Does a lower jaw protruding device improve running aerobic performance?

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ABSTRACT

Using occlusal splints aiming to increase sports performance has recently raised significant interest, being speculated that it could lead to anatomical and physiological changes like upper airway enhancement and corresponding higher oxygen uptake ($\dot{V}\dot{V}O_2$). We have studied the lower jaw protruding device effect in running aerobic performance. Nine active male subjects performed two testing sessions (with a placebo and with a jaw protruding device) on a treadmill, running 7 x 4 min until exhaustion with 1 km/h increments (48 h rest). $\dot{V}\dot{V}O_2$ and related variables, blood lactate concentrations and rating of perceived exertion were determined for both experimental conditions across three intensity domains. A t-test for repeated measures was used ($p < .05$) For both experimental conditions and through the low-moderate, heavy and severe running intensity domains, no significant differences were observed in any of the analysed variables (e.g. $\dot{V}\dot{V}O_2$ = 34.54 ± 3.42 vs 34.20 ± 4.89, 39.80 ± 2.39 vs 40.19 ± 4.48 and 43.58 ± 3.80 vs 44.36 ± 4.00 mL·kg^{-1}·min^{-1}, respectively). Data allowed to conclude that this specific lower jaw protruding device did not influence the analysed variables related with running aerobic performance at a large spectrum of exercise intensities.

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Um dispositivo de avanço mandibular implicará um melhor desempenho aeróbio na corrida?

RESUMO

O uso de dispositivos intraorais com o objetivo de aumentar o desempenho desportivo recentemente despertou interesse significativo, especulando-se que poderiam desencadear alterações anatómicas e fisiológicas como aumento das vias aéreas e do consumo de oxigénio ($\dot{V}\dot{V}O_2$). Estudou-se o efeito de um dispositivo de avanço mandibular no desempenho aeróbio na corrida. Nove indivíduos ativos do sexo masculino realizaram duas sessões de teste (com um dispositivo placebo e de protrusão mandibular) numa passadeira, correndo 7x4 min até à exaustão, com incrementos de 1 km/h (48 h intervalo). $\dot{V}\dot{V}O_2$ e variáveis relacionadas, concentrações de lactato sanguíneo e perceção subjetiva do esforço foram determinadas para ambas as condições experimentais em três domínios de intensidade. Foi utilizado um teste t de medidas repetidas ($p < .05$). Para ambas as condições experimentais nos domínios de intensidade baixa-moderada, pesada e severa não foram encontradas diferenças significativas em nenhuma das variáveis analisadas (ex: $\dot{V}\dot{V}O_2$ = 34.54 ± 3.42 vs 34.20 ± 4.89, 39.80 ± 2.39 vs 40.19 ± 4.48 e 43.58 ± 3.80 vs 44.36 ± 4.00 mL·kg–1·min-1, respetivamente). Os dados permitiram concluir que este dispositivo de protrusão mandibular não influenciou as variáveis analisadas relacionadas ao desempenho aeróbio na corrida num amplo espectro de intensidades do exercício.

PALAVRAS CHAVE:
Consumo de oxigénio Exercício aeróbio, Dispositivos oclusais, Avanço mandibular, Desempenho desportivo.

INTRODUCTION

The use of occlusal splints on sport activities have been analysed since 1890 due to its importance to avoid dental and/or orofacial injuries during contact sports. The splints use aiming to increase performance only appeared in 1960 and, since then, has raised significant interest and discussion (Gunepin et al., 2017). Traditional methods of occlusal splints manufacturing are highly related to the temporomandibular joint decompression, mandibular rest position, jaw advancement and occlusal vertical dimension increments (Garabee, 1981; Gunepin et al., 2017; Isselée et al., 2016). Sports related splints fabricants highlights its contribution for increasing aerobic and anaerobic capacity, muscle strength, flexibility, balance, concentration and proprioception, as well reducing stress, muscle fatigue and blood lactate levels (Gunepin et al., 2017).

