Original article

Analysis of the potential of the Elevation Training Mask on biomarkers, respiratory parameters, and sports performance indicators: What ergogenic mechanisms are involved? Systematic review

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Summary

Introduction: The Elevation Training Mask (ETM) is a respiratory muscle loading device that works by reducing airflow through a valvular system. The ETM was originally intended to simulate altitude by allowing the application of hypoxia during exercise and has been growing in popularity among athletes.
Objective: To systematically review studies evaluating the effect of ETM associated with exercise on biomarkers, respiratory parameters, and sports performance indicators in physically active subjects.
Material and method: A structured search following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was performed in the Medline database (PubMed) until October 2021.
Results: Six studies are included reporting that the use of ETM in comparison with the control group, presented a greater tendency to increase in forced inspiratory vital capacity, forced vital capacity, without significant changes in pulmonary function; it did not affect the total load volume of strength training but attenuated the speed of execution; it significantly increased cerebral oxygenation and decreased oxygen saturation; heart rate was higher while inter-beat interval and sympatho-vagal balance were lower; there were no changes in hematological variables although there was a tendency to decrease muscle damage and attenuate the direct catabolic effect derived from exercise; no improvements in sports performance were observed.
Conclusion: The use of ETM as an altitude simulation device induces, if at all, a mild hypoxic stimulus that is clearly insufficient to trigger adaptive physiological responses on target organ systems. However, it could have some utility as a respiratory training system without combined exercise load by adequately adjusting the working resistances on the respiratory muscles..

Key words:
Ventilatory restriction masks. Hypoxia. Respiratory training. Biological markers. Sports performance. Pulmonary function.

Análisis del potencial de la *Elevation Training Mask* sobre biomarcadores, parámetros respiratorios, e indicadores de rendimiento deportivo: ¿Qué mecanismos ergogénicos están implicados? Revisión sistemática

Resumen

Introducción: La *Elevation Training Mask* (ETM) es un dispositivo de carga muscular respiratoria que funciona reduciendo el flujo de aire a través de un sistema de valvular. La ETM fue originalmente pensada para simular la altitud permitiendo la aplicación de hipoxia durante el ejercicio y ha ido creciendo en popularidad entre los deportistas intentando maximizar su rendimiento deportivo.
Objetivo: Revisar sistemáticamente los estudios que evalúan el efecto de ETM combinada con ejercicio sobre biomarcadores, parámetros respiratorios e indicadores de rendimiento deportivo en sujetos físicamente activos.
Material y método: Se realizó una búsqueda estructurada siguiendo las directrices de los Elementos de Información Preferidos para Revisiones Sistemáticas y Metaanálisis (PRISMA) en la base de datos Medline (PubMed) hasta septiembre de 2021.
Resultados: Se incluyen 6 estudios reportando que el uso de la ETM en comparación con el grupo control, presentó una mayor tendencia al aumento en la capacidad vital inspiratoria forzada, capacidad vital forzada, sin cambios significativos en la función pulmonar; no afectó al volumen total de carga entrenamiento de fuerza pero atenuó la velocidad de ejecución; no se observaron mejoras en el rendimiento deportivo; aumento significativamente la oxigenación cerebral y disminuyó la saturación de oxígeno; la frecuencia cardíaca fue mayor mientras que el intervalo entre latidos y el equilibrio simpaticovagal fueron menores; no se produjeron cambios en las variables hematológicas aunque se observó una tendencia a disminuir el daño muscular y atenuar el efecto catabólico directo derivado del ejercicio.
Conclusión: La utilización de la ETM como dispositivo de simulación de altitud induce, un leve estímulo hipóxico que es claramente insuficiente para desencadenar en respuestas fisiológicas adaptativas sobre los sistemas orgánicos diana. Sin embargo, podría tener alguna utilidad como sistema de entrenamiento respiratorio sin carga combinada de ejercicio ajustando adecuadamente las resistencias de trabajo sobre los músculos respiratorios.

Palabras clave:
Máscaras de restricción ventilatoria. Hipoxia. Entrenamiento respiratorio. Marcadores biológicos. Rendimiento deportivo. Función pulmonar.

