A jaw protruding dental splint improves running physiology and kinematics

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Keywords:	occlusal splints, running economy, respiratory work, jaw advancement

Abstract

Wearing an intraoral jaw protruding splint could enhance respiratory function in clinical settings and eventually exercise performance. ***Purpose****:* We studied the acute effect of wearing a lower jaw forwarding splint at different protruding percentages across a wide range of running exercise intensities. ***Methods:*** A case study was undertaken with a highly-trained and experienced 27 y old female triathlete. She performed an incremental intermittent treadmill running protocol on three occasions wearing three different intraoral devices (30 and 50% maximum range, and a control device) to assess running physiological and kinematical variables. ***Results:*** Both the 30 and 50% protruding splints decreased both the oxygen uptake and carbon dioxide production (by 4-12 and 1-10%, respectively), as well as increased the ventilation and respiratory frequency (by 7-12 and 5-16%, respectively) during different exercise intensities. The exercise energy expenditure (~1-14%) and cost (7.8, 7.4 and 8.0 $J\cdot kg^{-1}\cdot m^{-1}$ for 30 and 50%, and placebo) were also decreased. The triathlete's lower limbs running pattern changed by wearing the forwarding splints, decreasing the contact time and stride length by ~4%, and increasing the stride rate by ~4%. ***Conclusions:*** Wearing a jaw protruding splint can have a positive biophysical effect on running performance.

Keywords: occlusal splints, running economy, respiratory work, jaw advancement

Introduction

A mandibular protruding splint is a customized dental device that is worn intraorally to advance and hold the lower jaw in a forward position. These splints are used to increase the upper airway space and respiratory volumes[1], and are now being manufactured specifically for sporting applications.[2] Increasing the upper airway volume, and reducing resistance to airflow passage, should increase ventilation and oxygenation, as well as lower the energy cost of breathing[2,3]. On this basis, manipulating the mandibular position has been evaluated as an intervention for enhancing aerobic performance via increased respiratory gas exchange.[2,4]

Despite the mechanical and potential respiratory benefits with wearing a protruding intraoral device, there are few reports to characterize its effect on exercise performance. Furthermore, since the available studies do not reveal the degree of forwarding jaw provided by the tested splints, it is unclear what degree of jaw advancement would be most effective in improving aerobic performance. The aim of this case study was to determine the acute effects of varying the degree of mandibular advancement on running performance.

Methods

Subjects

A well-trained female triathlete (Cross Triathlon World Champion 25-29 female y age group, height 1.67 m and body mass 56 kg) volunteered for this study and provided written informed consent after a full explanation of its purpose, benefits and risks. The experimental procedures were approved by the local University Ethics Committee (CEFADE282020) following the norms and standards of the Declaration of Helsinki.

Design

The triathlete visited the laboratory facilities on three occasions, 48 h apart, to complete an incremental intermittent treadmill running protocol until voluntary exhaustion. A different lower jaw splint was worn on each visit under randomized and single-blind conditions. The triathlete wore the same running shoes and clothing, was instructed to refrain from intensive training in the previous 24 h, and abstain from food, alcohol and caffeine in the 3 h before testing. Cardiorespiratory, metabolic and kinematic variables were recorded continuously throughout the incremental treadmill protocol, and continuous verbal feedback was provided for motivation.

Methodology

After the dental arch impressions were taken, two mandibular splints were custom manufactured to produce different jaw positions at 30 and 50% of the maximum range of the participant's protrusion (at a constant vertical dimension, Figure 1). A placebo splint was also produced that did not cover the occlusal teeth surfaces, nor changed the occlusion vertical dimension and mandibular position. All the intraoral splints were manufactured from thermoforming plates (Erkodur®, Germany) and checked for adaptability and comfortability.

Prior to each trial, the triathlete was familiarized with the specific splint and performed a 15 min warm-up run on the treadmill at low exercise intensity. The experimental protocol consisted of 7 x 4 min running stages, 1 km·h^{-1} increments and 30 s rest periods on a motorized treadmill (AMTI, Watertown, USA).[5] Breath-by-breath responses were measured using a calibrated gas analyzer (K4b^2, Cosmed, Rome, Italy), posteriorly smoothed by employing a moving and time average of three breaths and 5 s (respectively), with the last min of each stage being used for comparison between experimental conditions.[5] The maximal oxygen uptake ($\dot{V}O_{2max}$) was determined using conventional physiological criteria[5], and was always observed at the 7th stage of the protocol.

