

Physiotherapy improves symptoms of exercise-induced laryngeal obstruction in young elite athletes: a case series

Liv-Jorunn Kolnes,¹ Maria Vollsæter,^{2,3} Ola Drange Røksund,^{2,4} Trine Stensrud⁵

To cite: Kolnes L-J, Vollsæter M, Røksund OD, et al. Physiotherapy improves symptoms of exercise-induced laryngeal obstruction in young elite athletes: a case series. *BMJ Open Sport & Exercise Medicine* 2019;5:e000487. doi:10.1136/bmjsem-2018-000487

Accepted 18 December 2018

ABSTRACT

Objective A constricted, upper chest breathing pattern and postural dealignments habitually accompany exercise-induced laryngeal obstruction (EILO), but there are few effective treatments for athletes presenting with EILO. This case series was conducted to examine whether physiotherapy based on principles from the Norwegian psychomotor physiotherapy (NPMP) combined with elements of cognitive behavioural therapy can reduce laryngeal distress in athletes with EILO.

Methods Respiratory distress in four subjects was examined by interview prior to a physiotherapeutic body examination. Inappropriate laryngeal movements during exercise were measured by the continuous laryngoscopy exercise test, lung function was measured by flow-volume curves, and non-specific bronchial hyper-responsiveness was measured by a methacholine provocation test. History of asthma, allergy and respiratory symptoms was recorded in a modified AQUA₂₀₀₈ questionnaire. Parasympathetic activity was assessed by pupillometry. All data were gathered before and after 5 months of intervention.

Results Physiotherapy based on the principles from NPMP improved breathing problems in athletes with EILO. All athletes had less respiratory distress, improved lung function at rest and reduced inappropriate laryngeal movements during maximal exercise.

Conclusion A diaphragmatic breathing pattern, a more balanced tension in respiratory muscles, and sound cervical alignment and stability may help to reduce adverse stress on the respiratory system and optimise the function of the larynx during high-intensity exercise. Our results suggest that understanding and management of EILO need to extend beyond structures located in the anterior neck and include factors influencing the whole respiratory system.

INTRODUCTION

Adolescent athletes frequently present with inspiratory symptoms such as dyspnoea, throat tightness and wheezing during high-intensity exercise or competition. The symptomatology is consistent with exercise-induced laryngeal obstruction (EILO), where a narrowing at the glottic and/or supraglottic level develops in otherwise healthy individuals during physical exertion.^{1–5} EILO should not be misdiagnosed as exercised-induced

What are the new findings

- ▶ Physiotherapy treatment with the aim of facilitating a more functional pattern of breathing and cervical posture in individuals with exercise-induced laryngeal obstruction (EILO) results in the following:
 - A reduction in experienced respiratory distress during high-intensity exertion.
 - A reduction in inappropriate laryngeal movements during maximal effort, according to continuous laryngoscopy exercise tests prephysiotherapy and postphysiotherapy treatment.
 - Improved respiratory efficiency, increased minute ventilation and tidal volume.
 - Subjects being able to train and compete longer at higher intensity before experiencing symptoms of EILO.
 - Subjects having a sense of being more in control of their symptoms, if and when they occur.
 - Subjects having increased awareness of bodily and social features that may disrupt their breathing and an improved ability to take action to avoid stressors.

How might it impact clinical practice in the future

- ▶ To optimise treatment, athletes with EILO should undergo a full body assessment to identify the pattern of breathing and any postural dealignments that may negatively affect breathing.
- ▶ Clinicians should focus on normalising the breathing and postural dealignments in the first phase of intervention to see if this reduces the problem.
- ▶ The findings emphasise the need to identify and reflect on everyday stressors in athletes with EILO to create a healthy balance between training, competition, school/study, recovery, nutritional demands, sleep, and personal and social life.

asthma, which is localised at the bronchial level. The prevalence of EILO in the general adolescent population and in athletes is estimated to be 7%^{6 7} and 35%,³ respectively, and EILO appears over-represented among athletes involved in activities characterised by high-intensity intervals.⁸ The aetiology of



© Author(s) (or their employer(s)) 2019. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Department of Health and Care Sciences, University of Tromsø - The Arctic University of Norway, Tromsø, Norway

²Department of Pediatrics, Haukeland University Hospital, Bergen, Norway

³Department of Clinical Science, University of Bergen, Bergen, Norway

⁴The Faculty of Health and Social Sciences, Western Norway University of Applied Sciences, Bergen, Norway

⁵Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway

Correspondence to

Dr Liv-Jorunn Kolnes; l.j.kolnes@uit.no

EILO is not yet fully understood, and a number of theories have been proposed, including hypersensitivity,^{9–11} structural abnormalities,^{12–15} increased autonomic activation^{16 17} and psychological causes.¹⁸

There are few effective treatments for athletes with EILO. Treatment recommendations for exercise-induced closure at the glottic level include interventions used to manage vocal cord dysfunction, such as speech therapy,^{19–23} cognitive behavioural therapy²⁴ and psychotherapy.^{25 26} Surgery is considered in cases of severe supraglottic obstruction.^{27–29} To date, few studies have examined whether physiotherapy may be an appropriate treatment for EILO. Building on findings from singing and voice therapy and the understanding that divergences in bodily functions and structures are mutually related, it has been suggested that a dysfunctional breathing pattern, postural dealignments and a forward head posture (FHP) may trigger laryngeal tightness during high-intensity exercise.³⁰ In this case series, we examine whether a specialised physiotherapy approach—Norwegian psychomotor physiotherapy (NPMP)—targeting postural dimensions and the breathing pattern, in combination with elements of cognitive behavioural therapy and modification of training intensity, can help reduce laryngeal tightness in athletes presenting with EILO.