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Introduction

Athletes around the world have used altitude training for years using multiple methodologies, depending on where they live and where they train, in the pursuit of maximising athletic performance[1]. The potential benefits of altitude training are based on adaptive physiological responses, which compensate for the relative lack of oxygen (O_2) in the air, on the muscular, blood, cardiovascular, respiratory, hormonal, metabolic and nervous systems[2]. Since altitude training is not easily available, strategies have been developed in recent years to make simulated altitude training generate effects similar to those of real altitude training[3]. For this reason, some companies have started mass-producing simulated hypoxia equipment, making it easier to obtain and providing the opportunity for recreational and/or elite athletes to train in conditions mimicking altitude[4]. One method to simulate altitude is to induce normobaric hypoxia conditions, or to minimise the amount of air an individual is allowed to consume[5]. For this reason, restrictive devices are employed to limit airflow and potentially provide athletes with the physiological responses of altitude training[6].

The Elevation Training Mask 2.0 (ETM; Training Mask LLC, Cadillac, MI, USA) is a respiratory muscle loading device which works by reducing airflow through a valve system; when inhaling, you have to breathe deeper. The ETM was originally designed to simulate altitude by causing a moderate decrease in oxygen saturation (SpO_2) during exercise[7–9] through insufficient hyperventilation and rebreathing of carbon dioxide (CO_2)[8]. This mechanism is similar to that of hypoxicator masks, which modify the concentration of respirable gases to imitate altitude. In this way, microhypoxic environments (generated by ETMs)[8] and high altitude hypoxic conditions (generated by hypoxicators)[3] can give rise to the beneficial adaptations of altitude exposure.

However, ETMs are much cheaper than hypoxicators, such as the GO_2 Altitude, Vital Air Hypoxia or Altipower (www.biolaster.com), which raises the question: are ETMs really effective? For the above reasons, we set out to systematically review studies which assess the effect of ETMs on respiratory parameters, physiological biomarkers and sports performance in physically active subjects.

Our research question was defined using the PICOS framework according to the standard methods proposed by the Guidelines on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[10] as follows: Population: healthy adults (without any chronic disease) who perform physical activity; Intervention: physical training using the ETM device; Comparison: placebo/control group or data prior to the use of the ETM; Outcomes: protocols of use, methodology used, respiratory parameters, haematological, biochemical, hormonal and/or sports performance biomarkers; Study type: single randomised controlled trial or randomised controlled crossover trial without placebo.

Materials and method

Search strategy

A structured search was developed using the Medline (PubMed), Sportdiscus, Scopus, Science Direct, and Springerlink databases for articles published in the last 5 years, considering the evolution in ergogenic hypoxia devices applied in sport, until 30 September 2021. The search was restricted to English and Spanish.

The search terms included refer to the ETM and physical activity: *elevation training mask, performance, muscle, hematological, biochemistry, muscle performance,* and *exercise* (Table 1). The Boolean operator AND was used to connect these search terms. Different bibliographies were also analysed to include studies of interest not found through the first search and draw in as many studies as possible. Second, to cover grey literature, the same terms as those used in the main search were used on the social network *Research Gate* (www.researchgate.net).

Table 1. Articles selected from the different databases.

No. of search	Database	Search term	No. of papers after applying filters	No. of papers after reading title	No. of papers read abstract	No. of papers selected
1	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND performance	17	7	5	5
2	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND muscle	7	6	5	5
3	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND hematological	0	0	0	0
4	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND biochemistry	0	0	0	0
5	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND muscle performance	6	6	6	6
6	PubMed, Sportdiscus, Scopus, Science Direct, and Springerlink	Elevation training mask AND exercise	11	5	5	5

Eligibility criteria

The selection of the studies was based on the following inclusion criteria to pick out the most suitable studies from those obtained in the search: a) healthy adult volunteers without any chronic conditions who do physical activity, excluding studies using animals; b) well-designed studies which include randomised and non-randomised clinical trials, and pre-test/post-test studies; c) studies which assess respiratory, haematological, biochemical, hormonal and/or sports performance parameters; d) interventions which assess the effect of ETMs with clear information on the model, duration, time and simulated altitude used; e) papers with a methodological quality of ≥ 10 points according to the McMaster University Occupational Therapy Evidence-Based Practice Research Group. Results which did not meet the above criteria were excluded from this systematic review.

Methodological quality assessment

The critical review form for quantitative studies developed by the McMaster University Occupational Therapy Evidence-Based Practice Research Group was used as a quality appraisal tool[11]. These guidelines establish the methodological quality of each study, covering the following 16 items: purpose; review of the literature; design; blinded assessor; description of the sample; size of the sample; ethics and consent; validity of the results; reliability of the results; description of the intervention; statistical significance; statistical analysis; clinical importance; conclusions; clinical implications; limitations. The quality of the papers was rated as 'poor' (≤8 points), 'fair' (9-10 points), 'good' (11-12 points), 'very good' (13-14 points) and 'excellent' (≥15).

