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Physical and cognitive cycling performance wearing a training mask

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Abstract: Training mask is a respiratory muscle training device, although it was initially advertised as altitude simulators. The aim of the study was to assess the acute effects of wearing a training mask on physical and cognitive performance in cyclists. Twenty physically active subjects performed two graded exercise tests (GXT) until exhaustion, wearing and not wearing a mask, in counterbalanced order. Immediately after the GXT, they performed a cognitive task on a computer. Power, heart rate, lactate, Rating of Perceived Effort (RPE), peripheral oxygen saturation, lung capacity and cognitive variables (reaction time and response accuracy) were measured. Final power was 14.5 % lower when wearing a mask ($p < 0.001$; ES = 1.515). Heart rate ($p = 0.002$; ES = 0.790), lactate ($p = 0.002$; ES = 0.870), and RPE ($p = 0.008$; ES = 0.879) were also lower at the end of the mask test. However, in the intermediate stages of the test, at the same intensity, there was no difference in heart rate, while RPE was higher with mask. There were no differences between conditions in peripheral oxygen saturation or cognitive variables. In conclusion, the use of a training mask limits maximal aerobic performance, but there are no differences in cognitive variables or physiological parameters at the same intensity, while RPE increases at an equal intensity.

Keywords: Hypoxia; Altitude; Cycling; Respiratory Muscle Training; Reaction Time; Sports Performance.

1. Introduction

Cardiorespiratory fitness depends on the ability to obtain oxygen (O_2) and distribute it throughout the body (Cristina & Cătălin, 2015). It is usually measured by maximal oxygen uptake (VO_{2MAX}) (Levine, 2008; Loe, Rognmo, Saltin, & Wisløff, 2013). In endurance sports, the ability to consume O_2 is one of the keys of performance, with a strong relationship between high VO_{2MAX} and success (Warren, Spaniol, & Bonnette, 2017). The main limiting factor of VO_{2MAX} (~70 %) is the ability to transport O_2 (di Prampero & Ferretti, 1990). Therefore, some strategies to improve VO_{2MAX} involve manipulation of O_2 supply to enhance blood O_2 transport capacity, with hypoxia (both normobaric and hypobaric) being a widely used method in recent decades (McLean, Gore, & Kemp, 2014). In fact, it is a widely researched technique for improving performance at sea level (McLean et al., 2014). For example, following a hypoxia training programme, improvements in both VO_{2MAX} and ventilatory thresholds have been observed (Levine & Stray-Gundersen, 1997; Roberts et al., 2003; H. K. Rusko et al., 1999). From around 1500 m altitude, decreases in aerobic performance occur (Muza, 2007), and high altitude diminishes VO_{2MAX}, workloads, and speed in endurance sports (Warren et al., 2017). There are sports which are practised at moderate altitudes, while others, such as cycling, where altitude is variable. So, in cycling, the aims would be to improve performance at sea level and minimise performance losses at altitude. Hypoxia training has been shown to be valid for achieving both objectives (Sellers, Monaghan, Schnaiter, Jacobson, & Pope, 2016). However, as a training method, hypoxia is not available to all athletes due to economic or logistical reasons.

In the last years, new training concepts have emerged that can be effective, such as respiratory muscle training (RMT) or inspiratory muscle training (IMT). Performance improvements have been reported in cyclists, both at sea level and at altitude, after performing an RMT or IMT programme (Porcari et al., 2016; Salazar-Martínez, Gatterer, Burtscher, Naranjo Orellana, & Santalla, 2017), and RMT has even been considered as a new ergogenic aid (Shei, 2018). Specifically, improvements in peripheral oxygen saturation (SpO_2) at altitude have been found (Lomax, 2010; Porcari et al., 2016). Following an RMT or IMT programme, SpO_2 did not change at low altitude, while its decrease at altitude was minimised by 3-6% (Downey et al., 2007; Lomax, Massey, & House, 2017). Most IMT research follows the same methodology, using a device called PowerBreath® and performing 30 breaths at 50 % of maximal inspiratory pressure twice daily for 4-6 weeks (Lomax, 2010; Lomax et al., 2017; Salazar-Martínez et al., 2017). However, it has been proposed that performing RMT simultaneously with exercise, which has been called "functional RMT", might even have a more positive effect (Shei, 2018). A training mask (TM), consisting of a filter that hinders air intake to act as a resistive breathing device, is one method of IMT that can be used while training. Different TM exist (e.g. Elevation Training Mask, Altitude Resistance Mask, Phantom Training Mask or BQ Training Mask) and some of them have been advertised as being able to simulate altitude. Indeed, previous studies indicated that they fitted TM at altitudes of 914 m, 1829 m, 2743 m, and 3658 m, or 3000 ft, 6000 ft, 9000 ft, and 12000 ft, being even able to reach 5489 m or 18000 ft (Öncen & Pinar, 2018; Porcari et al., 2016; Romero-Arenas, López-Pérez, Colomer-Poveda, & Márquez, 2021; Sellers et al., 2016; Warren et al., 2017).

