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Effect of Mouthguard Use on Aerobic and Anaerobic Parameters: A Systematic Review and Meta-Analysis

MAYARA JERONYMO UEBE MANSUR[1]
Aluna Voluntária de Iniciação Científica do PROVIC/ISECENSA
Aluna do curso de Educação Física (ISECENSA)
VICTOR PAES DIAS GONÇALVES[2]
Mestrando em Odontologia na São Leopoldo Mandic (SLM-MANDIC)
Pesquisador Colaborador LABIMH/ISECENSA
ANDERSON PONTES MORALES[3]
Pesquisador Orientador LABIMH/ISECENSA
Institutos Superiores de Ensino do CENSA/ISECENSA
Laboratório de Pesquisa e Inovação em Ciências do Esporte (LAPICE/UFRJ-Macaé)
Secretaria Municipal de Esporte de Macaé (SEMEL-Macaé)
MARLANA RIBEIRO MONTEIRO[4]
Pesquisador Orientador LABIMH/ISECENSA
Institutos Superiores de Ensino do CENSA/ISECENSA

Abstract

Although authors demonstrate that the use of mouthguards (MG) can prevent the occurrence of orofacial traumas during sports practice, the influence of this device on athletic performance was little

[1] Formada em Arquitetura, Paisagismo e Urbanismo. Aluna de iniciação científica do curso de educação física. O principal interesse na pesquisa está relacionado ao campo investigativo de fisiologia do exercício. Possuí experiência em bioestatística aplicada à área da saúde.
[2] Atualmente possui graduação em Odontologia pelo Centro Universitário Fluminense (2017). Pós graduando em Cirurgia Buco-Maxilo-Facial E Anatomia Funcional. Professor do Curso de Atualização em Cirurgia Oral Menor (ABO-CAMPOS). Tem experiência na área de Odontologia, com ênfase em Anatomia, Odontologia do Esporte e Cirurgia Buco-Maxilo-Facial. Integrante da comissão técnica do Clube de Regatas Vasco da Gama – RJ.
[3] Doutor em Ciências Nutricionais pela Universidade Federal do Rio de Janeiro (UFRJ-RJ). Mestre em Ciências da Motricidade Humana pela Universidade Castelo Branco (UCB-RJ). Membro Parecerista do Comitê de Ética em pesquisas em seres humanos dos Institutos Superiores de Ensino do CENSA-ISECENSA-RJ. Coordenador e Docente do curso de Pós Graduação em Treinamento de Força e Fisiologia do Exercício (ISECENSA-RJ). Possui experiência nas áreas de Bioquímica, Biomecânica, Bioestatística, Fisiologia Humana e Fisiologia do Exercício. Docente dos cursos de Graduação em Educação Física, Fisioterapia e Enfermagem dos Institutos Superiores de Ensino do CENSA-ISECENSA-RJ.
[4] Graduação em Odontologia pela Faculdade de Odontologia de Campos-RJ, em 1997. Especialista em Anatomia e Cinesiologia Humana pela UCB-RJ, em 2000. Pós-graduação, nível mestrado, em Morfologia Aplicada à Área de Saúde, em 2002, pela UNIFESP-EPM. Atualmente é Professora Titular da Disciplina de Anatomia Humana da Faculdade de Odontologia de Campos-RJ, Professora de Anatomia Humana dos Institutos Superiores de Ensino do Censa,ISECENSA/Campos-RJ, Professora de Anatomia Humana da Faculdade de Medicina de Campos-RJ. Membro da Sociedade Brasileira de Anatomia.

systematically quantified through meta-analysis. However, research on athletic performance has shown controversial results, in part when the energy system used is not considered. The goal of the present study is to in Investigate the acute effect of using MG on athletic performance in tests that use different types of energy metabolism (anaerobic and aerobic metabolism). Fifteen published studies were included in the meta-analysis. A final meta-analysis was performed using the random effects model and pooled standardized mean differences (SMD). This revealed that the use of MG had beneficial effects in anaerobic performance tests (SMD, 0.52; 95% confidence interval - CI, 0.12 to 0.91; p = 0.00). However, the use of MG did not impact aerobic performance tests (SMD, 0.32; 95% CI, -0.09 to 0.75; p = 0.13). The data from the subgroup analysis revealed that the use of the two types (type 3: SMD, 0.27; 95% CI, -0.21 to 0.76; p = 0.25 and type 5: SMD, 0.27; 95% CI, -0.03 to 1.09; p = 0.06) of MGs does not improve or negatively impact anaerobic performance. The findings of the present study indicate that the use of MG does not negatively affect physiological and performance parameters in outcomes involving aerobic and anaerobic metabolism. Furthermore, an improvement in outcomes involving anaerobic metabolism was observed with the use of MG. However, this effect was not observed when MGs (type 3 and 5) were subdivided in the evaluation of outcomes involving predominantly anaerobic metabolism.

