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Effect of Nasal Versus Oral Breathing on Vo$_2$max and Physiological Economy in Recreational Runners Following an Extended Period Spent Using Nasally Restricted Breathing

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ABSTRACT

Background: In subjects who do not practice nasally restricted breathing, peak oxygen uptake (VO$_2$max) and time to exhaustion in a graded exercise protocol (GXT TE) are impaired while breathing nasally versus orally. **Objective:** This study investigated the effect of oral versus nasal breathing on VO$_2$max, GXT TE and physiological economy (PE) in subjects who had previously self-selected a nasal only breathing approach during training and racing. **Methods**: A mixed gender sample (N=10, 5 male and 5 female) of nasal breathing recreational runner's completed a maximal GXT and high level steady state trial at 85% of their maximal GXT running velocity (SS85) in both nasally and orally restricted breathing conditions. **Results:** In the GXT trials the subjects exhibited no significant mean difference in GXT TE, VO$_2$max or peak lactate. However, in the nasally restricted breathing condition they demonstrated a significantly lower mean ventilatory equivalent for both oxygen (VE/VO$_2$) ($p = 0.002$), and carbon dioxide (VE/VCO$_2$) ($p = 0.043$) at VO$_{2max}$ with large effect sizes. During the SS85 trials the subjects exhibited a significantly better PE ($P = 0.05$) and no significant difference in lactate production, as well as a significantly lower mean VE/VO$_2$ ($p = 0.002$) and VE/VCO$_2$ ($p = 0.002$) with large effect sizes. **Conclusion:** This study supports the ability of recreational runners to utilize a nasally restricted breathing pattern at all levels of running intensity without loss in VO$_2$max or GXT TE, and with superior PE and VE/VO$_2$, following an extended training period using this practice.

Key words: Lactate, Bronchoconstriction, Ventilatory, Efficiency, Oropharynx, Nasopharynx

INTRODUCTION

Within the last decade, a variety of health professionals and others have posted articles/blogs on the internet describing the value of breathing restricted to the nasopharynx during exercise (Cap, 2016; Mercola, 2013; Rakimov, 2004; Raman, 2006; Ruth, 2015). In general, the largely unexamined theoretical rationale they provide for doing so can be summarized as follows: 1) nasally restricted breathing during exercise allows for the filtration, humidification and temperature regulation of inhaled air in the nasopharynx thereby avoiding the health problems associated with breathing large volumes of unfiltered, non-humidified and non-temperature regulated air while breathing predominately through the oropharynx during exercise, 2) nasally restricted breathing improves oxygenation locally through the release of nitric oxide (NO), a potent vasodilator, and through increased serum carbon dioxide (CO$_2$); a competitive binder of hemoglobin with oxygen (O$_2$), thereby resulting in increased O$_2$ release from hemoglobin at the active tissues. However, many commenters to these same posts describe the sensation of air hunger while attempting to breathe in a nasally restricted manner during exercise, thereby rejecting the notion that such breathing is effective to support high intensity exercise (Cap, 201; Mercola, 2013; Rakimov, 2004; Ramon, 2006). The published research on the use of nasally restricted breathing during exercise is limited, however the following observations have been made. The vast majority of individuals appear to breathe through the mouth during intensive exercise (Veli, 1983). Most individuals will spontaneously switch from predominately nasal breathing to predominately oral breathing or oronasal breathing at some point during a graded exercise test, with a ventilation rate of approximately 40 liters per minute as the upper threshold for nasally restricted breathing (Saibene, et al., 1978). This switching point has been theorized to be related to the increased work of breathing (Fregosi & Lansing, 1995) or alternatively as an indirect effect of hypoventilation (Saibene, et al., 1978). A theoretical case can also be made that oral breathing during heavy exercise may precipitate the development of exercise induced bronchospasm (EIB) in athletes (Carlsen, 2012; Fitch, 2012; Price et al., 2013),

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and that the incidence of EIB is increased by those participating in competitive endurance sports (Rundell & Jenkinson, 2002). However, two studies strongly suggest that breathing in a nasally restricted manner will eliminate the EIB response in asthmatic patients at lower levels of exercise (Mangla & Menon, 1981; Shturmman-Ellstein et al., 1978), and nasal breathing has also been suggested as a possible strategy to reduce the occurrence of EIB in otherwise healthy athletes (Anderson & Kippelen, 2012).

