healthy controls: Healthy adolescents engaged in their usual day-to-day activities.	- Lung function: FEV₁, FVC, FEV₁/FVC, PEF, FEF₂₅₋₇₅ - FeNO - ACQ - PAQLQ - PedsQL-Teenager 4.0 - Cardiorespiratory fitness: Twenty-meter shuttle run, incremental ramp test (to determine VO₂ and the GET)	Asthma intervention: 50 Healthy intervention: 171 Asthma control: 105 Healthy control: 290	Asthma intervention: 13.1 $\pm$ 1.0 Healthy intervention: 13.2 $\pm$ 1.1 Asthma control: 12.9 $\pm$ 1.2 Healthy control: 12.9 $\pm$ 1.0
Toennesen et al. (22)	Aged 18–65 years with a body mass index of more than 20 and less than 30 kg/m ² an ACQ score 12 of 1.0 or more, and at least 1 positive diagnostic test demonstrating variable airflow obstruction: methacholine test, or reversibility test.	No information	Exercise group: high-intensity interval training using the “10–20–30” concept on indoor spinning bikes: 10-min warm-up at a low intensity followed by either two, three, or four 5-min intervals (during weeks 1–2, 3–5, and 6–8, respectively). Each 5-min interval consisted of 5 consecutive 1-min intervals divided into 30, 20, and 10 s at an intensity corresponding to less than 30%, less than 60%, and more than 90% of maximal intensity Diet group: Diet intervention on the basis of principles of an overall high protein content (25%–28% of energy) and a low GI (≤ 55). Exercise + Diet Group: Followed both the exercise and the diet intervention simultaneously	Exercise: 3 times a week for 8 weeks Diet: 8-week diet intervention	No intervention and were encouraged to maintain usual physical activity levels and diet.	- Incremental cardiopulmonary exercise tests: To determine VO_{2max} 5 item version of the Juniper ACQ - AQLQ - Sprometry, FeNO - mannitol provocation tests, - blood eosinophil counts, - serum levels of IL-6 - C-reactive protein concentration, - urine urea excretion, - skin prick test	Exercise Group: 29 Diet Group: 33 Exercise + Diet Group: 29 Control Group: 34	Exercise group: 39.4 $\pm$ 12.5 Diet group: 40.7 $\pm$ 14.7 Exercise + Diet Group: 43.7 $\pm$ 13.9 Control Group: 38.2 $\pm$ 12.7
Good et al. (23), Randomized crossover	Healthy adults and adults with exercise induced bronchoconstriction ages 18–44 years who engaged in regular physical activity (150 min of moderate to vigorous intensity exercise per week)	EIBC	CE: Starting with 5 min warm-up between 50 and 60W, continuous exercise on cycle at 80RPM at 65% maximal peak power output for 20 min followed by a 5 min cool-down at a self-selected cadence and resistance. SIT: After 5 min warm up between 50 and 60W, participants completed 30–20–10–5 s sprints (at 0.075 kg/kg of body weight) separated by 4.5 min of active recovery (unloaded cycling at 40 to 60RPM) and the protocol finished with 4.5 min active recovery. (20 min of total exercise).	Acute response	Control groups includes the same intervention program done by the healthy individuals.	- Spirometry: FEV₁ - Expired gas analysis: VO₂, V_E, V_T, RR - HR - ACQ	EIBC: 8 Healthy: 8	EIBC: 22.3 $\pm$ 3.0 Healthy: 22.3 $\pm$ 3.0
Good et al. (24)	Healthy adults and adults with EIBC ages 18–44 years who engaged in regular physical activity (150 min of moderate to vigorous intensity exercise per week)	EIBC	Moderate intensity CE: Starting with 2 min warm-up between 50 and 60 Watts, CE on cycle at 80RPM at 65% PPO for 20 min followed by a 5-min cool down at a self-selected cadence and resistance SIT: After 5 min warm up, participants completed 30–20–10–5 s sprints (at 0.075 kg/kg of body weight) separated by 4.5 min of active recovery (unloaded cycling at 40 to 60RPM) and the protocol finished with 4.5 active recovery. (20 min of total exercise).	Acute response	Control groups includes the same intervention program done by the healthy individuals.	- AQLQ - AFF - The Physical Activity Enjoyment Questionnaire - RPD - RPE - EIBC symptoms - Late Phase Asthma Symptom Questionnaire - BR	EIBC: 8 Healthy: 8	EIBC: 22.3 $\pm$ 3.0 Healthy: 22.3 $\pm$ 3.0