Entry of O_2 into the body depends on the pressure difference. At altitude, because the partial pressure of oxygen in air (PO_2) decreases, alveolar diffusion is hindered as the gradient between PO_2 and the arterial blood partial pressure of oxygen (PaO_2) is reduced. When using a TM, PO_2 does not change. Therefore, the gradient remains unchanged and the alveolar diffusing capacity remains the same, although the amount of air entering the lungs is likely to be reduced when ventilatory requirements increase (Granados, Gillum, Castillo, Christmas, & Kuennen, 2016). In addition, exhaled carbon dioxide (CO_2) accumulates in the mask dead space and is rebreathed. Although PO_2 does not change, the partial pressure of carbon dioxide (PCO_2) increases (Warren et al., 2017). The amount of CO_2 accumulated in the dead space and rebreathed is estimated to be about 240 mL (Granados et al., 2016). For this reason, it could perhaps cause effects similar to those of altitude on the body. If so, TM would certainly be a useful tool for athletes who cannot easily access training in hypoxia. Previous research has evaluated the acute effects of using a TM during a strength training session (Jagim et al., 2018; Motoyama, Joel, Pereira, Esteves, & Azevedo, 2016) or endurance training session (Jung, Lee, John, & Lee, 2019; López-Pérez, Romero-Arenas, Colomer-Poveda, Keller, & Márquez, 2020; Öncen & Pinar, 2018; Ott, Joyce, & Hillman, 2021; Romero-Arenas et al., 2021), as well as the effects of performing a training programme using TM (Abouzeid, ELnaggar, FathAllah, & Amira, 2023; Devereux, Le Winton, Black, & Beato, 2022; Faghy, Brown, Davis, Mayes, & Maden-Wilkinson, 2021; Porcari et al., 2016; Sellers et al., 2016; Warren et al., 2017). Endurance performance has been assessed at moderate or high intensity, continuously or intermittently, but in all cases at constant intensity. It may therefore be of interest to assess what happens when the mask is used at different intensities during an incremental protocol, as we can then see if its effects on the body vary according to the effort.

So far, reference has only been made to physical performance and physiological aspects, which are traditionally evaluated in Sport Science. However, mental aspects are equally important and are often not taken into account together. In fact, sport performance is subject to factors such as information processing, decision making, visual perception or reaction time (RT). Hypoxia is also one of the key factors affecting brain activity: in hypoxia, the brain is less efficient, as there is a decrease in the functional activity of neurons (Burykh & Sergeeva, 2007). Other effects include reductions in visual perception and information processing in terms of speed and accuracy, while response inhibition appears to be unaltered after a period of adaptation to altitude (Davranche et al., 2016). Thus, in sports where altitude can be decisive, the goal cannot be limited to thinking only about physical and physiological factors to improve performance. Cognition must also be considered and, in fact, may even be more decisive than the above in making the difference between success and failure. However, to the best of our knowledge, there are no previous studies assessing cognitive capacity during exercise in hypoxia or while using a TM. We are only aware of studies assessing cognition at rest at altitude, or during exercise in normoxia.

The aim was to evaluate the effects of using a BQ Training Mask on aerobic performance, cognition, and physiological parameters, ranging from low to high intensity. We hypothesised that aerobic performance would be reduced using a TM, so that maximal aerobic power (MAP) would be lower, as well as lung capacity would decrease. However, since PO_2 is unchanged, we expect that SpO_2, lactate (La^-), RT, and response accuracy will not be affected by the use of the mask. In addition, we expect that heart rate (HR) and Rating of Perceived Effort (RPE) to be higher at the same intensity when using the mask due to the increased work of the respiratory muscles.