Data extraction and synthesis

The information extracted from the selected studies included: name of the first author, year of publication, country in which the study was carried out, study type, sample size, sex and age of participants, model, simulated altitude used, time and duration of ETM application, physical activity intervention. The results and conclusions were also drawn independently by the review authors using a spreadsheet (Microsoft Inc, Seattle, WA, USA). Any disagreements were then resolved by discussion until consensus was reached.

Results

Bibliographic search

The systematic search for papers from the last 5 years to September 2021 gave 31 published results, of which 21 were obtained from the Medline (PubMed), Sportdiscus, Scopus, Science Direct and Springerlink databases, and 10 from additional sources. After excluding 17 duplicated papers, a total of 14 were examined. After reading the title and abstract, 9 papers were considered potentially relevant, and 5 were excluded because they did not involve an intervention. After reviewing the complete texts of 9 of the remaining publications, 2 were eliminated for using unhealthy subjects and 1 for not measuring any of the variables considered in the review. And so the six papers[4,6,7,9,12,13] included in this systematic review (Figure 1) were obtained.

Methodological quality rating

Table 2 details the results of the criteria evaluated, where the main shortcomings found in terms of methodological quality were associated with items 6 and 11 of the questionnaire, referring to insufficient justification of the sample size and specification of the existence of cointervention or not in the studies. Scores ranging from 12 to 15 points were obtained, reflecting a minimum methodological quality of 75% and a maximum methodological quality of 93.75%. Of the 6 studies found, 4 were considered to be of "very good" quality[6,7,12,13], 1 of "excellent" quality[4] and 1 of "good" quality[9]. No study was excluded for failing to reach the minimum quality threshold.

Characteristics of the studies

The 6 studies[4,6,7,9,12,13] included in this review gave a total sample of 110 participants of both sexes (91 men and 19 women). Of these, 51 were subjects trained to amateur level, and 59 did exercise on a recreational basis. All the studies included in the systematic review used the ETM

Figure 1. Flow chart of strategy for searching and selecting studies included in the systematic review.

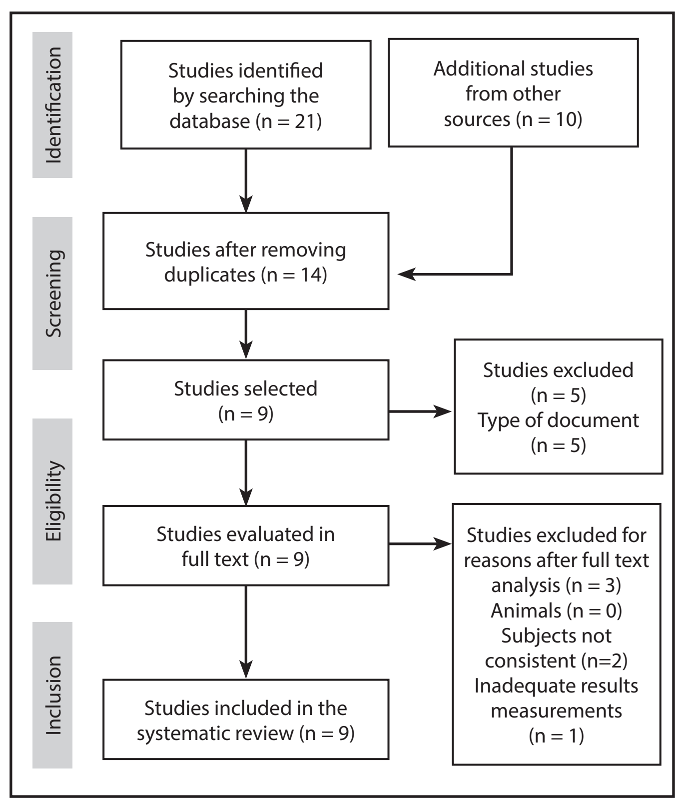

Table 2. Quality assessment of the studies included in the systematic review.

Author(s) /year/ reference	Ítems																T_s	%	MQ
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
Porcari *et al.*[13] 2016	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Jagim *et al.*[12] 2017	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Chul Jung *et al.*[7] 2018	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Romero-Arenas *et al.*[9] 2019	1	1	1	1	1	0	1	1	0	1	0	1	1	1	0	1	12	75	B
Biggs *et al.*[6] 2017	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	87.5	MB
Fernández-Lázaro *et al.*[4] 2021	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	15	93.75	E

Total items satisfied (T); Total items satisfied by study (TS); Criterion met (1); Criterion not met (0); Methodological quality (MQ): poor (P) ≤8 points; fair (F) 9-10 points; good (G) 11-12 points; very good (VG) 13-14 points; excellent (E) ≥15 points.