Keywords: mouthguard, performance, athletes

INTRODUCTION

The practice of physical contact sports, such as rugby, hockey, boxing, martial arts, basketball, handball, soccer, among others, can lead to an increased risk of orofacial injuries (Hawke and Nicholas 1969; Gialain, Coto, and Dias 2014; Emerich and Nadolska-Gazda 2013; Azodo et al. 2011). Thus, the use of mouthguards (MG) during practice has been recommended. With the development of mouthguards, the reduction in the extension and severity of these injuries has been achieved with greater frequency (Tanaka et al. 2015).

MGs are preferably used only in the athlete's upper arch, acting to absorb the energy of the blow/impact in the mouth, dissipating and distributing it to areas of resistance. In addition to preventing orofacial trauma, some MGs can also offer mandibular repositioning (Tanaka et al. 2015; Dias et al. 2019).

Recent literature shows a high prevalence of athletes choosing to use type 1 (universal) and type 2 (boil and bite) MGs, justified by the low cost (Gonçalves, Nahmias, and Azevedo 2020). However, these MGs are not recommended for use as they do not have occlusal adjustments and are uncomfortable due to their standard size. According to Knapik et al. (2019) and Tribst et al. (2020), the MGs recommended for use are individualized MGs (type 3), customized (type 4), and optimizers (type 5) because they are custom-made, extremely comfortable, and better dissipate impact forces.

Despite the clear potential of MGs in reducing the risk of injury, some athletes have difficulty using MGs because of their dryness in their mouths, breathing, and speech difficulties, and thus increasing the perception that it can negatively impact their exercise performance (McClelland, Kinirons, and Geary 1999; Brionnet et al. 2001). Previous clinical studies have evaluated the effect of MG use on aerobic (Gebauer et al. 2011) and anaerobic exercise (Allen et al. 2014, 2018).

Findings from studies by Garner and McDivitt (2009) and Zaman et al. (2017), indicate that depending on the type of MG used by the athlete, it can promote an increase in the width and diameter of the oropharynx, suggesting that airway openings can contribute to the improvement of parameters ventilation and increased performance in predominantly aerobic activities.

However, these findings remain controversial in the literature, because. Rapisura et al. (2010) did not observe differences in minute volume (VE) and respiratory exchange ratio (RER) when MG was used by eleven women in a test performed on a cycle ergometer. Likewise, Bailey et al. (2015) did not observe differences in gas exchange with the use of MG. Authors such as Lässing et al. (2021), observed an increase in metabolic effort and a significant reduction in ventilation parameters, which affected the performance of 17 healthy individuals using the MG on the cycle ergometer.

In predominantly anaerobic exercises, the mechanism proposed with the use of MG to improve muscle strength may be related to the concurrent activation potentiation (CAP) that are derived from a closed jaw and that constitute a remote voluntary contraction (RVC), which is the possible cause of the ergogenic effect. The use of mandibular repositioning MG is beneficial in improving muscle strength (Ebben, Flanagan, and Jensen 2008), where contraction of the jaw muscles can translate into improved neuromuscular responses of movement agonist muscles.

However, clinical studies investigating the use of MG did not observe improvement in muscle strength/power. For example, Buscà et al. (2018) did not observe differences in the output power of 13 basketball players in the leg press exercise verified by a linear encoder system. The findings of a recent study (Miró et al. 2021) indicated that the use of MGs can promote beneficial effects on lower limb muscle strength, especially on jumping ability and knee extension actions, but they do not extend to muscle actions isometric and isokinetic.

Due to the conflicting results of available clinical trials, a systematic review was carried out to investigate whether the use of mouthguards negatively impacts physiological and athletic performance parameters, considering tests that use aerobic and anaerobic energy metabolism.

MATERIAL AND METHOD

Protocol

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

Information sources and search

A systematic literature review was performed to analyze the acute effects of mouthguard use on performance, which was defined as 1) athletic performance and 2) anaerobic and aerobic testing. An extensive article search was carried out, with only articles published before January 2020, using databases PubMed, Scopus, Web of Science, Latin American e Literatura Caribenha em Ciências da

Saúde (LILACS) (Table 1). The selection process is described in Figure 1. No dates or language restrictions were applied. The MeSH terms "Mouthguard" were used. MeSH synonyms, related terms, and free terms were included. The terms were combined to refine the search results. The titles and abstracts of the identified articles were independently evaluated by two investigators to determine whether they met the inclusion criteria for the review. The electronic search was complemented by a manual search of the reference list of the articles used.

Eligibility Criteria

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

Population (P): Amateur; Elite; Professional Athletes.
Intervention (I): Mouthguard.
Comparison (C): Mouthguard control or without Mouthguard.
Outcome (O): Anaerobic and aerobic tests.
Study Design (S): Randomized clinical trial; Crossover randomized clinical trial.