2. Materials and Methods

Subjects —Twenty young healthy participants (15 males and 5 females), physically active and of recreational level, participated in the study (24.5 ± 5.5 years; 173.8 ± 9.2 cm; 71.9 ± 9.2 kg; mean ± standard deviation [SD]). All were healthy, non-smokers and had no previous experience with use of TM. Exclusion criteria were being allergic to silicone or having any type of lung disease. Participants were asked to refrain from strenuous exercise for 48 h prior to each visit, as well as caffeine or stimulants for 8 h prior to each visit. Sample size was based on power calculations using G*Power software (Faul, Erdfelder, Buchner, & Lang, 2009) and assuming a statistical power of 0.8, an alpha error of 0.05 and considering an effect size of 0.6. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the local research ethics committee. Informed consent was obtained from the participants.

Design —Two experimental conditions, TM and normal breathing (CT), counterbalanced and randomly assigned, were conducted to assess the acute effects of using a TM during a graded exercise test (GXT) on a cycle ergometer.

Methodology —Participants visited the laboratory on three different days: the first visit was a familiarisation session with the evaluation protocol and the TM, while the following two sessions were for assessing the experimental conditions. There was at least a 48 h interval between sessions.

When participants arrived at laboratory during the familiarization session, height (Seca 2016, Seca, Hamburg, Germany), body mass and body fat percentage (Tanita BC601, Tanita Corp., Tokyo, Japan) were measured, and the cycle ergometer (Phantom 5, CycleOps, Wisconsin, USA) was adjusted to replicate measurements on the following days. Three tests were performed: a maximal GXT, a forced spirometry (Pony FX, COSMED, Rome, Italy), and a Flanker task (E-Prime, Psychology Software Tools, Pittsburgh PA, USA). There was also familiarisation with the use of the TM (BC Training Mask, Biolaster, Guipuzkoa, Spain) while pedalling. The manufacturer's sizing instructions were followed and the resistance level used was number four (maximum).

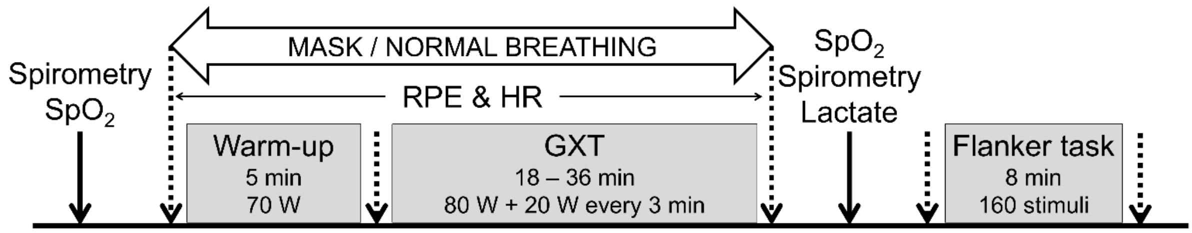

Figure 1. Schematic protocol of the experimental sessions.

Figure 1 shows the protocol followed during the experimental sessions. Both sessions differed in the use or non-use of the TM during the GXT. Only water was allowed to be drunk before the warm-up in both sessions. Prior to the GXT, participants underwent forced spirometry, had the HR band placed on their chest (H10, Polar Electro Oy, Kempele, Finland), and SpO_2 was measured on the index finger of the right hand (PO30, Beurer GmbH, Ulm, Germany). Then, they moved onto the ergometer and began a 5-min warm-up at 70 W, starting the GXT at 80 W and performing step increments of 20 W every 3 min until exhaustion. Subjects pedalled at their preferred cadence (the same in both sessions). Power, HR and cadence data were transmitted to an external device (Edge 1000, Garmin International, Inc., Kansas, USA). The RPE was recorded at the end of each step using the Borg CR-10 scale. The power achieved at the end of the GXT was defined as MAP. If a participant did not complete the last step, the MAP was the power corresponding to the last completed step added to the proportional part of the completed next step (Salas-Montoro, Mateo-March, Sánchez-Muñoz, & Zabala, 2022). The representative HR for each intensity was the average of the last 30 s of each step. Because each participant completed the GXT at a different intensity, intermediate intensities (e.g. 160 W) may represent a very different effort for each participant. For this reason, to compare efforts, the participant's intensity was relativised to their 100 % by dividing the GXT into two halves (1st half - low intensity, from the start of the GXT to 50 % of MAP; 2nd half - moderate/high intensity, from 50 % to MAP).