Table 3. Characteristics of the participants and the interventions of the studies included in this review.

Age range	20-23 23-26 26-29 >30	3 studies[6,9,13] 1 study[7] 1 study[13] 1 study[4]
Exercise level	Recreational Amateur	2 studies[9,12] 4 studies[4,6,7,13]
Mask model	ETM 2.0	6 studies[4,6,7,9,12,13]
Altitude simulated	914 m 1,829 m 2,743 m 3,658 m	2 studies[4,9] 3 studies[4,9,12] 5 studies[4,6,7,9,13] 1 study[13]
Type of exercise	Cycling Running Back squat Bench press CrossFit®	3 studies[7,9,12] 2 studies[6,13] 1 study[13] 1 study[13] 1 study[4]
Duration	1 week 3 weeks 4 weeks 6 weeks 12 weeks	1 study[7] 1 study[12] 1 study[13] 2 studies[6,9] 1 study[4]
Time of use of Elevation Training Mask	Before During After	6 studies[4,6,7,9,12,13] 6 studie[s4,6,7,9,12,13] 5 studies[4,6,9,12,13]

model Elevation Training Mask 2.0[4,6,7,9,12,13]. The simulated altitude ranged from 9144,9 to 3,658 metres[9] on top of the altitude of the location where the research was conducted, and two studies used progressive increases in simulated altitude during the research period[4,9]. The studies lasted from 1 to 12 weeks, using protocols of 1 week[7], 3 weeks[12], 4 weeks[9], 6 weeks[6,9] and 12 weeks[4]. The ETM was used before[4,6,7,9,12,13], during[4,6,7,9,12,13] and after[4,6,9,12,13] exercise (Table 3).

Results of the studies included

Table 4 analyses the information pertinent to the data obtained from the study sources (including authors, year of publications and country); study type: characteristics of the participants; mask model; altitude simulated and exercise intervention protocol used. Tables 5, 6 and 7 analyse the results of and conclusions drawn from the respiratory, physiological biomarker and sports performance parameters in the studies included in the systematic review.

Discussion

The main objective of this review was to critically analyse the scientific evidence of the effects of the ETM on respiratory parameters and haematological, biochemical, hormonal and/or sports performance biomarkers. To this end, 6 articles were included which analyse the use of the ETM 2.0 in healthy adults involved in different kinds of sporting activity, such as cycling[7,9,12], athletics[6,13], powerlifting[13] and Crossfit®[4]. Comparing the Mask Group (MG) with the Control Group (CG), the use of the ETM as a means of restricting breathing led to a greater tendency to increase forced inspiratory vital capacity (FIVC), forced vital capacity (FVC) and maximal oxygen uptake (VO_{2max})[6]; did not affect total strength training load volume but lowered execution speed[12]; significantly increased brain oxygenation[9] and decreased oxygen saturation (SpO_2)[7,9,12]; increased the heart rate (Fc)[7,12] and lowered the interval between beats and sympathovagal balance[12]; and did not change haematological variables[13], although a tendency was observed to decrease muscle damage and attenuate the direct catabolic effect of exercise[4]. However, it was difficult to determine the true effectiveness of the ETM on the different parameters and biomarkers proposed because the results could be influenced by the type of exercise, the altitude simulated (which ranged from 914 to 5,486 metres), the moment at which the ETM was used and the duration of the intervention with the ETM. Also, the characteristics of the participants, such as age, sex, ethnicity, body composition, level of training, differences in training, nutrition and health status, may also have influenced the results.

Table 4. Characteristics of the studies included in the systematic review.