In support of the possibility of using a nasally restricted breathing approach as a practical intervention, a recent study examining nasally restricted versus orally restricted and oronasal breathing in normal subjects (LaComb et al., 2017) suggests that healthy individuals can breathe entirely nasally at the lower levels of work necessary to improve aerobic fitness in healthy normal populations without any specific adaptation to the process. A second study from the same laboratory (Recinto et al., 2017) examined the effect of nasal breathing on maximal anaerobic work in active healthy students using a Wingate protocol and found no reduction in the peak work achieved. However, the only currently published study examining the ability of healthy normal subjects to complete maximal aerobic work while breathing in a nasally restricted manner demonstrated a significant reduction in both $VO2_{max}$ and the peak work accomplished in the nasal breathing condition in comparison to the oral and oronasal conditions (Morton et al., 1995). The last finding is strongly discouraging to most sport scientists, coaches and athletes who might consider adopting a nasally restricted breathing strategy, as it suggests that peak work capacity will be reduced and training intensity impaired. A recent article addressing various methods for preventing the development of EIB in elite athletes strongly suggests that a nasal breathing approach is untenable due to the previously described upper limits of ventilation at which previous research subjects switched to oral breathing (Fitch et al., 2012). Recently however, we published a case study design (Hostetter et all., 2016) supporting the claim of a highly trained triathlete that, following a 6 month training period spent using nasally restricted breathing, he was able race and train at all levels of running intensity while breathing only nasally without loss in performance ability or undue air hunger, as a means of eliminating his own EIB problems. Consequently, the purpose of this study was to extend those findings to determine if recreational runners, following an extended period of self-selected adaptation to nasally restricted breathing, can complete a maximal GXT and high level (85% of maximal velocity) steady state protocol without loss in VO_2max, peak running velocity or physiological economy.

METHODS

Subjects

The subjects were 10 mixed gender (5 males, 5 females) recreational runners who met inclusion criteria which required them to have utilized a nasally restricted breathing pattern during all training and racing for a minimum of 6 months. They were required to be in a good state of health and willing to maintain constant training conditions during the course of the study. The subjects were recruited from the Pueblo, Colorado community via flyer, internet postings and word of mouth. The subjects then signed an informed consent approved by the CSU-Pueblo Institutional Review Board, completed the American College of Sports Medicine screening procedure prior to participation (23), and were all assigned a low risk. Subject demographics by gender appear in Table 1, 3.1 in Results.

Study Design

The study design consisted of a repeated measures comparison of 10 participants across two conditions (nasally restricted versus orally restricted breathing) in randomized testing order, following a familiarization trial. The study was approved by the Institutional Review Board at Colorado State University – Pueblo and conducted there at an elevation of 1450 meters above sea level over a 2.5 year period.

Procedures

Upon arrival to the laboratory for the first test session, participants were weighed using a balance beam scale and had their height measured using a stadiometer (Detecto 439 Eye Level Beam Physician Scale, Detecto Scale Company, Webb City, MO). Upon returning for subsequent trials they were re-weighed in the same manner. In each trial, the participants first completed the same individualized graded exercise test (GXT) protocol designed to elicit a maximum workload and oxygen uptake within six to ten minutes on a motorized treadmill (TRUE Commercial Series 8.0 Treadmill, True Fitness, St. Louis, Missouri, USA.). The starting velocity was determined from the most recent performance data each participant was able to report. The protocol increased workload by 0.3 mph every 30 seconds until the subject reached voluntary termination. The time from the beginning of the protocol until volitional termination was recorded and is reported in seconds as GXT Time to Exhaustion (GXT TE). The ramping approach allowed for greater resolution at the end point in determining differences in run performance across conditions. Ten minutes after the maximal protocol the subject completed a six minute steady state protocol (SS85) at 85% of the maximal velocity achieved in their familiarization protocol and then used in both subsequent experimental trials. This protocol was designed to allow the subject to work at an achievable high level pace over a full six minutes whereby they would reach steady state values for the