If the session was performed with the TM, the resistance was set to minimum before the warm-up, and gradually increased (levels 2, 3, and 4 at seconds 90, 180, and 240, respectively). Immediately at the end of the GXT, SpO_2 was measured again, another forced spirometry was performed and La^- was measured in the right earlobe (Lactate Pro 2, Arkray, Kyoto, Japan). Participants then sat in front of a computer and performed the Flanker task, in order to check whether wearing the mask had any impact on cognitive parameters such as RT or response accuracy. Four different stimuli could be presented (Figure 2), to which participants had to respond as quickly as possible by using the keyboard to indicate the direction of the central arrow. Two types of stimuli were differentiated during the Flanker task, congruent (CO) or incongruent (IN). In the CO stimuli, all arrows pointed in the same direction (Figure 2, options A and B), whereas in the IN stimuli, the central arrow pointed in the opposite direction (Figure 2, options C and D).

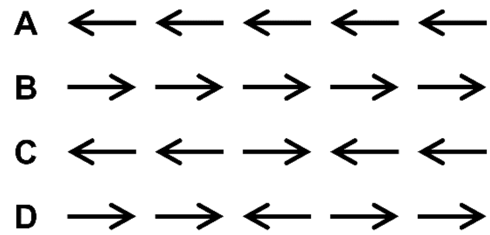

Figure 2. Possible stimuli in the Flanker task. Options A and B correspond to congruent stimuli and options C and D to incongruent stimuli.

A total of 160 stimuli appeared during the 8-minute task, with equal probability for CO and IN trials. Response accuracy was measured as the percentage of correct responses, while RT was the time lag between the appearance of the stimulus and the participant's response by pressing the keyboard. Only correct responses were considered for the RT analysis.

In this type of cognitive task, filtering is usually applied to delete responses with extreme values. In this case, a simple filter was applied, which consisted of discarding responses with a RT of less than 200 ms or greater than 1000 ms. Filtering should not remove more than 5 % of the results, as this would indicate that the range applied was not correct (Ruz et al., 2011).

Statistical Analysis —Statistical analysis was conducted using IBM SPSS Statistics (version 28.0, IBM Corp, Armonk, New York), accepting statistical significance when $p \leq 0.05$. All data are presented as mean and SD. Data were tested for normality using the Shapiro-Wilk test ($p > 0.05$), except for maximal HR (HRMAX) and RPE at the end of GXT, which did not follow a normal distribution. A paired samples T-test was used for MAP and La–, while the Wilcoxon test was used for RPE and HRMAX. Effect size (ES) was calculated when significant differences occurred and, considering that participants were physically active and of recreational level, the criteria for interpreting the magnitude of ES were: a) < 0.35 insignificant; b) 0.35 - 0.8 small; c) 0.8 - 1.5 moderate; d) > 1.5 large (Rhea, 2004).

A repeated measures ANOVA (condition x time) was performed with the data measured before and after GXT (SpO_2 and lung capacity). Another two-factor repeated measures ANOVA (condition and congruency) was performed with the data from the Flanker task (RT and response accuracy). In ANOVA analyses, ES was indicated by partial eta-squared (η_p^2), and Bonferroni *post hoc* tests were performed when a significant interaction occurred.

3. Results

Participants conducted both sessions at the same scheduled time of the day (± 1 h) and in a controlled environment (Temperature: 24.2º C in both sessions, p = 0.922; Humidity: 32.8 % in the TM session and 30.7 % in the CT session, p = 0.372).

Power, Lactate, RPE and Heart Rate —All values were lower at the end of the GXT using the TM (Table 1). In fact, only three participants reached the same intensity at the end of the GXT in both conditions. The remaining participants completed one (n = 6), two (n = 7), three (n = 3) or four (n = 1) fewer steps when wearing the TM. The corresponding HR and RPE values for each intensity can be seen in Table 2, considering only the participants who reached those intensities in both conditions.

Table 1. Data of maximal aerobic power (MAP) (absolute and relative to body mass), lactate (La^-), Rating of Perceived Effort (RPE), and maximal heart rate (HR_{MAX}) at the end of graded exercise test.

