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Review article

Exercise and asthma – trigger or treatment?

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ABSTRACT

Exercise is one of the most commonly reported symptom triggers for people with asthma. However, a growing body of evidence indicates that regular exercise and physical activity are associated with improved clinical and patient reported outcomes. In this article, we summarise and consolidate recent original studies evaluating exercise and physical activity profiles in people with asthma and provide an up-to-date perspective concerning the role of exercise training and physical activity promotion in the context of asthma management. To conclude, we identify key unmet needs and provide directions for future research.

1. Introduction

Asthma is a common inflammatory lower airways disease characterised by variable airflow obstruction and bronchial hyperresponsiveness in response to various endogenous and exogenous stimuli, including respiratory viral infection, allergen exposure and vigorous physical exertion [1]. Indeed, exercise as a trigger for breathing difficulty has long been recognised, with the first description provided in the 1st century by Aretaeus the Cappadocia (81-138 AD), who wrote: "If from running, gymnastic exercises, or any other work, the breathing becomes difficult, it is called asthma" [2]. To this day, dyspnoea or wheeze on exertion is considered to be one of the earliest clinical indications of asthma in children, and a hallmark feature of uncontrolled asthma in adults [3].

Physical inactivity is now considered an actual cause of chronic disease and thus the ability to undertake regular exercise and lead an active lifestyle is considered a key requirement for health maintenance [4]. However, over the past decade, it has become increasingly apparent that individuals with asthma typically engage in lower levels of physical activity in comparison to healthy counterparts [5]. This is despite evidence to suggest that exercise has the potential to modulate inflammatory and immune responses [6] and that regular physical activity is associated with improved asthma control, lung function and overall quality of life [7].

The Global Initiative for Asthma (GINA) (an annually updated evidence-based strategy for asthma management and prevention) endorse regular physical activity for people with asthma [1]. Despite this recommendation, there remains a lack of consensus regarding the optimal frequency, intensity, time and type of activity to undertake according to asthma sub-types and severity. This is an important consideration, on the basis that asthma is a complex heterogenous condition (according to disease endotype, sex and age-onset) that responds differently to specific treatment interventions [8].

With this in mind, the purpose of this article is to summarise and consolidate recent studies evaluating exercise and physical activity profiles in people with asthma, and to provide an up-to-date perspective concerning the role of exercise training and physical activity promotion in the context of asthma management. To achieve this objective, original research (i.e., observational studies and randomised controlled trials [RCTs]) published since January 2020 were identified in peer-reviewed literature using search terms such as 'asthma', 'exercise-induced asthma', exercise-induced bronchoconstriction', 'airway hyperresponsiveness' in combination with 'exercise' or 'physical activity' or 'sedentary behaviour'.

2. Functional and exercise capacity in people with asthma

Exercise capacity refers to the ability of the cardiorespiratory system and skeletal muscle to deliver and utilise oxygen and is typically defined as the maximal amount of oxygen an individual can consume ($\dot{V}O_{2\,max}$) or the highest amount of oxygen consumed at peak exercise ($\dot{V}O_{2peak}$). In contrast, functional capacity describes the ability to perform activities of

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daily living that require sustained, submaximal aerobic metabolism [9].

It is common for individuals with asthma, particularly those with severe or difficult-to-treat disease, to report activity limitation, and impaired exercise capacity [10]. It has previously been argued that exercise intolerance in people with asthma may occur due to factors other than cardiovascular limitation, such as persistent airway narrowing (i.e., contributing to impaired oxygen delivery), alveolar wall thickening and/or loss of elastic recoil. However, evidence from studies conducted in physically active or athletic cohorts indicate that well-trained individuals with evidence of moderate expiratory airflow limitation (i.e., FEV_1 <50% predicted) are still capable of achieving a high $\dot{V}O_{2\,max}$ (i.e., >60 mL $kg^{-1}.min^{-1}$) or at least values consistent with healthy non-asthmatic individuals [11].

Since 2020, six observational studies have evaluated functional and/or exercise capacity in people with asthma [12–17] (Table 1). Gianfrancesco et al. [12] assessed functional capacity via the 6-min walk test and Glittre ADL-test (TGlittre) in a large cohort of children and adolescents (aged 7–17 years). The authors reported that children with asthma covered significantly less distance in 6-min (543 ± 60 m) in comparison to healthy controls (618 ± 60 m). Similarly, time to complete the TGlittre was significantly higher in children with asthma vs. controls (3.07 ± 0.38 min vs. 2.62 ± 0.26 min). However, no difference in physical performance was observed between individuals with uncontrolled, partially controlled or controlled asthma.

Malmberg et al. [13] recently published data from the largest evaluation of field-based exercise challenge tests (n = 1120) in children and adolescents to date. The authors reported that exercise-induced bronchoconstriction (EIB) (defined by a fall of 15% or more in FEV_1) was detected in almost one in five individuals. Importantly, those with EIB completed a significantly shorter running distance in 6-min (916 ± 8 m) vs. healthy controls (969 ± 5 m). In-keeping with these findings, Winn et al. [14] observed a significantly reduced shuttle run score in adolescents with asthma (36.5 (10–120) shuttles) compared to controls (43 (8–127) shuttles). In the same study, a lower $\dot{V}O_{2peak}$ relative to body mass was observed in people with asthma in comparison to controls (36.9 ± 8.3 ml kg^{-1} min^{-1} vs. 41.1 ± 7.4 ml kg^{-1} min^{-1}, respectively). However, no difference was observed in absolute $\dot{V}O_{2peak}$ or scaled $\dot{V}O_2$ according to asthma status.

Several recent studies have investigated the mechanisms of exercise intolerance in people with asthma. Lagiou et al. [15] conducted cardiopulmonary exercise testing (CPET) (considered the gold-standard method of assessment to quantify aerobic capacity) in children and adolescents (8–18 years) with mild-moderate asthma and aged-matched controls. The authors noted lower $\dot{V}O_{2peak}$ in children with asthma (36.1 ± 7.4 ml kg^{-1} min^{-1} vs. 41.3 ± 6.7 ml kg^{-1} min^{-1}, respectively). Further, the number of children classified as physically deconditioned was two-fold higher in those with an asthma diagnosis. In-keeping with these findings, Schindel et al. [16] reported impaired exercise capacity in approximately one third of adolescents with severe therapy resistant asthma. However, no association was observed between $\dot{V}O_{2peak}$ and pulmonary function. In adults with mild-to-moderate and severe asthma, Hansen et al. [17] observed comparable fitness (39.3 ± 1.5 ml kg^{-1} min^{-1} and 36.7 ± 1.3 ml kg^{-1} min^{-1}, respectively). However, significant associations were observed between $\dot{V}O_{2\,max}$, body mass index (BMI), airway inflammation and asthma control. Taken together, recent studies provide further evidence to suggest that the degree of airflow limitation does not appear to directly impact exercise capacity. Despite this, low exercise and functional capacity is a common finding in people with asthma, which appears to be related, at least in part, to asthma control, body mass (i.e., overweight or obesity) and/or physical deconditioning.