METHODS

Subjects and study design

This study included four otherwise healthy adolescent athletes (15–17 years) referred for physiotherapy for treatment of EILO at a sports medicine clinic between January and July 2017. The athletes were competing at national or regional level in their respective sports (biathlon, cross-country skiing, orienteering, football, and track and field), with some competing in two sports. Symptom duration prior to inclusion was 1.5–3 years. Case 2 had been diagnosed with asthma in childhood, but none of the subjects had current doctor-diagnosed asthma. Three subjects had previously used antiasthmatic medication with no effect. Participant characteristics are summarised in table 1.

Respiratory distress was explored using a semistructured interview, and bodily restriction was evaluated by physiotherapeutic body assessment. Dynamic changes in laryngeal structures were graded using a continuous

laryngoscopy exercise (CLE) test. Lung function, bronchial hyper-responsiveness (BHR) and parasympathetic activity were also measured. Data were gathered before and after 5 months of physiotherapy.

Respiratory distress

Self-reported symptoms were explored in a semistructured interview conducted by the physiotherapist prior to physical examination and then again after the intervention. The interview was based on the questionnaire developed by Røksund.³¹ The subjects detailed their medical history, other diagnoses and symptoms, level of engagement in sport, exercise-related breathing symptoms, and the impact of breathing difficulties on their daily life activities.

Body examination

A physiotherapeutic body examination assessed bodily restriction and imbalances in the subjects.³² Breathing, posture, muscle tension, and function in terms of bodily flexibility and ability to relax were evaluated and considered in relation to how they may contribute to difficulties with inhalation during exercise (see table 2).

Laryngeal movements during exercise

Laryngeal movements were measured using the CLE test, which was developed to monitor the larynx during a maximal cardiopulmonary exercise test. The test permits visualisation of inappropriate movements of laryngeal structures during all phases of the respiratory cycle, via the use of a fiberoptic scope projecting through the nose towards the back of the throat and coupled to a video camera.^{5 33 34}

The scoring system assesses medial rotation of the aryepiglottic folds and the cuneiform tubercles (ie, supraglottic structures) and adduction of the vocal folds (ie, glottic structures).³⁴ The movements are graded from neutral (0) to a maximum score (3) at two points during the running session: at moderate effort during the first part of the test and at maximal exertion briefly before exhaustion. Four subscores from 0 to 3 reflecting glottic and supraglottic adduction at moderate (A and B) and maximal effort (C and D) are established, and the sum score E (E=A+B+C+D) determined.³⁴ Two experienced testers conducted the CLE test.

Table 1 Age, training volume, respiratory symptoms, history of doctor-diagnosed allergy or asthma, and history of antiasthmatic medication for the four cases at baseline

Participants, male (♂) and female (♀)	Age (years)	Training volume (days/week)	Training volume (hours/week)	Respiratory symptoms (yes/no)	Allergy (yes/no)	Asthma (yes/no)	Antiasthmatic medication (yes/no)
1 (♂)	14	4–6	8–10	Yes	No	No	Yes
2 (♀)	17	7	10–12	Yes	Yes	Yes	Yes
3 (♀)	16	7	12–14	Yes	No	No	Yes
4 (♀)	15	4–6	10–12	Yes	Yes	No	No

Table 2 Findings from the physiotherapy examination pre- treatment and post-treatment

