Journal of Sports Research
2020 Vol. 7, No. 1, pp. 1-10
ISSN(e): 2410-6534
ISSN(p): 2413-8436
DOI: 10.18488/journal.90.2020.71.1.10

THE EFFECT OF NASAL BREATHING VERSUS ORAL AND ORONASAL BREATHING DURING EXERCISE: A REVIEW

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Article History
Received: 3 October 2019
Revised: 6 November 2019
Accepted: 10 December 2019
Published: 13 January 2020

Keywords
Bronchoconstriction
VO2max
Ventilation
Economy
Nitric oxide
EIB.

ABSTRACT

Historically, exercise physiologists believed that humans produce the greatest physical work by breathing orally. Recently, however, authors from the fields of medicine, health and exercise have described the potential benefits of limiting breathing to the nasal airway during exercise, but actual effects have been infrequently examined in the literature. The purpose of this review was to examine the effects of nasal breathing as compared to oral and oronasal breathing during exercise from the available peer reviewed literature. Studies were identified using six search terms in Google Scholar. All related descriptive studies were included as were experimental studies with the following three criteria: a repeated measures design, randomization of condition order, and valid measurement techniques. The search results yielded a total of 30 published articles as of August, 2019, and both descriptive (n=7) and experimental studies (n=23) were reviewed for the effects of nasal breathing on exercise. The evidence suggests that exclusively nasal breathing is feasible for most people at moderate levels of aerobic exercise without specific adaptation, and that this breathing approach may also be achieved during heavy and maximal levels of aerobic exercise following a sustained period of use. Benefits of nasal breathing include a reduction in exercise induced bronchoconstriction, improved ventilatory efficiency, and lower physiological economy for a given level or work. The use of nasal dilation devices can increase the work intensity achieved during exercise while breathing nasally. Further research on the effects of nasal breathing during exercise is needed.

Contribution/Originality: The paper contributes the first logical analysis of the scientific literature addressing the use of nasal versus oral or oronasal breathing during exercise.

1. INTRODUCTION

The study of energy metabolism via indirect calorimetry in modern exercise physiology has long been predicated on the assumption that humans will be able to produce the greatest physical work by breathing orally. The best evidence for proving this assumption is in the Hans Rudolph Valve and mouthpiece Figure 1 a breathing apparatus historically used by exercise physiologists to measure expired air in research studies. Its original design allowed for breathing only from the mouth with the nasal passage clipped shut. This approach to the measurement of indirect calorimetry reflected the basic assumption that oral breathing would allow for greater maximal ventilation and thereby greater oxygenation during exercise.

Figure-1. The original hans rudolph valve and mouthpiece.

However, over the years a small number of research studies have examined the effect of breathing nasally versus orally and recently there has been a renewed scientific interest in this topic. This interest may have resulted from a growing number of internet bloggers and/or the book, the Oxygen Advantage (McKeown, 2016) which strongly advocates for a nasally restricted breathing approach during exercise as a means of reducing various health problems associated with exercise and improving exercise performance.

2. MATERIALS AND METHODS

In this short review, we have systematically queried and reviewed research which addressed the effect of nasal versus oral and oronasal breathing in conjunction with exercise. We utilized the database Google Scholar and the search terms "effect", "nasal", "oral", "oronasal", "breathing" and "exercise" to identify potential articles for inclusion in the review. The search was renewed periodically from May through August of 2019. Descriptive studies were included if the primary focus of the research was related to the use of one or more breathing pathways during exercise, and if the article was published in a peer reviewed journal. In order to achieve a high quality of experimental evidence for the review, we only included experimental research papers that met the following three criteria: 1) use of repeated measures design used to allow for direct comparisons across breathing conditions within subjects, 2) the use of randomization in the order of treatment versus control condition and 3) the application of valid measurement techniques in the research study. After identifying the articles for review, they were organized based on descriptive and experimental methodology as well as by the type of airway (s) focused on in the research, and analyzed for the effects of nasal breathing compared to oral and oronasal.