Table 1
Studies evaluating functional and exercise capacity in people with asthma.

Author (ref)	Cohort	Study design and measurements	Key findings
Gianfrancesco et al. [12]	Children and adolescents with (n = 145) and without (n = 173) asthma (7–17 years)	Cross-sectional study Study endpoints: 6MWT, Glittre-ADL, IPAQ, and daily step count	• Children with asthma had lower functional capacity (6MWT) and took longer to complete the Glittre-ADL test • No difference in 6MWT between uncontrolled, partially controlled and controlled asthma • IPAQ identified 13.9% of people without asthma were sedentary, compared with 26.2% in people with asthma
Malmberg et al. [13]	n = 1120 children (7–16 years)	Retrospective analysis of outdoor free-running tests Study endpoints: spirometry, 6-min running test, ECT and ISO-BMI	• EIB observed in 19% of the cohort • Individuals with EIB ran less distance in 6 min compared to children without EIB • Greater ISO-BMI and being overweight was associated with worse exercise performance
Winn et al. [14]	n = 155 adolescents with mild-to-moderate asthma and n = 461 healthy controls (13 ± 1 years)	Cross sectional study Study endpoints: 20-m shuttle run test, spirometry and 7-day objective physical activity measurements, ACQ, AQLQ and CPET	• Participants with asthma completed fewer shuttle runs vs. controls, 36.5 (10–120) shuttles vs. 43 (8–127) shuttles, respectively • Lower relative $\dot{V}O_{2peak}$ in people with asthma compared to control (36.9 ± 8.3 ml kg^{-1} min^{-1} vs. 41.1 ± 7.4 ml kg^{-1} min^{-1}, respectively. • No difference in absolute $\dot{V}O_{2peak}$ ($l{\cdot}min^{-1}$) and scaled $\dot{V}O_{2peak}$ ($ml{\cdot}kg^{-0.57}$ min^{-1}) according to asthma status • Adolescents with asthma engaged in less physical activity (53.9 ± 23.5 min vs. 60.5 ± 23.6 min) and had higher BMI (22.2 ± 4.8 vs. 20.4 ± 3.7 kg m^{-2}) in comparison to controls
Lagiou et al. [15]	n = 45 children with controlled mild-to-moderate asthma and n =	Cross-sectional study Study endpoints: Physical activity questionnaire,	• $\dot{V}O_{2peak}$ was lower in the asthma group compared to controls (36.1 ± 7.4 ml kg^{-1} min^{-1}

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Table 1 (*continued*)

Author (ref)	Cohort	Study design and measurements	Key findings
	61 age-matched healthy controls (8–18 years)	ACT, spirometry and CPET	vs. 41.3 ± 6.7 ml kg^{-1} min^{-1}, respectively) • Physical deconditioning was observed in 37.8% of children with asthma and in 14.8% of controls • 62.2% of children with asthma and 29.5% of controls categorized as inactive
Schindel et al. [16]	n = 24 children and adolescents with severe therapy resistant asthma (6–18 years)	Cross-sectional study Study endpoints: Spirometry, CPET, ECT	• Seven (29.2%) patients had reduced $\dot{V}O_{2peak}$ (below the 5th percentile), indicating poor physical fitness • Resting heart rate correlated with $\dot{V}O_{2peak}$ (r = −0.40; p = 0.04), V_E/VO_2 (r = 0.46; p = 0.02) and V_E/VCO_2 (r = 0.48; p = 0.01)
Hansen et al. [17]	n = 60 adults (n = 27 with mild-moderate asthma (GINA 1–3) and (n = 33 with severe asthma (GINA 4–5)) (44 ± 16 years)	Prospective follow-up study Study endpoints: Spirometry, FeNO, ACQ, CPET, physical activity via accelerometer, SF-12 and Mini AQLQ	• No significant differences in $\dot{V}O_{2\,max}$ between mild-to-moderate and severe asthma (39.3 ± 1.5 vs. 36.7 ± 1.3 ml kg^{-1} min^{-1}) • No difference in sedentary behaviour (73.5 ± 1.2% vs. 74.7 ± 1.1%) or number of daily steps (9888 ± 641 vs. 9287 ± 572) • $\dot{V}O_{2\,max}$ was significantly correlated with FeNO (r = −0.30, p < 0.05), Short Form-12 Mental Health (r = 0.37, p < 0.05), ACQ (r = −0.35, p < 0.05), and Mini AQLQ (r = 0.36, p < 0.05)

Definitions of abbreviations: 6-min walk test, 6MWT; Glittre Activities of Daily Living test, Glittre-ADL; International Physical Activity Questionnaire, IPAQ; exercise challenge test, ECT; body mass index modified for children, ISO-BMI; exercise-induced bronchoconstriction, EIB; asthma control questionnaire, ACQ; asthma quality of life questionnaires, AQLQ; asthma control test, ACT; cardiopulmonary exercise test, CPET; Global Initiative for Asthma, GINA; Fractional exhaled nitric oxide, FeNO; Short Form-12 Mental Health questionnaire, SF-12; Mini Asthma Quality of Life Questionnaire, Mini AQLQ.

3. Physical activity profiles in people with asthma

Physical activity refers to "any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level" [18]. Historically, most studies evaluating physical activity have primarily relied on patient recall via self-report and/or questionnaires. This approach, however, is now recognised to be susceptible to both over and underestimation and thus objective research grade devices such as pedometers and accelerometers are considered the optimal form of assessment. Alternatively, in-built smartphone pedometers have also recently been shown to provide a reliable estimate of step-based physical activity in this setting [19].

A substantial number of studies have compared habitual physical activity in people with asthma in recent years [12–36] (Table 2). Based on subjective methods of assessment, Gianfrancesco et al. [12] observed that 26% of children with asthma were classified as 'inactive' vs. 14% of children without asthma, when utilising the International Physical Activity Questionnaire (IPAQ). Likewise, Preftoulido et al. [20] reported that only 3% of children with asthma meet 'satisfactory' activity levels (86% classified as sedentary) according to the Godin Leisure-Time Exercise Questionnaire.

Similar findings have also been observed in studies objectively evaluating step-based physical activity. Abdo et al. [21] reported that adults with persistent uncontrolled asthma had a lower daily step count (6614 steps/day) compared to individuals with controlled asthma (7806 steps/day) and those without asthma (7839 steps/day). In support of these findings, Van der Kamp et al. [22] reported that children with EIB appear to complete significantly fewer steps in comparison to healthy counterparts (7994 steps/day vs. 11,444 steps/day, respectively). In contrast, a cross-sectional study by Sousa et al. [23] reported a high daily step count in children with and without asthma (13,379 ± 3837 vs. 14,055 ± 3914 steps/day).