(Continued)

Table 2. Continued.

Authors	Patients	Stage of asthma	Intervention group(s) parameters	Intervention duration and frequency	Control group(s) parameters	Outcome measures	I/C patients, n	I/C patient age, years; mean $\pm$ SD
McNarry et al. (2019) (25)	Healthy adolescents and stable asthma	Mild and severe	Sessions consisted of circuits and games-based activities designed to elicit a heart rate of $>90\%$ HR _{max} derived during the incremental ramp exercise test, with a 1:1 exercise to rest ratio.	30 min sessions, 3 days in a week during 6 months.	No exercise	- Spirometry: FEV₁; - Physical activity: accelerometer; - incremental ramp test: To determine VO₂ and the GET; - Square wave exercise tests	13 / 13	13.3 $\pm$ 0.9 / 13.6 $\pm$ 1.0
O'Neill et al. (2017) (26)	Adults with asthma aged 18–44 years who trained 150 min of moderate to vigorous intensity exercise per week)	Mild-moderate asthma	Warm up: Prior to each exercise session at 20W and 70–80RPM (5 min) HILE: 90% PPO for 1 min, 10%PPO for 1 min, repeated 10 times MILE: 65% PPO for 1 min, 10% PPO for 1 min repeated 10 times MICE: (65% PPO) for 20 min	Acute response (4 separate session)	- HR - FEV₁ (post-exercise and at 5, 10, 15, and 20-min post-exercise) - ACQ - Demographic questionnaire - Height-weight		13/-	21.2 $\pm$ 2.7/-
Sidiropoulou et al. (2007)(27)	10–14 years of age soccer players with EIBC subjected to a free running test	EIBC	Instructed to cycle at 70–80 RPM throughout the entire session. Soccer interval-training program Warm up: with alternation of low- (50–60% of HR _{rest} lasted for 100 s) and submaximal – (80–90% of HR _{max} did not exceed 20 s) intensity loading Main: Individually loading intensity calculation by $(HR_{max} - HR_{rest}) \times 0.8 + HR_{rest}$ formula Every 3–5 min breathing and relaxation techniques, 10-min cool down (relaxation, stretching, and special respiratory exercises)	8 weeks, 3 times a week for 45 min per each training unit	- Standard soccer-training program - Warm up: low-intensity (50–70% of HR_{max}) loading - Main: submaximal (80–90% of HR_{max}) or maximal (100% of HR_{max}) loading,	6 min running test - FEV₁ respiratory index at 2, 5, 10, 15, 20, and 30 min	18/11	11.1 $\pm$ 1.3 /11.5 $\pm$ 1.4

ACQ: asthma control questionnaire; AFF: one-item feelings scale; AQLQ: mini asthma quality of life questionnaire; BMI: body mass index; BR: breathing reserve; CE: continuous exercise; EIBC: exercise induced bronchoconstriction; FEV_{25–75}: forced expiratory flow between 25% and 75% of vital capacity; FENO: fractional exhaled nitric oxide; FEV₁: forced expiratory volume in the first second; FVC: forced vital capacity; GET: gas exchange threshold; HILE: high intensity interval exercise; HR_{max}: maximal heart rate; HR_{rest}: resting heart rate; IL-6: interleukin 6; MILE: moderate intensity interval exercise; MICE: moderate intensity continuous exercise; PAQLQ: Pediatric Asthma Quality of Life Questionnaire; PedsQL: Pediatric Quality of Life Inventory Teenager Version 4; PEF: peak expiratory flow; PPO: peak power output; RPM: repeat per minute; RPD: rating of perceived dyspnea; RPE: Borg rating of perceived exertion; SIT: sprint interval training; VO_{2max}: maximal oxygen consumption.