Table 1. Participant descriptive by gender

Variable (M±s)	Males (n=5)	Females (n=5)
Age (yr)	34.8±15.64	23.2±3.27
Running (yr)	18.4±12.30	6.1±5.38
Nasal breathing (yr)	5.75±3.36	3.25±3.5
Mass (kg)	71.09±5.32	58.09±3.98
Height (m)	1.81±0.07	1.66±0.08
Body mass index (kg/m^2)	21.60±1.95	21.04±2.04
VO_2 max (ml/kg/min)	48.14±5.19	37.58±4.41

various cardiorespiratory measures by the final two minutes. The oral condition was created by having the subject wear a swimming nose clip (Speedo Profile Nose Clip, Speedo, New York, NY, USA) underneath a full face style mask (VacuMed Full Face Ventilation Mask,-R113485- R113489, VacuMed, Ventura, CA, USA). The nasal condition was created by using the same mask with the mouth taped shut and a nasal splint placed on the nose to offset the slight pressure effect created by the mask on the nasal flares. Metabolic functions were measured using a metabolic cart (Medgraphics Ultima PFX, MGC Diagnostics Corporation, Saint Paul, MN, USA). Peak heart rate (HR_{peak}) was measured at volitional termination of the GXT protocol and steady state heart rate (HR_{SS}) was measured as an average during the final two minutes of the SS85 using a heart rate monitor (Polar FT1, Polar Electro Inc., Lake Success, NY, USA). Blood lactate concentrations were measured immediately post GXT (LA_{peak}) and again post SS85 (LA_{ss}) using a validated (Pyne et al., 2000) lactate meter (Lactate Pro LT-1710, ARKRAY USA, Minneapolis, MN, USA). The complete testing procedure was performed on successive weeks for familiarization first and then randomly following for both nasal and oral breathing conditions. The trials were conducted at the same time of day one week apart over three successive weeks. The subjects were blinded as to work output and physiological responses throughout the trials. The subjects verbally reported completing similar training volume, intensity and microcycle periodization in the weeks prior to each testing session and the testing was scheduled at the same time and day on subsequent weeks. Subjects were requested to maintain normal hydration and dietary intake during the course of the study, as well as to refrain from entering races.

During the GXT protocols, individual subject values for maximal oxygen consumption (VO_2max) and carbon dioxide production (VCO_2max), ventilation (VE), ventilatory equivalents for VO_2 (VE/VO_2) and CO_2 (VE/VCO_2), respiratory rate (RR), tidal volume (V_T), end tidal pulmonary partial pressure for oxygen (PET_{O2}) and carbon dioxide (PET_{CO2}), the fraction of expired oxygen (FE_{O2}) and carbon dioxide (FE_{CO2}) and the respiratory exchange ratio (RER), were obtained from 30 second averages of breath by breath data derived from the metabolic cart at VO_2max. The subject's maximal level of exertion reached in each GXT protocol was examined by recording the original Borg scale (6-20) rating of perceived exertion (RPE) reached after each subject self-terminated the protocol; by measuring the maximal 30 second average RER reached in the protocol; and by evaluating the final several 30 second average measurements of VO_2 for leveling or dropping prior to each subject's volitional termination of the maximal protocol. During the SS85 protocols the last two minutes of data were averaged for the same metabolic variables to produce each subject value with the VO_2 measures interpreted as measure of physiological economy at steady state (VO_{2ss}).

Statistical Analysis

Data analysis was completed using a spreadsheet (Microsoft EXCEL - Version 2013, Microsoft Corporation, Redmond, Washington). The mean and standard deviation were calculated and reported for the participant's demographic variables by gender. Means and standard errors were calculated and reported for the experimental measures. Student's paired samples t tests were used to analyze differences in the mean scores of the dependent variables between experimental trials. Statistical significance was established at $p < 0.05$. Effect sizes were calculated using the formula ($t/\sqrt{n}$) and reported as Cohen's d values. Moderate effects were interpreted as $d = 0.50 – 0.80$ and large effects were interpreted when $d > 0.80$. The small sample size (n=10) resulted from the difficulty in identifying participants who met the highly selective entry criteria described previously.