Step-based activity has recently been suggested to be the most relevant assessment of physical activity in people with asthma [37], however, moderate to vigorous physical activity (MVPA) is widely recognised as the intensity required to optimise health and well-being. Indeed, the World Health Organisation currently suggest that children and adolescents aged 5–17 should aim to complete at least an average of 60 min of MVPA per day, whereas adults should engage in at least 150–300 min of MVPA per week, or 75–150 min of vigorous intensity activity per week [38]. Kamps et al. [24] observed that time spent engaging in MVPA in children with asthma remained consistent when comparing periods of controlled and uncontrolled asthma, suggesting that physical activity is not temporarily modified by asthma control. Despite this, other observational studies have reported associations between time spent in MVPA and improved stress [25], sleep quality [26,27], lung function [27] and exacerbations [26]. Further, a recent large birth cohort study by Eijkemans et al. [28] reported that whilst physical activity at early school age was not associated with asthma development later in life, sedentary activity time was associated with worse lung function (i.e., lower FEV_1/FVC ratio). Several recent studies also report an association between BMI, physical activity engagement and asthma control [13,14,29–34]. Indeed, Zhang et al. [35] highlighted that physical activity is associated with improved asthma control in children, particularly in those with a high BMI. Similarly, Abdo et al. [21] observed higher fat and lower muscle mass in adults with persistent uncontrolled asthma.

4. Exercise training interventions

Exercise training refers to a sub-type of physical activity, that consists of planned, structured, and repetitive movement designed to improve or maintain fitness (i.e., ability to participate in sport or undertake specific occupational or daily activities) [18]. The role of exercise for asthma management has been studied in detail over the past two decades. However, the most recent systematic review and meta-analysis on the topic conducted by Hansen et al. [39] concluded that aerobic exercise training (>8 weeks in duration) has the potential to improve asthma control and lung function but has no meaningful effect on markers of airway inflammation. However, the findings from this analysis should be interpreted with caution, given the quality of evidence was graded as 'low' due to substantial heterogeneity and inconsistencies between studies [39]. Since this point, five RCTs [40–44] and one prospective clinical study [45] evaluating exercise training in

Table 2
Studies evaluating physical activity profiles in people with asthma.

Author (ref)	Cohort	Study design and measurements	Key findings
Peftoulidou et al. [20]	n = 44 children with asthma (7–14 years)	Cross sectional study Study endpoints: spirometry, GLTEQ, ACT, and DISABKIDS HRQoL	• GLTEQ revealed that only 3% of the studied population presented satisfactory activity levels, while 86% were sedentary • FEV_1 %pred and physical activity were significantly correlated to the children's HRQoL ($r^2 = 0.55$, $p < 0.001$) and ($r^2 = 0.45$, $p = 0.003$), respectively).
Abdo et al. [21]	n = 106 Individuals with controlled asthma (51 ± 14 years) n = 127 individuals with uncontrolled asthma (53 ± 15 years) n = 84 healthy controls (46 ± 19 years)	Longitudinal cohort study Study endpoints: body composition using bioelectrical impedance analysis, step count, MVPA, and asthma exacerbations	• Individuals with persistent uncontrolled asthma had lower step-based physical activity levels (6614 daily steps, 108 min of MVPA) compared to children with controlled asthma (7806 steps, 133 min of MVPA) and children without asthma (7839 steps or 132 min of MVPA) • Individuals with uncontrolled asthma had increased fat mass and decreased muscle mass compared to those with controlled asthma or healthy controls • Fat mass and muscle mass correlated better with asthma control than body mass index (BMI)
van der Kamp et al. [22]	n = 30 children with asthma	Cross sectional study Study endpoints: step count, MVPA.	• Children with EIB were less physically active compared to children without EIB (7994 steps/day vs. 11,444 steps/day) • Children with EIB engaged in less MVPA compared to children without EIB (117 min/day vs. 170 min/day)
Sousa et al. [23]	n = 130 children with asthma and n = 54 children without asthma (7–12 years)	Cross sectional study Study endpoints: step count, MVPA, questionnaire focusing on barriers to physical activity	• Children with and without asthma had similar total steps (13,379 ± 3837 steps vs 14,055 ± 3914 steps, respectively), number of steps in MVPA (5654 ± 1988 vs. 6025 ± 2058), and time spent in MVPA (46 ± 16 min vs. 50.8 ± 14.7 min) • Children with asthma reported that their condition (19%) and lack of parental encouragement (17.3%) was a key barrier to physical activity engagement
Kamps et al. [24]	n = 30 children with uncontrolled asthma (11 ± 3 years)	Longitudinal survey Study endpoints: seven-day recall questionnaire at baseline and at the time asthma control was achieved, MVPA, PAQ for children	• No difference in MVPA during time spent with controlled and uncontrolled asthma, median (IQR), 53 (35–63) vs. 56 (43–66) mins, respectively • No difference in self-reported physical activity at times of controlled and uncontrolled asthma, PAQ score 7.2 (6.5–11) vs. 7.4 (5.9–10.1), respectively
Kong et al. [25]	n = 4020 adolescents with asthma (15 ± 2 years) and n = 53,283 adolescents without asthma, (aged 15 ± 2 years)	Cross sectional survey Study endpoints: age, sex, BMI, and high school grade, smoking status, alcohol consumption, economic status, academic, health-related physical activity included moderate activity and resistance exercise	• Adolescents with asthma had higher stress levels than those without asthma; however, vigorous physical activity was associated with lower stress • OR of stress was 20% higher in the asthma group vs. non-asthma group ($P < 0.05$), however, the OR for the asthma group with vigorous physical activity versus non-vigorous physical activity was 0.70 (95% CI: 0.57–0.86)
Powers et al. [26]	n = 147 urban children with persistent asthma (7–9 years)	Cross sectional Study endpoints: lung function, MVPA, sleep (accelerometery) and asthma exacerbations	• Greater decline in daily MVPA was associated with lower OR of exacerbation • Greater number of sleep awakenings were associated with greater declines in daily MVPA
D'Angelo et al. [27]	n = 97 urban children with persistent asthma (7–9 years)	Prospective, observational study Study endpoints: lung function, sleep and MVPA	• More frequent night-time awakenings were associated with less time spent engaging in MVPA

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Table 2 (*continued*)

