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Review

Effects of Nasal and Oral Breathing on Respiratory Muscle and Brain Function: A Review

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Abstract

Nasal breathing (NB) and oral breathing (OB) are two modes of respiration, and the extent to which they affect respiratory muscles and brain function. The primary objective of this study was to explore the impact of NB versus OB on respiratory muscle and brain function. A literature review was conducted by searching the National Library of Medicine (PubMed) and Scopus databases from January 2000 and May 2024. One hundred twenty-six articles were retrieved from the databases searched, and at the end of the selection process, 11 articles were included in the present review. Most studies (91%) were experimental and had adult healthy volunteers; 64% of the included studies focused on the effects of NB and OB on brain function, while the remaining 36% focused on respiratory muscles. A total of 313 participants comprised the population, most of whom were women (63%). Although most studies were conducted on adults, a percentage of participants (15%) were children. NB and OB elicit different brain areas and heterogeneously influence respiratory muscle function. Knowledge of the underlying mechanisms could be beneficial for, for example, personalizing respiratory and manual techniques when rehabilitating individuals with neurological or respiratory impairments.

KEYWORDS: Brain, breathing mode, electroencephalography, electromyography, respiratory muscles

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INTRODUCTION

Respiration plays a crucial role in metabolism, providing oxygen for efficient physical and mental function. Nasal breathing (NB) is the commonly used mode of respiration and plays a significant role in the development of facial, oral, and respiratory muscles, as well as in the formation and physiological activity of facial bones.[1,2] Increased nasal resistance and conditions such as cold, nasal allergies, persistent rhinitis, and adenoid hypertrophy (producing airway blockage) disrupt the posterior oral seal with the soft palate and tongue, allowing air to flow into the oral cavity and causing the lips to open. It is possible for the NB to be replaced by the oral breathing (OB) in the absence of factors preventing air passage through the nasopharynx. In such cases, individuals frequently exhibit OB patterns that can result in a number of negative consequences, including headache, alterations in head position, fatigue, drowsiness, mouth-opening during sleep, snoring, nasal itching, saliva dripping onto the pillow, nocturnal dyspnea and nasal obstruction.[2-6] If the air breathed through the mouth is not filtered, humidified, and heated, this can result in decreased lung function and electromyography (EMG) activation of the respiratory muscles.[7] Previous evidence suggests that OB may be associated with an increased risk of impaired brain function related to low oxygen saturation in the human brain.[8,9] A study utilizing functional magnetic resonance imaging (fMRI) discovered that, in addition to impairments in working memory, olfactory memory, arithmetic abilities, and learning skills, individuals with OB exhibited a diminished blood oxygenation level-dependent signal in the hippocampus, brainstem, and cerebellum. Studies have found the achievements of academic skills in children using OB to be lower than those breathing via NB.[9-11] The impact of breathing mode on EMG activity

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of the respiratory muscles remains a topic of contention among researchers, with no consensus yet reached. Current evidence suggests that OB produces different brain activity than NB, but there is a lack of electroencephalographic (EEG) research on the relationship between cognitive ability and the breathing mode used.[10]

Aim

The present study aimed to investigate the effects of OB and NB on respiratory muscle and brain function.

Search Process

A literature review[12] was conducted by searching the National Library of Medicine (PubMed) and Scopus databases from January 2000 to May 2024. Two search strings, 'oral breathing' AND 'nasal breathing' AND 'EMG' and 'oral breathing' AND 'nasal breathing' AND 'EEG' were built, and an additional search was conducted on Google.

Two authors independently searched databases and assessed citations for inclusion, while a third author contributed to resolve disagreements over the appropriateness of the articles.

Duplicates were removed from the retrieved citations, and abstracts were evaluated for eligibility. The PRISMA guidelines were used as a guide.[13]

Inclusion and Exclusion Criteria

To be included in the study, research must focus on comparing NB and OB with EMG of respiratory muscles [upper trapezius (UT), sternocleidomastoid, and diaphragm] and reporting EEG activity and brain function.

There were no limits on age or gender, and only studies conducted in the English language were included.

Letters to the editor, conference proceedings, abstracts, and studies that did not describe NB or OB were excluded.

Data Analysis

The included citations were categorized based on their descriptive and experimental methodology and then analyzed. From the included articles, the first author's name, publication year, country where the study was conducted, study design, demographic characteristics of participants and their number, type of assessments, and main findings were retrieved and tabulated.