Acute responses of exercise on asthmatic patients

There were three studies showing the acute responses of high intensity interval exercise (HIIE) on patients with asthma (23,24,26).

O'Neill et al. (25) compared HIIE program with moderate intensity interval exercise (MIIE) and moderate intensity continuous exercise (MICE) (26). According to the results of the study, the decline in FEV_1 following the exercises was significantly higher in MICE than MIIE and HIIE ($p < 0.01$) and no difference was determined between MIIE and HIIT ($p > 0.05$).

Two studies were comparing the effects of SIT and continuous exercise (CE) among patients with EIBC which a phenotype of asthma. Only one of these studies assessed late phase asthma symptoms experienced, perceived breathlessness, and exertion to detect their effects on different groups (23). There were no significant interactions between exercise protocols and measurement–time points.

The study of Good et al. (23) revealed that there was no significant difference in the decline in forced expiratory volume in 1 s (FEV_1) in patients with EIBC ($p > 0.05$). However, tissue saturation index (TSI) significantly decreased throughout CE more than SIT ($p < 0.05$). Additionally, in the other study done by Good et al. (24), the results were similar between SIT and CE exercises in terms of affect, enjoyment, perceived breathlessness and exertion, breathing reserve, and EIBC symptoms ($p > 0.05$).

Two of the studies compared the EIBC group to healthy participants (23,24). In the study of Good et al. (23) there was no difference between the groups according to the acute changes in minute ventilation (V_E), tidal volume (V_T), respiratory rate (RR), or TSI ($p > 0.05$). Additionally, in the other study done by Good et al. (24), the results were similar between the EIBC and comparison group in terms of affect, enjoyment, perceived breathlessness and exertion, breathing reserve, and EIBC symptoms ($p > 0.05$).

Chronic effects of exercise on asthmatic patients

There were four studies showing the chronic effects of HIIT/SIT on patients with asthma (20,21,24,26). Intervention durations were 6 months in two of the studies (20,24), two months in two of the studies (21,26). Two of these studies assessed the quality of life and asthma control (20,21). According to Winn et al. (20), 6 months of school-based HIIT had no effect on asthma control or asthma-related quality of

life. On the other hand, Toennesen et al. (21) revealed that both the asthma control and quality of life could be improved after an 8-week HIIT program, diet program, or HIIT + diet program. However, this improvement was significant only in the HIIT + diet program when compared with the control group.

One of the studies compared the asthmatic adolescents with healthy peers getting the same exercise protocol (21). According to that study's results, there were no significant changes over time in lung function parameters such as FEV_1 , forced vital capacity (FVC), FEV_1/FVC ratio, peak expiratory flow, forced expiratory flow between 25% and 75% of vital capacity (FEF_{25-75}) and there was no difference between the groups at the end ($p > 0.05$). Additionally, HIIT intervention was associated with an increase in the cardiopulmonary parameters in both of the groups but there was no difference between the groups ($p > 0.05$). Adolescents with asthma and their healthy peers demonstrated a similar response to the HIIT intervention.

Sidiropoulou et al (27) compared the results of a designed interval soccer program with a standard soccer program in patients with EIBC, a phenotype of asthma. In the study, it was found that the mean value of the reduction rate in the final measurement of FEV_1 was lower than the reduction rate in the initial measurement of FEV_1 for the intervention group ($p < 0.01$). Despite there being no significant difference at the initial six-minute run test distance between groups, after the eighth week, the intervention group had the longer six-min run test distance than the control group ($p < 0.01$).