Author (ref)	Cohort	Study design and measurements	Key findings
			• Greater lung function was associated with higher levels of MVPA for children with better sleep efficiency and fewer night-time awakenings, and lower levels of MVPA for children with poorer sleep efficiency and more frequent night-time awakenings
Eijkemans et al. [28]	n = 1838 children (6–10 years)	Prospective, observational study Study endpoints: physical activity (questionnaire), spirometry, and accelerometery.	• Physical activity was not associated with reported asthma nor lung function • Accelerometery data showed that being just 1 h less active per day was associated with lower FEV_1/FVC
Koinis-Mitchell et al. [29]	n = 142 urban children with persistent asthma (7–9 years)	Longitudinal, observational study Study endpoints: ACT, MVPA, caregiver perceptions, BMI, neighbourhood safety	• MVPA was significantly below recommended guidelines. On average, participants met physical activity guidelines on 30.2% of days • Lower BMI associated with better asthma status and higher MVPA
Clarke et al. [30]	n = 310 parents of children and young people with asthma and without asthma n = 311 (10–16 years)	Cross sectional survey Study endpoints: parental feeding, parental attitudes toward child exercise, child eating, child activity level and asthma control and BMI	• Children living with asthma had a significantly higher BMIz (BMI standardised for weight and age) score, were significantly more likely to emotionally overeat and desired to drink more than their peers without asthma • Parental attitudes toward feeding and exercise, and child eating and exercise behaviours, between families may help to explain the increased obesity risk for children with asthma
Eisenberg et al. [31]	n = 147 urban children with persistent asthma (7–9 years)	Study design: Cross sectional study Study endpoints: subjective child/caregiver daily report of asthma symptoms and caregiver fears about their child's asthma, lung function, ECT, BMI	• Greater proportion of normal-weight children reported asthma symptoms compared to over-weight/obese children • Few children had confirmed EIB compared to the proportion of caregivers who endorsed exercise as a dangerous trigger for asthma
Freeman et al. [32]	n = 62 individuals with difficult asthma (39–65 years)	Cross sectional study Study endpoints: ETBQ, BMI, lung function, blood eosinophil count, FeNO, ACQ6, Nijmegen, SNOT-22 questionnaire and asthma exacerbations	• Participants had high BMI, impaired lung function and poor symptom control • Perceived barriers to exercise score was significantly correlated with increased asthma symptoms, anxiety, and depression, poor quality of life and number of rescue oral steroid courses in the past 12-months
Ricketts et al. [33]	n = 25 mild-moderate (healthy weight); n = 25 mild-moderate (overweight); n = 25 difficult-to-treat asthma (overweight) (18–80 years)	Study design: Cross sectional Study endpoints: physical activity and MVPA	• Inactivity was significantly higher, and light physical activity, MVPA, intensity gradient and average acceleration were significantly lower in difficult-to-treat overweight asthma versus mild-to-moderate healthy weight asthma and mild-to-moderate overweight asthma
Yourell et al. [34]	n = 125,164 adolescents	Cross sectional survey Study endpoints: physical activity, weight, height, BMI	• Overweight/obese adolescents with asthma had significantly lower physical activity levels compared to adolescents with asthma and healthy weight • Overweight/obese adolescents had significantly lower levels of physical activity regardless of asthma status
Zhang et al. [35]	n = 303 children with asthma (5–14 years)	Cross-sectional survey Study endpoints: physical activity, asthma control and BMI	• Physical activity is associated with improved asthma control, particularly in children with a high BMI
Abdo et al. [36]	n = 128 adults with mild to moderate asthma (35–56 years); n = 140 adults with severe asthma (50–65 years); n = 69 healthy controls (25–63 years)	Cross sectional analysis Study endpoints: small airway dysfunction, BMI, smoking status, type 2 inflammation (sputum and blood eosinophils, fractional exhaled nitric oxide), systemic inflammation (high-sensitivity C-	• Small airway dysfunction was between 75 and 90% in adults with severe asthma and 53–64% in mild to moderate asthma • Severe small airway dysfunction was associated with poor asthma control and lower physical activity

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Table 2 (*continued*)

Author (ref)	Cohort	Study design and measurements	Key findings
		reactive protein), asthma control, and physical activity via accelerometery	

Definitions of abbreviations: Godin Leisure-Time Exercise Questionnaire, GLTEQ; asthma control test, ACT; DISABKIDS health-related quality of life questionnaire, DISABKIDS HRQoL; moderate to vigorous physical activity, MVPA; exercise-induced bronchoconstriction, EIB; body mass index, BMI; physical activity questionnaires, PAQ; forced expiratory volume in 1 s/forced vital capacity ratio, FEV_1/FVC; exercise challenge test, ECT; exercise therapy burden questionnaire, ETBQ; sinonasal outcome test, SNOT-22; asthma control questionnaire, ACQ.

people with asthma have been published (Table 3).

Sanz-Santiago et al. [40] conducted a 12-week RCT comparing combined aerobic and resistance training (3 days per week for 60 min) vs. usual care in children and adolescents with mild-to-moderate asthma reporting exercise-related respiratory symptoms. The authors reported significantly greater improvements in $\dot{V}O_{2peak}$, cardiorespiratory test duration and skeletal muscle strength in the intervention group. However, no differences were observed in lung function, asthma control, and quality of life between groups. Winn et al. [41] conducted a RCT to evaluate the effectiveness of a 6-month high-intensity interval training (HIIT) intervention (30-min, 3 times per week, 10–30s bouts at >90% age-predicted maximum heart rate with equal rest) in adolescents with and without asthma. HIIT led to significant improvements in maximal aerobic fitness in those with and without asthma, however no change in sub-maximal parameters of aerobic fitness, lung function, or quality of life was observed pre-to-post intervention. Collectively, recent studies in children and adolescents with asthma indicate that combined aerobic and resistance-based exercise and/or HIIT are safe, well-tolerated and effective methods to promote strength and aerobic fitness adaptations.

The potential therapeutic benefit of exercise in adults with asthma has also been underlined by a recent series of studies [42–45]. Evaristo et al. [42] conducted a 12-week RCT comparing the effects of aerobic training vs. breathing exercises on asthma control, quality of life, exercise capacity, and airway inflammation in adults with moderate-to-severe asthma. The authors reported that aerobic training and breathing exercises induce similar effects in asthma control, psychological distress, and airway inflammation in the short-term, however, those in the exercise training arm were significantly more likely to experience improved asthma control at 3-month follow-up.

Scott et al. [43] conducted an eloquent study evaluating the effect of acute moderate and vigorous intensity exercise on airway inflammation in adults with physician diagnosed asthma. Importantly, a significant reduction in sputum eosinophil count and sputum percentage was observed following moderate intensity exercise. However, markers of airway inflammation remained unchanged following acute vigorous intensity exercise. Interestingly, the authors reported that the impact of moderate intensity exercise appears to vary by asthma sub-type, with a significantly greater anti-inflammatory effect observed in those with eosinophilic asthma (type-2 high asthma). da Silva et al. [44] provided further evidence to support the potential benefits of HIIT in adults with moderate-to-severe asthma. Indeed, data from a 12-week training intervention indicate that constant-load exercise and HIIT lead to comparable improvements in aerobic fitness, however, HIIT induces a significantly greater reduction in dyspnoea and perception of fatigue.

Finally, a detailed mechanistic study by Moraes-Ferreira et al. [45] evaluated the effects of supervised aerobic training (moderate intensity treadmill running at 50–60% heart rate reserve) over a 12-week period in adults with intermittent and mild asthma. Exercise training significantly increased levels of anti-inflammatory cytokines and antifibrotic mediators in exhaled breath condensate and significantly reduced the levels of pro-inflammatory cytokines and profibrotic markers. Further, total inflammatory cells in sputum, eosinophils and macrophages, blood eosinophils, lymphocytes and airway inflammation were significantly reduced post-intervention. The authors therefore concluded that moderate intensity aerobic exercise has the potential to modulate chronic airway inflammation and remodelling mediators in people with intermittent and mild asthma.