Inclusion Criteria

Muscle strength/power and endurance tests, randomized clinical trials, published in any language.

Exclusion Criteria

Use of mouthguard as a therapeutic form, without a control condition, chronic use of a mouthguard, animal study, pilot study, observational study, book chapter, systematic review or meta-analysis and without complete data for analysis.

Selection of Studies and Data Collection

All electronically identified articles were scanned by title and abstract. Articles that appeared in more than one database search were only considered once. Two examiners (MJUM and VPDG) independently performed the research process. In case of discrepancy, a decision was made by consensus with a third author (APM). Full texts were obtained for all articles identified and judged to be potentially relevant. Data were extracted from the following variables; **Anaerobic Test:** Vertical jump (Peak force), Jump height, Handgrip tests, Maximum power in cycle ergometer, Back-Row isometric force (Peak force), Countermovement vertical jump, Abduction + Adduction (torque), External rotation + Internal rotation (torque), Cycling sprint performance in Wingate anaerobic test, Maximal aerobic performance, Bench press performance. **Aerobic Test:** Cooper test, Maximal oxygen uptake (VO_2max), Minute ventilation (VE), Maximal aerobic performance. For the meta-analysis, data were generally extracted using means, standard deviation and sample sizes (n), types of mouthguards, and exercises performed.

Assessment of risk of bias and study quality

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 (Shuster 2011). The following dimensions were considered: Random sequence generation, allocation concealment, participant blinding, professional blinding, blinding of outcome evaluators, incomplete outcomes, selective outcome reporting, and sample calculation. The risk was assessed using pre-specified criteria for study suitability. 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

Data were extracted and converted into a standard format by calculating the standardized mean difference (SMD), referred to as the "size effect" in the Results and Discussion. All analyses were conducted in Comprehensive Meta-Analysis Software 3.2 (Biostat, Englewood, NJ, USA) using a random-effect model. A p-value ≤ 0.05

was considered statistically significant (Z-test). Statistical heterogeneity of the treatment effect among studies was assessed via the Chi^2 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. Studies with MGs (type 3 and 5) were used for subgroup evaluation in anaerobic parameters.

Table 1. Electronic databases used and search strategies - Date: 10/08/2020

Database	Search strategy
PubMed	
#1 (athletes) OR (athlete)	#2 ("Mouth Protector" OR "Protector, Mouth" OR "Protectors, Mouth" OR "Protetor bucal" OR "Mouth Pieces, Protective" OR "Mouth Pieces, Protective" OR "Mouth Piece, Protective" OR "Piece, Protective Mouth" OR "Pieces, Protective Mouth" OR "Protective Mouth Piece" OR "Protective Mouth Pieces" OR "Mouthpieces, Protective" OR "Mouthpiece, Protective" OR "Protective Mouthpiece" OR "Protective Mouthpieces" OR "Mouth Guards" OR "Guard, Mouth" OR "Guards, Mouth" OR "Mouth Guard" AND "Randomized Controlled Trial"
Scopus	
#1 TITLE-ABS-KEY (athletes) OR (athlete))	#2 TITLE-ABS-KEY ("Mouth Protector" OR "Protector, Mouth" OR "Protectors, Mouth" OR "Protetor bucal" OR "Mouth Pieces, Protective" OR "Mouth Pieces, Protective" OR "Mouth Piece, Protective" OR "Piece, Protective Mouth" OR "Pieces, Protective Mouth" OR "Protective Mouth Piece" OR "Protective Mouth Pieces" OR "Mouthpieces, Protective" OR "Mouthpiece, Protective" OR "Protective Mouthpiece" OR "Protective Mouthpieces" OR "Mouth Guards" OR "Guard, Mouth" OR "Guards, Mouth" OR "Mouth Guard" AND "Randomized Controlled Trial"
Web of Science	
#1 TOPIC= (athletes OR athlete)	#2 TOPIC= ("Mouth Protector" OR "Protector, Mouth" OR "Protectors, Mouth" OR "Protetor bucal" OR "Mouth Pieces, Protective" OR "Mouth Pieces, Protective" OR "Mouth Piece,

	Protective" OR "Piece, Protective Mouth" OR "Pieces, Protective Mouth" OR "Protective Mouth Piece" OR "Protective Mouth Pieces" OR "Mouthpieces, Protective" OR "Mouthpiece, Protective" OR "Protective Mouthpiece" OR "Protective Mouthpieces" OR "Mouth Guards" OR "Guard, Mouth" OR "Guards, Mouth" OR "Mouth Guard" AND "Randomized Controlled Trial"
Latin American e Literatura Caribenha em Ciências da Saúde (LILACS)	
#1(MH: athletes OR athlete)	#2 (MH: "Mouth Protector" OR "Protector, Mouth" OR "Protectors, Mouth" OR "Protetor bucal" OR "Mouth Pieces, Protective" OR "Mouth Pieces, Protective" OR "Mouth Piece, Protective" OR "Piece, Protective Mouth" OR "Pieces, Protective Mouth" OR "Protective Mouth Piece" OR "Protective Mouth Pieces" OR "Mouthpieces, Protective" OR "Mouthpiece, Protective" OR "Protective Mouthpiece" OR "Protective Mouthpieces" OR "Mouth Guards" OR "Guard, Mouth" OR "Guards, Mouth" OR "Mouth Guard"