RESULTS

Subject Descriptives

The subjects (N=10) consisted of 5 female and 5 male recreational runners with diverse abilities and physical characteristics as seen in Table 1.

Maximal GXT Results

In the maximal GXT trials the subjects exhibited no significant mean difference in GXT TVE, VO_2max or $LA_{peak.}$ All subjects reported an RPE of 20 following each GXT. In addition, there were no significant differences in RER, or HR_{peak} between trials. However, in the nasally restricted breathing condition the subjects demonstrated a significantly lower VE/VO_2 and VE/VCO_2 at VO_2max, with large and moderate effect sizes respectively. In addition, the nasal breathing condition produced a significantly lower maximal RR, VE, FE_{02} and PET_{O2}, with large effect sizes, along with a significantly higher FE_{CO2} and PET_{CO2} with large and moderate effect sizes respectively, and no significant difference in V_T. The subjects also demonstrated a significantly lower VCO_2max with a moderate effect size during nasal breathing as well. Complete data may be observed in Table 2.

Steady State Results

During the SS85 trials the subjects exhibited no significant difference in LA, RER, RPE or HR between trials. However, in the nasally restricted breathing condition they again demonstrated a significantly lower mean VE/VO_2 and VE/VCO_2, with large effect sizes, as well as a significantly lower $VO2_{ss}$.

In addition, the nasal breathing condition during steady state work produced a significantly lower RR, VE, FE_{O2} and PET_{O2}, with large effect sizes, along with a significantly higher PET_{CO2}, with a large effect size, and no significant difference in V_T, FE_{CO2} or VCO_2. Complete data may be observed in Table 3.

DISCUSSION

This study is the first to examine the effect of prior training using a nasally restricted breathing approach on running economy, the ability to produce peak work, and the ability

Table 2. Effect of breathing route on performance and cardiorespiratory variables at VO_{2max} in the GXT (n=10)

Variable	**Mean±standard error**		**p-value *significant at 0.05**	**Effect size (d) *moderate ** large**
	Nasal condition	**Oral condition**		
GXT TE (s)	428±24	421±18	0.74	0.11
VO_2 max (L/min)	2.55±0.25	2.75±0.25	0.09	0.60*
VCO_2 max (L/min)	3.19±0.36	3.55±0.33	0.02*	0.93**
LA_{peak} (mg/dl)	7.20±0.76	7.03±0.76	0.74	0.11
RER	1.31±0.06	1.28±0.03	0.53	0.21
RR (bpm)	39.20±2.13	49.40±2.53	0.008*	1.06**
HR_{peak} (bpm)	180.50±3.92	185.40±3.57	0.16	0.48
RPE (Borg 6-20)	20.00	20.00	n/a	n/a
VE (L/min)	90.50±9.92	117.76±12.73	0.001*	1.42**
V_T (L/min)	2.33±0.21	2.35±0.19	0.812	0.08
FE_{O2} (%)	16.28±0.15	16.89±0.16	0.002*	1.35**
PET_{O2} (mm/hg)	85.60±1.11	89.70±1.21	0.007*	1.07**
VE/VO_2	35.20±1.34	41.30±1.59	0.002*	1.35**
FE_{CO2} (%)	7.67±0.24	6.92±0.28	0.028*	0.82**
PET_{CO2} (mm/hg)	44.70±1.55	40.20±1.46	0.035*	0.78*
VE/VCO_2	29.40±1.33	32.80±1.13	0.043*	0.74*

Table 3. Effect of breathing route on cardiorespiratory variables at 85% of maximal GXT velocity for six minutes at steady state (n=10)