Case	Pretreatment	Post-treatment
1 (♂)	<p>Respiration: Constricted. Upper chest pattern. Respiratory movement during inhalation and exhalation barely observable. Observable respiratory responses.</p> <p>Posture: Standing position seems stiff. Minor postural dealignments (ie, protracted shoulders, forward head posture [FHP], asymmetry in thorax during forward flexion of the back).</p> <p>Muscle: Increased tension in the muscles of the whole body, particularly in respiratory muscles (including muscles of the anterior and posterior neck).</p> <p>Function: Whole body tension. Reduced ability to relax and to let go during passive movements of the extremities, particularly when in supine position.</p> <p>Other: Extremely ticklish. Trains and competes in two sports.</p>	<p>Respiration: Less constricted. Respiratory movement to a greater extent abdominal. Distinct respiratory responses during treatment sessions.</p> <p>Posture: Good postural alignment. Standing position seems more flexible.</p> <p>Muscle: Increased tension remains in some respiratory muscles.</p> <p>Function: Less tense in the body as a whole. Manages to relax in supine position.</p> <p>Other: Less ticklish. Trains and competes in two sports.</p>
2 (♀)	<p>Respiration: Constricted. Upper chest pattern. Observable respiratory responses.</p> <p>Posture: Minor postural dealignments (eg, FHP).</p> <p>Muscle: Increased tension in the muscles of the whole body, particularly in respiratory muscles.</p> <p>Function: Whole body tension. Reduced ability to relax and let go during passive movements of the extremities.</p> <p>Other: Ambitious. Extremely high training intensities and volume in recent years. Also concerned about performing well at school, aspires to achieve top grades.</p>	<p>Respiration: Less constricted. Respiratory movement to a greater extent abdominal. Distinct respiratory responses during treatment sessions.</p> <p>Posture: Good postural alignment, including cervical posture.</p> <p>Muscle: Increased tension in muscles in large parts of the body, respiratory muscles included.</p> <p>Function: More relaxed in the whole body. Allows physiotherapist to perform passive movements of all extremities.</p> <p>Other: Has moderated training volume and intensity.</p>
3 (♀)	<p>Respiration: Constricted. Upper chest pattern. Observable respiratory responses.</p> <p>Posture: Standing position seems stiff (hyperextended knees, contracted quadriceps muscles). Minor postural dealignments (increased extension of the lower back and anteriorly tilted pelvis).</p> <p>Muscle: Increased tension in the muscles of the whole body particularly in respiratory muscles, in the neck and in the gluteal region. Describes stiffness in the neck and shoulders during exercise.</p> <p>Function: Tense in the whole body. Reduced ability to relax and let go in passive movements of the extremities. Ticklish.</p> <p>Other: Ambitious and extremely busy in everyday life. Active in two sports at high levels. Little time for recovery/rest.</p>	<p>Respiration: Less constricted. Respiratory movement to a greater extent abdominal. Distinct respiratory responses during treatment sessions.</p> <p>Posture: Seems more flexible in standing position.</p> <p>Muscle: Increased tension in the muscles in large parts of the body, respiratory muscles included.</p> <p>Function: More relaxed in the whole body. Physiotherapist can perform passive movements of all extremities.</p> <p>Other: Has decided to concentrate on one sport, which provides her with more time for rest and recovery. Takes a day off from training more often than before.</p>
4 (♀)	<p>Respiration: Constricted. Barely observable respiratory movements. Modest respiratory responses.</p> <p>Posture: Increased extension of the lower back, anteriorly tilted pelvis, enhanced thoracic kyphosis, protracted shoulders, FHP. Increased extension of cervical spine in standing and supine position. Feet slightly pronated in standing.</p> <p>Muscle: Increased tension in all respiratory and upper neck muscles.</p> <p>Function: Reduced ability to let go in passive movements of the extremities.</p> <p>Other: Tendency to press tongue towards the palate. Being an athlete, feels pressure about performing in physical education (PE) classes. PE teacher not familiar with actions she needs to take to avoid triggering breathing problems.</p>	<p>Respiration: Less constricted. Respiratory movement now more visible and abdominal. Still only modest respiratory responses during treatment sessions.</p> <p>Posture: Good postural alignment. Physiotherapist has provided strength and extension exercises to counteract thoracic kyphosis and FHP. Still tendency to FHP.</p> <p>Muscle: Moderately enhanced tension in respiratory muscles.</p> <p>Function: More relaxed in the whole body during the sessions.</p> <p>Other: Breathing becomes deeper when she maintains the cervical spine in neutral position and when she does not press tongue towards the roof of her mouth.</p>

Measure of lung function and BHR

Lung function was measured by maximal expiratory flow-volume curves (MasterScreen Pneumo spirometer; CareFusion, Hochberg, Germany) according to current guidelines.³⁵ Forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1) were measured. Predicted values are according to Quanjer *et al.*³⁶

Non-specific BHR was measured by tidal breathing using the inspiration-triggered Aerosol Provocation System Jäger (Würzburg, Germany), and methacholine was inhaled in doubling doses until FEV_1 decreased 20% from baseline, as measured after inhalation of nebulised isotonic saline. The provocation dose of methacholine causing 20% reduction in FEV_1 (PD_{20met}) was determined by linear interpolation on the semilogarithmic dose-response curve. All tests were performed according to current guidelines from the American Thoracic Society.³⁷

A modified allergy questionnaire for athletes (AQUA₂₀₀₈), developed and validated for the assessment of asthma, allergy and other respiratory symptoms in athletes participating in the summer Olympic Games in Beijing in 2008,³⁸ was administered to record history of or present asthma, allergy and exercise-induced asthma-like symptoms.

Parasympathetic activity

Autonomic regulation was assessed by pupillometry according to Filipe *et al.*³⁹ A portable infrared PLR-200 pupillometer (NeuroOptics, California, USA) stimulated the eye with a light flash (180 nm peak wavelength) and measured the diameter (mm) of the pupil at the peak of the constriction.³⁹ Pupil constriction (%) was used as a measure of parasympathetic activity. One pupil light

response curve was recorded for each eye in each subject and the mean values were calculated.

Intervention

The physiotherapy treatment was based on findings from the body examination of each subject (table 3) and consisted of massage, stretching and exercises focusing on releasing tension in respiratory and laryngeal muscles. The aims were to change the breathing towards more abdominal respiration and improve postural dealignments (in particular of the cervical spine). In addition, treatment involved releasing tension in other parts of the body where muscle tension was increased. The intervention was based on the main principles of the NPMP approach, as well as on the elements of cognitive-behavioural therapy. NPMP is described in more detail elsewhere.³² The method differs from traditional physiotherapy in that it understands the body to be a functionally integrated entity, such that (1) constriction in one part of the body influences the steadiness of the entire body and (2) that lived experiences and feelings are embedded within the body.^{32 40} The assessment of the breathing pattern is of particular interest, as it is assumed that emotional or physical stress over time may constrict the breathing and cause tension in bodily function and movements.³⁰ The approach has therapeutic potential for individuals presenting with complications associated with the respiratory system. The intervention also draws on insights from the field of clinical voice therapy and vocal pedagogy, indicating that the optimal laryngeal position for laryngeal movements is a neutral or lower vertical position, as opposed to an elevated position, which may induce spasms and tightness in the larynx,

Table 3 Reported respiratory exercise-related symptoms prepsychomotor and postpsychomotor physiotherapy combined with cognitive behavioural elements, on a scale from 1 to 5: 1=never; 2=sometimes; 3=often; 4=regularly; 5=always