Author(s), year and country	Type of study	Population	Mask and altitude simulated	Exercise intervention
Porcari *et al.*[13] 2016. USA	Randomised controlled trial without placebo	N = 24 >18 y.o. GC: n=12 (4 ♀, 20.8 y.o., 169 cm, 66.1 kg, BMI = 23.2%; 8 ♂, 21 y.o., 185 cm, 83.8 kg, BMI = 24.4%). MG: n=12 (4 ♀, de 21 y.o., 165 cm, 58.8 kg, BMI = 21.6%; 8 ♂ 22.9 y.o., 178 cm, 82.4 kg, BMI = 25.9%)	ETM 2.0 Wk 1 → 914 m Wk 2 → 1,829 m Wk 3-4 → 2,743 m Wk 5-6 → 3,658 m	Prog. of 6 weeks of cycle ergometer HIT (2 sessions/week). 30´ session (5´ WU, 20´ HIT and 5´ CD)
Jagim *et al.*[12] 2017. USA	Randomised controlled crossover trial without placebo	n= 20 ♂, 21.4 ±2.1 y.o. 180.7 ±8.8 cm 85.5±12.1 kg BFP=13.5±4.9%	ETM 2.0 Session 1-2-3-4 → 2,743 m	1st Session: 2 series of 10 rep at 50% 5 RM (back squat and bench press) + 25´´ sprint. 2nd Session: 2 series of WU 5-10 rep at 50% 5RM (back squat and bench press) with 3´ R + 25´´ sprint (100% effort). 3rd and 4th Sessions: 5´ WU with dynamic mov. + 6 series of 10 rep at 85% 5RM with 2´ R+ another series to failure. (1st back squat rest of 20´ and bench press) +25´´ sprint.
Chul Jung *et al.*[7] 2018. USA	Randomised controlled crossover trial without placebo	n= 15 (9♂ and 6♀) 27±1.14 y.o., 171.3±2.6 cm 72.7±4.04 kg BFP= 16.4±2.4%	ETM 2.0 Session 1-2-3 → 1,829 m	1st session: measure h, body weight, fat%, Resp. Func., VO_{2peak} 2nd and 3rd sessions: 2 pp. of cycling (with and without ETM), each pp. 40´ (10´ WU + 10´ at 50% VO_{2peak}+ 10´ at 70% VO_{2peak} +10´ Rec.). 7 days between sessions.
Romero-Arenas *et al.*[9] 2019. Spain	Randomised controlled crossover trial without placebo	n = 14 ♂ 24.2 ±3 y.o. 177.4 ±6.0 cm 74.8±6.9 kg	ETM 2.0 Test → 2,743 m	1 week before: complete session to familiarise with ETM. Test session: 2 cycling tests, 1st 5´ WU followed by test at 0W and P ↑ 25 W per ´ at 70-75rpm to exhaustion. The test ended when they could not carry on above 65rpm. The 1st test was with ETM and the 2nd without.
Biggs *et al.*[6] 2017. USA	Randomised controlled trial without placebo	n = 17 12 ♂ and 5 ♀, 21.2 ±1.7 y.o.	ETM 2.0 Entire pp → 2,743 m	6-week pp. of 4 days/week M-Th. The running pp. (HIIT) was modified from 90% VO_{2max} to HRR. The subjects had to maintain 80% HRR for 6 intervals of 90´´ followed by 3´ active R. In the active R, the subjects had to maintain 50-60% HRR. First there was a WU and afterwards a CD lasting 5´-10´.
Fernández-Lázaro *et al*[4]. 2021. Spain	Randomised controlled trial without placebo	n = 20 ♂ CG: n = 10 38.4 ±3.8 y.o. BMI: 24.6±2.7 kg/m² 51.5 ± 6.5 mL-kg⁻¹-min⁻¹ MG: n = 10 36.7 ±5.3 y.o. BMI: 22.9±3.1 kg/m² 53.1±7.3 mL-kg⁻¹-min⁻¹	ETM 2.0 Wk 1 → 914 m Wk 2 → 1,829 m Wk 3-12 → 2,743 m	12-Week Pgm. of 3 days/week of CrossFit. Warm-up, a strength and/or skill component + programmed strength or conditioning training 10-30') + cooldown and/or mobility work.

n: number of participants; y.o.: years old; CG: control group; MG: mask group; ♂:male; ♀:female; cm: centimetres; kg: kilograms; BMI: body mass index; BFP: body fat percentage; ETM: elevation training mask; HIT: high intensity; WU: warm-up; Pp: protocol; h: height; Pgm: Programme: CD: Cooldown; R: Rest; wk: week; m:metre; ´:minute; ´´: seconds; rep: repetition; mov: movement; RM: repetition maximum; %:percentage; VO_{2peak}/ VO_{2max}: maximum oxygen consumption; W:watts; rpm: revolutions per minute; HIIT: high intensity interval training; HRR: heart rate reserve; Resp. Func.: Respiratory function; Rec.: recovery; P: Power; M: Monday; Th: Thursday.; USA: United States of America.