	TM	CT	*p*	ES
MAP (W)	194 ± 39	227 ± 41	< 0.001	1.515
MAP ($W \cdot kg^{-1}$)	2.74 ± 0.51	3.21 ± 0.55	< 0.001	1.459
La^- ($mmol \cdot L^{-1}$)	5.1 ± 2.4	8.8 ± 4.5	0.002	0.870
RPE (0-10)	9.25 ± 1.03	9.70 ± 0.52	0.008	0.879
HR_{MAX} (bpm)	176 ± 16	185 ± 9	0.002	0.790

TM, training mask; CT, normal breathing; ES, effect size.

Table 2. Average heart rate (HR) during the last 30 s of each step and Rating of Perceived Effort (RPE) values in the graded exercise test.

POWER (W)	n	HR (bpm)		RPE (0-10)	
		TM	CT	TM	CT
80	20	119 ± 15	119 ± 15	1.95 ± 1.18	1.40 ± 0.70
100	20	127 ± 16	128 ± 16	3.33 ± 1.26	2.63 ± 0.92
120	20	136 ± 17	136 ± 17	4.98 ± 1.63	3.95 ± 1.27
140	20	147 ± 174	147 ± 18	6.48 ± 1.88	5.20 ± 1.40
160	17	155 ± 16	154 ± 17	7.38 ± 1.83	6.44 ± 1.58
180	13	161 ± 13	159 ± 12	7.65 ± 1.42	7.00 ± 1.58
200	10	168 ± 13	166 ± 13	8.35 ± 1.23	7.80 ± 1.57
220	8	173 ± 8	170 ± 8	9.06 ± 0.82	8.19 ± 1.22
240	5	179 ± 4	172 ± 6	9.60 ± 0.55	8.40 ± 1.29
260	1	189	174	9.5	9

TM, training mask; CT, normal breathing.

When intensity is related to 100% of each participant, HR showed no differences between conditions at either low (TM: 128 ± 14 bpm; CT: 128 ± 14 bpm; p = 0.891) or moderate/high intensity (TM: 162 ± 13 bpm; CT: 162 ± 12 bpm; p = 0.888). However, RPE was significantly higher wearing TM in both the first half (TM: 3.33 ± 0.97; CT: 2.63 ± 0.84; p = 0.003; ES = 0.765) and the second half (TM: 8.16 ± 1.14; CT: 6.90 ± 1.57; p < 0.001; ES = 0.895).

Lung Capacity and Peripheral Oxygen Saturation —Data on forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), the ratio of FEV1 to FVC, and SpO2 are shown in table 3. For SpO2 there was a main effect of moment ($F(1, 19) = 50.343$; $p < 0.001$; $\eta_p^2 = 0.726$), with lower values after GXT ($p < 0.001$), but no difference was found in the interaction of moment and condition ($p = 0.892$). There was also a main effect of moment for FVC ($F(1, 19) = 25.921$; $p < 0.001$; $\eta_p^2 = 0.577$), with lower values after GXT. Significance was also observed in the interaction for FVC ($F(1, 19) = 4.645$; $p = 0.044$; $\eta_p^2 = 0.196$) and the Bonferroni post hoc test revealed that differences occurred between before and after GXT for CT condition ($p < 0.001$). There were no differences for FEV1 or for the FEV1/FVC ratio.

Table 3. Peripheral oxygen saturation (SpO_2), forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1) and ratio FEV_1/FVC values before and after the graded exercise test.

	TRAINING MASK			NORMAL BREATHING		
	Pre	Post	Difference (%)	Pre	Post	Difference (%)
SpO_2 (%)	97.40 ± 0.50	95.80 ± 2.04	-1.64	97.55 ± 0.76	95.85 ± 1.53	-1.73
FVC (L)	4.72 ± 0.88	4.56 ± 0.81	-3.18	4.75 ± 0.85	4.47 ± 0.77	-5.75
FEV_1 (L)	4.20 ± 0.80	4.06 ± 0.84	-3.09	4.21 ± 0.73	4.02 ± 0.79	-4.35
FEV_1/FVC (%)	88.97 ± 5.97	89.18 ± 9.89	0.17	88.90 ± 5.89	90.33 ± 10.70	1.42

Difference = Post – Pre, considering the previous values as 100% to determine the percentage of variation.

Cognition —After applying the filtering indicated in the methodology to remove outliers, the number of results went from 6400 to 6233, thus discarding 2.6% of the responses.