Capillary blood samples (5µl, Lactate Pro2, Arkay, Inc, Kyoto, Japan) were collected from a fingertip for measuring lactate concentration at rest, immediately after each stage and 3 min after the end of the protocol. The lactate-velocity curve was used to assess the anaerobic threshold (AnT)[6], which was always observed at the 3rd running stage for all the trials. The energy expenditure was determined for each protocol stage and energy cost assessed as the slope of a regression line between the energy expenditure and the corresponding running velocities.[5]

Lower limb kinematic data were recorded from the right sagittal plane using a video camera (GoPro HERO6 Black, California, EUA) at a sampling rate of 60 Hz, fixed on a tripod placed 2 m from the treadmill and 1 m above the ground level. In each running stage, 10 consecutive strides were analyzed frame-by-frame using two-dimensional motion analysis software (Kinovea, v.0.8.27) to determine the contact and stride times, stride rate (1/stride time) and length (velocity/stride rate), as well as knee angular kinematics.

Figure 1

Statistical analysis

The statistical analyses were completed using IBM® SPSS® Statistics 27.0.1.0 (IBM Corp, USA). Mean and standard deviation were computed for all variables. A linear mixed effects model was performed with repeated measures analysis comprising both fixed (splint conditions) and random effects (changes over time). Significance accepted at $p < 0.05$.

Results

The assessed physiological and kinematical data are detailed in Table 1 and Figure 1 (respectively) for each intraoral splint condition. When the protruding splints were used, oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were ~4% lower, while the ventilation and respiratory frequency were higher (7-12 and 5-16%, respectively), across the different exercise intensities. For each protocol stage, the energy expenditure (~1-14%) and energy cost (7.8, 7.4 and 8.0 J·kg^{-1}·m^{-1} for 30 and 50% and placebo) were lower when running with both protruding splints. Similarly, there were differences in the biomechanical variables in-between experimental conditions, with shorter contact times (~4%), higher stride rates (~4%) and lower stride lengths (~4%) when using the 30 and 50% splints.

Table 1

Figure 2

Discussion

The current results demonstrate that forwarding the jaw led to ~4% lower $\dot{V}O_2$ and $\dot{V}CO_2$ values, and induced a higher ventilatory response, along a wide range of running intensities (from low to severe exercise domains). A 30% jaw protrusion seems to be sufficient to improve respiratory responses at submaximal exercise intensities, with the 50% protrusion being more favorable at higher exercise demands. When the protruding splints were worn, the lower limb running pattern was also modified, even if this effect was not clear for the angular variables. These physiological and kinematical outcomes show a positive influence of wearing protruding splints on performance at submaximal and maximal aerobic exercise intensities.

The protruding splints reduced the exercise energy expenditure and cost by decreasing the $\dot{V}O_2$ at the same running velocity, concurrently with decreased $\dot{V}CO_2$ and increased ventilation and respiratory frequency. The differences between 30 and 50% splints were clearer for the intensities above the AnT, probably related to the increasing importance of the respiratory system at higher exercise intensities.[3] These findings are similar to those previously reported where lower $\dot{V}O_2$[3,7] and hiperventilatory[2,3] responses were observed in subjects wearing intraoral splints or by unloading the respiratory muscle work during exercise. Taken together, these data support the hypothesis that placing the jaw forward increases the airflow and decreases the work of breathing. In contrast, previous studies reported little effects on gas-exchange[8] or even higher $\dot{V}O_2$ values[4] when wearing occlusal or jaw forwarding splints. Differences between studies are most likely related to variations in the methodological assessment or, eventually, differences in splint design.