One hundred twenty-six articles were retrieved from the searched databases, and after removing duplicates (n = 24), 102 citations were screened for eligibility, with 86 being excluded for not meeting the inclusion criteria. At the end of the selection process, 11 articles were included in this review (Figure 1). The majority of studies (91%) were experimental and had adult healthy volunteers (Table 1); 64% of the included studies focused on the effects of NB and OB on brain function (Table 2), while the remaining 36% focused on respiratory muscles (Table 3). A total of 313 participants comprised the population, most of whom were women (63%). Although most studies were conducted on adults, a minority of participants (15%) were children (Table 1).

DISCUSSION

Effects of Nasal and Oral Breathing on Brain Function

NB enhances the activity and connectivity of brain regions associated with the default mode network (DMN) in healthy subjects.[14] This effect is not limited to the DMN, but may also spread to a broader brain area, as DMN connectivity indicates proper attention and self-cognitive skills. NB can affect different olfactory cortical and subcortical regions, which may be essential in transitioning from unconsciousness to wakefulness.[14]

In a study on the effects of music and breathing mode on emotions, listening to various types of music during NB increased the participants' arousal levels and perceived relaxation.[15]

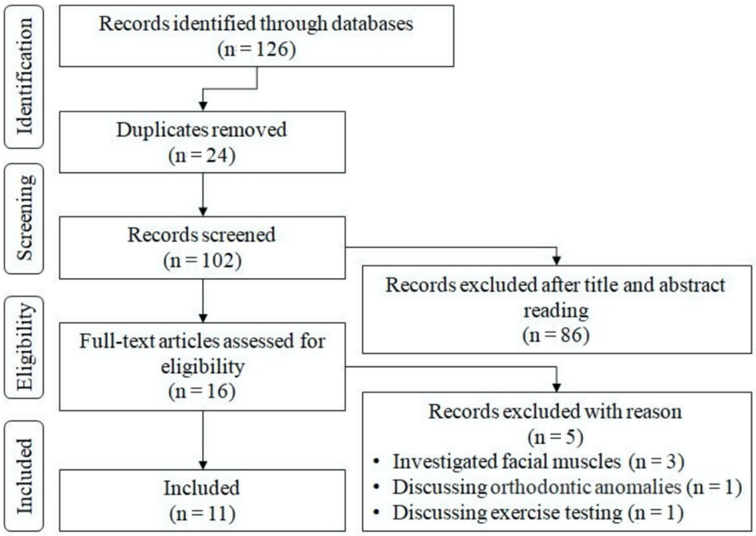

Figure 1. Study flow chart

Table 1. Characteristics of the included studies

First author (year)	Country	Study design	Participants n of the defined	Age years	Gender n of men, (%)
Salimi et al.[14] (2023)	Iran	Experimental	16 healthy volunteers	30 (IQR 25-38)	7 (44)
Mollakazemi et al.[15] (2023)	USA	Experimental	12 healthy individuals	18-35	6 (50)
Zaccaro et al.[16] (2022)	Italy	Experimental	12 healthy volunteers	48±12	3 (25)
Jung and Kang[21] (2021)	Korea	Experimental	22 healthy volunteers	22.27±1.42	10 (45)
Hong et al.[22] (2021)	Korea	Experimental	20 healthy volunteers	23.7±2.28	7 (35)
Lee et al.[10] (2020)	Korea	Experimental	20 healthy volunteers	23.7±2.28	7 (35)
Zelano et al.[23] (2016)	USA	Experimental	8 patients with temporal lobe epilepsy	48 (IQR 29-59)	8 (100)
Trevisan et al.[6] (2015)	Brazil	Cross-sectional	39 healthy volunteers (NB) 38 healthy volunteers	22.6±2.9 22.7±3.5	11 (28) 13 (34)
Ribeiro et al.[26] (2004)	Brazil	Experimental	46 healthy children	8-12	33 (72)
Tafil-Klawe and Klawe[27] (2003)	Poland	Experimental	35 healthy volunteers 35 healthy volunteers	20-30 41-55	N/A N/A
Takahashi et al.[28] (2002)	Japan	Experimental	10 healthy volunteers	28.6±2.3	10 (100)

IQR: interquartile range, NB: nasal breathing, OB: oral breathing, N/A: not available

Table 2. Procedures and main findings of the included studies investigating the effects of NB and OB on brain function