3. RESULTS

In total, 23 experimental studies and 7 descriptive studies met inclusion criteria and were included in this review.

After analyzing the articles for the effects of nasal breathing on exercise, other than general contributions of nasal breathing during exercise, seven categories of topics emerged and are included in the forthcoming discussion.

4. DISCUSSION

4.1. General Contributions of Nasal Breathing during Exercise

During rest and very light cycling exercise of less than 60% of maximal work capacity, or approximately 50 watts of power, the nasal contribution to ventilation is pronounced, with the relative oral contributions increasing substantially as exercise intensity is increased within this range from rest . However, the relative contribution of each airway varies widely among individuals, and differs among people of differing races and genders (Bennett *et al.*, 2003). Children appear to adopt an oronasal breathing pattern more frequently at rest and earlier in progressive exercise (Becquemin *et al.*, 1999) potentially increasing their exposure to airborne contaminants.

As cycling exercise intensity is further increased a switch to a predominately orally dominated breathing pattern occurs in most individuals at a mean ventilation of approximately 11 liters/min and power output of 105 watts (Niinimaa *et al.*, 1980). The maximal ventilation seen in subjects achieved prior to switching is approximately 40 liters/min while wearing a face mask and increases slightly to approximately 44 liters/min without the mask (Saibene *et al.*, 1978). Both studies demonstrate the considerable inter-individual variability that exists in breathing approach and the individual switching point as well.

Both non-empirical observation (Saibene *et al.*, 1978) and a single descriptive paper derived from observations of a ten kilometer running race (Niinimaa, 1983) suggest that the vast majority of exercisers breathe oronasally, with the mouth open continuously, during intensive exercise. This breathing approach can be a non-deliberate choice and the natural default during heavy exercise in most people.

However, the seminal study comparing the effect of nasal, oral and oronasal breathing during running on VO2 max (Morton *et al.*, 1995) illustrated that any additional nasal contribution during oronasal breathing produces no effect on maximal oxygen uptake beyond that achievable by oral breathing alone. Another study examining the effect of a nose clip to create an oral breathing condition versus an oronasal breathing condition also found no effect of using the clip on high intensity shuttle running performance (Meir *et al.*, 2014) suggesting no benefit of oronasal breathing versus orally restricted breathing in this condition.

As a result, the available evidence suggests that restricted oral breathing and oronasal breathing are effectively the same in their ability to increase ventilation and support muscle oxygenation during heavy exercise, with any nasal contribution being negligible. This observation also offers a hypothesis as to why research looking at the use of nasal splints during normal oronasal exercise breathing conditions has found no significant effect of doing so (Chinevere *et al.*, 1999). When breathing orally or oronasally, widening the nasal passage is not likely to be helpful if the nasal component of total ventilation under high workloads is not significant.

Finally, during exercise nasal resistance to air flow falls, regardless of the airway used for breathing (Saketkhoo *et al.*, 1979; Forsyth *et al.*, 1983; Olson and Strohl, 1987) suggesting that increased airway resistance by itself is not a likely to be the sole cause of the switch to an orally dominated breathing pattern during heavy exercise seen in most subjects. Saibene *et al.* (1978) also found no relationship between flow resistance and the onset of oronasal breathing and further suggested that the switch is possibly related to the conditions of relative hypoventilation while breathing nasally (Saibene *et al.*, 1978) while Niinimaa *et al.* (1980) speculated that the switch was related to perceptions of increase effort during nasal breathing (Niinimaa *et al.*, 1980). In contrast, Fregosi and Lansing (Fregosi and Lansing, 1995) found an association between an increase in turbulent airflow in the nasal passage and an exponential rise in total ventilation, suggesting the onset of oronasal breathing was a possible strategy to reduce the nasal turbulence resulting in a reduction in total airflow resistance.