RESULTS

Flowchart of scientific research

After database screening and removal of duplicates, 140 studies were identified (Fig. 1). After title selection, 34 studies remained after careful examination of the abstracts. The full texts of these 34 studies, including 19 studies, were excluded for the following reasons: (1) pilot study; (2) non-athlete individuals; (3) chronic use of mouthguards and (4) studies that did not assess performance parameters.

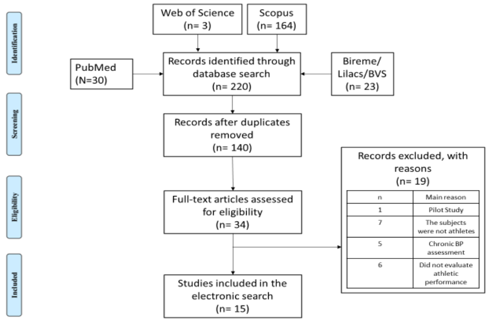

Figure 1. Research Flowchart

Study bias risk

The assessment of the risk of bias of the selected studies is shown in Figure 2. Regarding sequence randomization and allocation concealment, most of the studies presented an uncertain risk. The blinding item was divided into two parts, participants and professionals, due to the fact that the studies did not address these results. However, as respiratory assessments were performed during exercise tests, with or without the use of MG, blinding would not be possible for both the subjects and the examiners. The blinding of outcome evaluators was not mentioned in any of the articles. All articles presented low risk regarding incomplete outcomes and selective outcome reports. In "Other sources of bias", the sample calculation was chosen, being the same performed in only one article.

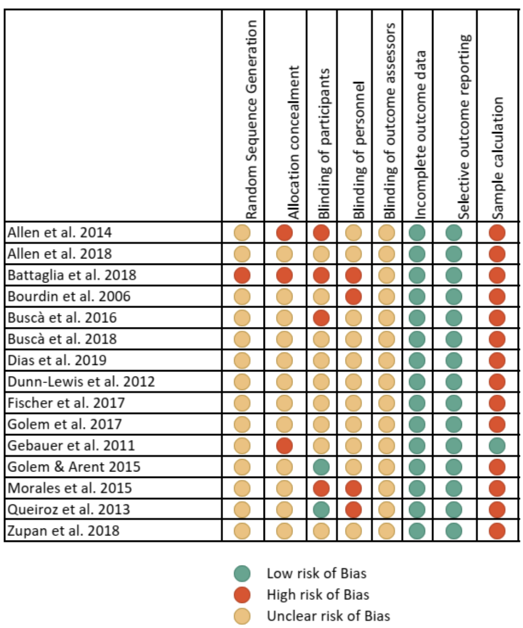

Figure 2. Detailed Risk of Bias

Study characteristics

The characteristics of the 15 selected studies are listed in Table 2. All studies met the inclusion criteria and were considered randomized controlled and crossover clinical trials, published in English between 2006 and 2019. Of the 15 selected studies, 12 studies (Allen et al. 2014, 2018; Battaglia et al. 2018; Bourdin et al. 2006; Buscà et al.

2016, 2018; Dias et al. 2019; Fischer, Weber, and Beneke 2016; Golem, Davitt, and Arent 2017; Gebauer et al. 2011; Golem and Arent 2015; Morales et al. 2015) included used participants of gender male. One study (Queiróz et al. 2013) used female participants, and two studies (Dunn-Lewis et al. 2012; Zupan et al. 2018) used both genders. In a total of 373 individuals investigated, the age ranged between 20.9 and 27.8 years. One study (Queiróz et al. 2013) used MG (type 1). Six studies (Bourdin et al. 2006; Dunn-Lewis et al. 2012; Golem, Davitt, and Arent 2017; Golem and Arent 2015; Queiróz et al. 2013; Zupan et al. 2018) used the MG (type 2). Twelve studies (Allen et al. 2014, Allen et al. 2018; Bourdin et al. 2006; Buscà et al. 2016; Fischer, Weber, and Beneke 2016; Buscà et al. 2018; Golem, Davitt, and Arent 2017; Gebauer et al. 2011; Golem and Arent 2015; Morales et al. 2015; Queiróz et al. 2013; Zupan et al. 2018) used MG (type 3), and five studies (Allen et al. 2018; Battaglia et al. 2018; Dias et al. 2019; Dunn-Lewis et al. 2012; Fischer, Weber, and Beneke 2016) used the MG (type 5) (table 2).