Statements/Cases	Case 1		Case 2		Case 3		Case 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
I have breathing problems during low-intensity training.	1	1	1	1	1	1	1	1
I have breathing problems during high-intensity training or sporting competitions.	5	5	4	1	3	2	5	3
The breathing problems are worse during competitions compared with high-intensity training.	5	1	5	1	4	2	4	4
I feel tightness in my chest.	1	1	1	2	1	1	2	1
I become dizzy/nauseous and feel I am fainting.	4	2	4	1	2	1	3	1
The breathing problems begin quickly.	1	2	3	1	4	2	3	2
The breathing problems end quickly.	1	5	3	1	4	2	4	3
I hear abnormal sounds/wheezing.	5	3	5	1	1	1	5	4
I become anxious when breathing problems occur.	5	2	2	–	2	2	–	2
I stop doing high-intensity training due to the breathing problems.	4	5	2	1	3	2	2	2
The breathing problems continue when I stop or rest from the activity.	3	1	5	1	5	2	2	1
I can control the breathing problems when they occur.	3	5	3	5	2	4	1	2

and that cervical stability and balanced tension in the muscles of the neck are necessary to optimise laryngeal function and airflow.^{41–48}

Adolescent athletes aspiring to elite-level performance are exposed to multiple stressors as they strive to balance training, competition, school, recovery, nutritional demands, sleep, and personal and social life.⁴⁹ This situation was also the case for the subjects in our study. The sessions explored how management of everyday life situations might contribute to overall stress levels and examined the need to adjust priorities (eg, more time for recovery and sleep, fewer competitions) to avoid triggering inspiratory symptoms. The subjects were also encouraged to reflect over dysfunctional movements prior to the occurrence of symptoms and how to avoid these. For instance, when training intensity increased, some reported a tendency to elevate their shoulders, a behaviour associated with an upward breathing movement that triggers a simultaneous hyperextension of the cervical spine and which induces stress in the laryngeal area.

Low-intensity exercises did not trigger inspiratory symptoms and subjects were allowed to continue these as normal. To allow recovery of laryngeal structures and to avoid triggering laryngeal obstruction, the subjects were advised to engage in interval sessions with moderate intensities, rather than high-intensity and anaerobic threshold intervals, for the first 3–4 weeks of treatment. As tension in the laryngeal area decreased over the first few weeks and breathing became less high costal, the subjects were encouraged to gradually increase training intensity while avoiding provoking symptoms of EILO. Each participant received 10–12 physiotherapy sessions lasting about 50–60 min over the course of 5 months. The sessions included a conversation prior to the physical treatment. During the first 3–4 weeks, the clients had physiotherapy sessions once a week, and then later every 2–4 weeks.

RESULTS

Respiratory distress

The interviews revealed the subjective experience of respiratory symptoms in each participant and the changes post-treatment.

Case 1

Case 1 reported having experienced inspiratory breathing problems during moderate-intensity and high-intensity training, particularly throughout intervals but occasionally also during strength training, for the past 2 years. The difficulties prevented him from competing at a higher level and from training as much as he wished. After the intervention, he confirmed that the breathing problems now occur only occasionally and are less prominent; he tolerates higher intensities during training and competition, and can train longer without invoking respiratory difficulties. He also feels more capable of adjusting his training intensity to a level where breathing problems

are avoided. He believes that mental strain and stress are important triggers for his breathing problems.

Case 2

Case 2 described having experienced inspiratory breathing problems during moderate-intensity and high-intensity training or competition for the past year. Although her breathing difficulties have not affected her engagement in sport as such, they have reduced her training quality. She stated that her breathing problems are triggered by mental strain and stress. After the intervention, she reports being able to tolerate higher training and competition intensity without respiratory distress, and feels that she has fully recovered.

Case 3

Case 3 reported having experienced problems with inspiration during moderate-intensity and high-intensity training and competition during the past 18 months. She stated that she would like to have trained in higher intensity zones and competed more often, but that the respiratory problems prevented her from doing so. After the intervention, she reports that the breathing problems are less prominent; she can train longer and at higher intensities without symptoms, and the episodes are more sporadic and less distressing. Inspiration problems rarely arise, but may occur if she begins an interval or competition at too high intensity. If she begins at a more moderate pace, she manages to remain in control and to avoid symptoms and complete the activity satisfactorily. She sees mental strain and stress to be triggers for her breathing problems.

Case 4

Case 4 described having experienced breathing problems during high-intensity training and competition for the past 3 years. The problems have prevented her from taking part in sport as much as she wants to and from competing at her preferred level. Postintervention, she reports that her breathing problems are reduced, that episodes are not as distressing as before, and that she tolerates higher training and competition intensity without respiratory distress. She believes this change is associated with being more in control of the situation, as she is able to adjust training intensity to a level where she avoids symptoms. She recognises mental strain and stress, and swimming classes at school, to be triggers for her breathing problems.

Table 3 shows how the participants score specific statements regarding their breathing problems on a scale from 1 to 5. Overall, the inspiratory difficulties that occurred during high-intensity training or competition pretreatment were less prominent after the intervention. All participants reported that it was easier to inhale during physical exertion, that throat tightness was reduced, that they could train longer and with higher intensities before experiencing any symptoms, and also that they felt more in control of the symptoms if and when they occurred.

While patients with EILO typically report audible wheeze, three of the four participants reported reduced wheezing during high-intensity exercise post-treatment. All subjects (except for case 2, post-treatment) recognise mental strain and stress to be triggers for their breathing problems, both pretreatment and post-treatment.