The results showed a main effect of congruency ($F(1, 19) = 224.294$; $p < 0.001$; $\eta_p^2 = 0.922$), with a slower RT in the IN trials (CO, 394 ± 6 ms; IN, 474 ± 7 ms; $p < 0.001$). There was no difference between using or not using TM ($p = 0.499$) or in the interaction between condition and congruency ($p = 0.495$).

Response accuracy also showed a main effect of congruency ($F(1, 19) = 26.226$; $p < 0.001$; $\eta_p^2 = 0.580$), with a higher level of correct responses in the CO trials (CO, 96.4 % ± 2.1 %; IN, 90.4 % ± 1.8 %; $p < 0.001$). There was no difference between using or not using TM, with an accuracy level of 94.2 % ± 1.8 % and 92.6 % ± 2.3 % for TM and CT, respectively ($p = 0.098$). There was also no interaction effect ($p = 0.148$) (Figure 3).

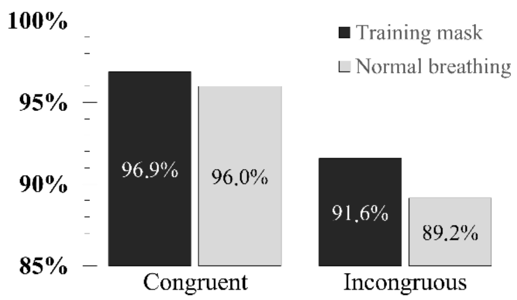

Figure 3. Success rate for congruent (CO) and incongruent (IN) stimuli as a function of training mask use.

4. Discussion

The main objectives of this study were to assess the impact of wearing a BQ training mask while pedaling at different intensities on aerobic performance, as well as acute physiological responses and their subsequent effects on cognitive performance. The main findings, as we expected, were that power at the end of the GXT was lower with the TM, while neither SpO_2 nor cognitive variables were affected by the use of the mask. However, contrary to expectations, FVC was not affected by the use of the TM (whereas it was reduced after GXT without mask), and HR_{MAX} and La^- were lower using the mask. Finally, while RPE was higher throughout the range of intensities of GXT with mask, HR was not affected.

The results of our study indicate that the use of a TM reduces MAP by 14.5 %. Reductions in MAP had also been found in a previous study, although only 6.9 % (Romero-Arenas et al., 2021). These changes could be due to differences in the protocol used during GXT, as the steps were smaller (25 W every minute). Performance was also reduced when a mask was used in a time-to-exhaustion test at high intensity (López-Pérez et al., 2020), so it seems clear that TM reduces aerobic performance. At altitude, aerobic performance is known to be negatively affected above 1500 m (Muza, 2007) and VO_{2MAX} decreases (Warren et al., 2017), so the same occurs as with a TM. However, the reasons for this reduction are different. At altitude, the decrease in PO_2 hinders alveolar diffusion, reducing the availability of O_2 to the muscles, whereas, with the mask, the reduction in O_2 availability is due to the resistance of the mask towards air entry. In fact, one of the physiological responses to the reduction in PO_2 at altitude is a decrease in SpO_2 (Lomax, 2010; Lomax et al., 2017; Porcari et al., 2016), leading to an increase in ventilation in an attempt to maintain SpO_2 (Burtscher, Faulhaber, Flatz, Likar, & Nachbauer, 2006; Faiss, Orelli, Dériaz, & Millet, 2014; H. Rusko, Tikkanen, & Peltonen, 2004).

At an altitude of 914 m (similar to the laboratory), SpO_2 is about 97 % and decreases as altitude increases: 95 % at 1829 m, 89 % at 2743 m, 79 % at 3658 m and 63 % at 4572 m (Porcari et al., 2016). Previous studies stated that SpO_2 was lower when using a TM during workouts (Jung et al., 2019; López-Pérez et al., 2020; Porcari et al., 2016; Romero-Arenas et al., 2021), but differences only occurred at high intensities (Jung et al., 2019; Romero-Arenas et al., 2021). However, in our case, the SpO_2 decrease after GXT was between 1.5 % and 2 % in both cases, with no significant differences. However, the magnitude of the decrease in SpO_2 depends on exercise intensity (Cockcroft, Beaumont, Adams, & Guz, 1985). Because SpO_2 was only measured at the end of GXT, intensities with and without TM are not comparable, since, with the mask, power was lower. If a higher power had been achieved with the mask, perhaps SpO_2 could have decreased to a greater extent, but this is only a hypothesis.