Table 2. General characteristic of the studies included in the systematic review and meta-analysis.

First Author, Year	Number of subjects (gender)	Subjects' age mean± SD (yrs.)	Anthropometric data Height Mean ± SD (cm) Body mass ± SD (Kg)	Interval between tests (Washout)	Type of MG (description according to the studies)	Test	Measurement test
Allen et al. 2014	21 (male)	21.5 ± 1.3	177.5 ± 7.9 87.1 ± 10.8	1 Week	- Control: no mouthguard - Mouthguard Custom Made (Type 3)	Muscle strength / power Peak force in Vertical Jump Assessment	Control: 2304.5 ± 345.9 MG (Type 3): 2515.2 ± 560.8
Allen et al. 2018	36 (male)	23 ± 2.8	178.54 ±9.0 83.09 ± 7.8	1 Week	- Control: no mouthguard - Mouthguard Custom Made (Type 3) - Mouthguard Optimizer / neuromuscular (Type 5)	Muscle strength / power Jump Height Control	Control: 2185.30 ± 263.76 MG (Type 3): 2177.85 ± 292.14 MG (Type 5): 2148.79 ± 276.30
Battaglia et al. 2018	24 (male)	20.9 ± 7.06	170.5 ± 5.7 75.1 ± 7.3	2 Days	- Control: no mouthguard - Mouthguard Optimizer / neuromuscular (Type 5)	Muscle strength / power Handgrip Tests	Control: 37.77 ± 9.15 MG (Typo 5): 39.39 ± 9.29
Bourdin et al. 2006	19 (Male)	27 ± 4.8	180.9 ± 8.7 91.4 ± 18.6	2 Days	- Control: no mouthguard - Mouthguard Custom Made (Type 3)	Muscle strength / power Maximum power in cycle ergometer	Control: 1184.8 ± 225.4 MG (Type 3): 1180.9 ± 246
Buscà et al. 2016	28 (Male)	23.60 ± 3.48	1.79 ± 7.4 77.01 ± 8.11	2 Days	- Control: no mouthguard - Mouthguard Custom Made (Type 3)	Muscle strength / power Back-Row Isometric Force(peakforce)	Control: 1216.48 ± 44.290 MG (Type 3): 1322.39 ± 45.861
Buscà et al.	13	21.07 ±	1.98 ± 7.31	N.R	- Control: no	Muscle strength /	Control:

2018	(Male)	4.11	91.05 ± 10.92		mouthguard - Mouthguard Custom Made (Type 3)	power: Countermovement vertical jump	1160 ± 114 MG (Type 3): 1184 ± 116
Dias et al. 2019	14 (Male)	21.67 ± 0.86	1.76 ± 0.61 76.33 ± 7	3 Days	- Control: no mouthguard - Mouthguard Optimizer / neuromuscular (Type 5)	Muscle strength / power Test 1: Abduction+ Adduction Test 2: External Rotation Internal Rotation	Test1 Control 52.76 ± 9.88 61.3 ± 2.47 MG (Type 5): 57.72 ± 2.70 68.53 ± 1.47 Test 2 Control: 32.15 ± 0.95 33.72 ± 1.79 MG (Type 5): 36.99 ± 1.92 40.93 ± 2.72
Dunn-Lewis et al. 2012	26 (male) 24 (women)	25 ± 4 23 ± 3	Male 1.78 ± 0.07 83.3 ± 11.4 Women 1.65 ± 0.08 62.6 ± 7.8	N.R	- Control: no mouthguard - Mouthguard Optimizer / neuromuscular (Type 5)	Muscle strength / power Vertical jump performance (peak power)	Male Control: 4053 ± 938 MG (Type 5): 4137 ± 893 Women Control: 2358 ± 367 MG (Type 5): 2373 ± 350
Fischer et al. 2016	23 (male)	26.0 ± 2.0	1.82 ± 0.06 79.4 ± 7.7	1 Week	- Control: no mouthguard - Mouthguard Custom Made (Type 3) - Mouthguard Optimizer / neuromuscular (Type 5)	Muscle strength / power Cycling sprint performance in Wingate Anaerobic Tests	Control: 862 ± 118 MG (Type 3): 866 ± 121 MG (Type 5): 864 ± 108
Golem et al. 2017	20 (male)	21.5±2.7	176.5±6.5 79.8±11.7	N.R	- Control: no mouthguard - Mouthguard Custom Made (Type 3)	Endurance Test: Test 1: Maximal aerobic performance Test 2: Respiratory flow dynamics	Test 1 Control: 49.9±4.5 MG (Type 3): 48.7±5.1 Test 2 Control: 94.15 ± 18.27 MG (Type 3): 92.13 ± 18.72
Gebauer et al. 2011	27 (male)	23.5 ± 3.8	182 ± 0.08 81.7 ± 8.6	1 Week	- Control: no mouthguard - (MG1) custom laminated MG with normal palatal surface	Endurance Test: Test 1: Ventilation Test 2: Oxygen uptake	Test 1 Control: 124.19 ± 15.62 MG (Type 1): 122.51 ± 18.80 Test 2 Control: 57.22 ±6.14 MG (Type 1): 56.09 ±4.82
Golem & Arent 2015	20 (male)	21.5 ± 2.7	176.5 ± 6.5 79.8 ± 11.7	2 Days	- Control: no mouthguard - - Mouthguard Custom Made(Tipo 3)	Vertical Jump Height and Power Output	Control: 5261.4 ± 613.7 MG (Type 3): 5212.1 ± 613.6
Morales et al. 2015	28 (male)	24.50 ± 3.32	181.34 ± 7.4 78.14 ± 8.21	3 Days	- Control: no mouthguard - Custom Made MG(Tipo 3)	Mean power	Control: 9.01 ± 0.15 MG (Type 3): 9.14 ± 0.15
Queiroz et al. 2013	25 (women)	N.R	N.R	1 Week	- Control: no mouthguard - Mouthguard Custom Made(Tipo 3)	Endurance Test: Test 1: Cooper test Test 2: VO2 max and physical fitness	Test 1 Control: 2243.2 ± 344.4 MG (Type 3): 2612.7 ± 369.8 Test 2 Control: 38.6 ± 7.7