4.2. Effects of Nasal versus Oral Breathing on Filtering

One commonly proposed rationale for utilizing a nasal breathing approach during exercise involves the potential to improve the filtering of airborne particles and/or gases during the increased ventilatory rates seen during exercise. Unfortunately, only limited work has been done in this area. In 2005, Bennet and Zeman found that race has a small effect on filtering efficiency with African Americans subjects demonstrating lower filtering efficiency in comparison to Caucasian subjects for both 1 and 2 um mass particles during light exercise while breathing nasally, an effect the authors attributed to differences in nasal resistance and nostril shape. However, they did not report significant differences in particle filtration efficiency between nasal and oral breathing conditions. More than a decade earlier, Hynes found that nasal versus oral breathing has no effect on subsequent lung spirometry or symptomology following exposure to increased ozone (0.4 ppm O3) during 30 minutes of continuous moderate exercise in both breathing conditions (Hynes *et al.*, 1988). Consequently, the limited available evidence does not sufficiently support the hypothesis that nasal breathing during exercise will improve the filtering of airborne particles or gases in comparison to oral breathing.

4.3. Effects of Nasal versus Oral Breathing on Nitric Oxide Production

Another widely hypothesized potential benefit of breathing in a nasally restricted manner during exercise is the potential for increased release of nitric oxide (NO) from the nasal cavity and its subsequent effects on vasodilation and red blood cell (RBC) deformability in the cardiovascular system. The existing research (Phillips, 1996; Yasuda *et al.*, 1997; Bizjak *et al.*, 2019) suggests that exercise increases exhaled NO (which suggests greater NO is produced by the tissues) and that occlusion of the nasal passage while breathing orally reduces the production overall (Phillips, 1996). Further, Phillips concluded that the increase in exhaled nitric oxide was more closely related to increased ventilation than increased blood flow.

In a direct manipulation of nasal versus oral breathing conditions during submaximal cycling exercise, Yasuda *et al.* (1997) demonstrated both an increase in exhaled NO as a result of exercise, as well as a greater NO production overall in the nasal breathing condition (1997), a finding also seen by Bizjak *et al.* (2019). However, the two breathing conditions in the Phillips study had no effect on cardiorespiratory responses, although only a limited number of basic variables were measured.

Finally, Bizjak *et al.* (2019) recently examined the effect of customary oronasal breathing, oronasal breathing with an internal nasal stent, and nasal breathing on pre and post NO production and red blood cell deformability and found decreased red blood cell deformability during the nasal breathing condition, although they also found no differences in plasma NO concentrations (2019). Greater red blood cell deformability is associated with improved blood flow, so this finding suggests that nasal breathing may have a negative impact on red blood cell flow.

Consequently, although the available evidence suggests that nasal breathing during exercise may offer the potential for increased nitric oxide release, the effect on downstream cardiorespiratory factors is still unclear and/or contradictory to the hypothesis that nasal breathing is beneficial. However, the research addressing this topic is also still very limited.

4.4. *Effects of Nasal versus Oral Breathing on Exercise Induced Bronchoconstriction*

Three older studies completed prior to 1982 illustrate the potentially beneficial effect of breathing in a nasally restricted manner versus breathing in an oral/oronasal manner on the occurrence of exercise induced bronchoconstriction (EIB) in asthmatic subjects with a previously identified EIB/asthma response when breathing normally (Shturman-Ellstein *et al.*, 1978; Mangla and Menon, 1981; Kirkpatrick *et al.*, 1982). In the Kirkpatrick study, sulfur dioxide gas was used to initiate and intensify the bronchoconstriction response during exercise, while the other two studies relied on the natural occurrence of EIB during exercise in asthmatics. In all three studies, the use of nasally restricted breathing, in comparison to orally restricted or oronasal breathing, reduced and/or eliminated the subject's post exercise EIB as measured by a fall in one second forced expiratory volume (FEV1) post exercise (1982). Consequently, it was concluded by all three researchers that the choice of airway (nasopharynx versus oropharynx) plays a significant role in the development and resolution of EIB.