First author (year)	Performed analyses	Main findings
Salimi et al.[14] (2023)	Three random experiments with EEG acquisition were performed to evaluate DMN: 1) NB, 2) OB, 3) OB + nasal air puff. EEG data were recorded using a 32-channel active electrode system. EEG electrodes were attached according to the 10-20 system, with reference and ground channels placed respectively on the left mastoid and right earlobe. Nasal air puffs consisted of a brief puff of odorless air delivered to the nasal cavity via a nasal cannula for 3 min (7-10 L/min; 1.1 bar, frequency 0.2 Hz).	NB had a higher DMN power, particularly in the gamma range, than OB. OB + nasal air puff significantly increased signal power compared to OB. In the frontal area, the power of signals was enhanced during OB + nasal air puffing (not observed during NB). NB and OB + nasal air puffs were associated with increased signal coherence compared with OB. OB + nasal air puff increased the number of synchronized channels compared to OB.
Mollakazemi et al.[15] (2023)	8-channel EEG recording from the scalp to evaluate whether NB or OB affect emotions triggered by music delivered to participants through a pair of circumaural headphones. The music comprised three two-minute songs (one happy, one peaceful, and one sad song).	Participants found songs more relaxing during NB than OB ($P = 0.00013$), and felt more aroused than during OB ($P = 0.036$). During NB, participants found the songs happier ($P = 0.069$), more exciting ($P = 0.063$), and less boring ($P = 0.082$) than during OB. During NB, the respiratory rate ($P < 0.001$) and heart rate were higher than during OB.
Zaccaro et al.[16] (2022)	SNB and SOB recordings were compared with EEG recordings to investigate olfactory epithelium stimulation's role in disentangling its effects from those related to respiratory vagal stimulation. For SOB, participants were asked to breathe only through their nostrils for 15 min at a respiratory rate of 2.5 breaths per min; A respiratory cycle consisted of four consecutive phases, each lasting 6 s (inspiration-pause-expiration-pause). For SNB, participants were asked to breathe only through their mouth for 15 min at a respiratory rate of 2.5 breaths per min. Nostrils were closed using a clinically approved nasal clip.	A higher power spectral density in the theta and delta bands was observed after SNB compared to post-SOB in the prefrontal and frontal areas. Higher theta band connectivity during post-SNB compared to post-SOB. The connectivity increase was mostly lateralized, involving the left hemisphere (from prefrontal to occipital regions). Increase of theta-high-beta coupling after SNB compared with baseline and post-SOB. Significant increases were found in midline prefrontal/frontal areas and midline posterior regions with the theta phase modulating the high-beta amplitude. Post-SNB was accompanied by an increase in experienced positive emotions compared with post-SOB ($P < 0.04$). During post-SNB, participants experienced a heightened perception of being in an altered state of consciousness. The post-SNB phase was associated with lower physical and psychological tension than the post-SOB phase, although the differences were not significant ($P < 0.32$ and $P < 0.06$).

Table 2. Continued

First author (year)	Performed analyses	Main findings
Jung and Kang[21] (2021)	Determine the differences in active brain regions and functional connectivity between the NB and OB groups during a 2-back working memory task using fMRI. On the same day, participants underwent one brain structure scan and two fMRI scans for the working memory task during NB and OB.	Fifteen and 10 regions were activated during NB, while 10 were activated during OB. Among the 15 regions during NB, five (inferior parietal gyrus, insula, cerebellum, precentral gyrus and middle frontal gyrus) appeared in both hemispheres. The functional connection decreased significantly during a working memory task in the OB group compared with the NB group. Functional connections of the left cerebellum and left and right inferior parietal gyrus were observed only during NB but not during OB. Brain areas closely related to working memory function were less active during OB.
Hong et al.[22] (2021)	EEG analysis of changes in brain oscillatory activity caused by breathing. Measurements were performed using a 32-channel EEG in a soundproof room. To examine the EEG signal differences in working memory performance during NB and OB tasks, the EEG signals were measured for 5 min each in the rest, 1-back, and 2-back task states. During the rest state with closed eyes, the tasks included NB, OB, and OB with O_2 supply.	The working memory accuracy did not differ significantly between NB and OB ($P = 0.711$). An additional O_2 supply during OB is recognized as NB, at least by the brain waves.
Lee et al.[10] (2020)	EEG recording was performed to analyze the physiological changes associated with NB and OB. A multi-parameter patient monitor was used to measure the physiological data, SpO_2, $ETCO_2$, and RR during resting and n-back working memory tasks.	Compared with NB, discomfort scores were significantly higher during OB in all three states (resting $P < 0.001$, 0-back $P < 0.001$, 2-back $P < 0.001$). $ETCO_2$ was significantly increased during OB ($P = 0.0064$). The delta wave power increased during OB in the 2-back task. The beta and gamma wave power decreased significantly in the 2-back task during OB (β $P = 0.0031$, γ $P = 0.0057$).
Zelano et al.[23] (2016)	iEEG from depth electrodes inserted into the PC, amygdala, and hippocampus of seven patients with surgical epilepsy during natural breathing (five with PC coverage; all seven with amygdala and hippocampal coverage).	The inspiratory phase of NB was associated with increased power in the delta frequency range in five patients in PC and seven patients in the amygdala and hippocampus. The nasal route of respiration provides an entry point to limbic brain areas for modulating cognitive function. Air plumes periodically entering the nose at a quiet breathing rate may elicit slow and rhythmic neuronal oscillations that propagate throughout limbic brain networks.