Two of the studies compared the asthmatic adolescents with healthy peers getting no intervention (20,24). HIIT intervention was found to be associated with significant changes in frequency domain heart rate variability (HRV), but there was no difference in time-domain HRV in the intervention group. In the same study, the total power, low frequency, and normalized low-frequency power and sympathovagal balance increased in the HIIT group by the third month but decreased toward the baseline value in the evaluation made at the sixth month. It has been reported that asthma does not affect HRV baseline or after HIIT (25). Similarly, other parameters like VO_{2max} , FEV_1 , FEF_{25-75} , and body mass index were not different between the groups (21).

Two of the studies compared the asthmatic patients getting an HIIT intervention with the asthmatic controls getting no intervention (20,21). According to the lung function parameters like FEV_1 , FEV_{25-75} , and fractional exhaled nitric oxide, there were no changes

over time (20,21) ($p > 0.05$). Additionally, there was no difference between the groups regarding the asthma symptoms and quality of life (20,21) ($p > 0.05$). An increase in maximal $\text{VO}_{2\text{max}}$ was found in the exercise group when compared to the control group ($p < 0.05$) (22). However, the other study revealed that even though the intervention group showed significant improvement after intervention ($p < 0.05$), there was no difference between the groups for the $\text{VO}_{2\text{max}}$ ($p > 0.05$). Adding to the control and HIIT intervention groups, Toennesen et al. (22) studied the diet and combination of HIIT + diet intervention, however they did not compare the intervention groups with each other. Instead, they compared both intervention groups with the control group.

Discussion

The results of this study, which aimed to evaluate the effects of HIIT/SIT on patients with asthma, showed that the HIIT and SIT protocols, which have been applied increasingly in recent years, are comparable with other treatment methods.

Since the HIIT/SIT protocols and the evaluated parameters on these protocols are very different in the included studies, the effects of HIIT/SIT were reviewed under the headings of acute responses and chronic effects in our study. The protocols applied to the patients and the warm-up periods before these protocols were different from each other. The most preferred method for the warm-up period was the bicycle ergometer and its duration varied between 2 and 10 min. There is evidence that different warm-up protocols can affect the power of the individual (28). Longer duration and higher intensity during warm up can decrease the power production because of the increased physiological stress (29). However, warming up is necessary to regulate metabolic, neural, and psychological mechanisms before the exercise protocols (30). Since the HIIT and SIT protocols include both low intensity and high intensity parts, future studies could focus on the effects of different warm-up protocols on HIIT/SIT.

The prominent protocols for the calculation of HIIT intensity were the use of formulas based on calculating the maximum and resting heart rate, peak power output, and $\text{VO}_{2\text{max}}$ (27). The SIT protocols used in the two included studies, which were led by the same authors, were the same and based on the 30–20–10–5 protocol (22,23). To create an appropriate protocol for asthma patients, future studies comparing different intensities are needed.

Studies evaluating the acute effects of HIIT/SIT protocols on asthmatic patients have been structured differently. When the effects of SIT and CE on EIBC patients were compared, a significant difference was observed only for TSI values (CE more than SIT, $p < 0.05$), but no significant difference was observed when the results were compared with healthy controls. In the only study evaluating the acute effect of HIIT on asthma patients, the results of the HIIT, MICE, and MIIE protocols were compared, and as a result, the MICE protocol was found to be associated with the greatest decline in lung function and interval training protocols were well tolerated for asthmatic adults (26). Moreover, a study done with healthy young men suggested that HIIT protocol has acute beneficial effects on the recovery period after exercise when compared to continuous exercise regimen (31). Recovery is also important for asthmatic patients because it takes a longer amount of time among asthmatic patients when compared to their healthy peers (32). For this reason, future studies could focus on the effects of different HIIT/SIT protocols on the recovery parameters.