Bodily assessments

At the outset, the body examination of the participants revealed a constricted and upper chest pattern of breathing, postural dealignments (typically hyperextension in the neck and/or FHP), increased tension in the muscles of the whole body, including respiratory muscles (eg, scalenes, sternocleidomastoids, omohyoids, upper trapezius, intercostals), and a reduced bodily flexibility and ability to relax. 'Respiratory responses', an NPMP concept that offers some indication as to whether or not the breathing pattern is changeable, were positive in all cases. Post-treatment, the participants' breathing was less restricted, the respiratory movement to a greater extent abdominal, and posture in general and neck posture in particular were more aligned. Also, all participants seemed more able to relax (eg, capable of letting go during passive movements of the upper and lower extremities), despite sustained tension in the muscles of large parts of the body and in the muscles of the upper body commonly associated with the function of breathing. Further details are provided in table 2.

Laryngeal movements

The CLE test, measuring laryngeal movements at moderate and maximal running effort, showed a reduction in paradoxical laryngeal movements during maximal effort post-treatment in all subjects. Inappropriate laryngeal movements were not apparent during moderate efforts. Table 4 shows the test results for movements at the glottic and supraglottic levels at moderate (A and B) and maximal (C and D) effort pretreatment and post-treatment for each subject, as well as the sum score (E). A CLE sum score ≤ 1 is considered a normal laryngeal response.

Lung function, BHR and exercise test results

Table 5 shows increased lung function in terms of FVC and FEV₁ and a tendency towards improved minute ventilation and tidal volume post-treatment in cases 1, 3 and 4. Case 2 had a moderate BHR pretreatment (PD_{20met}: 3.57 μ mol) and was still bronchial hyper-responsive (PD_{20met}: 1.68 μ mol) post-treatment. The maximal oxygen uptake (VO_{2max}) was stable in all cases pretreatment and post-treatment, except for case 2 where VO_{2max} and tidal volume were significantly reduced post-treatment.

Parasympathetic activity

No changes in parasympathetic variables were observed from pretreatment to post-treatment (results not shown).

DISCUSSION

The findings of this case series suggest that physiotherapy based on the principles of NPMP combined with elements of cognitive behavioural therapy can reduce symptoms in athletes with EILO. The four participants report a reduction in inspiratory problems during high-intensity training and/or competition, they are capable of training longer and with higher intensity before detecting any symptoms, and they feel more in control of the symptoms if and when they occur. The subjects also seem more relaxed in their bodies, their breathing is less restricted, and the respiratory movement is more abdominal post-treatment. Further, postural alignment in general, and cervical posture in particular, has improved, and the participants are more aware of the need to keep the neck in a neutral position to optimise air passage through the larynx during strenuous physical exertion. In addition, the results from the CLE test show a post-treatment reduction in inappropriate laryngeal movements during maximal effort in all cases. Finally, all cases increased their FVC and FEV₁, and there was a tendency towards improved minute ventilation and tidal volume post-treatment. The length of the intervention (5 months) was important given that readjustment of bodily restrictions (including respiratory) and habitual patterns, as well as

Table 4 Measures of laryngeal movements during moderate and maximal exertions by the continuous laryngoscopy exercise test. Maximum possible sum score at maximal effort is 6 (C+D).

Case	Pre-treatment test: movements at moderate (A and B) and maximal (C and D) effort					Post-treatment test: movements at moderate (A and B) and maximal (C and D) effort				
	Glottic adduction*		Supraglottic medial rotation†			Glottic adduction		Supraglottic medial rotation		
	A	C	B	D	Sum (E)	A	C	B	D	Sum (E)
1	0	2	0	2	4	0	1	0	1	2
2	0	2	0	1	3	0	0	0	1	1
3	0	1	0	1	2	0	0	0	1	1
4	0	2	0	1	3	0	1	0	1	2

The maximum possible sum score at maximal effort is 6 (C+D).

*Of the vocal folds.

†Of aryepiglottic folds and cuneiform tubercles.

Table 5 Lung function (FVC and FEV₁), bronchial hyper-responsiveness (PD_{20met}), VO_{2max}, VE_{max}, TV_{max}, HR_{max}, RER_{max}, running time and running distance before and after the 5-month treatment of the four subjects

Cases, male (♂) and female (♀)	FVC (L) (%pred)	FEV ₁ (L) (%pred)	PD _{20met} (µmol)	VO _{2max} (mL/kg/min)	VE _{max} (L/min)	TV _{max} (L)	HR _{max} (beats/min)	RER _{max} (CO ₂ /VO ₂)	Running time (min)	Running distance (m)
1 (♂)	Pre 4.74 (95)	4.40 (107)	11.22	52.3	135	2.87	179	1.16	11.21	800
	Post 5.14 (101)	4.71 (113)	12.54	53.2	138	3.07	183	1.24	12.49	1015
2 (♀)	Pre* 4.94 (139)	3.71 (123)	3.57	58.7	109	2.73	181	1.04	12.19	930
	Post 5.12 (141)	3.85 (125)	1.68	49.8	105	2.23	182	1.23	12.28	965
3 (♀)	Pre 4.18 (92)	3.89 (102)	10.10	54.4	128	2.06	189	1.21	13.01	1043
	Post 4.57 (100)	4.11 (107)	8.56	54.4	133	2.29	199	1.24	13.22	1096
4 (♀)	Pre 4.29 (94)	4.18 (109)	>16.01	37.4	66	2.13	192	1.23	9.20	563
	Post 4.59 (101)	4.40 (115)	>16.01	37.0	80	2.24	197	1.26	10.01	641

*The physiological test results pretest are most likely due to equipment measure error.