							MG (Type 3): 46.8 ± 8.2
Zupan et al. 2018	4 (women) 21 (men)	27.8 ± 2.5 23.6 ± 1.3	Women 67.3 ± 1.4 140.8 ± 4.3 Male 70.1 ± 0.4 174.7 ± 4.6	2 Days	- Control: no mouthguard - Custom Made MG (Tipo 3)	Muscle strength / power: Test 1: Bench press performance Endurance Test: Test 2: 1.5- mile run performance	Test 1 Control: 17.2 ± 1.7 reps MG (Type 3): 17.7 ± 1.8 reps Test 2 Control: 667.4 ± 9.4 MG (Type 3): 679.8 ± 9.7

Synthesis of the results: meta-analyses

For the meta-analysis, studies were grouped according to outcome used to report anaerobic and aerobic tests. To verify the outcomes involving aerobic metabolism, 4 studies (Zupan et al. 2018; Golem, Davitt, and Arent 2017; Gebauer et al. 2011; Queiróz et al. 2013) were included, and 3 studies (Golem, Davitt, and Arent 2017; Gebauer et al. 2011; Queiróz et al. 2013) evaluated more than one outcome involving aerobic metabolism. There was no statistically significant difference ($p>0.05$) between the conditions (Control x MG) in the outcomes involving aerobic metabolism (Fig. 4). The heterogeneity parameter I^2 was 73.44% (SMD, 0.32; 95% CI, -0.09 to 0.75; p = 0.13). For the pooled analysis (type of MG vs. control) of the aerobic test parameters (subgroups), it was not possible to be performed due to an insufficient number of studies.

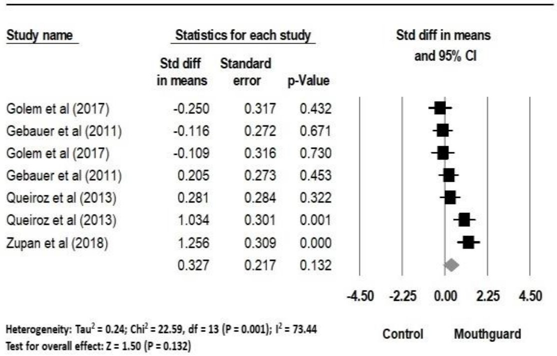

Figure 4. Forest Plot comparing the effects of MG use on aerobic performance.

To verify the outcomes involving anaerobic metabolism, 12 studies (Allen et al. 2014; Zupan et al. 2018; Golem and Arent 2015; Allen et al. 2018; Bourdin et al. 2006; Fischer, Weber, and Beneke 2016;

Dunn-Lewis et al. 2012; Battaglia et al. 2018; Buscà et al. 2018; Morales et al. 2015; Dias et al. 2019; Buscà et al. 2016) were included. 2 studies (Dunn-Lewis et al. 2012; Dias et al. 2019) evaluated more than one outcome involving anaerobic metabolism. A statistically significant difference ($p<0.05$) was observed between the conditions (Control x MG) in the outcomes involving anaerobic metabolism, favoring the MG group (Fig. 5). The heterogeneity parameter I^2 was 82.39% (SMD, 0.52; 95% confidence interval (CI), 0.12 to 0.91; p = 0.00).