5. Physical activity promotion interventions

Studies evaluating physical activity promotion in the context of chronic airways disease have historically focussed on people with COPD, with a recent systematic review and meta-analysis highlighting a paucity of evidence in other respiratory conditions characterised by exertional dyspnoea and activity limitation [46]. However, four RCTs have recently been published specifically evaluating the efficacy of physical activity promotion in people with asthma [47–50] (Table 4).

Freitas et al. [47] evaluated an 8-week multicomponent behaviour change intervention designed to improve physical activity in adults with moderate-severe disease. Specifically, the intervention consisted of a weekly 40-min face-to-face counselling session, supported by a workbook and commercially available physical activity monitor. The findings from this study suggest that the intervention led to a significant improvement in asthma control and physical activity (increased daily step count and time spent in MVPA), improved sleep efficiency, reduced sedentary time and exacerbations) in comparison to usual care. In support of these findings, a study conducted by Passos et al. [48] observed an increase in daily steps, MVPA, symptom free days and improved sleep quality in adults with moderate to severe asthma following a similar behavioural intervention. It is important to note that for both studies, intervention and control groups received disease specific education post-baseline assessment, suggesting that action planning with individualised or personalised goals (i.e., established behaviour change techniques recognised to promote health-enhancing behaviours) appear to be more effective at improving physical activity and reducing symptom burden and exacerbation frequency.

Hiles et al. [49] conducted a novel 16-week feasibility RCT designed to explore the impact of a yoga and mindfulness programme on health-related quality of life, asthma control, physical activity breathlessness and inflammation in adults with severe asthma. The intervention consisted of two supervised 75-min group yoga and mindfulness classes per week in addition to usual care. The findings from this study indicate that whilst yoga is feasible and beneficial to health-related quality of life in people with severe asthma, all other parameters, including daily physical activity, remained unchanged. Finally, Nyenhuis et al. [50] assessed the acceptability and feasibility of a culturally tailored physical activity promotion intervention designed specifically for low-active urban black women with uncontrolled asthma (i.e., asthma education, Fitbit, monthly group sessions, text messaging, individual step goals and a study manual). In total, 92% remained in the intervention and 76% completed the 24-week outcome assessment. Importantly, a greater proportion of patients receiving the intervention had controlled asthma compared to usual care at 24-weeks and a clinically significant improvement in quality of life was observed post intervention.

6. Summary: current perspectives and future challenges

The role of exercise and physical activity as an adjunct therapy for asthma management has received considerable attention from the scientific and respiratory medicine community over the past three years. Whilst exercise is one of the most commonly reported symptom triggers in individuals with underlying asthma, recent studies support the concept that exercise is associated with improved clinical and patient reported outcomes and should thus be considered and discussed during routine asthma review. However, as this review highlights, children and

Table 3
Studies evaluating exercise-training interventions in people with asthma.

Author (ref)	Cohort	Study design and measurements	Key findings
Sanz-Santiago et al. [40]	n = 53 children and adolescents (12 ± 3 years) with mild-to-moderate asthma reporting exercise-related respiratory symptoms	12-week RCT Intervention: combined aerobic and resistance training 3 days per week for 60 min (n = 25) Control: usual care (n = 28) Study endpoints: cardiorespiratory fitness, muscle strength, lung function, QoL, asthma control and functional assessment 3-months post intervention	• Lung function, asthma control, quality of life and functional assessment was not different between groups post intervention • Ventilatory equivalent for oxygen consumption, peak oxygen consumption, test duration and skeletal muscle strength significantly greater post intervention
Winn et al. [41]	n = 616 adolescents (n = 155 with asthma) (13 ± 1 years)	6-month RCT Intervention: school-based HIIT (30 min, 3 times per week, 10–30s bouts at >90% age-predicted maximum heart rate with equal rest) (n = 171 without asthma; n = 50 asthma) Control: usual activities (n = 290 without asthma; n = 105 asthma) Study endpoints: baseline, mid-intervention, post-intervention, and 3-month follow-up, measurements for 20-m shuttle run, BMI, lung function, ACQ and quality of life Sub-group: n = 33 controls and n = 36 with asthma) completed an incremental ramp exercise test	• No significant difference was observed in any parameter of aerobic fitness at any time point between adolescents with and without asthma • Adolescents with asthma were characterised by greater BMI • HIIT resulted in a significant improvement in maximal aerobic fitness but no change in sub-maximal parameters of aerobic fitness, lung function, or quality of life irrespective of asthma status
Evaristo et al. [42]	n = 54 adults (30–65 years with moderate-to-severe persistent asthma	12-week RCT Intervention: aerobic exercise training group (n = 29) vs. breathing exercise group (n = 25) 24 sessions (twice per week lasting 40 min in duration) Control: N/A Study endpoints: asthma control (ACQ and AQLQ), asthma symptom free days, airway inflammation, exercise capacity, psychological distress, daily physical activity, lung function	• Aerobic training and breathing exercises induce similar effects on asthma control, psychological distress, and airway inflammation • Aerobic training is 2.6 times more likely to experience clinical improvement (ACQ >0.5) at 3-month follow-up
Scott et al. [43]	n = 56 physically inactive adults with asthma (33 ± 10 years)	RCT Intervention: acute bout of 45 min moderate exercise vs. acute bout of 30 min vigorous exercise Control: usual activities Study endpoints: induced sputum and blood samples collected at baseline and 4 h post-intervention	• Moderate exercise induced a significant reduction in sputum eosinophil count and sputum %eosinophils relative to control. Vigorous exercise had no effect on airway inflammation • Anti-inflammatory effects of moderate exercise were greatest in participants with eosinophilic asthma (i.e., reductions in sputum eosinophils and increases in plasma IL-1ra compared to participants with non-eosinophilic asthma) • Vigorous exercise induced a systemic pro-inflammatory response in those with eosinophilic asthma, indicated by an increase in serum IL-5 and IL-1β; however, this had no effect on airway inflammation
da Silva et al. [44]	n = 55 adults with moderate-to-severe asthma (20–59 years)	12-week RCT CLE (n = 27) (40 min cycling, twice per week, at 70% maximal watts) HIIT (n = 28) (40 min cycling, twice per week, starting at 80% and increasing to 140% maximal watts) Study endpoints: ACQ, VO2peak, HRQoL, physical activity levels (PAL accelerometer), HADS, dyspnoea, systemic and airway inflammation	• CLE and HIIT resulted in similar improvements in aerobic fitness • HIIT resulted in lower dyspnoea and fatigue perception scores and higher physical activity level than the CLE intervention and clinical improvements in the psychosocial distress • HIIT group achieved a minimal clinically important difference in asthma symptoms • No change in the systemic and airway inflammation
Moraes-Ferreira et al. [45]	n = 21 adults with intermittent and mild asthma	3-month prospective clinical study Intervention: moderate intensity supervised aerobic exercise performed 3 times per week Control: N/A Study endpoints: FeNO, inflammatory and fibrotic mediators in EBC, induced sputum and bloods. Lung function and breathing mechanics. Functional capacity via 6MWT	• Aerobic exercise increased the levels of anti-inflammatory cytokines and of antifibrotic mediators in EBC • Aerobic training significantly reduced the levels of pro-inflammatory cytokines and of profibrotic markers • Total inflammatory cells in sputum, eosinophils and macrophages, blood eosinophils, lymphocytes and FeNO were reduced post intervention