4.5. *Effect of Nasal versus Oral Breathing on Submaximal Exercise*

Most early studies of the nasal versus oral breathing effect on exercise have utilized subject populations who were not specifically adapted to nasally restricted breathing, a detail which may have greatly influenced how the outcomes were interpreted (Morton *et al.*, 1995; Garner *et al.*, 2011; LaComb *et al.*, 2017). However, two more recent studies (Hostetter *et al.*, 2016; Dallam *et al.*, 2018) have examined this effect in subjects who had chosen of their own accord to adapt to a nasally restricted breathing pattern during exercise, and their results markedly shift the prevailing interpretation of the previous work. Both types of studies are addressed below.

Several studies directly examining the effect of nasal versus oral breathing on the ability to complete submaximal endurance exercise (up to 80% of VO2max) in subjects not specifically accustomed to nasally restricted breathing (Morton *et al.*, 1995; Garner *et al.*, 2011; LaComb *et al.*, 2017) suggest that healthy individuals can perform such work without any specific need for adaptation to breathing in a nasally restricted manner. This strongly suggests that a nasal breathing approach is potentially viable during submaximal exercise for a large proportion of the healthy population without specific need for adaptation.

During steady state submaximal exercise the available research consistently demonstrates that a nasally restricted breathing approach results in a lower respiration rate (RR), a lower ventilation (VE), a lower ventilatory equivalent for both oxygen (VE O2) and carbon dioxide (VE CO2), and a lower oxygen uptake (VO2) at a given steady state work level; a finding which seems to be universal among researchers examining this effect (Morton *et al.*, 1995; Garner *et al.*, 2011; Hostetter *et al.*, 2016; LaComb *et al.*, 2017; Dallam *et al.*, 2018). In addition, several of these researchers reported a decreased fraction of oxygen (FEO2) and/or end tidal pulmonary oxygen partial pressure (PETO2) and an increased fraction of carbon dioxide (FECO2) and/or increased end tidal carbon dioxide partial pressure (PETCO2) in the expired air of their subjects while breathing nasally at the same tidal volumes and workloads, suggesting that the slower respiration rate of the nasally restricted breathing approach results in greater diffusion of both oxygen and carbon dioxide breath to breath (Morton *et al.*, 1995; Hostetter *et al.*, 2016; LaComb *et al.*, 2017; Dallam *et al.*, 2018).

The lower VO2 seen during nasal breathing has been interpreted speculatively by some researchers as an indication that such an approach is less effective in oxygenating the body (Garner *et al.*, 2011; LaComb *et al.*, 2017). However, these studies did not include any measure of anaerobic energy production, which would logically increase if the lower VO2 resulted from a compromised oxygen uptake, so no real conclusion can be drawn in that regard.

However, the two most recent studies including a comparison of nasal versus oral breathing during submaximal running and performed in our laboratory (Hostetter *et al.*, 2016; Dallam *et al.*, 2018) examined this effect in subjects who chose to adopt a nasally restricted breathing pattern in training and racing for significant periods of time (> 6 months) prior to participating in the research. In addition, these studies examined anaerobic energy production through the measurement of blood lactate allowing for a clearer interpretation of relative aerobic versus anaerobic energy production. In these studies the decreased VO2 during submaximal work was accompanied by no increase in blood lactate or rating of perceived exertion, suggesting that oxygen uptake was not compromised in the nasal breathing condition. Consequently, we offered an alternative interpretation which is that the lower oxygen uptake seen during submaximal work while breathing nasally represents an improvement in physiological economy as a consequence of the improved ventilatory efficiency of this breathing approach in those experienced with the breathing approach (Hostetter *et al.*, 2016; Dallam *et al.*, 2018).

4.6. Effects Nasal versus Oral Breathing on Maximal Exercise

The seminal study performed by Morton et al. in 1995 on the effect of nasal versus oral versus oronasal breathing on maximal work and VO2max found that normal healthy not specifically adapted to nasal breathing subjects will experience a significant loss in both VO2max and peak work achieved in a maximal graded exercise protocol while breathing nasally (Morton *et al.*, 1995) The authors suggested this was primarily due to a large drop in peak ventilation of approximately 35% in the nasal breathing condition, although they also noted the significantly better ventilatory efficiency and relatively smaller drops in VO2max (~11%) and time to exhaustion (~8%)in their subjects at the peak workloads they achieved in the nasal breathing condition. These results supported the prevailing hypothesis that a nasal breathing approach is insufficient to support heavy exercise due to the inherent ventilation limitations. However, even Morton et al. questioned this conclusion in their paper as other published data suggested that ventilation is not a primary limiter to muscle oxygenation (1995).

