

# Mouthguard Use and Cardiopulmonary Capacity – A Systematic Review and Meta-Analysis



## Authors

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## ABSTRACT

This study aimed to perform a systematic review and meta-analysis of the literature to determine the effects of the use of mouthguards (MGs) on cardiopulmonary capacity in athletes (oxygen uptake: VO<sub>2</sub> max, and minute ventilation: VE max). Seven electronic databases and reference lists of relevant papers were searched for randomized clinical trials (RCTs) that compared the cardiopulmonary capacity in athletes with and without the use of an MG. The risk of bias tool of the Cochrane Collaboration was used for quality assessment. Fourteen studies were included. For both the overall VO<sub>2</sub> max and VE max analyses, significant differences were observed between the MG and no MG conditions, favoring no MG, which presented the highest VO<sub>2</sub> max values ( $p = 0.0001$ ; 95% CI;  $-2.638$  to  $-1.728$ ) and the highest VE max values ( $p = 0.0001$ ; 95% CI;  $-4.103$  to  $-1.354$ ). When the results were analyzed separately for each subgroup (type of MG and place of use), the meta-analysis showed that the effect of the use of an MG on VO<sub>2</sub> max and VE max was not significant when custom-made MGs were used. The use of an MG overall decreased VO<sub>2</sub> max and VE max compared to the control. Nevertheless, custom-made MGs seem to have no effect on these parameters.

## Introduction

The practice of contact sports, such as rugby, hockey, boxing, martial arts, basketball, handball, soccer, and others can lead to an increased risk of orofacial injuries [3, 16, 23, 25]. Thus, it has been recommended to use mouthguards (MG) during practice. They are designed to minimize the occurrence and severity of oral and dental injuries through the absorption of the energy associated with blows to the mouth [5, 29, 40]. Besides orofacial trauma prevention, some MGs also may offer mandibular repositioning [14, 31].

On the other hand, despite the clear potential of MGs to reduce the risk of injury, some athletes find it difficult to wear MGs because

of instability, oral dryness, difficulties in breathing and speaking, nausea, and the perception that it hinders their performance [8, 11, 30].

There are different types of MGs and they can be divided into three main types: custom-made, stock, and boil-and-bite. Custom-made MGs are fabricated personally for each individual using a model of the patient's mouth, usually taken by a dental professional. These MGs are more expensive than other versions but usually offer a better fit. Stock MGs are inexpensive and come preformed. They are essentially plastic trays that fit loosely over the teeth. Also available commercially, boil-and-bite MGs are made from a ther-

► **Table 1** Electronic database and search strategy (15 Jun 2016).

<b>Pubmed</b>	
#1 (Sports[MeSH Terms] OR Sport * [Title/Abstract] OR Athletic * [Title/Abstract] OR Athlete * [Title/Abstract] OR Player * [Title/Abstract])	#2 (Mouth protectors[MeSH Terms] OR Protectors Mouth[Title/Abstract] OR Guards Mouth[Title/Abstract] OR Mouthguard * [Title/Abstract] OR Mouth guard * [Title/Abstract] OR Mouth Protector * [Title/Abstract] OR Mouth piece OR Mouthpiece * [Title/Abstract])
#1 AND #2	
<b>Scopus</b>	
#1 TITLE-ABS-KEY ( sports OR sport OR athletic OR athletics OR athlete OR athletes OR player OR players )	#2 TITLE-ABS-KEY ( "Mouth protectors" OR "Protector Mouth" OR "Protectors Mouth" OR "Guards Mouth" OR Mouthguard OR Mouthguards OR "Mouth Protector" OR "Mouth Protectors" OR "Mouth Piece" OR "Mouth Pieces" OR Mouthpiece OR Mouthpieces OR "Mouth guard" OR "Mouth guards" )
#1 AND #2	
<b>Web of Science</b>	
#1 TOPIC = (Sports OR Sport OR Athletic OR Athletics OR Athlete OR Athletes OR Player OR Players)	#2 TOPIC = (Mouth protectors" OR "Protector Mouth" OR "Protectors Mouth" OR "Guards Mouth" OR Mouthguard OR "Mouthguards" OR "Mouth Protector" OR "Mouth Protectors" OR "Mouth Piece" OR "Mouth Pieces" OR Mouthpiece OR Mouthpieces OR "Mouth guard" OR "Mouth guards")
#1 AND #2	
<b>Lilacs and BBO</b>	
#1(MH:Sports or Sports or Desportes or Deportes or Athletics or "Atividades Esportivas" or "atividades deportivas")	#2 (MH: "mouth protectors" or "Protetores da Boca" or "Peças Protetoras da Boca" or "Protetor bucal" or "Protectores Bucales" )
#1 AND #2	
<b>Cochrane Library</b>	
#1	MeSH descriptor: [Sports] explode all trees
#2	Sport * or Athletic * or Athlete * or Player *
#3	#1 or #2
#4	MeSH descriptor: [Mouth Protectors] explode all trees
#5	Protector Mouth or Protectors Mouth or Guards Mouth or Mouthguard or Mouthguards or Mouth Protector * or Mouth Piece * or Mouthpiece * or Mouth guard *
#6	#4 or #5
#7	#3 and #6

moplastic material that is immersed in hot water and then formed in the mouth by the athlete using finger, tongue and biting pressure [34]. The type of MG may impact the athlete's comfort and ability to speak or breathe during activities [10, 21].

Previous clinical studies assessed the effect of the use of different types of MGs on some physiological parameters, such as gas exchange, muscle strength, agility, and others. Garner and McDivitt [20] found the use of an MG promotes an increase of oropharynx width and diameter and a decrease of lactate levels during endurance exercises, suggesting the airway openings could contribute to performance enhancement. However, this finding remains controversial in the literature because Bailey et al. [4] did not observe differences in gas exchange if an MG was used.