Table 5. Summary of respiratory parameter results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	FVC (L) FEV_1 (L) FEV_1/FVC MIP (cmH_2O) SpO_2 (%)	↔ MG ↔ CG ↔ MG ↔ CG ↔ MG ↔ CG ↑ MG ↑ CG ↓* MG ↓* CG	↔ ↔ ↔ † †
Jagim *et al.*[12] 2017 USA	SpO_2 back squat (%) SpO_2 press bench (%) SpO_2 sprint (%)	↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↓ CG	† † †
Chul Jung *et al.*[7] 2018 USA	SpO_2 (%) RPBE	↓* MG ↓* CG ↑ MG ↑ CG	# †
Biggs *et al.*[6] 2017 USA	FIVC (L/second) FVC (L)	↑ MG ↑ CG ↑ MG ↑ CG	† †
Romero-Arenas *et al.*[9] 2019 Spain	SpO_2 (%)	↓ MG ↓* CG	#

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; FVC: forced vital capacity; FEV1: forced expiratory volume in the first second; MIP: maximum inspiratory pressure; SpO_2:oxygen saturation; RPBE: rate of perceived breath effort; FIVC: forced inspiratory vital capacity; MG: Mask group; CG: Control group; L: litres; cmH_2O: centimetres of water.

Table 6. Summary of biomarker results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	Hb (g/dL) Hct (%) Max HR (beats/minute)	↓ MG ↓ CG ↑ MG ↑ CG ↔ MG ↔ CG	↔ ↔ ↔
Chul Jung *et al.*[7] 2018 USA	Systolic BP (mmHg) Diastolic BP (mmHg) HRV → IBI (seconds) time domain HRV → InLF seconds) frequency domain HRV → InHF InHF (seconds) frequency domain InLF / InHF HR (beats/minute)	↑ MG ↑ CG ↑ MG ↑ CG ↔ MG ↔ CG ↔ MG ↔ CG ↔ MG ↔ CG ↑ MG ↑ CG ↑* MG ↑* CG	† † ↔ ↔ † # #
Romero-Arenas *et al.*[9] 2019 Spain	HR (beats/minute) Muscle O_2Hb (μM-cm) Muscle HHb (μM-cm) Muscle tHb (μM-cm) Cerebral O_2Hb (μM-cm) Cerebral HHb (μM-cm) Cerebral tHb (μM-cm)	↑* MG ↑ CG ↓* MG ↓* CG ↑* MG ↑* CG ↑* MG ↑* CG ↑ MG ↑ CG ↑* MG ↑* CG ↑* MG ↑* CG	# # # # † # #
Fernández-Lázaro *et al.* 2021[4] Spain	LDH CK Mb TT C	↑* MG ↔ CG ↑ MG ↑ CG ↓ MG ↓ CG ↑ MG ↑ CG ↓ MG ↑ CG	↔ ↔ ↔ ↔ ↔

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; Hb: haemoglobin; Hct: haematocrit; HR: heart rate; SP: systolic pressure; HRV: heart rate variability; IBI: inter-beat interval; InFL: natural logarithm of low frequency; InHF: natural logarithm of high frequency; O_2Hb:oxyhaemoglobin; HHb: concentration of deoxyhaemoglobin; tHb: total tissue haemoglobin; LDH: lactate dehydrogenase; CK: creatine kinase.

The ETM aims to simulate training at altitude, adding from 914 to 5,486 metres to the real altitude at which the physical activity is carried out, by restricting oxygen (O_2) by means of a valve system[14]. The studies used different simulated altitudes and some even used more than one (Table 3). Substantial improvements in haematological variables have been reported after exposure to hypobaric hypoxia, normobaric hypoxia or during training in athletes[2,3,15–18]. However, the ETM caused a slight decrease in SpO_2 during exercise[7,12,13] with no changes in haemoglobin

Table 7. Summary of sports performance parameter results from the studies included in this systematic review.