More recently our research group published work examining the effect of nasal versus oral breathing on maximal exercise in an initial case study of a triathlete whose chose to adopt a nasally restricted breathing pattern to self-treat exercise induced bronchoconstriction (Hostetter *et al.*, 2016) and a group of recreational runners who chose to do the same (Dallam *et al.*, 2018). In these actively nasal breathing runners, we found that they were able to achieve the same peak work output and VO2max, without an increase in lactate, while breathing nasally as they were able to do while breathing orally. As in the Morton et al study, their peak ventilation was lower while breathing nasally (~25%) although not to the same degree as Morton's non-adapted subjects (~35%). We hypothesized that the peak work reduction seen in Morton subject's may have been due to air hunger limitations, the sensitivity to the increased end tidal CO2 necessitated by the lower respiratory frequency seen during nasal breathing. By contrast our subjects may have down regulated their sensitivity to end tidal CO2 allowing them to continue to further increase work and ventilation while breathing nasally to the level necessary to achieve the same VO2max and peak work achieved while breathing orally (Dallam *et al.*, 2018).

Further, all three studies suggest the mechanism by which a reduced peak ventilation can be overcome to allow for adequate oxygenation during high level work is the increased diffusion of oxygen with each breathe (Morton *et al.*, 1995; Hostetter *et al.*, 2016; Dallam *et al.*, 2018). This mechanism was illustrated by a decreased end tidal fraction of oxygen and pulmonary end tidal oxygen pressure at the same tidal volume while in the nasal breathing condition at a given work level in all three studies. This phenomenon may result directly from the reduced respiration rate seen when breathing nasally in comparison to breathing orally during exercise, which logically allows more time for diffusion.

However, the slower respiratory rate in nasal breathing also results in a higher end tidal carbon dioxide (CO2) fraction and pulmonary end tidal CO2 pressure as well, suggesting a greater diffusion of CO2 from the blood to the lung. We speculated that because increased end tidal CO2 has been previously associated with increased air hunger at rest and will down regulate with increased exposure at rest, that this may occur during exercise as well (Hostetter *et al.*, 2016; Dallam *et al.*, 2018) suggesting a possible mechanism by which nasal breathing is initially limiting to maximal exercise, as well as a means by which one might adapt to this breathing approach to remove such limitations. In addition, this proposed mechanism parallels the suggestions of both Saibene *et al.* (1978) and

Niinimaa (1983) that the nasal to oronasal switching point may be related to hypoventilation and an increased perception of effort respectively.

4.7. Effects of Nasal versus Oral Breathing on Supramaximal Anaerobic Work

A single study has been published looking at the effect of nasal versus oral breathing on the ability to perform workloads beyond those achievable at VO2max, whereby anaerobic metabolic processes dominate energy production (Recinto *et al.*, 2017). This study found no significant effect of breathing route on 30 second Wingate cycling protocol performance, a finding that logically reflects the idea that such very short maximal work is limited primarily by anaerobic energy mechanisms, whereby the route of ventilation may be inconsequential. They further demonstrated a smaller increase in ventilation while breathing nasally, as has been seen in all other studies examining nasal versus oral breathing during exercise (Recinto *et al.*, 2017). This finding suggests that a nasally restricted breathing approach may be possible for most healthy people when using short anaerobically dominated work such as weight training and sprinting without prior adaptation.

4.8. Effects of Dilator Devices on Nasal Breathing

In spite of the fact that nasal splints have been shown to have little or no effect on traditional oronasal breathing and performance (Chinevere *et al.*, 1999) several studies suggest that such devices are beneficial under the conditions of nasally restricted breathing during exercise (Petruson and Bjurö, 1990; Seto-Poon *et al.*, 1999; Gehring *et al.*, 2000; Tong *et al.*, 2001). These studies identified a small increase in nasal ventilation using the dilator strip which results from a reduced resistance to nasal flow (Gehring *et al.*, 2000) and allows for both an increased tolerance to a given level of submaximal work (Tong *et al.*, 2001) and a later switching point to oronasal breathing (Seto-Poon *et al.*, 1999).