Due to the mandibular protrusion created by advancement occlusal splints, it might be suggested anatomical and physiological changes, namely enhancing the upper airway and improving oxygen uptake ($\dot{V}\dot{V}O_2$) (Garner, 2016; Shultz, Girouard, Elliott, & Mekary, 2018). Further ergogenic effects of these devices were associated with genioglossus, the major responsible for increments in respiratory muscle tone during the breathing inspiratory phase and, therefore, pharyngeal dimension enlargement (Garner, 2016; Garner, Dudgeon, Scheett, & McDivitt, 2011). Similarly, the mandibular forward position results in pulling the tongue complex down and forward, consequently placing the hyoid bone to an anterosuperior position and opening the upper airway (Aras, Pasaoglu, Olmez, Unal, & Aras, 2016; Garner, 2016; Guarda-Nardini, Manfredini, Mion, Heir, & Marchese-Ragona, 2015).

Sports performance potentiation related to jaw advancement devices may be linked with airway resistance decrease, airflow enhancements and possibly aerobic capacity changes (Bailey et al., 2015; Piero et al., 2015; Shultz et al., 2018). However, data have been controversial, and more investigation is necessary to understand the mechanisms that can be proportioned by using intraoral devices in sport activities. The aim of the current study was to analyse the effect of a lower jaw protruding device in running aerobic performance by evaluating respiratory and metabolic variables of healthy and physically active subjects. In accordance with the available knowledge about protruding devices and its potential to improve the airway space, it was hypothesized that a lower jaw advancement would enhance running aerobic performance.

MATERIAL AND METHODS

Nine healthy and active male subjects (mean ± SD: 22.7 ± 3.9 years old, 71.8 ± 8.6 kg of body mass, 177.2 ± 5.3 cm of height, ≥ 4-5 training units/week of physical conditioning and > 10 years of sport experience) voluntarily participated in this study. All subjects were submitted to a clinical exam adapted from Diagnostic Criteria for Temporomandibular Disorders (Schiffman et al., 2014) and answered a questionnaire screening for cardiorespiratory and metabolic diseases, as well as physical injuries and/or limitations. Participants with muscular tenderness, articular and/or muscular pain, temporomandibular disorders, during orthodontic treatment, poor oral health, absence of all molar teeth of one or more hemiarcades, physical injury and/or limitation and that did not finish the testing protocol were excluded. Subjects signed an informed consent conformed to the Declaration of Helsinki and approved by the local University Ethics Committee (code nº 000519).

Dental arches impressions were taken using alginate (orthoprint®, Zhermack®, Italy) to obtain study casts in dental gypsum type III (Crystacal®, Formula, Germany) for each participant. The jaw protruding devices were fabricated from thermoforming plates (Erkodur, Erkodent®, Germany) following previous reports in the field of splints design and mandibular repositioning (Aarab et al., 2010; Garner et al., 2011; Gelb & Gelb, 1991). The placebo splints were produced in a similar manner despite not covering the occlusal teeth surfaces and not modifying the occlusal vertical dimension or mandibular position (adapted from Greenberg et al., 1981; Schubert et al., 1984). All intraoral devices were custom fitted. Devices comfort, breathing, speaking, adaptability and comfortability were also checked by qualified dentists and technicians.

Participants performed a running continuous incremental protocol of 7 x 4 min until exhaustion, with 1 km/h increments (Billat et al., 1996; Sousa et al., 2015), on a treadmill (H/P/ Cosmos Quasar 4.0, Nussdorf, Germany), once wearing a placebo and 48 h latter with a jaw protruding device (single blind condition). Subjects were familiarized with both intraoral devices, instructed to avoid high intensity physical conditioning in the previous 24 h of each testing session and abstained from caffeine and alcohol in the 3 h before the experiments. The $\dot{V}\dot{V}O_2$, minute ventilation (V_E), respiratory frequency, respiratory quotient, blood lactate concentration ([La-]) and rating of perceived exertion (RPE) were determined for both experimental conditions. During the testing sessions, all participants were verbally encouraged to perform their maximal effort throughout the incremental protocol.