Definitions of abbreviations: randomised controlled trial, RCT; quality of life, QoL; high-intensity interval training, HIIT; body mass index, BMI; asthma control questionnaire, ACQ; asthma quality of life questionnaire, AQLQ; constant load exercise, CLE; fractional of exhaled nitric oxide, FeNO; exhaled breath condensate, EBC.

adults living with asthma often have lower functional capacity and undertake less habitual physical activity in comparison to healthy age and sex matched counterparts. This is despite convincing evidence that exercise elicits comparable physiological adaptations in those with and without asthma [11] and the fact very few asthma-related deaths or serious adverse events have occurred in association with sports participation or vigorous physical exertion over the past three decades [51].

The reasons underpinning exercise avoidance and physical inactivity in people with asthma remain to be fully established, however, likely relate, at least in part, to disease specific barriers including fear of provoking symptoms and severe exacerbation [32]. It is therefore important moving forward that people with asthma (and parents or guardians of children and adolescents with asthma) are educated and receive reassurance that the disease specific and health-related benefits of undertaking exercise outweigh the relatively low risks. It is also important that evidence-based guidelines are developed to enable clinicians and healthcare professionals to provide tailored/personalised exercise prescription.

In this respect, further high-quality RCTs with adequate statistical power are required to explore inflammatory and immune responses to

Table 4
Studies evaluating physical activity promotion interventions in people with asthma.

Author (ref)	Cohort	Study design and measurements	Key findings
Freitas et al. [47]	Moderate-severe asthma(n = 51)	8-week, assessor-blinded, RCT Intervention: usual care and disease-specific education + 40-min face-to-face weekly counselling session (supported by workbook and a commercially available physical activity monitor) Control: usual care and disease-specific education (n = 26) Study endpoints: ACQ, physical activity, sedentary time and sleep quality, AQLQ, HADS. Exacerbations were recorded 12-months prior to and throughout the intervention	• Physical activity promotion improved asthma control, daily step count, sleep efficiency and reduced sedentary time. • Exacerbations during the intervention were significantly lower (27%) in the intervention group vs. control (60%) • Time spent in moderate-intensity physical activity was inversely associated with change in ACQ • Higher proportion of individuals in the intervention group reported a reduction in anxiety symptoms
Passos et al. [48]	Physically inactive adults with moderate-severe asthma (n = 49) (18–60 years)	8-week RCT Intervention: educational program post baseline assessment, usual care (pharmacological treatment) and eight 40 min weekly face-to-face behavioural sessions (n = 24) Control: educational program post baseline assessment, usual care (pharmacological treatment) (n = 25) Study endpoints: sleep quality, PADL, ACQ, AQLQ, HADS	• Intervention led to increased daily steps, moderate to vigorous physical activity, asthma symptom free days and improved sleep efficiency • Higher proportion of participants in the intervention group had improved sleep quality, asthma-related quality of life and a reduction in anxiety symptoms
Hiles et al. [49]	Severe asthma(n = 24)58% female (67 ± 9 years)	16-week RCT Intervention: 75-min group yoga and mindfulness class twice per week (and physical activity monitor) in addition to usual care (n = 15) Control: minimal physical activity goal setting supported through telephone contact with an exercise physiologist (and physical activity monitor) in addition to usual care (n = 9) Study endpoints: HRQoL, ACQ, physical activity, breathlessness, and inflammation. Face-to-face qualitative interviews were conducted to determine acceptability	• Yoga had a greater improvement in HRQoL in comparison to the control group • No differences observed in other outcome measures • Intervention deemed acceptable. Key barriers and facilitators included social connection, setting, addressing breathing and asthma symptoms, mindset, and the intersection of different elements
Nyenhuis et al. [50]	Black females with uncontrolled asthma (n = 53) (18–70 years)	24-week RCT feasibility study Intervention: asthma education, Fitbit, monthly group sessions, text messages, individual step goals, and study manual (n = 25) Control: enhanced usual care (asthma education and Fitbit) (n = 28) Study endpoints: feasibility and acceptability of intervention, ACQ, QoL, health care use, and physical activity levels	• 92% remained in the intervention (23 of 25) and 76% completed the 24-week outcome assessment • Intervention satisfaction and individual components were high at 24-weeks, however no difference in ACQ was observed between groups • Higher proportion receiving the intervention had controlled asthma compared usual care at 24-weeks • Clinically significant improvements in QoL were found in the intervention group at 24-weeks

Definitions of abbreviations: randomised controlled trial, RCT; asthma control questionnaire, ACQ; asthma quality of life questionnaire, AQLQ; hospital anxiety depression scale, HADS; personal activities of daily living, PADL; health-related quality of life, HRQoL; quality of life, QoL.

acute and chronic aerobic ± resistance-based exercise to elucidate underpinning mechanisms according to specific clinical phenotypes (e.g., obese asthma) with consideration for common co-morbidities (i.e., laryngeal dysfunction and breathing pattern disorder) and disease endotypes (i.e., type-2 high vs. type-2 low asthma). The incidence and impact of extrapulmonary manifestations that potentially contribute to activity limitation (e.g., skeletal muscle weakness/dysfunction) in people with asthma also requires further research.

It is also important to acknowledge that athletic individuals at the upper end of the activity spectrum appear to be at heightened risk of developing asthma-related issues [52,53] and therefore longitudinal population-based studies evaluating the dose-response relationship between exercise engagement and asthma control remains a key unmet need. In addition, real-world observational studies are required to determine how improved asthma control in response to established and emerging pharmacological therapies translates to improved exercise capacity and physical activity engagement. Finally, developing patient specific physical activity promotion interventions (with consideration for age, sex, ethnicity and culture) to facilitate long-term behaviour change/habit formation, remains an important avenue for future research.

CRediT authorship contribution statement

Oliver J. Price: contributed equally to the submitted work. **Andrew J. Simpson:** contributed equally to the submitted work.

Declaration of competing interest

OJP and AJS have no conflict of interest in respect to the submitted work.