Variable	**Mean±standard error**		**p-value *significant at 0.05**	**Effect size (d) *moderate ** large**
	Nasal condition	**Oral condition**		
VO_{2ss} (L/min)	2.64±0.27	2.76±0.25	0.05*	0.71*
VCO_{2ss} (L/min)	2.98±0.31	3.10±0.24	0.40	0.28
LA_{ss} (mg/dl)	9.05±0.88	7.92±0.98	0.11	0.57*
RER	1.19±0.04	1.11±0.03	0.13	0.53*
RR (bpm)	36.45±1.78	43.28±2.27	0.01*	0.99**
HR (bpm)	182.70±4.39	181.20±5.27	0.27	0.37
RPE (Borg 6-20)	14.40±0.65	15.10±0.38	0.24	0.40
VE (L/min)	84.41±8.48	102.14±8.22	0.0001*	1.94**
V_T (L/min)	2.32±0.19	2.39±0.18	0.53	0.20
FE_{O2} (%)	16.07±0.12	16.55±0.12	0.004*	1.19**
PET_{O2} (mm/hg)	85.05±0.80	88.25±1.06	0.03*	0.84**
VE/VO_2	32.43±0.77	36.70±1.03	0.002*	1.40**
FE_{CO2} (%)	7.52±0.29	6.96±0.94	0.13	0.52*
PET_{CO2} (mm/hg)	44.63±1.17	40.20±1.46	0.01*	0.94**
VE/VCO_2	28.47±0.68	32.92±0.92	0.002*	1.37**

maintain a high aerobic capacity while breathing nasally versus orally. In the only previously published study addressing the effect of nasally restricted versus orally restricted breathing on VO_2max and peak work, both were substantially reduced in the nasally restricted breathing condition (Morton et al., 1995). However, the participants in that study were normal healthy volunteers who had made no specific attempt to utilize a nasally restricted breathing approach prior to the study. In our study of self-selected nasal breathers, the participants had specifically chosen to utilize a nasally restricted breathing pattern over a minimum of 6 months prior to their inclusion in the study. Subsequently, these participants were able to achieve the same peak work and maximal oxygen consumption in a GXT while breathing nasally that they achieved while breathing orally. As in the previously mentioned Morton et al. study (Morton et al., 1995), our participants exhibited a significantly reduced RR and VE at VO_{2max} in the nasal breathing condition. On average, VE was reduced by 22%. However, unlike the previous study, they were still able achieve adequate oxygenation in this condition and continue to increase work to levels as high as in the oral breathing condition with no significant difference in anaerobic energy contribution. By contrast, Morton's participants experienced a 35% reduction in maximal VE, a 10.2% reduction in VO_2max, and an 8.4% reduction in their GXT TE (Morton et al., 1995). These differences in results between studies strongly suggest that our study's subjects achieved an adaptation as a result of their extended time spent using nasally restricted breathing. This study's subjects achieved adequate oxygenation in spite of a reduced ventilation while breathing nasally by increasing their total oxygen diffusion breath to breath. This is evidenced by the decreased PET_{O2} and FE_{O2} in their expired air at VO_{2max} at the same V_T. Assuming the concentration of oxygen in the ambient air is constant, by inhaling and exhaling the same volume of air (V_T) with each breath and achieving a lower fraction of oxygen at the end of each exhalation (FE_{O2}), the partial pressure of oxygen was reduced at the end of each exhalation (PET_{O2}) indicating that a larger volume of oxygen was removed during nasal breathing. This phenomenon is very likely the direct result of the lower RR necessitated by breathing exclusively through the nasal passage, thereby allowing greater time for diffusion with each breath, and has been observed in other studies examining nasal breathing during exercise (LaComb et al 2017; Morton et al., 1995). In support of this hypothesis, Nalbandian, et al. (Nalbandian, et al., 2017) demonstrated a similar outcome by reducing RR without changing the breathing route during cycling. In their study, peak work and VO_2max were similarly maintained across three RRs of 30, 45 and 60 breaths per minute.