Respiratory and pulmonary gas exchange variables were directly and continuously measured breath-by-breath using a portable telemetric gas analyser (Cosmed $K4b^2$, Cosmed, Italy). The oximeter was calibrated before each test using a mixed gas of known concentrations (16% O_2 and 5% CO_2) and the turbine volume transducer regulated with a 3 L syringe according to the manufacturers specifications (see also Zacca et al., 2019). Capillary blood samples were collected at rest and during the 3rd min of the recovery period from the indicator finger (de Jesus et al., 2015; Fernandes et al., 2012; Sousa et al., 2015) using a portable lactate analyser (Lactate Pro, Arkay, Inc, Kyoto, Japan). The RPE values were obtained through subjects direct feedback at each exercise step using a 6-20 points scale (Borg, 1982).

For each running intensity domain, the averaged values of the last 30 s of the corresponding step were calculated. Afterwards, data were edited to exclude errant values (e.g. caused by swallowing, coughing or signal failures) and, for absolute and relative $\dot{V}\dot{V}O_2$ analysis, only values between $\dot{V}\dot{V}O_2$ mean 4 SD were considered (de Jesus et al., 2015; Fernandes et al., 2012; Sousa et al., 2015). Each subject ventilatory threshold was assessed by the interception point of a combined linear and exponential pair of regressions (V_E vs velocity) using the least square method and confirmed by visual inspection (Ribeiro et al., 2015). All physiological variables, as well as RPE, were evaluated in three exercise intensity exertions: (i) at the upper limit of the low-moderate domain, i.e., at the step corresponding to the ventilatory threshold; (ii) at the heavy domain, i.e., at the step immediately above the ventilatory threshold; and (iii) at the severe domain, i.e., at the step corresponding to $\dot{V}\dot{V}O_{2max}$ (determined by the occurrence of a $\dot{V}\dot{V}O_2$ plateau (differences 2.1 mL·kg^{-1}·min^{-1} in last 30 s of the step).

The collected data were exported from K4b^2 software to Excel (version 15.0 for Windows) and to Statistical Package for the Social Sciences (SPSS, version 25.0 for Windows) for posterior analysis. Data distribution and homogeneity were checked using the Shapiro-Wilk test. Standard statistical methods were used for the calculation of individual mean and standard deviation and reported for all variables of the study. To assess the differences between experimental conditions, a t-test for repeated measures was used. A Bland-Altman plot analysis (MedCalc Software, version 19.2.1 for Windows) (Bland & Altman, 1986) was also performed to characterize the differences between the two experimental conditions in the three previous determined running intensity domains (using placebo as the reference) and to assess the absence or presence of systematic and proportional errors between conditions. Statistical significance was set at a two-tailed .05 level.

RESULTS

All participants finished the experimental protocol without adverse events and no impairments in their comfort, breathing or concentration were reported while wearing both intraoral devices. Table 1 displays the mean ± SD values of all the studied variables at low-moderate, heavy and severe running intensity domains using the placebo and the jaw protruding device. [La-] were only compared for the severe intensity domain since blood samples were only collected at the final of the incremental protocol. No differences between experimental conditions were observed for any variable independently of the running intensity.

TABLE 1.¾ Mean and SD values of the tested variables in both experimental conditions at different running intensity domains.

	LOW-MODERATE		
	Placebo device	Jaw protruding device	*p*
Absolute oxygen uptake (mL·min^{-1})	2492.74 ± 334.11	2456.33 ± 259.73	.76
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	34.54 ± 3.42	34.20 ± 4.89	.85
Minute ventilation (L·min^{-1})	63.18 ± 8.76	67.63 ± 8.74	.28
Respiratory frequency (f·min^{-1})	32.32 ± 5.67	35.44 ± 6.80	.25
Respiratory quotient	1.05 ± 0.12	1.02 ± 0.07	.56
Rating of perceived exertion	10 ± 3	8 ± 2	.18
	HEAVY		
	Placebo device	Jaw protruding device	*p*
Absolute oxygen uptake (mL·min^{-1})	2877.12 ± 352.53	2889.99 ± 243.35	.91
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	39.80 ± 2.39	40.19 ± 4.48	.82
Minute ventilation (L·min^{-1})	85.19 ± 20.12	89.47 ± 12.10	.54
Respiratory frequency (f·min^{-1})	41.51 ± 9.09	43.17 ± 8.12	.66
Respiratory quotient	1.13 ± 0.20	1.07 ± 0.05	.41
Rating of perceived exertion	15 ± 2	14 ± 3	.52
	SEVERE		
	Placebo device	Jaw protruding device	*p*
Absolute oxygen uptake (mL·min^{-1})	3140.87 ± 361.26	3191.75 ± 205.20	.91
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	43.58 ± 3.80	44.36 ± 4.00	.82
Minute ventilation (L·min^{-1})	111.41 ± 8.37	114.54 ± 18.98	.54
Respiratory frequency (f·min^{-1})	52.78 ± 8.29	52.45 ± 11.80	.66
Respiratory quotient	1.21 ± 0.16	1.14 ± 0.07	.41
Rating of perceived exertion	19 ± 1	20 ± 1	.52
Blood lactate concentration (mmol·L^{-1})	10.3 ± 4.2	9.9 ± 3.1	