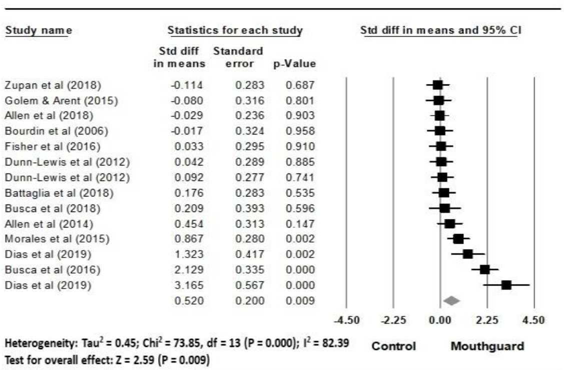

Figure 5. Forest Plot comparing the effects of MG use on anaerobic performance.

For the joint analysis of outcomes involving anaerobic metabolism (each type of MG X control), 16 data parameters were considered, although 13 studies were included. There was a statistical difference ($p>0.05$) between the conditions (Control x MG), favoring the use of MG. The heterogeneity parameter I^2 was 82.92% (Overall: SMD, 0.38; 95% CI, 0.01 to 0.75; p = 0.04). When the results were analyzed separately for each subgroup (MG type 3 x Control; MG type 5 x Control), the findings of the meta-analysis indicated that the effect of the type of MG use on the outcomes involving anaerobic metabolism did not show significant difference ($p>0.05$) (Fig. 6).

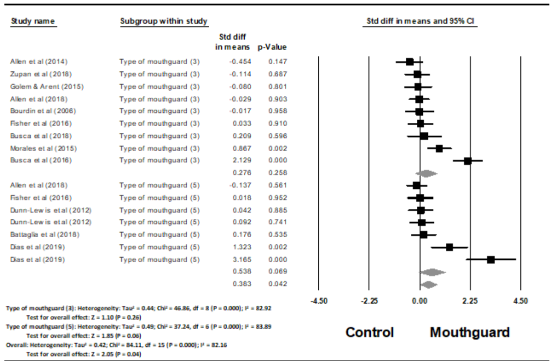

Figure 6. Forest Plot of subgroup analysis comparing the effects of type of MGs (Type 3 and 5) on anaerobic performance.

DISCUSSION

The main finding observed in the present study is that the use of MG does not negatively affect the physiological and performance parameters in outcomes involving aerobic and anaerobic metabolism when compared to the control. Furthermore, an improvement in outcomes involving anaerobic metabolism was observed with the use of MG. However, this effect was not observed when the types (type 3 and 5) of MGs were subdivided in the evaluation of outcomes involving the predominantly anaerobic metabolism.

All studies included in this systematic review and meta-analysis were performed in a cross-over fashion. The essential feature that distinguishes a crossover trial from a conventional trial compared to a parallel group is that each individual evaluated serves as its control. This type of experimental design avoids comparability problems between the experimental condition and the control to confounding variables (for example; age, sex, and level of trainability).

The two experimental intervention periods (MG x Control) in which the individual receives the different treatments must be separated by a washout phase, an interval period sufficient to exclude any residual effect (i.e., sufficient energy recovery time between treatments), between the experimental tests. Among the 15 studies included in this systematic review and meta-analysis, only the studies by Golem, Davitt, and Arent (2017); Buscà et al. (2018); Dunn-Lewis et al. (2012) did not report washout days, which can be considered an important risk of bias. Furthermore, it is noteworthy that only the study by Gebauer et al. (2011) presented the sample calculation (Fig. 2), which is an important methodological reliability factor in terms of the power of hypothesis testing in randomized crossover trials.

Despite the findings of the present systematic review and meta-analysis neither indicate improvements nor negatively affect the outcomes that predominantly involve aerobic metabolism (Fig. 4), the mechanisms remain unclear. Authors as Garner and McDivitt (2009), and Zaman et al. (2017) suggest that some MGs can promote an increase in the width and diameter of the oropharynx, suggesting that airway openings can contribute to the improvement of ventilatory and performance parameters. Zupan et al. (2018) evaluated 25 military subjects where they performed a run on a treadmill at a distance of 24.14 km in the shortest time. The findings indicated that the use of MG (type 5) significantly improved the time compared to the control condition. However, no reduction in performance was observed when subjects used MG (type 3) about the control condition.

In the study by Queiróz et al. (2013), it was observed in the Cooper test an improvement in the distance covered and in the estimated VO_2max of 25 female soccer players using the MG (type 3), compared to the control condition. However, the use of MGs (type 1 and 2) hurt these analyzed variables. Despite questions regarding the exercise protocol used, the lack of control in the verification of centric occlusion (Queiróz et al. 2013) and for not measuring the gas exchange parameters during the test, the studies by Golem, Davitt, and Arent (2017) and Gebauer et al. (2011), observed that the use of MG (type 3) did not present significant differences in the values obtained for minute volume and VO_2max compared to the control condition in the test performed on a treadmill.