There are different parameters that could be used to assess the cardiopulmonary capacity, for example, respiratory oxygen uptake ( $VO_2$ ), carbon dioxide production ( $VCO_2$ ), and ventilatory measures during a symptom-limited exercise test [1]. Oxygen consumption increases with activity and there is an upper limit during exercise requiring maximal effort. Maximal  $VO_2$  is defined as the point at which no further increase in measured  $VO_2$  occurs despite an increase in work rate (a plateau is reached) during graded exercise testing [33]. Direct measures of  $VO_2$  are reliable, reproducible, and provide the most accurate assessment of functional capacity. Thus,

$VO_{2max}$  has become the preferred laboratory measure of cardiorespiratory fitness and is the most important measurement during functional exercise testing [1].

The minute ventilation increases at times of stress and exercise. This increase compensates for the increase in the demand of oxygen and the increased production of carbon dioxide.

Due to the conflicting results of the available clinical trials, a systematic review was conducted with the aim of answering the following focused question: Does the use of an MG affect cardiopulmonary capacity in athletes?

## Methods

### Protocol and registration

This systematic review was registered on the Prospero database and was performed according to PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) guidelines (<http://www.prisma-statement.org>).

### Information sources and search

To identify clinical trials to be included for this review, the topic was searched (up until June, 2016) on the electronic databases MED-

LINE (via PubMed), Scopus, Web of Science, Latin American and Caribbean Health Sciences Literature (LILACS), Brazilian Library in Dentistry (BBO), and The Cochrane Library (► **Table 1**). An expert librarian guided the whole search strategy. The reference lists of all primary studies were hand-searched for additional relevant publications. No restrictions were placed on the publication date or language. For the abstracts and manuscripts in languages other than English, a native speaker performed the translation. A “Search Alert” with the search strategy in the PubMed, Scopus, and Web of Science databases was created and the search was updated weekly for six months after the first search.

The grey literature was searched using the System for Information on Grey Literature in Europe (SIGLE) database. Dissertations and theses were explored using the ProQuest Dissertations and Theses Full-Text database as well as the Periódicos Capes Theses database.

The search strategies defined for the databases described above are listed in ► **Table 1**. The search strategy was appropriately modified for each database and performed by two reviewers to identify eligible studies. Full-text versions of the papers that appeared to meet the inclusion criteria were retrieved for further assessment and data extraction.

### Eligibility criteria

The inclusion criteria outlines, according to the population, interventions, comparisons, and outcomes (PICOS), were performed as follows:

- Population (P): Adult athletes;
- Intervention (I): Use of an MG during sports practice;
- Comparison (C): The intervention should be compared with non-use of an MG during sports practice;
- Outcome (O): Cardiopulmonary capacity ( $VO_{2\max}$ , oxygen uptake;  $VE_{\max}$ , minute ventilation).

The null hypothesis stated that there is no difference between the use and non-use of an MG during sport practice.

Only randomized clinical trials (RCTs) comparing cardiopulmonary capacity during sports practice of adult individuals with and without an MG were eligible.

$VO_{2\max}$  and  $VE_{\max}$  were the outcomes evaluated. At least one of these parameters should be assessed in each included manuscript. No restrictions regarding settings (academic university department, sports clubs, hospital, etc.) were established. Non-controlled clinical trials, pilot studies, historical reviews, editorial letters, in vitro studies, cohort, observational and descriptive studies, such as case reports and case series, were excluded. Additionally, RCTs were excluded if: (1) indirect measurement of  $VO_{2\max}$  and  $VE_{\max}$  were performed; and (2) there was a lack of an adequate control group.

### Study selection and data collection process

All electronically identified records were scanned by title and abstract. Articles appearing in more than one database search were considered only once. Two examiners independently performed the search process. In case of a discrepancy, a decision was made by consensus with a third author. Full texts were obtained for all articles identified and judged as being potentially relevant. A manual search was performed of the references in the included studies.

Data were extracted using customized extraction forms and the following data were recorded for each included study: (1) details of the study, including author(s) and year of publication; (2) details of participants, including number, age, gender, sport type, and anthropometric data; (3) details of the interval among tests; (4) details of the type of MG used; (5) details of the arch used; and (6) details of the outcomes, including  $VO_{2\max}$  (ml/Kg/min or L/min) and  $VE_{\max}$  (L/min).

For absent data, the correspondence author and/or co-author were contacted in order to send the requested data. Requests were sent via electronic message.