Agreement analyses between the two experimental conditions along the running intensity domains are presented in Table 2. It was found that the two conditions were almost unbiased and between the 95 % limits of agreement. However, the amplitude of the limits of agreement showed that, in some of the participants, the differences between conditions can be recognizable. In addition, the slopes and intercepts of the Bland Altman regressions showed evidence of proportional and systematic errors (respectively) for $\dot{V}\dot{V}O_2$ (absolute), V_E and respiratory quotient in the severe intensity domain (FIGURE 1). The same errors were found for respiratory quotient in the heavy intensity domain.

TABLE 2.¾ Bias and 95% limits of agreement of estimations between experimental conditions at different running intensity domains, using placebo as the standard.

	LOW-MODERATE		
	Bias	95% IC	*p*
Absolute oxygen uptake (mL·min^{-1})	36.41	-639.76 – 712.57	.76
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	0.33	-9.68 – 10.34	.85
Minute ventilation (L·min^{-1})	-4.46	-27.27 – 18.35	.28
Respiratory frequency (f·min^{-1})	-3.12	-17.97 – 11.72	.25
Respiratory quotient	0.03	-0.27 – 0.33	.56
Rating of perceived exertion	1.1	-3.32 – 5.54	.18
	HEAVY		
	Bias	95% IC	*p*
Absolute oxygen uptake (mL·min^{-1})	-12.87	-657.42 – 631.68	.91
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	0.39	-8.22 – 10.23	.82
Minute ventilation (L·min^{-1})	-4.28	-43.48 – 34.92	.54
Respiratory frequency (f·min^{-1})	-1.66	-23.12 – 19.80	.66
Respiratory quotient	0.06	-0.37 – 0.49	.41
Rating of perceived exertion	0.67	-5.21 – 6.55	.52
	SEVERE		
	Placebo device	Jaw protruding device	*p*
Absolute oxygen uptake (mL·min^{-1})	-50.89	-529.67 – 427.90	.55
Relative oxygen uptake (mL·kg^{-1}·min^{-1})	0.77	-8.56 – 7.02	.58
Minute ventilation (L·min^{-1})	-3.13	-31.77 – 25.52	.54
Respiratory frequency (f·min^{-1})	0.33	-16.04 – 16.69	.91
Respiratory quotient	0.07	-0.35 – 0.48	.38
Rating of perceived exertion	-0.33	-1.31 – 0.65	.08
Blood lactate concentration (mmol·L^{-1})	0.4	-11.5 – 12.3	.84