However, the participants in this study also demonstrated an increased flux of CO_2 breath to breath during nasal breathing as established by their increased PET_{CO2} and FE_{CO2} at the same V_T at both VO_2max and during steady state running. This is significant because the available resting state evidence suggests that an increase in PET_{CO2} is associated with increased air hunger (Banzett et al., 1996). In addition, nasal breathing at rest also increases PET_{CO2} (Tanaka et al., 1988) so this effect during exercise is not surprising. This may be the mechanism by which those not adapted to nasally restricted breathing during exercise experience an unacceptable sensation of air hunger at some level of intensity, causing them to switch over to an oral breathing pattern at a relatively low ventilation rate, thereby reducing PET_{CO2} and air hunger for a given level of exertion. In addition, experimental resting data suggests that sustained exposure to breathing conditions that increase PET_{CO2} and air hunger over normal also results in a loss of air hunger over time (Bloch-Salisbury et all., 1996), very likely as a result of down regulation of the receptor response to the increased flux of CO_2 breath to breath. Although previous work suggests that the mechanism driving the spontaneous switch to oral breathing patterns during increasing exercise intensities is related to a disproportionate increase in nasal resistance associated with increased turbulence (Fregosi & Lansing, 1995), our study suggests that this may manifest itself via the volume of breath to breath CO_2 flux and its effect on the sensation of airlessness. In support of this possible mechanism are numerous anecdotal accounts of experiencing a sense of air hunger upon initially attempting to exercise while breathing in a nasally restricted manner and the gradual loss of that sensation in those who persist (Davidson, 2012; Fields, 2004; Hostetter et al., 2016; Smith, 2013). This phenomenon may also represent the primary mechanism by which athletes are able to gradually adapt to a nasally restricted breathing pattern during exercise and avoid switching to oral breathing as work intensity is increased. In light of this interpretation, it is also not surprising that few individuals choose spontaneously to breathe in a nasally restricted manner during heavy exercise (Saibene et al., 1978). In addition, the data from our study, along with the Nalbandian study data (Nalbandian et al., 2017) suggests that total ventilation is not a primary limiter to oxygenation and peak work regardless of breathing route.

During the SS85 the participants exhibited the same results as in the GXT, suggesting that they were not limited in the sustained work they could achieve while breathing nasally. Interestingly, this protocol produced even higher VE and VO_2 values than the preceding GXT, possibly as a result of the increase in total body cooling necessary to sustain high level work on a treadmill. However, the HR, RPE and LA were not significantly different in the two breathing conditions. In addition, VE, VO2, VE/VO_2, and VE/VCO_2 were all significantly lower in the nasally restricted breathing condition, further supporting the case that nasal breathing produces superior ventilatory efficiency and a reduced oxygen cost in comparison to oral breathing during exercise as also observed in other published studies examining a comparison between nasal and oral breathing routes (Hostetter et al., 2016; LaComb et al., 2017; Morton et al., 1995; Recinto et al., 2017).

This study produced a significantly lower VO_2 at steady state while breathing nasally which is similar to the findings of LaComb (LaComb et al., 2017) and Morton (Morton et al., 1995). However, in contrast with the LaComb et al. interpretation that the lower VO_2 they measured during nasal only breathing represented an inefficiency (LaComb et al., 2017), an alternative explanation is that the nasal breathing condition requires less metabolic energy production to produce the same external work (lower VO_2, VCO_2 and the same RER, RPE and LA while breathing nasally) and is more physiologically economic as a result. This seems reasonable in light of the consistent observation across our participants and across studies (Hostetter et al., 2016; LaComb et al., 2017; Morton et al., 1995; Recinto et al., 2017) that nasal breathing reduces total VE at a given level of work by approximately 22%. As VE is produced by muscular work, a reduced VE logically reflects a reduced work of breathing which might result in a reduced gross metabolic cost during exercise, further resulting in a small improvement in gross economy. This concept has been demonstrated theoretically by measuring the independent cost of high ventilation rate breathing as a percentage of overall metabolic cost of exercise (Aaron et al., 1992) and by demonstrating that increases and decreases in overall oxygen costs during cycling can be produced by artificially increasing and decreasing the work of breathing respectively, while keeping exercise work constant (Harms, et al., 2000). In addition, other studies have demonstrated that potential improvements in performance occur through the application of specific respiratory muscle training which results in improved ventilatory efficiency (HanjGhanbari et al., 2013; Sheel, 2002).