### Risk of bias in individual studies

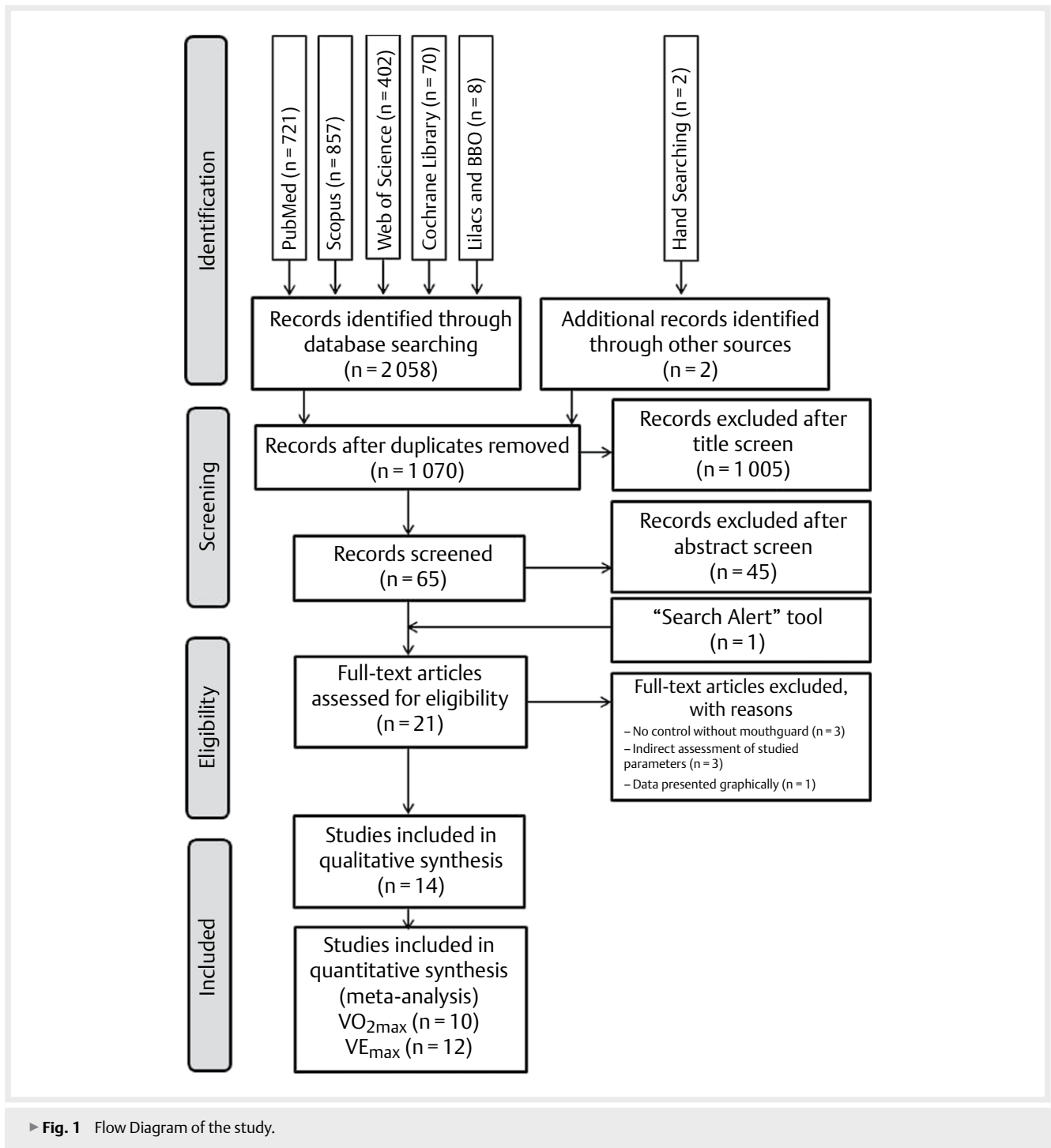
Two review authors independently undertook the risk of bias assessment for the included trials. Disagreements were solved by discussion with a third review author until a consensus was reached. The assessment was carried out according to the criteria described in Chapter 8 of the Cochrane Handbook for Systematic Reviews of Interventions [26]. The assessment criteria contained six items: sequence generation, allocation concealment, blinding of the outcome assessors, incomplete outcome data, selective outcome reporting, and other possible sources of biases. This study considered the interval between physical tests as another possible source of bias. Three out of the six domains in the Cochrane risk of bias tool were considered the key domains for the assessment of the studies' risk of bias. Studies were considered to be at 'low' risk of bias if missing outcome data were well managed, they were free of selective reporting, and a minimum of 24 h occurred between physical tests. When the study was judged as 'unclear' in their key domains, attempts were made to contact authors to obtain more information and allow a definitive judgment of 'yes' or 'no'.

The overall risk of bias of the included studies was categorized and reported according to the following:

- Low risk of bias (plausible bias unlikely to seriously alter the results) if all key domains were assessed as a low risk of bias;
- Unclear risk of bias (plausible bias that raises some doubt about the results) if one or more key domains were assessed as an unclear risk of bias; or
- High risk of bias (plausible bias that seriously weakens confidence in the results) if one or more key domains were assessed as a high risk of bias.

### Summary measures and synthesis of results

For the meta-analysis, only the data from  $VO_{2\max}$  in ml/Kg/min were considered. In studies where  $VO_{2\max}$  was reported in L/min, the data was requested in ml/Kg/min. Data of  $VO_{2\max}$  in L/min were included only in the systematic review and the data were presented as a descriptive analysis. For the meta-analysis,  $VO_{2\max}$  (ml/Kg/min) and  $VE_{\max}$  (L/min) data (means and standard deviations) for MG vs. control were pooled and the subgroups analyzed. Pooled analyses took into account all included studies, and subgroup analyses assessed the different types of MG (boil-and-bite, custom-made, and stock) and the arch used (upper, lower, and upper/lower jaw). All analyses were conducted in Comprehensive Meta-Analysis Software 3.2 (Biostat, Englewood, NJ, USA) using a fixed-effect model. Pooled effect estimates were obtained by comparing the mean values of  $VO_{2\max}$  and  $VE_{\max}$  and were expressed as the raw



► **Fig. 1** Flow Diagram of the study.

mean difference among the groups. A  $p$ -value  $\leq 0.05$  was considered statistically significant (Z-test). Statistical heterogeneity of the treatment effect among studies was assessed via the Cochran Q test, with a threshold  $p$  value of 0.1, and the inconsistency  $I^2$  test, in which values  $> 50\%$  were considered indicative of high heterogeneity. For studies that evaluated more than one MG, each type was considered independently (subgrouped) for each evaluated parameter (VO<sub>2max</sub> and VE<sub>max</sub>).