EEG: electroencephalography, DMN: default mode network, NB: nasal breathing, OB: oral breathing, SNB: slow nasal breathing, SOB: slow oral breathing, fMRI: functional magnetic resonance imaging, SpO_2: oxygen saturation, $ETCO_2$: end-tidal CO_2, RR: respiratory rate, β: beta, γ: gamma, iEEG: intracranial electroencephalography, PC: piriform cortex

Table 3. Procedures and main findings of the included studies investigating the effects of NB and OB on respiratory muscles

First author (year)	Performed analyses	Main findings
Trevisan et al.[6] (2015)	sEMG signals were acquired using a 14-bit surface electromyograph to evaluate the electrical activity of the SCM, UT, sternocleidomastoid, upper trapezius, and amplitude of diaphragm movement during NB and OB. Muscle activity was recorded at rest for 10 s and in four inspiratory tests: Sniff, TLC, PNIF, and MIP.	The EMG activities of the SCM and UT did not differ between the OB and NB groups at rest and at TLC, except for the left UT, which exhibited significantly higher activity at TLC in the OB group. The mean MIP value was significantly lower in the OB group than in the NB group. Among the Sniff, PNIF, and MIP, SCM activity was lower in the OB group.
Ribeiro et al.[26] (2004)	EMG recording analysis to evaluate SCM and UT muscle activity in children during NB and OB, during relaxation and maximal voluntary contractions.	At rest, children had higher electrical activity during OB than during NB ($P < 0.05$). In the maximal voluntary contraction, there was lower activity during OB compared with NB ($P < 0.05$).

Table 3. Continued

First author (year)	Performed analyses	Main findings
Tafil-Klawe and Klawe[27] (2003)	EMG recording of the GG muscle activity during NB and OB to determine the influence of NB on GG in progressive hypoxia.	Compared with NB, there are smaller increases in GG-EMG-activity in response to hypoxia during OB. Participants aged >40 years showed reduced GG muscle response to hypoxia, which was most pronounced during OB.
Takahashi et al.[28] (2002)	EMG recording of the GG and GH muscles to evaluate the influence of NB and OB can influence their activity. Activities were recorded simultaneously over 20 respiratory cycles during NB and repeated during OB.	A substantial difference was observed during NB in the upright position, with greater activity in the GG muscle. The GH muscle showed greater EMG activity during maximal jaw opening.

NB: nasal breathing, OB: oral breathing, sEMG: surface electromyography, SCM: strenocleidomastoideus, UT: upper trapezius, TLC: total lung capacity, PNIF: peak nasal inspiratory flow, MIP: maximal inspiratory pressure, GG: genioglossus muscle, GH: geniohyoid

A study was conducted to compare the psychophysiological and phenomenological impacts of slow nasal breathing (SNB) and slow oral breathing (SOB) among meditation practitioners. The cardiorespiratory parameters were not significantly different between the SNB and SOB groups.[16] After SNB and SOB, an elevation in slow rhythms (delta and theta rhythms) in EEG activity compared with baseline was observed. The increase after SNB was related to the prefrontal and central posterior areas associated with the intrinsic network[17] and/or the DMN,[18] whereas the enhancement after SOB was limited to posterior areas. Compared with SOB, SNB led to a significant amplification of slow rhythms in the medial prefrontal region. The results suggest that there is an increase in theta-high-beta coupling following SNB, potentially contributing to the regulation of brain functions supported by frontoparietal networks,[17] thus facilitating large-scale integration processes associated with self-awareness[19] and consciousness.[20]

This study aimed to investigate how cognitive function is affected during OB using fMRI. The authors performed a 2-back working memory task on a group of healthy participants during NB and OB and measured changes in neural activity.[21] Specifically, the study found a significant association between working memory and functional connections among the left cerebellum and the left and right inferior parietal gyri, which were more activated in nasal breathers.

Another study investigated the effects of oxygen deprivation during OB on brain function in different working memory tasks with varying oxygen demand levels.[22] The analysis of the EEG signals revealed that the difference in oxygenation was one of the main factors differentiating the influence of OB and NB on brain function.