In this study, the mean reduction in oxygen consumption during nasal breathing while running at 85% of the velocity at VO_2max was approximately 4%, which contrasts with the findings of LaComb who reported greater reductions of 8-10% at lower relative exercise intensities while breathing nasally during cycling (LaComb et al., 2017). However, our findings align with the Morton study, which found a 5% reduction in oxygen consumption in their participants while running in a steady state trial at 12 kilometers per hour (Morton et al., 1995). Further, these improvements in economy can be considered comparable to those achieved by an intervention using explosive weight training in highly competitive collegiate runners which resulted in an approximately 5-6% reduction in oxygen cost and a parallel improvement in running performance of approximately 3% (Paavolainen et al., 1999). Should this improvement in physiological economy prove to be the case in future studies, nasally restricted breathing during exercise might be viewed as not only a means of preventing/treating EIB, but also as a potential way to improve performance in endurance events whereby economy is a critical performance factor (Joyner & Coyle, 2008).

The primary limitation in performing this study was the difficulty in finding subjects who met the inclusion criteria of running and racing using a nasally restricted breathing approach over an extended period as this practice is very rare (Veli, 1983). Consequently, our low subject number was achieved only after 2.5 years spent recruiting and testing subjects. Another reasonable concern in regards to our methodology was that our participants might, by self-selecting a nasally restricted breathing pattern prior to the study, logically hold a bias predisposing them to limit their peak work in the oral breathing condition to validate their own beliefs. We attempted to reduce the possible influence of such bias by blinding the participants as to output during the testing, by controlling the use of nasal versus oral breathing through the test apparatus and by using short 30 second stages in the GXT protocol making the tracking of stages difficult. Further, the participants reached a similarly high RER in each condition, as well as having no significant differences in maximal HR, RPE or LA. This strongly suggests that the subjects made a maximal effort in both breathing conditions. It should be noted that our decision to use a nasal strip in the nasal breathing condition may have altered our results somewhat, as such devices have been shown to increase maximal inspiratory flow while breathing nasally (Di Somma, 1999), increase the volitional switching point from nasal to oronasal breathing during incremental exercise (Seto-Poon et al., 1999), and increase time to exhaustion at submaximal work rates while breathing in a nasally restricted state (Tong et al., 2001). Our choice to use the nasal strips was made following pilot testing, as we found that any pressure created by the face mask on the nasal flares drastically reduced some of our participant's ability to breathe nasally during testing. In addition, because we were not able to collect data on VO_2max prior to the participant's self-selected nasally restricted breathing process, we cannot determine what effect, if any, their choice may have had on their prior aerobic capacities. Further, our study did not include a measure of the work outcomes while breathing in an oronasal condition. However, Morton et al. did include an oronasal condition in their study and found no significant difference in VO_2max or VEmax in comparison to the oral only condition (Morton et al., 1995), strongly suggesting that there is no meaningful contribution of nasal breathing while breathing oronasally at high exercise intensities. Finally, our mixed gender sample (5 males, 5 females) suggested the use of a factorial analysis to examine the possible effect of gender. However, we employed the use of t-tests due to prior evidence that gender has no effect on the response of cardiorespiratory variables to the nasal versus oral breathing intervention (LaComb et al., 2017). In addition, our low participant number was insufficient to produce adequate power in a factorial analysis. While our study confirms the assumption that nasally restricted breathing results in a lower peak VE, it further demonstrates that VO_2max and peak work output can be maintained following a period of training using nasally restricted breathing. One possible explanation for this phenomenon is that individuals who choose to do so adapt to nasally restricted breathing by increasing their tolerance to CO_2 flux breath to breath before experiencing air hunger. These findings suggest that it may be beneficial to advocate that exercisers, and particularly endurance athletes, attempt to adapt to a nasally restricted breathing pattern as a means of maintaining respiratory health and improving performance. Beyond this most basic implication, it will be important for future research to further establish that such an adaptation occurs, as well as to investigate the validity of other suggested benefits of using a nasally restricted breathing pattern during exercise. Possible additional benefits of breathing in a nasally restricted manner during exercise that should be explored include increased parasympathetic influence and relaxation, increased pulmonary and cardiac blood flow, and a reduced exposure to airborne particulate matter and pathogens.

CONCLUSION

This study supports the ability of recreational runners to utilize a nasally restricted breathing pattern at all levels of running intensity without loss in VO_2max or GXT TE and with superior PE and ventilatory efficiency, following an extended training period using this practice. These findings suggest that a nasally restricted breathing pattern may be successfully utilized by recreational runners as means of improving health, without sacrificing performance ability, following an extended period of time spent adapting to this practice.

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