As in the analysis of what happened with SpO_2, an erroneous analysis of the data from our study could lead us to state that the use of the TM reduced HR, La^- and RPE. As before, this decrease may be due, exclusively, to the lower power at the end of GXT using the mask. In fact, we believe that this incorrect analysis led to the claim that the use of a TM caused bradycardia due to lower HR values at the end of an incremental activity using the mask, when the power was also lower (Öncen & Pinar, 2018). Therefore, based on the final test data, it cannot be stated that the use of the TM had any effect. To describe possible effects, it would be necessary to analyze what happened under the same intensity conditions. While HR and RPE were recorded at the end of each step, La^- was only measured at the end of the GXT, so no precise conclusions can be drawn in this case. During the GXT there were no differences in HR when a TM was used, neither at the lowest nor at the highest intensities, while RPE was 0.7 and 1.3 units higher at low (1st half) and high (2nd half) intensity, respectively. Our findings were in agreement with previous studies that found no differences in HR (Granados et al., 2016; López-Pérez et al., 2020; Ott et al., 2021; Romero-Arenas et al., 2021), as well as increases in RPE when the mask was used (Granados et al., 2016; Motoyama et al., 2016; Porcari et al., 2016) Specifically, in our case, the RPE was between 0.5 and 1.28 units higher in all steps when the mask was used (Table 2). There are different factors that can influence RPE, such as psychological (Okano et al., 2015), metabolic (Bishop, 2012) or cardiorespiratory (Tomczak, Guenette, Reid, Mckenzie, & Sheel, 2011). Difficulty in air entry with a TM discomforts breathing and increases anxiety levels (López-Pérez et al., 2020), which can lead to increases in RPE values. Regarding La^-, our findings were also in line with previous studies that obtained lower values when a TM was used in a strength session (Motoyama et al., 2016), in an incremental cycling test (Romero-Arenas et al., 2021) or in a time-to-exhaustion cycling test (López-Pérez et al., 2020). In all cases, two common elements were that, in the TM session, the intensity (final power output) or workload (number of repetitions performed or duration of effort) were lower and that La^- was measured only at the end of the test. As stated above, the values could be compared if the intensity were equal, since La^- is a marker that increases with intensity (Motoyama et al., 2016). Therefore, we cannot claim that the lower values of La^- when wearing a mask were due to its use. In fact, they were probably a consequence of lower intensity. Nevertheless, let us hypothesize about some aspects: Traditionally, the anaerobic threshold or second La^- threshold (LT_2) has been placed at 4 mmol/L (Mader et al., 1976). However, although it is the most commonly used value, it should not be a universal criterion and can vary considerably among individuals from 2 to 10 mmol/L (Faude, Kindermann, & Meyer, 2009; Salas-Montoro et al., 2022). In our case, the final La^- value without TM was 8.8 ± 4.5 mmol/L and corresponded to the intensity of MAP, so the intensity of LT_2 should be lower. With the TM, the final La^- value was 5.1 ± 2.0 mmol/L and we believe it could correspond to LT_2 or be slightly higher. When exceeding LT_2 intensity, ventilation is accelerated and, when using a TM, these demands may be limiting due to shortness of breath. In the future, it might be interesting to investigate what happens at LT_2 intensity and to assess whether, when using a TM, a GXT ends when exceeding this intensity.

Regarding lung capacity, wearing a TM had no effect on either FEV_1 or FEV_1/FVC ratio and, contrary to expectations, FVC showed a more pronounced reduction when the mask was not used. Initially, we thought that with TM the respiratory muscles would be fatigued and this would negatively affect all pulmonary variables. However, the work performed with the TM during GXT provided a stimulus to generate more force with the respiratory muscles and, despite the fatigue, when the TM resistance was removed, the result was positive.

We are not aware of previous studies that have evaluated the effects of using a TM on cognition. In our case, using the TM had no effect on either RT or response accuracy, consistent with the previous hypothesis. Regardless of whether or not to use the mask, the only effect observed for both RT and response accuracy was on congruency. Specifically, RT was 80 ms slower on IN trials, while response accuracy was 6 % higher on CO trials. This was in line with what happens in general situations, since, as the level of conflict increases, RT becomes slower and response accuracy decreases (Davranche, Hall, & McMorris, 2009).