Evaluating subjective responses to exercise is interesting in terms of understanding the psychosocial aspect of asthma. Only one study evaluated the subjective responses throughout exercise using validated scales. Although affect and perceived breathlessness were worse during the initial stages of SIT than CE; the differences disappeared by the end of the exercise. Perceived breathlessness may impact affect during the early stages of exercise among those with EIBC. Enjoyment was similar for both exercise types (24). Previous studies have found higher affect (33) and lower enjoyment (34) during HIIT compared to moderate intensity CE. These subjective parameters impact long-term adherence to exercise and may be a significant barrier to the adoption or maintenance of regular physical activity.

The number of reviewed studies evaluating the chronic effects of interval training was higher than the number of studies evaluating the acute effects of interval training. When the chronic effects of HIIT in the EIBC group were compared with the results of EIBC patients who received standard football training within the same age group, a significant increase in six minutes running distance was found at the end of 8 weeks of training. In addition to that, a considerable amount of improvement was found between the baseline and final FEV_1 values of the HIIT group. According to the results of the studies in which healthy adolescents of the same age group were included as the control group, HIIT training

did not provide a significant difference between the groups on VO_{2max} , FEV_1 , FEF_{25-75} , or FVC. A possible reason could be that HIIT has similar effects on both healthy and asthmatic adolescents. This information could be important in allowing the selection of similar exercises for both groups without fearing the negative effects of exercise induced bronchoconstriction.

In addition, only one study reported a considerable difference in frequency domain heart rate variability in the HIIT group. According to the results of the studies in which the control group had asthma patients who did not receive HIIT training, improvements were only observed in VO_{2max} . Nevertheless, one study reported that this improvement was significant enough to make a difference between groups, while the other study reported that the amount of improvement achieved did not differ between groups. However, it should be noted that there is a lack of knowledge about the comparison of the individuals who have asthma but participate in different exercise programs, and future studies are needed.

In general, interval trainings like HIIT and SIT are well tolerated in individuals with asthma and EIBC, and therefore might be used to support pulmonary rehabilitation, although the severity and intensity of the training performed depends on individual goals. Based on the results of the studies examined, we can say that HIIT application is not very effective in short-term results in asthmatic individuals, but more successful results are obtained in long-term applications, especially in VO_{2max} and functional capacity.

Our review highlighted that HIIT protocol has beneficial effects on asthma patients. To our knowledge, it is the first systematic review evaluating the effects of the HIIT protocol on asthma patients.

The limitations of our study are the limited number of databases examined and the inclusion of studies only published in English. In addition, most of the studies included in this review have a risk of bias, and only one study reported that the outcome assessors were blinded. Beyond that, the methodological quality of the studies was not high. The applied protocols and the participant characteristics were heterogeneous therefore these features of the studies can have an impact on the results. Asthma diagnostic criteria were not reported without detail in the studies included in the review, and patients were included in their study according to their physician's diagnosis. It was assumed that physician diagnoses were made according to GINA criteria (35). The number of studies on this subject in the literature was very limited

but recently the subject matter has been gaining more and more traction. Therefore, higher methodological quality and results of more studies are needed.

Conclusion

In conclusion, HIIT and SIT could be beneficial protocols for asthmatic patients. However, high-quality randomized controlled studies with a higher number of participants are needed to better understand the results of HIIT training applied in individuals with asthma.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [GKA], upon reasonable request.

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Inappropriate study type

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Appendix: Excluded studies

Different exercise programs or patient groups

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Only clinical trial number obtained and unpublished

1. Comparison between continuous versus interval exercise training in asthmatic patients. NCT02489383.
2. Atrovent in exercise induced laryngeal obstruction (EILO). NCT02755714.
3. Salbutamol, pharmacogenetics and breathing mechanics. NCT01903785.
4. Cardiopulmonary responses to exposure to ozone and diesel exhaust. NCT01874834.
5. The effect of very low-calorie diet with and without exercise on muscle synthesis in middle-aged overweight male NCT03116256.