FEV₁, forced expiratory volume in 1 s; FVC, forced vital capacity; HR_{max}, maximal heart rate; PD_{20met}, provocation dose of methacholine causing 20% reduction in FEV₁ from baseline; RER_{max}, maximal respiratory exchange ratio; TV_{max}, maximal tidal volume; VE_{max}, maximal minute ventilation; VO_{2max}, maximal oxygen uptake.

altering of the person's physical and emotional habitual reactions and integration of such changes in the individual, inevitably takes time.⁵⁰

How might NPMP reduce respiratory symptoms?

These findings may reflect a more functional breathing pattern, including a reduction of inspiratory constriction and more efficient neural communication within the entire respiratory system post-treatment. The constricted and high thoracic breathing pattern observed preintervention, accompanied by elevation of the upper thorax and shoulders to enable upward expansion of the trunk to compensate for lack of abdominal breathing, may underpin the increased tension in respiratory muscles identified in all cases. In conjunction with the extrinsic laryngeal muscles serving to support and maintain the larynx in a neutral position within the trachea, all respiratory muscles may become stressed and functionally weakened during compensation for the lack of diaphragmatic breathing. Thus, the effort required to support the respiratory process, work and oxygen cost of breathing are likely to increase such that contractile and metabolic functions of the respiratory muscles become impaired, as frequently seen in conditions where dyspnoea is a prevalent symptom.⁵¹ Over time, the increased mechanical loading on respiratory muscles may also generate conflicting forces and a sensitisation at the laryngeal level. Compensatory postural adaptations such as dealignment of the cervical spine, changes in thoracic configuration and an FHP (comprising an elevated position of the larynx) may well follow.³⁰ The phrenic nerve, which receives innervation from the C3–C5 and courses within the fascia of the anterior scalene, supplies both motor and sensory nerve fibres to the diaphragm. A chronically overloaded scalene, as frequently seen in FHP, may disrupt the function of the phrenic nerve. A frequent response to such continued compression is reduction of sensory and motor drives, which may subsequently cause changes to the tissue the nerve supplies.⁵²

In line with the results from the CLE tests showing a reduction in inappropriate laryngeal movements, it may be that a diaphragmatic breathing pattern, a more balanced tension in respiratory muscles, and sound cervical alignment and stability help to minimise stress on the respiratory system and optimise the function of the larynx during high-intensity exercise. The tendency towards improvements in lung function, minute ventilation and tidal volume is also consistent with a more functional breathing pattern and the participants' subjective experience of improved breathing.

Increasing the participants' awareness of circumstances that may disrupt their breathing and improving their ability to take action to avoid symptoms (eg, through postural modifications, reduction of everyday stressors) may also have had a positive impact on their respiration. Whereas symptoms used to force the study participants to stop exercising or competing, their improved ability to prevent symptom intensification by

modifying their training and competition intensity seems to have increased their feeling of being in charge of the situation, and reduced the anxiousness and mental stress associated with respiratory distress.

The lack of changes in parasympathetic variables may be attributable to the measurement procedure, as Stang *et al.*⁵³ recently suggested. Afferent fibres in the vagal nerve mediate constriction of smooth muscles of the upper and lower airways, as well as bradycardia. This may explain why there is a link between regulation of the heart and the airways, but not the pupils.⁵³

Strengths and limitations

Conducting a study where athletes with EILO undergo physiotherapy treatment over such a long time (5 months) is demanding, and to our knowledge this study is the first of its kind. Although the number of participants was small, a key strength of this study is the diversity of methodological approaches employed, including objectively measured variables from the lung function test, recordings from the CLE test, qualitative data from the semistructured interviews and clinical body assessments. The physiotherapist's continuous clinical observation of the athletes from pretreatment to post-treatment may also be considered a particular strength of the study. All results point towards reduced respiratory distress during high-intensity exertion in the subjects.

While generalisation of data gathered from these four young athletes is not possible, this pilot study may form the basis for further investigations of physiotherapy treatment efficacy in athletes suffering from EILO. It may be valuable, for instance, to video-record athletes with EILO during training and competition. This would offer rich data about breathing pattern and cervical alignment during physical exertion, and could possibly help the athletes to change their breathing patterns by enabling them to study their own bodily habits/adaptations more closely. Given the presumed importance of abdominal breathing for optimal function of the larynx,³⁰ a more comprehensive study of diaphragmatic movements, or the lack of such, in individuals with EILO would also be worthwhile.

Despite the CLE test being widely used, the scoring system may have weaknesses in terms of reliability in classifying the severity of EILO, as the classification can vary depending on the experience and skills of the testers.^{54 55}

CONCLUSION

The present study indicates that physiotherapy treatment based on the principles from NPMP improves breathing problems in athletes with EILO. All athletes had less respiratory distress, improved lung function at rest and reduced inappropriate laryngeal movements during maximal exercise. We suggest that a diaphragmatic breathing pattern, a more balanced tension in respiratory muscles, and sound cervical alignment and stability are key components in reducing adverse stress on the respiratory system and optimising laryngeal function

during high-intensity exercise. Our results support the view that the understanding and management of EILO need to extend beyond structures located in the anterior neck and include factors influencing the whole respiratory system.

Acknowledgements The authors are grateful for some financial support from the foundation for promoting sports medicine and sports physiotherapy in Norway, and are indebted to the athletes who agreed to participate in the study.