Among these findings, it is possible that the use of MG (type 3), as it offers stability, occlusal adjustment, and congruence in the upper dental arch (Knapik et al. 2019), allows subjects to reduce the concern with keeping their mouths closed to retain the MG in the oral cavity, improving the capacity and adequate supply of oxygen to the muscles during the performance of the endurance exercise. However, the authors (Zupan et al. 2018; Queiróz et al. 2013; Golem, Davitt, and Arent 2017; Gebauer et al. 2011) did not report whether these subjects were used to using these MGs, as it is believed that used subjects can create MG retention mechanisms in the oral cavity during endurance exercises.

The findings of the present systematic review and meta-analysis indicated a significant improvement with the use of different MGs in outcomes related to anaerobic metabolism (Fig. 5). In predominantly anaerobic exercises, the mechanism proposed with the use of MG to improve muscle strength may be related to the simultaneous activation potentiation, as the use of MG with the jaw clenched can translate into improved neuromuscular responses of the agonist's muscles to movement (Ebben, Flanagan, and Jensen 2008). Furthermore, the use of mandibular muscle relaxation techniques before placing the MG may impact outcomes involving anaerobic metabolism. Arent, McKenna, and Golem (2010) observed significant differences in the height of the vertical jump and in the peak power in an anaerobic test (Wingate test) of the subjects, when performing the relaxation of the jaw muscles, through transcutaneous electrical nerve stimulation (TENS) before the MGs placement process of type 3 and 5. The association of the use of the MG type with a clenched jaw and remote muscle contraction (i.e., contraction of the jaw muscles and movement agonists) can increase the rate of muscle strength/power development (Ebben, Flanagan, and Jensen 2008). As a result, the activation of these muscles simultaneously can contribute to improved performance in activities such as rowing, cycling, and running (Milani et al. 2000). Ebben et al. (2010) when analyzing muscle activation using electromyography in a group of healthy/active men and women, it was observed that the muscles involved in remote muscle contraction are more active; this increase in activity results in greater activity in the primary motor muscles in isokinetic knee extension flexion. The study by Morales et al. (2015) observed an improvement in the output power generated by 28 subjects in the Wingate test, using MG (type 3) compared to the control condition. When observing an improvement in the output power of the cycle ergometer, the authors attributed the maintenance of the closed jaw (i.e., closed mouth) as a possible explanation of the improvement in the performance parameters of the anaerobic capacity (i.e., lactic and alactic).

Among the 12 studies analyzed in this systematic review on outcomes related to anaerobic metabolism (Fig. 5), 5 studies (Allen et al. 2014, Allen et al. 2018; Morales et al. 2015; Buscà et al. 2016, 2018) performed the tests with the jaw closed. Thus, the tests performed with the jaw clenched may represent an ergogenic potential for improving performance in strength/muscle power activities. Furthermore, as some studies revealed that the type of MG can affect the parameters evaluated in predominantly anaerobic outcomes, a subgroup analysis by type of MG was included. In the 15 studies included in this meta-analysis, we were only able to investigate 13 studies that used MGs (type 3 and 5) (Fig. 6).

The physiological explanation for the use of MG (type 5) in inducing improvements in muscle strength/power parameter outcomes compared to MG (type 3) is related to the enhancement of dental occlusion (i.e., dynamic relationship between upper and lower teeth when they approach) (Verban et al. 1984; Gray 2004). Thus, changes in the vertical dimension of the occlusion caused by MG (type 5) influence the activation of the electrical signal from the muscles of the upper limbs. Dias et al. (2019) observed in participants using MG (type 5) compared to MG (placebo), a significant increase in electrical activity (EMG) of the main muscles involved in shoulder movements (anterior deltoid and pectoralis major). In addition, the authors observed an improvement in peak torque in the shoulder isokinetic internal rotation movement. However, the findings of this review did not indicate superiority in the use of MG (type 5) compared to MG (type 3). In addition, the use of MG (types 3 and 5) did not negatively affect the evaluated parameters of anaerobic energy predominance.

The findings of this systematic review and meta-analysis had some limitations that should be discussed for the correct application of the results. In the present study, we were unable to include studies for a possible analysis of subgroups that used MGs (type 1 and 2). Another limitation of this review is related to the lack of additional information regarding the level of habituation of subjects with the use of MGs used in the studies included in this review.

CONCLUSION

The findings of the present study indicate that the use of MG does not negatively affect physiological and performance parameters in outcomes involving aerobic and anaerobic metabolism. Furthermore, an improvement in outcomes involving anaerobic metabolism was observed with the use of MG. However, this effect was not observed when MGs (type 3 and 5) were subdivided in the evaluation of outcomes involving predominantly anaerobic metabolism. These findings must be interpreted carefully, as most of the selected studies did not present important methodological details.

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