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References

[1] Global Initiative for Asthma (GINA). www.ginasthma.org/gina-reports/. (Accessed 10 December 2022).
[2] F. Adams, The Extant Works of Aretaeus: the Cappadocian, Sydenham Society, 1856.
[3] O.J. Price, E.S. Walsted, M. Bonini, J.D. Brannan, V. Bougault, K.H. Carlsen, et al., Diagnosis and management of allergy and respiratory disorders in sport: an EAACI task force position paper, Allergy 77 (10) (2022) 2909–2923.
[4] P.T. Katzmarzyk, C. Friedenreich, E.J. Shiroma, I.M. Lee, Physical inactivity and non-communicable disease burden in low-income, middle-income and high-income countries, Br. J. Sports Med. 56 (2) (2022) 101–106.
[5] M.M. Kuder, M. Clark, C. Cooley, V. Prieto-Centurion, A. Danley, I. Riley, et al., A systematic review of the effect of physical activity on asthma outcomes, J. Allergy Clin. Immunol. Pract. 9 (9) (2021) 3407, 21.e8.
[6] A.T. Freeman, K.J. Staples, T.M.A. Wilkinson, Defining a role for exercise training in the management of asthma, Eur. Respir. Rev. 29 (156) (2020).
[7] L. Cordova-Rivera, P.G. Gibson, P.A. Gardiner, V.M. McDonald, A systematic review of associations of physical activity and sedentary time with asthma outcomes, J. Allergy Clin. Immunol. Pract. 6 (6) (2018) 1968, 81.e2.
[8] J. Lötvall, C.A. Akdis, L.B. Bacharier, L. Bjermer, T.B. Casale, A. Custovic, et al., Asthma endotypes: a new approach to classification of disease entities within the asthma syndrome, J. Allergy Clin. Immunol. 127 (2) (2011) 355–360.
[9] R. Arena, J. Myers, M.A. Williams, M. Gulati, P. Kligfield, G.J. Balady, et al., Assessment of functional capacity in clinical and research settings: a scientific statement from the American heart association committee on exercise, rehabilitation, and prevention of the council on clinical cardiology and the council on cardiovascular nursing, Circulation 116 (3) (2007) 329–343.
[10] L. Cordova-Rivera, P.G. Gibson, P.A. Gardiner, H. Powell, V.M. McDonald, Physical activity and exercise capacity in severe asthma: key clinical associations, J. Allergy Clin. Immunol. Pract. 6 (3) (2018) 814–822.
[11] O.J. Price, J.H. Hull, V. Backer, M. Hostrup, L. Ansley, The impact of exercise-induced bronchoconstriction on athletic performance: a systematic review, Sports Med. 44 (12) (2014) 1749–1761.
[12] L. Gianfrancesco, A.P.G. Malheiro, N.Y. Matsunaga, M.S. Oliveira, M.B. Grotta, A. M. Morcillo, et al., Are there differences in the physical activity level and functional capacity among children and adolescents with and without asthma? J. Pediatr. 97 (3) (2021) 295–301.
[13] M. Malmberg, L.P. Malmberg, A.S. Pelkonen, M.J. Mäkelä, A. Kotaniemi-Syrjänen, Overweight and exercise-induced bronchoconstriction - is there a link? Pediatr. Allergy Immunol. 32 (5) (2021) 992–998.
[14] C.O.N. Winn, K.A. Mackintosh, W.T.B. Eddolls, G. Stratton, A.M. Wilson, G. A. Davies, et al., Asthma, body mass and aerobic fitness, the relationship in adolescents: the exercise for asthma with commando Joe's® (X4ACJ) trial, J. Sports Sci. 38 (3) (2020) 288–295.
[15] O. Lagiou, S. Fouzas, D. Lykouras, X. Sinopidis, A. Karatza, K. Karkoulias, et al., Exercise limitation in children and adolescents with mild-to-moderate asthma, J. Asthma Allergy 15 (2022) 89–98.
[16] C.S. Schindel, D. Schiwe, J.P. Heinzmann-Filho, M.F. Gheller, N.E. Campos, P. M. Pitrez, et al., Determinants of exercise capacity in children and adolescents with severe therapy-resistant asthma, J. Asthma 59 (1) (2022) 115–125.
[17] N.B. Hansen, M. Henriksen, C.H. Dall, S. Vest, L. Larsen, C. Suppli Ulrik, et al., Physical activity, physical capacity and sedentary behavior among asthma patients, Eur Clin Respir J 9 (1) (2022), 2101599.
[18] C.J. Caspersen, K.E. Powell, G.M. Christenson, Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research, Publ. Health Rep. 100 (2) (1985) 126–131.
[19] C. Reilly, A. Stavropoulos-Kalinoglou, I. Clifton, J. McKenna, D. Peckham, O. J. Price, Smartphone pedometers in adults with asthma: a practical approach to physical activity assessment? A pilot validation study, J. Asthma 59 (5) (2022) 967–975.
[20] P. Peftoulidou, M. Gioulvanidou, E.A. Chrysochoou, E. Hatziagorou, Physical activity and quality of life in children with well-controlled asthma, J. Asthma (2022) 1–11.
[21] M. Abdo, B. Waschki, A.M. Kirsten, F. Trinkmann, H. Biller, C. Herzmann, et al., Persistent uncontrolled asthma: long-term impact on physical activity and body composition, J. Asthma Allergy 14 (2021) 229–240.
[22] M.R. van der Kamp, B.J. Thio, M. Tabak, H.J. Hermens, J. Driessen, J. van der Palen, Does exercise-induced bronchoconstriction affect physical activity patterns in asthmatic children? J. Child Health Care 24 (4) (2020) 577–588.
[23] A.W. Sousa, A.L.B. Cabral, M.A. Martins, C.R.F. Carvalho, Barriers to daily life physical activities for Brazilian children with asthma: a cross-sectional study, J. Asthma 57 (6) (2020) 575–583.
[24] A.W.A. Kamps, A.F. Clevering, B.W. Nieuwdorp, W.W. de Weger, L. van Lente, Asthma control is not associated with physical activity level in children with asthma during regular follow-up, J. Asthma 59 (10) (2022) 1933–1939.
[25] S. Kong, W.Y. So, S. Jang, The association between vigorous physical activity and stress in adolescents with asthma, Int. J. Environ. Res. Publ. Health 18 (7) (2021).
[26] K.E. Powers, E. Jelalian, S. Dunsiger, M. Farrow, L.G. Miranda, P. Mitchell, et al., Physical activity, lung function, and sleep outcomes in urban children with asthma, Pediatr. Pulmonol. 56 (7) (2021) 1938–1945.
[27] C. D'Angelo, E. Jelalian, S. Dunsiger, R. Noga, S.J. Kopel, J. Boergers, et al., Physical activity among urban children with asthma: does sleep matter? J. Clin. Psychol. Med. Settings 29 (3) (2022) 666–677.
[28] M. Eijkemans, M. Mommers, T. Remmers, J.M.T. Draaisma, M.H. Prins, C. Thijs, Physical activity and asthma development in childhood: prospective birth cohort study, Pediatr. Pulmonol. 55 (1) (2020) 76–82.