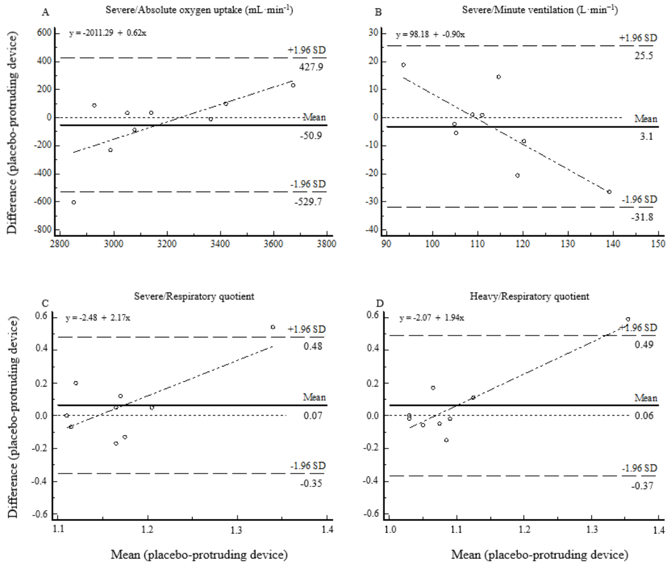

FIGURE 1. ¾ Bland Altman analyses for absolute oxygen uptake and minute ventilation in severe intensity domain (upper panels) and respiratory quotient in severe and heavy intensity domains (lower panels) between placebo and protruding devices. Black dotted lines representing bias and black dashed lines 95 % limits of agreement and linear regression of the respective variables.

DISCUSSION

Several athletes have been using occlusal splints for dental and orofacial protection during contact sports, as well to optimize performance. They report feeling stronger and more relaxed when wearing occlusal splints, suggesting aerobic and anaerobic ergogenic effects (Dudgeon, Buchanan, Strickland, Scheett, & Garner, 2017; Egret, Leroy, Loret, Chollet, & Weber, 2002; Lee, Hong, Park, & Choi, 2013). The mandibular repositioning appliances are commonly used when managing patients with mild-to-moderate obstructive sleep apnea due to its important contribution on airway volumetric changes. Based on the same rational, these devices have been introduced in sports to maximize performance (Shultz et al., 2018). Thus, we aimed to observe the effect of a lower jaw protruding device in healthy active subjects during running at a large spectrum of intensities.

Pharyngeal airway improvements when using repositioning devices has been frequently suggested, resulting from a neuromuscular effect that provids the genioglossus muscle contraction, upgrading the ventilatory dynamics by promoting the upper airway relaxation (particularly the pharyngeal area) (Garner, 2016; Garner et. al., 2011; Remmers, 2001). Despite the potential benefits of advancement appliances, the effects of protective devices (e.g. mouthguards) during exercise have been much more studied along the years. This could be due to the fact that wearing different splints during exercise (even those that do not provide a mandibular advancement) seem to result in biomechanical and physiological improvements, like increasing running pattern symmetry and muscle strength, and decreasing [La-] and cortisol levels (Garner & McDivitt, 2009; Maurer et al., 2015; Shultz et al., 2018).

Researchers are still unable to clarify which degree of forwarding jaw movement would be the most suitable for improving athletic performance when wearing repositioning jaw devices. However, by placing the jaw to a more forward position (providing a greater mandibular advancement) the airway opening is largely increased (Garner & Miskimin, 2009). As it was not yet known which is the best mandibular advancement degree, the protrusion gradation chosen in the current study was based upon obstructive sleep apnea treatment (Aarab et al., 2010). Moreover, as there is no certainty regarding the consequences of large mandibular advancements, it was selected the lowest mandibular advancement value used for apnea devices to manufacture our advancement splint.

Although with a significant anaerobic contribution, $\dot{V}\dot{V}O_{2max}$ is a physiological marker frequently used to assess aerobic performance (de Jesus et al., 2015; Fernandes et al., 2012; Zacca et al., 2019), being considered a reliable indicator of physical conditioning status (Sousa et al., 2015). The occurrence of a $\dot{V}\dot{V}O_2$ plateau is the primary physiological criteria for achieving $\dot{V}\dot{V}O_{2max}$, but it is not unusual to complete a maximal graded exercise without reaching it (Howley, Bassett, & Welch, 1995). Thus, a variety of secondary criteria have been proposed to validate the $\dot{V}\dot{V}O_{2max}$ achievement, particularly $[La-]_{max}$ 8 $mmol \cdot L^{-1}$, respiratory quotient 1.10, > 90% of an age-adjusted estimate of maximal heart rate (220-age) and volitional exhaustion (Howley et al., 1995; Sousa et al., 2015; Zacca et al., 2019). A $\dot{V}\dot{V}O_2$ plateau was observed in the current study for both experimental conditions. Respiratory quotient and [La-] values were also used to corroborate $\dot{V}\dot{V}O_{2max}$ achievement, together with the visual observation of participants exhaustion at the last step of the incremental protocol.