Contributors L-JK has made substantial contributions to conception and design, coordination of the paper, and drafting and revising the manuscript before submission. She has performed the physical examinations and physiotherapy treatment. TS has made substantial contribution to conception and design, and drafting and revising the manuscript. She measured lung function and bronchial hyper-responsiveness. MV and ODR conducted the CLE test, and have made substantial contribution to conception and design and revising of the manuscript. All authors have given their approval of the final version to be submitted.

Funding The study has received some financial support from the foundation for promoting sports medicine and sports physiotherapy in Norway.

Competing interests None declared.

Patient consent for publication Obtained.

Ethics approval The study received ethical approval from the Regional Ethics Committee of Southern Norway (REC, 2016/1723).

Provenance and peer review Not commissioned; internally peer reviewed.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

REFERENCES

- Hall A, Thomas M, Sandhu G, *et al.* Exercise-induced laryngeal obstruction: a common and overlooked cause of exertional breathlessness. *Br J Gen Pract* 2016;66:e683–e685.
- Hull JH, Hull PJ, Parsons JP, *et al.* Approach to the diagnosis and management of suspected exercise-induced bronchoconstriction by primary care physicians. *BMC Pulm Med* 2009;9:29.
- Nielsen EW, Hull JH, Backer V. High prevalence of exercise-induced laryngeal obstruction in athletes. *Med Sci Sports Exerc* 2013;45:2030–5.
- Røksund OD, Heimdal JH, Clemm H, *et al.* Exercise inducible laryngeal obstruction: diagnostics and management. *Paediatr Respir Rev* 2017;21:86–94.
- Røksund OD, Heimdal JH, Olofsson J, *et al.* Larynx during exercise: the unexplored bottleneck of the airways. *Eur Arch Otorhinolaryngol* 2015;272:2101–9.
- Christensen PM, Thomsen SF, Rasmussen N, *et al.* Exercise-induced laryngeal obstructions: prevalence and symptoms in the general public. *Eur Arch Otorhinolaryngol* 2011;268:1313–9.
- Johansson H, Norlander K, Berglund L, *et al.* Prevalence of exercise-induced bronchoconstriction and exercise-induced laryngeal obstruction in a general adolescent population. *Thorax* 2015;70:57–63.
- Rundell K, Weiss PMD. Exercise-induced bronchoconstriction and vocal cord dysfunction: two sides of the same coin? *Curr Sports Med Rep* 2013;12:41–6.
- Ayres JG, Mansur AH, Dysfunction VC. Vocal cord dysfunction and severe asthma: considering the total airway. *Am J Respir Crit Care Med* 2011;184:2–3.
- Benninger C, Parsons JP, Mastrorade JG. Vocal cord dysfunction and asthma. *Curr Opin Pulm Med* 2011;17:45–9.
- Perkner JJ, Fennelly KP, Balkissoon R, *et al.* Irritant-associated vocal cord dysfunction. *J Occup Environ Med* 1998;40:136–43.
- Hočvar-Boležar I, Krivec U, Šereg-Bahar M. Laryngeal sensitivity testing in youth with exercise-inducible laryngeal obstruction. *Int J Rehabil Res* 2017;40:146–51.
- Wysocki J, Kielska E, Orszulak P, *et al.* Measurements of pre- and postpubertal human larynx: a cadaver study. *Surg Radiol Anat* 2008;30:191–9.