Author(s), year and country	Parameters analysed	Main results	
		Pre-PA vs. Post-PA	MG vs. CG
Porcari *et al.*[13] 2016 USA	VO_2max (ml·kg·$^{-1}$min^{-1}) PPO (watts) RCT (ml·kg·$^{-1}$min^{-1}) PO at RCT (watts) VT (ml/kg/min) PO at VT (watts) Max HR (beats/minute) La$^+$ (mmol·l^{-1})	↑* MG ↑* CG ↑* MG ↑* CG ↑* MG ↑ CG ↑* MG ↑ CG ↑* MG ↑ CG ↑* MG ↑ CG ↔ MG ↔ CG ↔ MG ↔ CG	† † # # † † ↔ ↔
Jagim *et al.*[12] 2017 USA	No. rep. back squat No. rep. bench press Max speed/squat rep Max speed/bench press rep La$^+$ (mM*L^{-1}) Alertness & focus	↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↓ CG ↓ MG ↔ CG	† † † † † #
Romero-Arenas *et al.*[9] 2019 Spain	PPO La+ (mM*L^{-1}) RPE (BORG CR-10)	↓* MG ↓* CG ↓ MG ↓ CG ↑* MG ↑*CG	# † †
Biggs *et al.*[6] 2017 USA	VO_{2max} (ml·kg·$^{-1}$min^{-1}) VO_{2max} (ml·kg·$^{-1}$min^{-1}) over time	↔ MG ↔ CG ↑* MG ↑* CG	↔ #
Fernández-Lázaro *et al.* 2021[4] Spain	Press (kg) Deadlift (kg) Squat (kg) Crossfit Total (kg) Grace (seconds) RPE (BORG CR-10)	↑* MG ↑* CG ↑ MG ↑ CG ↑* MG ↑ CG ↑* MG ↑* CG ↓* MG ↓* CG ↔ MG ↔ CG	↔ ↔ ↔ ↔ ↔ ↔

PA: Physical activity; ↑*: Statistically significant increase; ↑: Statistically insignificant increase; ↓*: Statistically significant decrease; ↓: Statistically insignificant decrease; †: Statistically insignificant change; #: Statistically significant change; ↔: No change; VO_{2max}: maximal oxygen uptake; PPO: peak power output; RCT: respiratory compensation threshold; PO: power output; VT: ventilatory threshold; Max HR: maximal heart rate; La$^+$: plasma lactate concentration; No. rep.: number of repetitions; RPE: rate of perceived exertion; kg: kilogram.

(Hb) or haematocrit (Hct) in healthy participants after 6 weeks of cycling training with the ETM[13] or physically active subjects during 20 minutes of exercise on a cycle ergometer at 60% maximum power[19]. Therefore, any hypoxemia with the ETM is probably not caused by the simulation of altitude but is likely due to its modest dead space and the deterioration of alveolar ventilation[19]. Hypoxemia could also be intensified by re-inhaling carbon dioxide (CO_2) and the subsequent shift of the O_2 dissociation curve[8]. However, at 'real' altitudes such as those that the ETM is able to simulate (914 to 5,486 metres), saturation levels typically fall from 97-95% to 79-63%, much greater drops than those reported when using the ETM at those same altitudes[9]. This suggests that, if the ETM induced hypoxic conditions, the exposure stimulus was not sufficient to achieve haematological adaptations. In addition, the generation of hypoxia with the ETM is not clear because Barbiere *et al.*[19] and Boyle *et al.*[20] found no modifications in SpO_2 between the different conditions in their studies.

On the other hand, hypoxia affects the function of the hypothalamic-pituitary-adrenal (HPA) axis, increasing the levels of adrenocorticotropic hormone (ACTH) in plasma, and expression of the steroidogenic acute regulatory (StAR) protein, increasing the secretion of glucocorticoids such as cortisol[21,22]. Hu *et al.*[23] demonstrated that testosterone secretion is suppressed during exercise in hypoxia. However, Fernández-Lázaro *et al.*[4] reported modest increases in testosterone (3.6±0.52%) and a minimal decrease in cortisol (-0.18±4.01%) in Crossfit® athletes during 12 weeks of ETM training, with similar hormonal adaptations in the CG. Therefore, this hormonal response would not appear to be related to the use of the ETM but would rather reflect the high levels of physical fitness of the athletes[24] and an optimal training programme because in the ratio rest times/physical routines these are enough to restore the function of the HPA axis[25]. An optimised endocrine response to resistance training is of great importance for muscle adaptations and performance improvement[26]. In this sense, both groups (MG and CG) show improvements in muscle recovery and the 'Workout of the Day' (WODs), without significant differences between them[4].