## Results

### Study selection

After the database screening and removal of duplicates, 1,070 studies were identified (► **Fig. 1**). After title screening, 65 studies remained and this number was reduced to 20 after careful examination of the abstracts. One study was included after 'search alert' updated the search. The full texts of these 21 studies were assessed

► **Table 2** Summarized data collected from the selected studies.

First Author, Year	# of subjects (gender)	Sports	Subjects' age mean $\pm$ SD [range] (yrs.),	Anthropometric data Height mean $\pm$ SD (cm) Body mass $\pm$ SD (kg) Body mass index $\pm$ SD ( $\text{Kg m}^{-2}$ )	Interval between tests	Type of MG (description according to the studies)	Area (arch)	Cardiopulmonary Capacity	
								$\text{VO}_2$ max Mean $\pm$ SD	$\text{VE}_{\text{max}}$ (L/min)
Bailey, 2015 [4]	15 (male)	n.r.	24 $\pm$ 1 [n.r.]	n.r. $\pm$ n.r. n.r. $\pm$ n.r. 25.2 $\pm$ 0.9	At least 1 week	- (MG1) traditional boil-and-bite; - (MG2) "vented" boil-and-bite	Upper	(L/min) C* - 3.49 $\pm$ 0.13 MG1 - 3.48 $\pm$ 0.13 MG2 - 3.48 $\pm$ 0.17	C - 123.29 $\pm$ 6.21 MG1 - 121.94 $\pm$ 6.45 MG2 - 113.16 $\pm$ 7.66
Bourdin, 2006 [7]	19 (male)	2 Handball, 1 ice hockey, 16 rugby	27 $\pm$ 4.8 [n.r.]	180.9 $\pm$ 8.7 91.4 $\pm$ 18.6 n.r. $\pm$ n.r.	At least 2 days	- (MG1) self-adapted thermoplastic (boil-and-bite) - (MG2) custom-made methyl methacrylate resin	Upper	(ml/Kg/min) C - 47.1 $\pm$ 9.18 MG1 - 48.2 $\pm$ 9.03 MG2 - 48.1 $\pm$ 9.46 (15 subjects)	C - 144.2 $\pm$ 19.76 MG1 - 147.4 $\pm$ 17.21 MG2 - 148.2 $\pm$ 18.06 (15 subjects)
Delaney, 2005 [10]	12 (female)	Ice hockey	19.8 $\pm$ 0.8 [n.r.]	166.8 $\pm$ 7.2 63.8 $\pm$ 6.6 n.r. $\pm$ n.r.	Average of 6.8 days	- (MG1) boil-and-bite	Upper and lower	(ml/Kg/min) C - 52.4 $\pm$ 0.8 MG1 - 48.8 $\pm$ 0.7	C - 114.1 $\pm$ 3.8 MG1 - 108.5 $\pm$ 4.0
El-Ashker, 2015 [15]	18 (male)	Elite boxer	19.4 $\pm$ 2.01 [17.8-24.2]	174 $\pm$ 7.9 74.5 $\pm$ 5.1 n.r. $\pm$ n.r.	6-10 days	- (MG1) custom-fitted: ethylene vinyl acetate copolymer sheets, with standard thickness 4 mm - (MG2) stock MG	Upper	(ml/Kg/min) C - 47.37 $\pm$ 5.34 MG1 - 46.48 $\pm$ 3.65 MG2 - 40.54 $\pm$ 5.68	C - 99.51 $\pm$ 13.42 MG1 - 95.71 $\pm$ 14.82 MG2 - 92.74 $\pm$ 11.26
Francis, 1991 [17]	10 (male) 7 (female)	n.r.	27.2 $\pm$ 5.2 [20-37]	175.51 $\pm$ 9.65 72.72 $\pm$ 15.59 n.r. $\pm$ n.r.	24-48 h	- (MG1) unfitted, made of a soft rubberized material - (MG2) unfitted, made of the same material and construction as MG - (MG3) bimaxillary guard composed of a more rigid vinyl material with a small breathing hole between the upper and lower plates.	MG1 - upper MG2 and MG3 - upper and lower	(ml/Kg/min) C - 30.46 $\pm$ 4.37 MG1 - 27.38 $\pm$ 5.34 MG2 - 28.1 $\pm$ 3.47 MG3 - 27.39 $\pm$ 5.68	C - 50.98 $\pm$ 19.72 MG1 - 43.57 $\pm$ 9.47 MG2 - 44.63 $\pm$ 12.98 MG3 - 41.34 $\pm$ 14.24
Gamer, 2011 [21]	13 (male) 3 (female)	n.r.	21.2 $\pm$ 0.75 [18-21]	176.37 $\pm$ 7.3 75.2 $\pm$ 12.96 n.r. $\pm$ n.r.	2-3 days	- (MG1) custom-fitted	Lower	(ml/Kg/min) C1 - 24.8 $\pm$ 5.8 MG1 - 31.19 $\pm$ 7.5 (14 subjects)	C - 58.3 $\pm$ 13.7 MG1 - 56.9 $\pm$ 11.5 (14 subjects)
Gamer, 2015 [19]	21 (n.r.)	n.r.	n.r. [18-21]	n.r. n.r. n.r.	At least 3 days	- (MG1) boil-and-bite - (MG2) polypropylene, custom-fit - (MG3) ethylene vinyl acetate, custom-fit	Lower	(ml/Kg/min) C - 30.59 $\pm$ 3.24 MG1 - 29.98 $\pm$ 4.42 MG2 - 30.59 $\pm$ 4.76 MG3 - 30.64 $\pm$ 4.35 (16 subjects)	C - 45.60 $\pm$ 7.50 MG1 - 42.93 $\pm$ 7.11 MG2 - 46.02 $\pm$ 8.60 MG3 - 45.26 $\pm$ 7.67 (16 subjects)

► **Table 2** Continued.