When the jaw was placed in more forward position, shorter contact times and stride lengths, as well as higher stride rates were observed. These effects are consistent with lower energy demand of locomotion and center of mass vertical excursion, indicative of more economical running.[9,10] Reductions in the degree of knee flexion are also related to running performance improvements[10,11] and a higher protrusion with the 50% splint had a positive contribution across all running stages. Small changes in running patterns have been reported when different occlusal splints were worn[12] and, consequently, when the vertical dimension of occlusion was increased. However, it is difficult to justify why the 30% splint yielded different knee angular kinematics comparing to the 50% splint despite both splints providing the same degree of vertical dimension of occlusion.

Practical applications

The possibility of better supporting the high ventilatory demands by decreasing the airway resistance and the respiratory work when wearing a protruding splint would be of great interest for the sporting community. We investigated the biophysical effects of different protruded splints across a wide range of running intensities, with this being the first study to clarify and compare different protrusion ranges. We acknowledge the limitations of a case study design and the importance of studying the effects of protruding splints in larger cohort of runners. Since it is possible that a protruding splint might be more effective for subjects with narrow airways or, even, at certain environments, studying individual athletes in a case-by-case approach should not be discounted.

Conclusions

The outcomes of this case study support the assertion that protruding splints can have a positive impact on running performance. Placing the jaw forward enhanced the ventilatory response to exercise, with higher protrusion seeming to be better at higher intensities. Running kinematics were also improved when using an intraoral protruding splint device.

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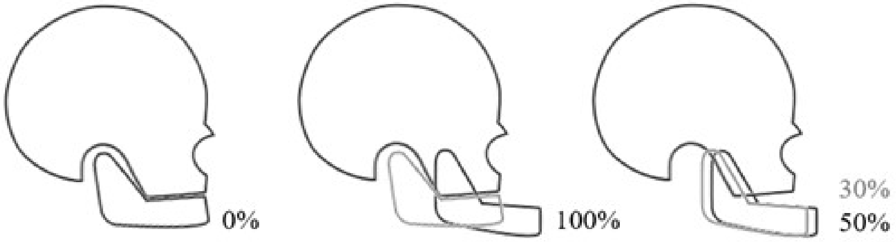

Figure 1 – Antero-posterior lower jaw position at different mandibular protrusions: 0% (without protrusion), 100% (absolute range of maximal protrusion) and 30 and 50% of the absolute range of maximal protrusion (left, center and right panels, respectively).

146x45mm (96 x 96 DPI)

Table 1. Physiological assessment across the incremental running protocol. The three intraoral mandibular splints assessed where placebo (0% advancement), 30 and 50% advancement of the jaw´s maximum protrusion. Treadmill running velocity (v).

	Stage	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	v (km·h^{-1})	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Oxygen consumption (ml·kg^{-1}·min^{-1})	Placebo	40.1 (1.4)*†	44.4 (0.2)*†	45.0 (0.6)*†	47.1 (1.0)*†	52.3 (0.9)*†	53.1 (0.8)*†	56.1 (1.1)*†
	30%	34.9 (1.2)	39.3 (1.0)	43.2 (0.9)	46.0 (0.5)†	49.4 (0.8)†	52.0 (1.0)†	54.5 (1.2)†
	50%	36.3 (1.0)	38.6 (0.6)	42.0 (1.7)	44.5 (1.5)	46.6 (1.3)	49.9 (0.7)	52.4 (0.8)
Carbon dioxide production (ml·kg^{-1}·min^{-1})	Placebo	32.8 (0.9)*†	38.9 (0.4)*†	39.3 (0.7)†	42.9 (0.9)†	50.0 (1.1)*†	54.0 (1.0)*†	56.3 (1.1)†
	30%	30.3 (0.7)	34.5 (0.7)	40.2 (1.1)†	43.3 (1.1)†	48.8 (0.8)†	52.5 (1.7)†	56.8 (0.8)†
	50%	29.9 (0.9)	35.2 (0.5)	37.8 (1.0)	41.1 (1.3)	44.5 (1.3)	50.7 (1.2)	53.5 (1.2)
Ventilation (L·min^{-1})	Placebo	63.5 (1.7)	70.9 (1.0)†	73.8 (1.6)*†	86.6 (2.4)*†	103.9 (1.2)	113.4 (2.2)*†	124.9 (1.6)†
	30%	65.4 (2.1)	71.0 (2.3)†	83.0 (2.2)	94.0 (3.3)	103.7 (1.7)	117.8 (1.5)†	125.6 (2.5)
	50%	64.3 (1.1)	75.2 (2.0)	81.9 (1.3)	91.7 (2.7)	102.7 (1.4)	124.0 (1.3)	127.0 (1.6)
Respiratory frequency (b·min^{-1})	Placebo	40 (2)*†	42 (2)*†	44 (2)*†	52 (2)*†	55 (2)	58 (1)*†	60 (1)*†
	30%	45 (2)	48 (1)	51 (1)	56 (2)	57 (2)	61 (2)	64 (1)
	50%	43 (1)	47 (1)	51 (1)	55 (1)	56 (2)	61 (2)	64 (1)
Energy expenditure (ml·kg^{-1}·min^{-1})	Placebo	33.0	39.4	40.0	49.3	54.8	67.3	69.1
	30%	31.1	34.3	39.1	49.4	54.6	62.9	64.5
	50%	28.6	33.6	37	46.7	53.9	59.6	60.9