Several authors have been reporting relevant results regarding the occlusal splints use in sports (Garner et al., 2011; Schultz et al., 2018), but others evidenced conflicting data (Golem et al., 2017; Bailey et al., 2015). This controversy is possibly justified by the use of different methodologies and devices. In the current study, no differences between conditions were observed in any exercise intensity domain for $\dot{V}\dot{V}O_2$ (absolute and relative) values and respiratory-related variables, which is consistent with previous reports (Collares et al., 2013; Gebauer et al., 2011; Piero et al., 2015). Nevertheless, other studies founded significant improvements on $\dot{V}\dot{V}O_2$ and V_E when wearing repositioning devices during treadmill running protocols (Garner et al., 2011; Schultz et al., 2018), resulting from a jaw forward repositioning, leading to a greater upper airway volume, width and a decrease of the airway resistance to airflow (Guarda-Nardini et al., 2015; Shultz et al., 2018).

The individual exertion perception during exercise is also an important variable to evaluate since it is considered one of the single best indicators of physical stress and is very relevant for prescribe exercise intensities (Borg, 1982). The RPE scale offers a simple method to monitor exercise intensity, but also has demonstrated large inter-individual variability (Johnson et al., 2017). Although RPE data did not differ between placebo and device conditions in the current study, it provide relevant central and peripheral information from the central nervous system, the musculoskeletal work and the cardiovascular and respiratory functions (Borg, 1982). The RPE has not yet been deeply studied regarding the use of occlusal splints in sport activities. However, concurrently used with other variables, it has been considered when validating the use of mouthguards without negatively impairing performance (Bailey et al., 2015; Piero et al., 2015).

The high 95% limits of agreement amplitudes for all studied variables at the three running intensity domains, as well as the presence of proportional and systematic errors at the severe intensity exertion, shows, even without significant differences between the studied conditions, a tendency to differ depending on the level of the runners (proportional) and conditions (systematic). Therefore, this methodology should be extended for more numerous samples.

CONCLUSIONS

We conclude that the current lower jaw protruding device did not influenced the running aerobic performance of subjects engaged in regular exercise practice. Although important effects are reported when wearing occlusal splints during sport, these remain not fully understood. Hence, the current results should be cautiously interpreted. In fact, there is a significant literature inconsistency regarding experimental outcomes, as well as an evident lack of methodological details, existing heterogeneous samples and distinct sports, devices design and protocols tested. Furthermore, the current results might have been influenced by the small sample size, inter-subjects variability and the use of a device with a minimal jaw protrusion. The inclusion of a more homogenous sample with better trained subjects and the use of a device with a greater protrusion degree should be considered in future investigations to clarify the advancement occlusal splints effects in sport.

REFERENCES

Aarab, G., Lobbezoo, F., Hamburger, H. L., & Naeije, M. (2010). Effects of an oral appliance with different mandibular protrusion positions at a constant vertical dimension on obstructive sleep apnea. *Clin Oral Investig, 14*(3), 339-345. doi:10.1007/s00784-009-0298-9.

Allen, C. R., Dabbs, N. C., Zachary, C. S., & Garner, J. C. (2014). The acute effect of a commercial bite-aligning mouthpiece on strength and power in recreationally trained men. *Journal of Strength & Conditioning Research, 28*(2), 499-503. doi:10.1519/JSC.0b013e3182a95250

Aras, I., Pasaoglu, A., Olmez, S., Unal, I., & Aras, A. (2016). Upper airway changes following single-step or stepwise advancement using the Functional Mandibular Advancer. *Journal of Orofacial Orthopedics, 77*(6), 454-462. doi:10.1007/s00056-016-0062-0

Bailey, S. P., Willauer, T. J., Balilionis, G., Wilson, L. E., Salley, J. T., Bailey, E. K., & Strickland, T. L. (2015). Effects of an over-the-counter vented mouthguard on cardiorespiratory responses to exercise and physical agility. *Journal of Strength & Conditioning Research, 29*(3), 678-684. doi:10.1519/jsc.0000000000000668

Billat, V., Faina, M., Sardella, F., Marini, C., Fanton, F., Lupo, S., . . . Dalmonte, A. (1996). A comparison of time to exhaustion at VO2 max in elite cyclists, kayak paddlers, swimmers and runners. *Ergonomics, 39*(2), 267-277. doi:10.1080/00140139608964457

Bland, J.M.; Altman, D. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet, 327: 307–310.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise, 14*(5), 377-381.