First Author, Year	# of subjects (gender)	Sports	Subjects' age mean ± SD [range] (yrs.),	Anthropometric data Height mean ± SD (cm) Body mass ± SD (Kg) Body mass index ± SD (Kg m <sup>-2</sup> )	Interval between tests	Type of MG (description according to the studies)	Area (arch)	Cardiopulmonary Capacity	
								VO <sub>2</sub> max Mean ± SD	VE max (l/min)
Gebauer, 2011 [22]	27 (male)	Hockey or water polo	23.5 ± 3.8 [n.r.]	182 ± 0.08 81.7 ± 8.6 24.6 ± 2.1	1 week	- (MG1) custom laminated MG with normal palatal surface - (MG2) custom laminated MG with palatal coverage up to the gingival margin	Upper	(ml/Kg/min) C - 124.19 ± 15.62 MG1 - 122.51 ± 18.80 MG2 - 124.22 ± 14.68	(l/min) C - 56.09 ± 4.82 MG1 - 57.22 ± 6.14 MG2 - 56.76 ± 6.33
Kececi, 2005 [28]	11 (male) 11 (female)	Elite taekwondo athletes	16 ± 1.11 [14-17]	n.r. ± n.r. n.r. ± n.r. n.r. ± n.r.	48 h	- (MG1) custom-made EVA	Upper	(ml/Kg/min) C - 106.32 ± 5.75 MG1 - 108 ± 4.41	(ml/Kg/min) C - 51.79 ± 2.12 MG1 - 52.73 ± 1.81
Piero, 2015 [36]	10 (male)	Amateur road cyclists	34 ± 6 [n.r.]	178 ± 7 70 ± 10 22 ± 2	1 week	- (MG1) custom-made	Upper and lower	(ml/Kg/min) C - 140 ± 23 MG1 - 141 ± 22	(ml/Kg/min) C - 57.8 ± 6.5 MG1 - 58.1 ± 5.8
Rapisura, 2010 [39].	11 (female)	n.r.	22 ± 3.3	159.8 ± 4.3 n.r. 63.7 ± 8.9	Average of 9.1 days	- (MG1) universal self-adapted MG (boil-and-bite) - (MG2) self-adapted MG made for women (boil-and-bite)	MG1 - upper MG2 - upper and lower	(ml/Kg/min) C - 68.5 ± 17.3 MG1 - 64.7 ± 13.2 MG2 - 56.8 ± 6.4	(ml/Kg/min) C - 31.0 ± 6.7 MG1 - 30.4 ± 7.1 MG2 - 29.6 ± 5.4
von Arx, 2008 [41]	13 (male)	n.r.	22 ± n.r. [18-27]	n.r. ± n.r. n.r. ± n.r. n.r. ± n.r.	48 h	- (MG1) multiple-EVA pressure-laminated MG	Upper	(l/min) C - 112.9 ± 28.3 MG1 - 105.3 ± 17.8	(l/min) C - 3.29 ± 0.36 MG1 - 3.16 ± 0.49
Wenta, 2014 [44]	6 (male) 1 (female)	n.r.	19.4 ± 1.6 [n.r.]	175 ± 2.5 79.4 ± 8.89 n.r.	7 days	- (MG1) self-adapted (boil-and-bite)	n.r.	(ml/Kg/min) C - 57.75 ± n.r. MG1 - 56.77 ± n.r.	(ml/Kg/min) C - 27.8 ± n.r. MG1 - 27.9 ± n.r.
Yarar, 2013 [45]	8 (male)	Combat sports	22 ± 2.2 [n.r.]	173.5 ± 3.38 70.45 ± 8.14 n.r.	1 week	- (MG1) MG (non-specified)	n.r.	(ml/Kg/min) C - 53.87 ± 6.42 MG1 - 53.37 ± 5.57	(ml/Kg/min) C - 53.87 ± 6.42 MG1 - 53.37 ± 5.57

C\* - Control (without mouthguard); n.r.: not reported



to check if they were eligible. Among them seven were excluded due to the following reasons: (1) lack of adequate control [2, 13, 27]; (2) indirect assessment of studied parameters [9, 37, 38]; and (3) data presented graphically [32].

### Study characteristics

The characteristics of the 14 selected studies are listed in ► **Table 2**. All the studies that met the inclusion criteria were randomized controlled trials published in English between December 1991 and December 2015. All studies were cross-over designed. Seven studies [4, 7, 15, 22, 36, 41, 45] recruited male participants, two studies [10, 39] recruited female participants, four studies [17, 21, 28, 44] recruited participants of both genders, and one study [19] did not report the gender of participants. The number of athletes included in these studies ranged from 7 to 28 participants. The range of age of the athletes was 16–37 years old. Eight studies reported each sport the athletes participated in. The interval between exercise tests varied from 24 h to 10 days. The type of mouthguard also varied among the retrieved studies. Eight studies [10, 21, 28, 32, 36, 41, 44, 45] compared the use of one type of MG with no MG. However, some studies [4, 7, 15, 17, 19, 22, 39] tested more than one type of MG. There was variability with respect to MG placement. Six studies [4, 7, 15, 22, 28, 41] tested MGs placed over the upper jaw, two studies [19, 21] tested MGs placed over the lower jaw, four studies [10, 17, 36, 39] tested MGs placed over the upper and lower jaws, and two studies [44, 45] did not report where the MG was placed. There was a great variability of the protocol of maximal exercise tests. Some studies presented the absolute data of  $VO_{2\max}$  in L/min [4, 7, 41]. The relative data in ml/Kg/min was requested, however only one author [7] answered the request. In regards to the outcomes, one study [45] assessed only  $VO_{2\max}$ ; the others [4, 7, 10, 15, 17, 19, 21, 22, 28, 36, 39, 41, 44] assessed both parameters.