14. Castelli WA, Ramirez PC, Nasjleti CE. Linear growth study of the pharyngeal cavity. *J Dent Res* 1973;52:1245–8.
15. Morris MJ, Christopher KL. Diagnostic criteria for the classification of vocal cord dysfunction. *Chest* 2010;138:1213–23.
16. Ayres JG, Gabbott PL. Vocal cord dysfunction and laryngeal hyperresponsiveness: a function of altered autonomic balance? *Thorax* 2002;57:284–5.
17. Idrees M, FitzGerald JM. Vocal cord dysfunction in bronchial asthma. A review article. *J Asthma* 2015;52:327–35.
18. Powell SA, Nguyen CT, Gaziano J, et al. Mass psychogenic illness presenting as acute stridor in an adolescent female cohort. *Ann Otol Rhinol Laryngol* 2007;116:525–31.
19. Christopher KL, Morris MJ. Dysfunction VC. Vocal cord dysfunction, paradoxical vocal fold motion, or laryngomalacia? Our understanding requires an interdisciplinary approach. *Otolaryngol Clin North Am* 2010;43:43–66.
20. Newsham KR, Klaben BK, Miller VJ, et al. Paradoxical vocal-cord dysfunction: management in athletes. *J Athl Train* 2002;37:325–8.
21. Mathers-Schmidt BA. Paradoxical vocal fold motion: a tutorial on a complex disorder and the speech-language pathologist's role. *Am J Speech Lang Pathol* 2001;10:111–25.
22. Sullivan MD, Heywood BM, Beukelman DR. A treatment for vocal cord dysfunction in female athletes: an outcome study. *Laryngoscope* 2001;111:1751–5.
23. Patel RR, Venediktov R, Schooling T, et al. Evidence-based systematic review: effects of speech-language pathology treatment for individuals with paradoxical vocal fold motion. *Am J Speech Lang Pathol* 2015;24:566–84.
24. Richards-Mauzé MM, Banez GA. Vocal cord dysfunction: evaluation of a four-session cognitive-behavioral intervention. *Clin Pract Pediatr Psychol* 2014;2:27–38.
25. McQuaid EL, Spieth LE, Spirito A. The pediatric psychologist's role in differential diagnosis: vocal-cord dysfunction presenting as asthma. *J Pediatr Psychol* 1997;22:739–48.
26. Olin JT, Clary MS, Dearnoff EH, et al. Inducible laryngeal obstruction during exercise: moving beyond vocal cords with new insights. *Phys Sportsmed* 2015;43:13–21.
27. Maat RC, Hilland M, Røksund OD, et al. Exercise-induced laryngeal obstruction: natural history and effect of surgical treatment. *Eur Arch Otorhinolaryngol* 2011;268:1485–92.
28. Norlander K, Johansson H, Jansson C, et al. Surgical treatment is effective in severe cases of exercise-induced laryngeal obstruction: A follow-up study. *Acta Otolaryngol* 2015;135:1152–9.
29. Mehlum CS, Walsted ES, Godballe C, et al. Supraglottoplasty as treatment of exercise induced laryngeal obstruction (EILO). *Eur Arch Otorhinolaryngol* 2016;273:945–51.
30. Kolnes L-J, Stensrud T. Exercise-induced laryngeal obstruction in athletes: contributory factors and treatment implications. *Physiotherapy Theory and Practice* 2018;31:1–12.
31. Røksund OD. *Larynx in exercising humans - the unexplored bottleneck of the airways*. Bergen Norway: University of Bergen, 2012.
32. Bunkan BH, Thornquist EP. Psychomotor therapy: an approach to the evaluation and treatment of psychosomatic disorders. *Int Perspect Phys Ther* 1990;5:45–74.
33. Heimdal JH, Røksund OD, Halvorsen T, et al. Continuous laryngoscopy exercise test: a method for visualizing laryngeal dysfunction during exercise. *Laryngoscope* 2006;116:52–7.
34. Maat RC, Røksund OD, Halvorsen T, et al. Audiovisual assessment of exercise-induced laryngeal obstruction: reliability and validity of observations. *Eur Arch Otorhinolaryngol* 2009;266:1929–36.
35. Miller MR. Standardisation of spirometry. *Eur Respir J* 2005;26:319–38.
36. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. *Eur Respir J* 2012;40:1324–43.
37. Crapo RO, Casaburi R, Coates AL. Guidelines for methacholine and exercise challenge testing-1999. This official statement of the American thoracic society was adopted by the ATS board of directors, July 1999. *Am J Respir Crit Care Med* 2000;163:292–3.
38. Bonini M, Braido F, Baiardini I, et al. Aqua: allergy questionnaire for athletes. Development and validation. *Med Sci Sports Exerc* 2009;41:1034–41.
39. Filipe JA, Falcão-Reis F, Castro-Correia J, et al. Assessment of autonomic function in high level athletes by pupillometry. *Auton Neurosci* 2003;104:66–72.
40. Kolnes LJ. Exercise and physical therapy help restore body and self in clients with severe anorexia nervosa. *J Bodyw Mov Ther* 2017;21:481–94.
41. Mathieson L, Hirani SP, Epstein R, et al. Laryngeal manual therapy: a preliminary study to examine its treatment effects in the management of muscle tension dysphonia. *J Voice* 2009;23:353–66.
42. Rubin JS, Mathieson L, Blake E. Posture and voice. *J Singing* 2004;60:271–5.
43. Van Houtte E, Van Lierde K, Claeys S. Pathophysiology and treatment of muscle tension dysphonia: a review of the current knowledge. *J Voice* 2011;25:202–7.
44. Cardoso R, Meneses RF, Lumini-Oliveira J. The Effectiveness of physiotherapy and complementary therapies on voice disorders: a systematic review of randomized controlled trials. *Front Med* 2017;4:45.
45. Craig J, Tomlinson C, Stevens K, et al. Combining voice therapy and physical therapy: a novel approach to treating muscle tension dysphonia. *J Commun Disord* 2015;58:169–78.
46. Tomlinson CA, Archer KR. Manual therapy and exercise to improve outcomes in patients with muscle tension dysphonia: a case series. *Phys Ther* 2015;95:117–28.
47. Kennard EJ, Lieberman J, Saaid A, et al. A Preliminary comparison of laryngeal manipulation and postural treatment on voice quality in a prospective randomized crossover study. *J Voice* 2015;29:751–4.
48. Staes FF, Jansen L, Vilette A, et al. Physical therapy as a means to optimize posture and voice parameters in student classical singers: a case report. *J Voice* 2011;25:e91–e101.
49. Kristiansen E, Stensrud T. Young female handball players and sport specialisation: how do they cope with the transition from primary school into a secondary sport school? *Br J Sports Med* 2017;51:58–63.
50. Bunkan BH. [Psychomotor physiotherapy--principles and guidelines]. *Tidsskr Nor Laegeforen* 2001;121:2845–8.
51. O'Donnell DE, Ora J, Webb KA, et al. Mechanisms of activity-related dyspnea in pulmonary diseases. *Respir Physiol Neurobiol* 2009;167:116–32.
52. Wallden M. The diaphragm – more than an inspired design. *Physiother Theor Pr* 2017;21:342–9.
53. Stang J, Stensrud T, Mowinckel P, et al. Parasympathetic activity and bronchial hyperresponsiveness in athletes. *Med Sci Sports Exerc* 2016;48:2100–7.
54. Walsted ES, Hull JH, Hvedstrup J, et al. Validity and reliability of grade scoring in the diagnosis of exercise-induced laryngeal obstruction. *ERJ Open Res* 2017;3:00070-2017-9.
55. Liyanagedara S, McLeod R, Elhassan HA. Exercise induced laryngeal obstruction: a review of diagnosis and management. *European Archives of Oto-Rhino-Laryngology* 2016:1–9.