Additionally, Petruson and Bjurö (1990) demonstrated a large increase (29%) in nasal flow using an internal nasal dilator (Nasovent™) which allowed non-adapted subjects to reach peak exercise workloads similar to those they could reach breathing oronasally (Petruson and Bjurö, 1990). The reported increase in peak ventilation in their study is similar to the reductions in peak ventilation found in the nasal only breathing condition in Morton et al. study looking at maximal work responses, so their finding suggests that initial limitations in exercise tolerance in a nasally restricted breathing condition may be largely overcome simply by using such a breathing device. They further identified a smaller increase in systolic pressure in the subjects when breathing nasally with the internal nasal dilating device.

Speculatively, the increase in nasal flow when using a dilating device may serve to lower end tidal CO2 and air hunger at a given work level, allowing for increased work tolerance in the nasally restricted breathing condition. In addition our studies using subjects previously adapted to nasally restricted breathing (Hostetter *et al.*, 2016; Dallam *et al.*, 2018) utilized nasal dilator strips during testing to offset the potentially inhibiting effect to the nasal flares created by a full face mask design, an outcome we experienced in pilot testing, and which severely compromised peak work capacity in the nasally restricted breathing condition. This effect may be further evidenced by the Saibene study which found a significantly greater ventilation at the nasal to oronasal switching point in their subjects when not wearing a full face mask (1978).

4.9. Methodological Limitations

The primary methodological limitation of this review is that a relatively small volume of controlled experiments have been conducted to date examining the direct effect of oral and oronasal breathing versus nasal breathing, consequently, many potential effects remain unexamined. However, the recent increase in interest in this topic may reflect new studies which address the primary limitation of a nasally restricted breathing approach, which is the effect of slower rates of respiration on peak ventilation and breath to breath CO_2 exchange and the resulting occurrence of air hunger and reduction in peak work capacity.

5. CONCLUSIONS AND RECOMMENDATIONS

In summary, while limited research exists examining the effect of nasal breathing during exercise in comparison to the more conventional oral and/or oronasal breathing approach, some evidence supports the idea that a nasally restricted breathing approach may be a feasible way to improve respiratory health during exercise, particularly in asthmatics with existing EIB. A significant body of evidence also unanimously illustrates the concept that nasal breathing results in better ventilatory efficiency than oral/oronasal breathing during exercise, which may also result in an improvement in physiological economy. Further, the available evidence suggests that most healthy individuals should be able to complete both moderate intensity aerobic exercise and/or short term anaerobic exercise in the nasal breathing condition without need to for specific adaptation. However, heavy and/or maximal aerobic exercise may require specific long term adaptation (> 6 months) to a nasal breathing approach to overcome initial limitations to peak VO_2 and work capacity. In addition, the use of a device designed to further open the nasal flares will increase ventilation in the nasal breathing condition and increase the peak workload which can be achieved prior to adaptation. Finally, new evidence is suggestive of the concept that the switch to oral/oronasal breathing during progressively increasing intensity exercise, as the well as the limits to the intensity of work that may be achieved while breathing nasally, may be a consequence of increased air hunger resulting from an increased PET CO_2, a limitation which can be overcome through adaptation resulting from the increased use of nasal breathing in practice.

Accordingly, our primary recommendation is that researchers continue to examine the viability and effects of using a nasal breathing approach during exercise. Specifically, we suggest the need for studies examining the adaptive process required to adapt to breathing in a nasally restricted manner during heavy exercise, as well as studies examining the effects nasal breathing during exercise has on performance outcomes, autonomic regulation, nitric oxide production, cardiac blood flow and the filtering of airborne particles and gases.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: Both authors contributed equally to the conception and design of the study.

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