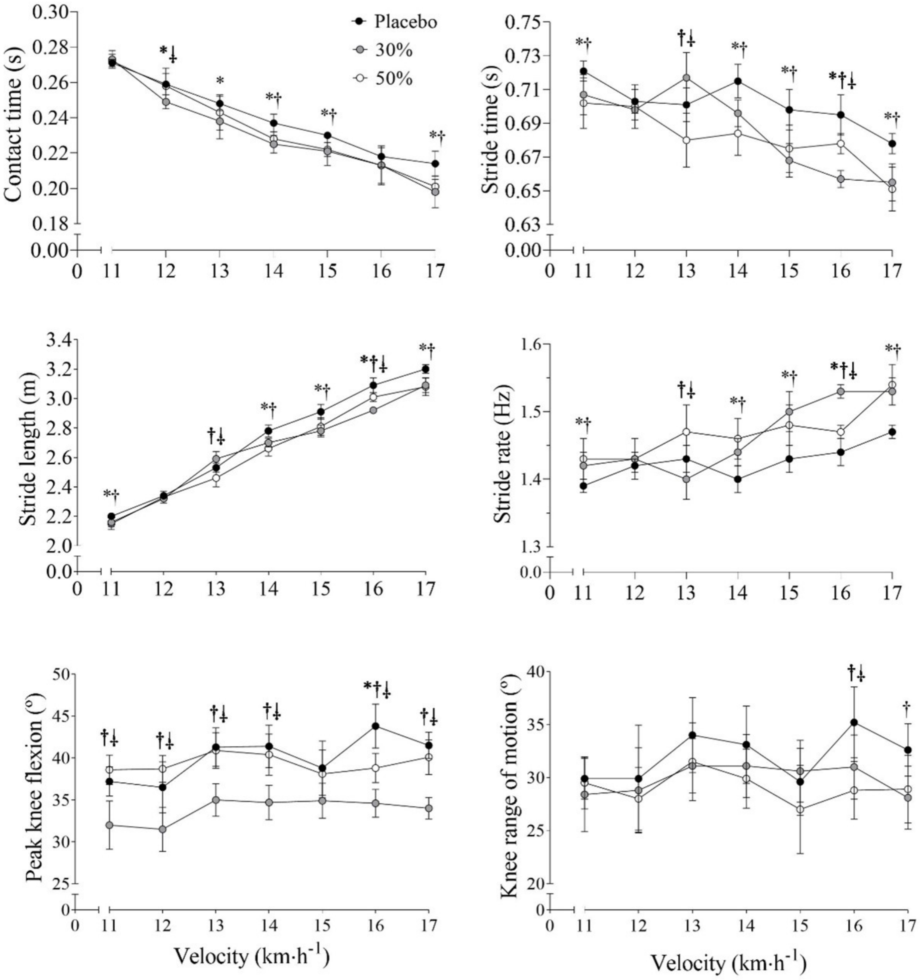

Figure 2 – Running linear and knee angular kinematics for 0 (placebo), 30 and 50% intraoral splint devices. *, † and ☐ indicates differences between placebo and 30 and 50%, and between 30 and 50% (respectively).

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