Collares, K., Correa, M., Silva, I., Hallal, P., & Demarco, F. (2013). Effect of wearing mouthguards on the physical performance of soccer and futsal players: a randomized cross-over study. *Dental Traumatology, 30.* doi:10.1111/edt.12040

de Jesus, K., Sousa, A., de Jesus, K., Ribeiro, J., Machado, L., Rodriguez, F., . . . Fernandes, R. J. (2015). The effects of intensity on VO2 kinetics during incremental free swimming. *Applied Physiology, Nutrition and Metabolism, 40*(9), 918-923. doi:10.1139/apnm-2015-0029

Dudgeon, W. D., Buchanan, L. A., Strickland, A. E., Scheett, T. P., & Garner, D. P. (2017). Mouthpiece use during heavy resistance exercise affects serum cortisol and lactate. *Cogent Medicine, 4*(1), 1403728. doi:10.1080/2331205X.2017.1403728

Egret, C., Leroy, D., Loret, A., Chollet, D., & Weber, J. (2002). Effect of mandibular orthopedic repositioning appliance on kinematic pattern in golf swing. *International Journal of Sports Medicine,* 23(2), 148-152. doi:10.1055/s-2002-20135

Fernandes, R., Jesus, K., Baldari, C., Sousa, A., Vilas-Boas, J. P., & Guidetti, L. (2012). Different V˙O2max Time-Averaging Intervals in Swimming. *International Journal of Sports Medicine,* 33(12), 1010-5. doi:10.1055/s-0032-1316362

Garabee, W. F., Jr. (1981). Craniomandibular orthopedics and athletic performance in the long distance runner: a three year study. *Basal Facts, 4*(3), 77-81.

Garner, D. P., Dudgeon, W. D., Scheett, T. P., & McDivitt, E. J. (2011). The effects of mouthpiece use on gas exchange parameters during steady-state exercise in college-aged men and women. *Journal of American Dental Association, 142*(9), 1041-1047.

Garner, D. P., & Miskimin, J. (2009). Effects of mouthpiece use on auditory and visual reaction time in college males and females. *Compendium of Continuing Education in Dentistry, 30(2)*, 14-17.

Garner., D. P. (2016). A Comparative Study and Review of Research Related to Oral Appliances and Athletic Performance: Understanding the Physiological Impacts. *Jacobs Journal of Sport Medicine, 3(4): 025.*

Gebauer, D. P., Williamson, R. A., Wallman, K. E., & Dawson, B. T. (2011). The effect of mouthguard design on respiratory function in athletes. *Clinical Journal of Sport Medicine, 21*(2), 95-100. doi:10.1097/JSM.0b013e31820428b0

Gelb, M. L., & Gelb, H. (1991). Gelb appliance: mandibular orthopedic repositioning therapy. *Cranio Clinics International, 1*(2), 81-98.

Golem, D. L., Davitt, P. M., & Arent, S. M. (2017). The effects of over-the-counter jaw-repositioning mouthguards on aerobic performance. *Journal of Sports Medicine and Physical Fitness, 57*(6), 865-871. doi:10.23736/S0022-4707.16.06325-8

Guarda-Nardini, L., Manfredini, D., Mion, M., Heir, G., & Marchese-Ragona, R. (2015). Anatomically Based Outcome Predictors of Treatment for Obstructive Sleep Apnea with Intraoral Splint Devices: A Systematic Review of Cephalometric Studies. *Journal of Clinical Sleep Medicine, 11*(11), 1327-1334. doi:10.5664/jcsm.5198

Gunepin, M., Derache, F., Blatteau, J.E., Trousselard, M., Castagna, O., & Risso, J.J. (2017). Potential of mouthguards for enhancing sport and physical performances: A review of 50 years of medical research.