Finally, we would like to mention the fact of the original naming of these devices and their supposed use to simulate altitude training. In the absence of a comparison with a hypoxia condition, we cannot affirm that the acute effects of the use of a TM are the same or different from those of breathing under hypoxia or altitude. However, some of the results obtained differ with respect to what occurs under hypoxia or altitude conditions, suggesting that the acute effects might be different. Specifically, we found different responses for HR, lung capacity and cognition than expected under hypoxia. Acute exposure to altitude increases HR at rest (Vogel & Harris, 1967) and at exercise (Hahn & Gore, 2001; Lomax et al., 2017), in contrast to a TM, which remained unchanged regardless of intensity. Furthermore, altitude exposure was associated with decreases in FVC, while FEV_1 remained unchanged (Deboeck, Moraine, & Naeije, 2005; Mason et al., 2000). Thus, although the same occurred for FEV_1 using the mask, the opposite was true for FVC. As for cognition, acute exposure to hypoxia increases RT (Davranche et al., 2016; Ma et al., 2015) and, at an altitude of 4000 m, the percentage error compared to low altitude increased from 3.5 % to 6 % for CO trials and from 8.5 % to 9 % in IN trials (Davranche et al., 2016), so response accuracy decreases in both cases. However, with a TM, there was no difference in both variables. In contrast, RPE increased both in hypoxia (Gronwald, Hoos, & Hottenrott, 2019) and when a TM was used, although the reasons for these increases could be conditioned by different stimuli. A typical response observed at altitude is an increase in ventilation (Lomax, 2010), mediated by stimulation of peripheral chemoreceptors (Townsend et al., 2002) and aiming to maintain SpO_2 (Faiss et al., 2014), which could lead to an increase in RPE for cardiorespiratory reasons. When using the mask, we believe that one of the main reasons for the increase in RPE may be psychological, due to increased anxiety levels (López-Pérez et al., 2020). Thus, although RPE increased both in hypoxia and with a TM, we do not know if it was due to the same causes, although we believe that the reasons could be different. Finally, it has been observed that in hypoxia, La^- was higher during a GXT, but only above the anaerobic threshold (Mateika & Duffin, 1994). However, on certain occasions, with natives of high altitude territories or individuals acclimatized to hypoxia, lower than expected La^- values have occurred, something that has been termed the La^- paradox (Hochachka et al., 2002). In fact, this is what was stated in a previous study with TM, which indicated that lower La^- values when using the mask could be explained by the La^- paradox (Motoyama et al., 2016). In our opinion, as argued above, the lower La^- values with the TM were a direct consequence of the lower exercise intensity and had nothing to do with the phenomenon indicated. If the subjects had reached MAP with a TM, would La^- be higher than the values we have seen without a mask? We are not in a position to answer this question with the available data. Regarding possible similarities between mask use and chronic hypoxia exposure, previous studies have concluded that the mask does not simulate altitude. Specifically, the mask did not cause hematological changes (Porcari et al., 2016) nor were the same benefits observed as with intermittent hypoxia training (Sellers et al., 2016). Regardless of whether the use of a TM may have similar or different acute effects to hypoxia exposure, it seems difficult for chronic effects to be reproducible with the methodology used to date. To achieve chronic adaptations after altitude requires at least 12 h of daily exposure to hypoxia for 3 weeks (H. Rusko et al., 2004). None of the TM methodologies studied to date have been evaluated beyond the use of approximately 1 h per day for a maximum of 4 days per week.

5. Practical Applications.

A TM can be a very useful tool to perform "functional" IMT while cycling. Since HR does not vary at low intensities and RPE increases only slightly, the use of a TM could be an interesting strategy in low-intensity or active recovery sessions, as the workload would not be affected too much. In high-intensity training, we have found that TM limits performance and increases RPE, so its use would be advisable only if the aim is to exercise the respiratory muscles.

6. Conclusions

In summary, the main findings were that wearing a TM limits aerobic performance, probably by exceeding LT_2 intensity, due to the difficulty of increasing ventilation. As a consequence of this limitation, HR, RPE and La^- at the end of GXT using a TM were lower. At the same intensity there was no difference in HR, while RPE increased. In addition, the use of a TM had no effect on SpO_2 or cognition. Different effects were observed with the TM than those previously described for acute exposure to altitude or hypoxia on several variables, so it appears that the performance of a TM could be identified with RMT.

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