### Risk of bias within studies

The assessment of the risk of bias of the selected studies is presented in ► **Fig. 2**. All studies reported the randomization of the tests' sequence, but few full-text studies reported the method of randomization employed and how the allocation concealment was performed. Authors were contacted for further information. Seven full texts were considered 'unclear' for the method of randomization employed and all of them were considered 'unclear' for the allocation concealment.

In relation to blinding of participants and evaluators, all included studies were considered 'unclear' because all of the studies did not address these outcomes. Nevertheless, since the respiratory assessments were performed during exercise tests, with or without use of MG, blinding would not be possible both for subjects and examiners. In the assessment of the domain "incomplete outcome data", only one abstract [44] was considered to be 'unclear', because no information about dropouts was reported. Only three [7, 19, 21] of the 14 studies included in the qualitative analysis were missing outcome data. Despite this, they were considered as 'low' risk of bias for this domain because the reason for the missing outcome data was not related to the true outcome: the expiratory volumes of subjects were underestimated in one session because of full face mask displacement due to sweating.

	Random Sequence Generation?	Allocation Concealment?	Blinding?	Incomplete outcome data addressed?	Free of selective reporting?	Other bias?
Bailey, 2015	?	?	?	+	+	+
<u>Bourdin, 2006</u>	+	?	?	+	+	+
<u>Delaney, 2005</u>	+	?	?	+	+	+
El-Asker, 2015	?	?	?	+	+	+
Francis, 1991	?	?	?	+	+	+
<u>Garner, 2011</u>	+	?	?	+	+	+
<u>Garner, 2015</u>	+	?	?	+	+	+
Gebauer, 2011	?	?	?	+	+	+
Keçeci, 2006	?	?	?	+	+	+
<u>Piero, 2015</u>	+	?	?	+	+	+
<u>Rapisura, 2010</u>	+	?	?	+	+	+
<u>Vom Arx, 2006</u>	+	?	?	+	+	+
Wenta, 2014	?	?	?	?	?	+
Yarar, 2013	?	?	?	+	+	+

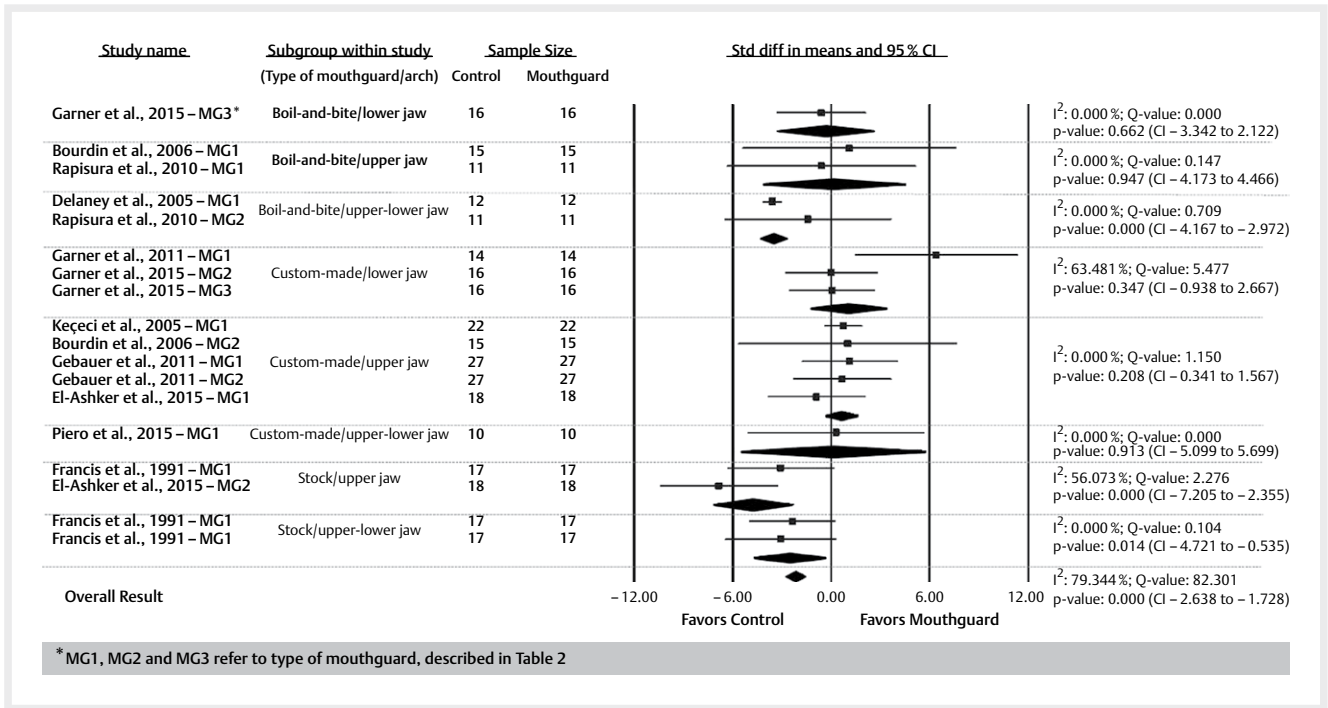
► **Fig. 2** Summary of the risk of bias assessment according to the Cochrane Collaboration tool. Underlined authors provided extra information by e-mail to allow assessment of the risk of bias.

Regarding selective reporting, all studies were considered 'low' risk of bias (► **Fig. 2**) because the study protocol was available, and all of the studies' outcomes were reported, except for the one abstract [44] judged as 'unclear'. Regarding other sources of bias, all studies were considered 'low' risk of bias, because there was a minimum interval of 24 h between exercise tests.