[29] D. Koinis-Mitchell, S.J. Kopel, S. Dunsiger, E.L. McQuaid, L.G. Miranda, P. Mitchell, et al., Asthma and physical activity in urban children, J. Pediatr. Psychol. 46 (8) (2021) 970–979.
[30] R. Clarke, G. Heath, P. Nagakumar, H. Pattison, C. Farrow, Parental feeding, child eating and physical activity: differences in children living with and without asthma, Int. J. Environ. Res. Publ. Health 18 (7) (2021).
[31] S.R. Eisenberg, E. Jelalian, M. Farrow, S.J. Kopel, N. Vehse, P. Mitchell, et al., Perceptions of asthma and exercise, and associations with weight status and asthma morbidity in urban children, Acad Pediatr 20 (1) (2020) 55–62.
[32] A.T. Freeman, D. Hill, C. Newell, H. Moyses, A. Azim, D. Knight, et al., Patient perceived barriers to exercise and their clinical associations in difficult asthma, Asthma Res Pract 6 (2020) 5.
[33] H.C. Ricketts, D.S. Buchan, F. Steffensen, R. Chaudhuri, J.S. Baker, D.C. Cowan, Physical activity levels in asthma: relationship with disease severity, body mass index and novel accelerometer-derived metrics, J. Asthma 60 (4) (2023) 824–834, https://doi.org/10.1080/02770903.2022.2102037.
[34] J. Yourell, N. Koskela-Staples, J. Doty, D.A. Fedele, Risk and protective factors for physical activity engagement among adolescents with comorbid asthma and obesity, J. Pediatr. Psychol. 48 (1) (2023) 39–50, https://doi.org/10.1093/jpepsy/jsac061.
[35] Z. Zhang, L. Wang, J. Wang, Y. Jia, M. Yi, O. Chen, Physical activity and childhood asthma control: mediation and moderation role of body mass index, Pediatr. Pulmonol. 56 (12) (2021) 3720–3727.
[36] M. Abdo, F. Trinkmann, A.M. Kirsten, F. Pedersen, C. Herzmann, E. von Mutius, et al., Small airway dysfunction links asthma severity with physical activity and symptom control, J. Allergy Clin. Immunol. Pract. 9 (9) (2021) 3359–33568.e1.
[37] C. Rist, N. Karlsson, S. Necander, C.A. Da Silva, Physical activity end-points in trials of chronic respiratory diseases: summary of evidence, ERJ Open Res 8 (1) (2022).
[38] World Health Organisation. https://www.who.int/news-room/fact-sheets/detail/physical-activity. https://www.who.int/news-room/fact-sheets/detail/physical-activity2022.
[39] E.S.H. Hansen, A. Pitzner-Fabricius, L.L. Toennesen, H.K. Rasmusen, M. Hostrup, Y. Hellsten, et al., Effect of aerobic exercise training on asthma in adults: a systematic review and meta-analysis, Eur. Respir. J. 56 (1) (2020).
[40] V. Sanz-Santiago, I. Diez-Vega, E. Santana-Sosa, C. Lopez Nuevo, T. Iturriaga Ramirez, F.M. Vendrusculo, et al., Effect of a combined exercise program on physical fitness, lung function, and quality of life in patients with controlled asthma and exercise symptoms: a randomized controlled trial, Pediatr. Pulmonol. 55 (7) (2020) 1608–1616.
[41] C.O.N. Winn, K.A. Mackintosh, W.T.B. Eddolls, G. Stratton, A.M. Wilson, M. A. McNarry, et al., Effect of high-intensity interval training in adolescents with asthma: the eXercise for Asthma with Commando Joe's® (X4ACJ) trial, J Sport Health Sci 10 (4) (2021) 488–498.
[42] K.B. Evaristo, F.A.R. Mendes, M.G. Saccomani, A. Cukier, R.M. Carvalho-Pinto, M. R. Rodrigues, et al., Effects of aerobic training versus breathing exercises on asthma control: a randomized trial, J. Allergy Clin. Immunol. Pract. 8 (9) (2020) 2989, 96.e4.
[43] H.A. Scott, L.G. Wood, E.J. Williams, N. Weaver, J.W. Upham, Comparing the effect of acute moderate and vigorous exercise on inflammation in adults with asthma: a randomized controlled trial, Ann Am Thorac Soc 19 (11) (2022) 1848–1855.
[44] R. Aparecido da Silva, P.G. Leite Rocco, R. Stelmach, L. Mara da Silva Oliveira, M. N. Sato, A. Cukier, et al., Constant-load exercise versus high-intensity interval training on aerobic fitness in moderate-to-severe asthma: a randomized controlled trial, J. Allergy Clin. Immunol. Pract. 10 (10) (2022) 2596, 604.e7.
[45] R. Moraes-Ferreira, M.A.R. Brandao-Rangel, T.G. Gibson-Alves, A. Silva-Reis, V. H. Souza-Palmeira, H.C. Aquino-Santos, et al., Physical training reduces chronic airway inflammation and mediators of remodeling in asthma, Oxid. Med. Cell. Longev. 2022 (2022), 5037553.
[46] C. Reilly, J. Sails, A. Stavropoulos-Kalinoglou, R.J. Birch, J. McKenna, I.J. Clifton, et al., Physical activity promotion interventions in chronic airways disease: a systematic review and meta-analysis, Eur. Respir. Rev. (2022) (in press).
[47] P.D. Freitas, N.F.P. Passos, R.M. Carvalho-Pinto, M.A. Martins, V. Cavalheri, K. Hill, et al., A behavior change intervention aimed at increasing physical activity improves clinical control in adults with asthma: a randomized controlled trial, Chest 159 (1) (2021) 46–57.
[48] N.F. Passos, P.D. Freitas, R.M. Carvalho-Pinto, A. Cukier, C.R.F. Carvalho, Increased physical activity reduces sleep disturbances in asthma: a randomized controlled trial, Respirology 28 (1) (2022) 20–28.
[49] S.A. Hiles, P.D. Urroz, P.G. Gibson, A. Bogdanovs, V.M. McDonald, A feasibility randomised controlled trial of Novel Activity Management in severe ASthma-Tailored Exercise (NAMASTE): yoga and mindfulness, BMC Pulm. Med. 21 (1) (2021) 71.
[50] S.M. Nyenhuis, N. Shah, H. Kim, D.X. Marquez, J. Wilbur, L.K. Sharp, The feasibility of a lifestyle physical activity intervention for black women with asthma, J. Allergy Clin. Immunol. Pract. 9 (12) (2021) 4312–43121.e2.

[51] O.J. Price, K.L. Kucera, H.M. Price, J.A. Drezner, A. Menzies-Gow, J.H. Hull, Asthma-related sudden death in athletes: a retrospective analysis of the US NCCSIR database (1982-2018), Eur. Respir. J. 58 (1) (2021).
[52] O.J. Price, N. Sewry, M. Schwellnus, V. Backer, T. Reier-Nilsen, V. Bougault, et al., Prevalence of lower airway dysfunction in athletes: a systematic review and meta-analysis by a subgroup of the IOC consensus group on 'acute respiratory illness in the athlete, Br. J. Sports Med. 56 (4) (2022) 213–222.
[53] O.J. Price, L. Ansley, A. Menzies-Gow, P. Cullinan, J.H. Hull, Airway dysfunction in elite athletes–an occupational lung disease? Allergy 68 (11) (2013) 1343–1352.