These results could lead to a change in the marketing of the ETM, which originally focused on simulating altitude[14]. The ETM has been proposed as a respiratory muscle resistance training device[9,19,20]. In a meta-analysis[27], we recently described that inspiratory muscle training (IMT) in isolation improves lung function associated with increases in aerobic and anaerobic performance. However, there were no significant changes between groups (MG vs. CG) or in the ETM condition during the study in the lung function parameters of forced vital capacity (FVC)[6,13], forced inspiratory vital capacity (FIVC)[6], forced expiratory volume in the first second (FEV1)[13] or maximum inspiratory pressure (MIP)[13]. These results agree with those reported by Kido *et al.*[28], who did not inform as to any significant improvement in lung function after using the ETM. These differences between IMT and the ETM on lung function monitoring parameters could be due to the different musculature which is worked with the ETM and in IMT. The ETM does not train the diaphragm musculature or the inspiratory intercostal muscles, which are the ones that carry out the work of inspiration[14]. Furthermore, the scalene and sternocleidomastoid muscles, which are also involved in inspiratory mechanics during more intense exercise, also have to be trained through IMT[27]. Another cause could be the respiratory resistive load applied to the athletes. The working resistance should be > 30% MIP with incremental application up to 50-70% MIP, considering that loads <15% MIP are ineffective[27]. Therefore, the respiratory resistive loading (by means of a valve system) applied with the ETM may not reach the ideal working thresholds to generate an ergogenic effect on the strength of the respiratory muscles. This could explain why no effects are achieved on respiratory fatigue, the metabolic reflex mechanism of the respiratory musculature 'metaboreflex' (RMMR), hypertrophy of the diaphragm, modification of the composition of muscle fibres towards type I and increase of type II intercostal muscle fibres, optimisation of neuro-motor control of the respiratory musculature, and greater economy of the respiratory musculature[27]. These results call into question the application of the ETM as a respiratory muscle resistance training tool.

The popularity of the ETM is fundamentally based on improving sports performance by generating hypoxia[14]. However, the study by Fernández-Lázaro *et al.*[4] did not report significant changes in WODs in Crossfit® athletes, and Porcari *et al.*[13] did not describe significant improvements in VO_{2max} in highly trained athletes. Furthermore, the ETM has been shown to reduce performance during incremental exercise [7] and attenuate the ability to maintain working speed in back squat, bench press, and sprint[12]. These results are consistent with other studies not included in this review which used the ETM in constant load 29 and incremental load until exhaustion[20] exercises. Therefore, the ETM limits sports performance probably because increasing the respiratory load simultaneously during resistance training decreases overall exercise performance compared to resistance training without adding respiratory resistance. This could occur due to the significant increase in transdiaphragmatic pressure[20] and the possible fatigue of the respiratory muscles[30], which could reduce the total training load of the locomotor muscles by decreasing the time and/or intensity of exercise. The increase in respiratory muscle fatigue means that RMMR requires a lower intensity before activation, thus decreasing the tolerance to exercise[30]. Increased dyspnoea could also influence a reduction in exercise time/intensity and, therefore, the training load on the skeletal muscle system during respiratory load combined with physical activity[20,30]. Moreover, as described above, there are no improvements in lung function, thereby preventing improvements in sports performance. It has been shown that the effectiveness of the EMI on aerobic and anaerobic performance requires an increase in IMP of 20% and 6.8% respectively post EMI[27]. Even the modest hypoxemia produced by the use of the ETM[7,12,13] seems insufficient to achieve improvements in sports performance compared with hypoxia exposure programmes[1–3]. Therefore, the ETM has little influence on sports performance.

The use of the ETM in athletes increased the rate of perceived respiratory effort [7], and negatively influenced alertness and focus during exercise[13]. However, the mask caused an increase in cerebral oxygenation compared with the CG[9] while not conditioning the total training schedule of the athletes, because there were no significant differences in the MG between the study times or in the group-by-time interaction on the Borg-10 scale[4,9]. Given these discrepancies, future studies are needed to determine the comfort and convenience of the ETM during exercise, assessing whether it alters the perception of exertion or conditions performance through psychological and/or subjective factors related to the attention process in sports activity.

The use of the ETM as an altitude simulation device induces, if anything, a slight hypoxic stimulus which is clearly insufficient to trigger adaptive physiological responses in the target organ systems. However, it could serve a useful purpose as a respiratory training system in isolation (without combined exercise load) by properly adjusting the working loads (valve resistance) on the respiratory muscles to achieve gains in lung function which contribute to sports performance as an alternative to resistive loading IMT devices (PFlex, TrainAir), voluntary isocapnic hyperpnea devices (SpiroTiger) and threshold devices (PwB, Powerlung, Threshold IMT, Respifit-S) in those individuals or situations which make it impossible to use IMT devices, such as a lack of handling skills, cognitive impairment impeding their use or disabling pathologies affecting the upper limbs.

Conflict of interest

The authors declare that they are not subject to any type of conflict of interest.

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