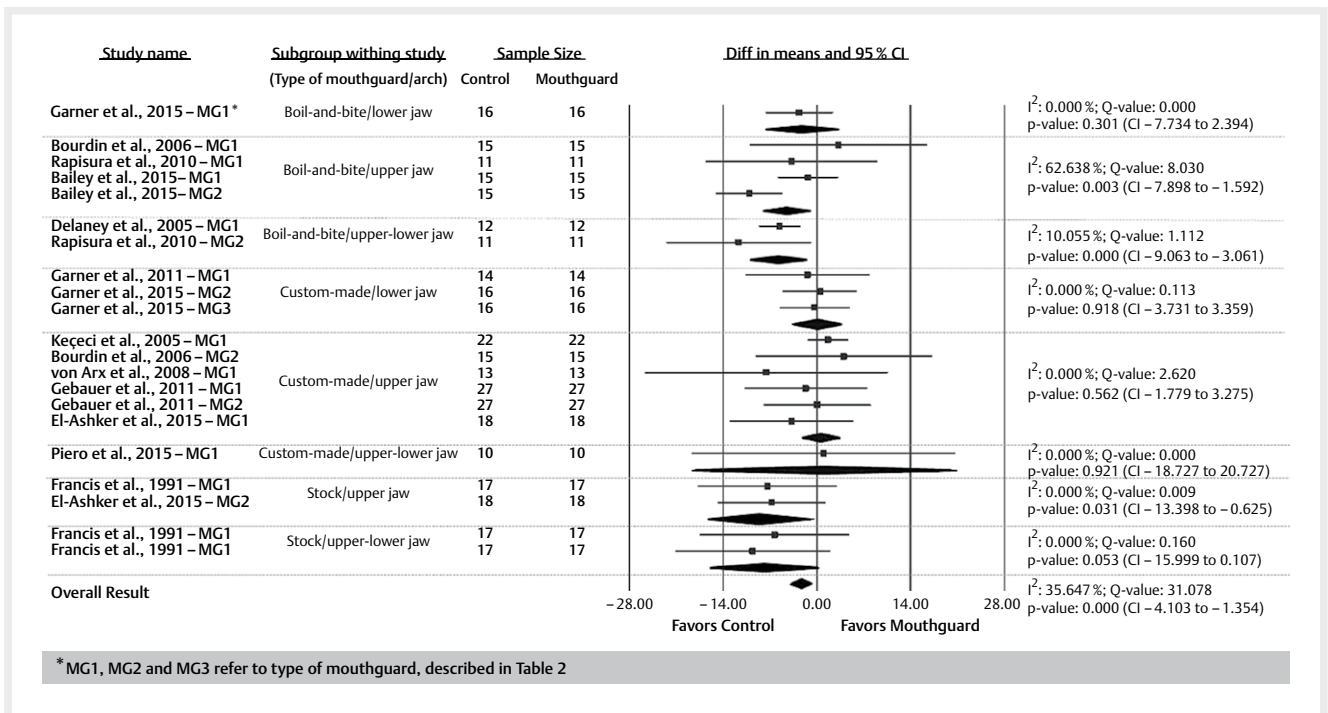
Incomplete outcome data, selective reporting, and other sources of bias were considered as key domains for this systematic review. In summary, from the 14 studies, only one abstract [44] was considered 'unclear' in the key domains of the Cochrane risk of bias tool.

### Synthesis of the results: meta-analyses

For the meta-analysis, studies were grouped according to the kind of outcome used to report cardiopulmonary capacity ( $VO_{2\max}$  or  $VE_{\max}$ ). This resulted in a total of 10 studies [7, 10, 15, 17, 19, 21,



► Fig. 3 Forest Plot of Pooled and Subgroup Analysis of VO<sub>2max</sub>.



► Fig. 4 Forest Plot of Pooled and Subgroup Analysis of VE<sub>max</sub>.

22, 28, 36, 39], which reported both outcomes and were included in the two pooled meta-analyses. Two studies [4, 41] were included only in the pooled meta-analysis of VE<sub>max</sub> because the data for VO<sub>2max</sub> were in L/min.

For the pooled analysis of VO<sub>2max</sub> (each type of MG vs. control), 18 data sets were considered (subgroups), although 10 studies

were included (► Fig. 3). It was observed that a statistical difference (p<0.05) between conditions (MG x no MG) favored the control group, which presented the higher VO<sub>2max</sub> values. The heterogeneity parameter I<sup>2</sup> was 79.344%. For the pooled analysis of VE<sub>max</sub> (each type of MG vs. control), 21 data sets were considered, although 12 studies were included (► Fig. 4). A statistical difference



( $p < 0.001$ ) was observed between conditions (MG x no MG) favoring the control group, which presented the higher  $VE_{max}$  values. The heterogeneity parameter  $I^2$  was 35.647 %.

When the results were analyzed separately for each subgroup (type of MG and arch used), the meta-analysis showed that the effect of the use of MG on  $VO_{2max}$  was not significant when some types of MGs were used (boil-and-bite/lower jaw, boil-and-bite/upper jaw, custom-made/upper jaw, custom-made/lower jaw, custom-made/upper-lower jaw) compared to control. The subgroup analysis of  $VE_{max}$  showed that the use of custom-made MGs had no effect on this parameter compared to control. For subgroup analyses, the heterogeneity parameter  $I^2$  was predominantly low.

## Discussion

The current systematic review and meta-analysis results rejected the null hypothesis.

The main finding of this meta-analysis is that the use of an MG overall adversely affects cardiopulmonary capacity when compared with not using an MG. However, when the types of MGs were subgrouped, this effect did not occur for some types. Nevertheless, no MG improved cardiopulmonary capacity.