Medicine Buccale Chirurgie Buccale, 23(1):21-31. doi:10.1051/mbcb/2016025

Howley, E. T., Bassett, D. R., Jr., & Welch, H. G. Criteria for maximal oxygen uptake: review and commentary. *Medicine & Science in Sports & Exercise,* 1995; 27(9): 1292-1301.

Isselée, H., Asscherickx, A., De Mot, B., Dankaerts, W., Staes, F., Deklerck, J., . . . Laat, A. (2016). The immediate effect of different mandibular positions on muscle force in the upper and lower limb: A pilot study in asymptomatic subjects. *Physical Medicine and Rehabilitation Research*, 1(1):19-22. doi: 10.15761/PMRR.1000107

Johnson, E. C., Pryor, R. R., Casa, D. J., Ellis, L. A., Maresh, C. M., Pescatello, L. S., . . . Armstrong, L. E. (2017). Precision, Accuracy, and Performance Outcomes of Perceived Exertion vs. Heart Rate Guided Run-training. *Journal of Strength & Conditioning Research*, 31(3), 630-637. doi:10.1519/jsc.0000000000001541

Lee, S. Y., Hong, M. H., Park, M. C., & Choi, S. M. (2013). Effect of the Mandibular Orthopedic Repositioning Appliance on Trunk and Upper Limb Muscle Activation during Maximum Isometric Contraction. *Journal of Physical Therapy Science, 25*(11), 1387-1389. doi:10.1589/jpts.25.1387

Maurer, C., Stief, F., Jonas, A., Kovac, A., Groneberg, D. A., Meurer, A., & Ohlendorf, D. (2015). Influence of the Lower Jaw Position on the Running Pattern. *PLoS One, 10*(8), e0135712. doi:10.1371/journal.pone.0135712

Piero, M., Simone, U., Jonathan, M., Maria, S., Giulio, G., Francesco, T., . . . Giovanni, G. (2015). Influence of a custom-made maxillary mouthguard on gas exchange parameters during incremental exercise in amateur road cyclists. *Journal of Strength & Conditioning Research, 29*(3), 672-677. doi:10.1519/jsc.0000000000000695

Remmers, J. E. (2001). Wagging the tongue and guarding the airway. Reflex control of the genioglossus. *American Journal of Respiratory and Critical Care Medicine, 164*(11), 2013-2014. doi:10.1164/ajrccm.164.11.2110043a

Ribeiro, J., Figueiredo, P., Sousa, M., De Jesus, K., Keskinen, K., Vilas-Boas, J. P., & Fernandes, R. J. (2015). Metabolic and ventilatory thresholds assessment in front crawl swimming. *Journal of Sports Medicine and Physical Fitness, 55*(7-8), 701-707.

Schultz Martins, R., Girouard, P., Elliott, E., & Mekary, S. (2018). Physiological Responses of a Jaw-Repositioning Custom-Made Mouthguard on Airway and Their Effects on Athletic Performance. *Journal of Strength & Conditioning Research*, 34(2):422-429. doi:10.1519/jsc.0000000000002679

Schiffman, E., Ohrbach, R., Truelove, E., Look, J., Anderson, G., Goulet, J. P., List, T., Svensson, P., Gonzalez, Y., Lobbezoo, F., Michelotti, A., Brooks, S. L., Ceusters, W., Drangsholt, M., Ettlin, D., Gaul, C., Goldberg, L. J., Haythornthwaite, J. A., Hollender, L., Jensen, R., ... (2014). Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. *Journal of Oral & Facial Pain and Headache*, *28*(1), 6–27. doi: 10.11607/jop.1151.

Sousa, A., Figueiredo, P., Zamparo, P., Pyne, D. B., Vilas-Boas, J. P., & Fernandes, R. J. (2015). Exercise Modality Effect on Bioenergetical Performance at V O2max Intensity. *Medicine & Science in Sports & Exercise, 47*(8), 1705-1713. doi:10.1249/mss.0000000000000580

Zacca, R.; Azevedo, R.; Silveira, R.; Vilas-Boas, J.P.; Pyne, D.B.; de Castro, F.A.S.; Fernandes, R.J. (2019). Comparison of incremental intermittent and time trial testing in age-group swimmers. *Journal of Strength & Conditioning Research,* 33 (3): 801-810.

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