Due the difficulties in finding articles that assessed several variables, the authors chose to assess  $VO_2$  and VE. Besides proper reporting of cardiopulmonary capacity and performance, these parameters were the most commonly evaluated in the studies. In this meta-analysis, assessments of  $VO_2$  and VE at maximal effort were included. Some studies [4, 7, 10, 15, 19, 21, 22, 39] also evaluated these parameters at a submaximal effort, thus, sometimes different results were found and could be applicable to sports requiring maximal effort during their practice. Despite the type of sport, the analyses of cardiopulmonary capacity were done with the athletes doing specific exercises for this type of analysis.

All studies included in this systematic review and meta-analysis were cross-over designed. The essential feature distinguishing a cross-over trial from a conventional parallel-group trial is that each patient serves as his/her own control. The cross-over design thus avoids problems of comparability of study and control groups with regard to confounding variables (e. g., age and gender). Moreover, the cross-over design is advantageous regarding the power of the statistical test carried out to confirm the existence of a treatment effect, and it requires lower sample sizes than parallel-group trials. The two trial periods in which the patient receives the different treatments must be separated by a washout phase that is sufficiently long enough to rule out any carry-over effect. In fact, the effect of the first treatment must have disappeared completely before the beginning of the second period [43]. Therefore, the intervals between the exercise tests were considered an important risk of bias.

The mechanisms that could explain the reduction in ventilation and oxygen uptake when MGs are used at the higher workloads still remain unclear. Francis and Brasher [17] observed a decrease in oxygen uptake and minute ventilation when subjects used an MG and hypothesized that MGs caused “pursed-lip breathing” (PLB), which has been shown to improve respiratory efficiency during exercise in people with lung disease. During PLB, less air has to be breathed to absorb a given amount of oxygen. Peak and mean expiratory flow rates are reduced, respiratory rates are decreased, and tidal

volume is increased. All these factors result in improved alveolar ventilation and the enhancement of ventilation of previously underventilated areas [6]. However, it is unclear if PLB has similar effects in people with normal lung function. This phenomenon was observed in studies in which some stock and boil-and-bite MGs were tested [15, 17]. These MGs are not well fitted and need a contraction of the perioral muscles to be maintained in position.

Gardner and McDivitt [20] observed the use of a boil-and-bite upper MG, which had a greater bite opening, favored an increase in airway diameter and a decrease of blood lactate. As a result, they hypothesized that lactate was reduced because subjects had increased ventilation and thus were better able to eliminate  $CO_2$ . However, this study did not measure gas exchange parameters during the test, so it is unclear if ventilation was increased or decreased during this investigation. Nevertheless, Amis et al. [2] found that custom-made maxillary MGs were unlikely to interfere with breathing at high ventilatory rates and where recruitment of compensatory mechanisms is possible. The degree of such compensation to the presence of an MG may vary considerably between individuals. Thus, although the obstruction associated with wearing an MG can be overcome by most individuals, some subjects may have persistent oral airway obstruction in the presence of an MG. On the other hand, Garner et al. [21] found an improvement of  $VO_2$  and VE when a custom-made mandibular MG was tested. The authors explained that this specific MG did not create any obstruction in breathing.

In the twelve studies included in this meta-analysis, a great variety of MGs were tested. Since some studies revealed that the type of MG could affect the assessed parameters, a subgroup analysis by type and placement of mouthguards was included. By this analysis, custom-made MGs did not affect the assessed parameters. Duarte-Pereira et al. [12] showed that the custom-made MG, compared with the boil-and-bite MG, interferes less with speech, breathing, and oral dryness. It is more comfortable, better adapted, and causes less nausea. For these reasons, custom-made MGs are the favorite and have the highest level of acceptance in most of players.

Stock MGs are inexpensive and come preformed. They are essentially plastic trays that fit loosely over the teeth. Consequently, this type of MG usually does not fit very well, and the mouth should be closed for retention [11, 24]. The results of this meta-analysis showed this type of MG negatively affected  $VO_{2max}$  and  $VE_{max}$ . Moreover, according to Patrick et al. [35], this type of MG offers a less protective effect compared to the boil-and-bite and custom-made MGs.

Since the number of studies testing only lower-jaw mouthguards is small in the MG type subgroups (one study with boil-and-bite [19], 3 studies with custom-made [19, 21], and no studies with stock), the influence of arch on the studied parameters could not be estimated. This lack of studies may be due to the fact that mouthguards are usually used in the upper jaw in order to provide better protection against tooth trauma.

In a recent systematic review and meta-analysis, Vucic et al. [42] revealed that the average proportion of field hockey players who had sustained at least one dentofacial injury varied from 12.7 % among junior and senior players to 45.2 % among elite players. They also showed a significantly higher proportion of players regularly wore an MG (84.5 %) as compared with players 20 years ago

(31.4%). The most common complaints about the MG were that it was unnecessary and uncomfortable. There was an increasing in awareness about the importance of the use of this apparatus against oral injuries. Indeed, for some sports the use of an MG during official competition is mandatory. Besides the protection against oral injuries, some studies have reported increased strength, balance, and coordination as a result of changing the maxillomandibular relationship with an MG [14, 36]. Although it has been demonstrated that wearing an MG reduces orofacial injury, many athletes do not wear one during training sessions or in competition for various reasons, including speech and breathing difficulties or discomfort [18].

## Conclusion

Based on this systematic review and meta-analysis, there is scientific evidence showing the use of an MG negatively affects  $VO_2$  and VE at maximal effort. However, custom-made MGs seem to have no effect on these parameters. Therefore, considering the importance of MGs during sport practice, the evidence collected from the present meta-analysis support the use of custom-made MGs.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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