The oxygen supply was more effective in reducing the characteristic changes between the EEG signals during NB and OB during the more complex tasks that required more oxygen.[22]

A previous study investigated alterations in brain activity during OB while simultaneously performing a cognitive task, utilizing EEG to measure brain waves at rest and during the n-back tasks (0-back and 2-back), alongside physiological variables, including SpO_2, $ETCO_2$, and respiratory rate.[10] Theta and alpha powers exhibited decreased levels during OB compared to NB while at rest, and alpha power demonstrated reduced levels during the 0-back and 2-back tasks. Beta and gamma waves exhibit diminished power, specifically during the 2-back task. Additionally, SpO_2 and respiratory rate significantly decreased during OB compared with NB, whereas $ETCO_2$ levels were substantially elevated during OB. Although behavioral outcomes, including accuracy and reaction time, did not differ significantly between the two groups, the observed pattern of cerebral activity in the OB group was distinct from that of the NB group. This pattern of activity was linked to brain regions involved in cognitive processes. The observed alterations seem connected to the reduced oxygen saturation during OB, suggesting that OB could be a factor leading to different brain activity patterns when cognitive skills are involved.

To explore the hypothesis suggesting a connection between cortical oscillatory activity and the human respiratory cycle, albeit at a considerably slower rhythm of approximately 0.16-0.33 Hz, researchers gathered intracranial EEG data from a limited sample of patients with medically refractory epilepsy.[23] They found that high-frequency oscillations were entrained not only in the piriform cortex but also in the amygdala and hippocampus, and dysregulation of limbic oscillatory synchrony occurred in all three brain regions, suggesting that variations in low-frequency (delta) power might act like a carrying rhythm within the lower rate of NB, with higher frequency oscillations embedded or entangled within the limbic system.[24] It has been demonstrated that OB has a detrimental effect on cognitive performance, whereas NB has been shown to have a beneficial effect, including improvement in reaction time to fearful stimuli and accuracy in visual object recognition.

Effects of Nasal and Oral Breathing on Respiratory Muscle Activity

The EMG activities of the UT and sternocleidomastoideus (SCM) muscles and DA were evaluated in adults during NB and OB.[6] The EMG activity of the SCM muscle was significantly lower in the OB group during sniffing, peak nasal inspiratory flow, and maximum inspiratory pressure, whereas no changes were found in the resting state and total lung capacity (TLC). For the UT muscle during rest and TLC, EMG activity did not differ between the OB and NB groups, but for the left part of the UT muscle, EMG activity was significantly higher in the OB group. The SCM muscle had greater activation in both groups during fast and short inspiratory workloads, with lower activation in the OB group. DA was markedly lower in the OB group at

TLC, but no change was observed during sniffing.[6] The forward head posture commonly seen in OB causes the chest to rise due to overuse of the SCM, which reduces the effectiveness of the diaphragm. In addition, OB can lead to hypertrophy of the accessory inspiratory muscles, which impede diaphragmatic movement because of their reduced mobility and lack of coordination with the abdominal muscles.[25]

A further study will examine the SCM and UT EMG activities during OB and NB in children. The results indicated that children who breathe through their mouths exhibited increased EMG activity during rest and decreased EMG activity during maximal voluntary contraction compared to children who breathe through their noses.[26] In children with OB, increased SCM and UT activity indicates a change in head posture due to nasal obstruction, which requires more effort for inspiration and consequently heightens the EMG activity of the accessory inspiratory muscles.

One study examined the effects of NB and OB on genioglossus-EMG (GG-EMG) activity in response to hypoxia and found that OB resulted in significantly less increased GG-EMG activity compared with NB.[27] Additionally, older subjects exhibited decreased GG response to hypoxia, which was most prominent during OB. In both examined groups, there was no difference in minute ventilation (MV) and tidal volume/inspiratory time (VT/TI). All subjects displayed a linear increase in MV, VT/TI, and GG-EMG activity in response to progressively induced isocapnic hypoxia. The authors have investigated the EMG activity of the GG and geniohyoid (GH) muscles and whether differences in breathing mode, as well as changes in posture, affect GG and GH activity.[28] During maximal jaw opening, GH-EMG activity was higher than GG activity; moreover, GG activity varied significantly in terms of breathing mode and posture (the OB group had higher EMG activity than the NB group). In human studies, the GH has been identified as an accessory respiratory muscle. However, the GH muscle EMG activity remained unaffected by changes in breathing mode and posture, whereas the GG muscle was affected, as previously noted. Although the GH muscle may have a lesser role as a respiratory muscle compared with the GG muscle, it still plays a significant role in respiratory function by virtue of its direct attachment to the hyoid bone, which is crucial for maintaining upper airway patency. Despite the absence of detectable alterations in GH muscle activity in response to changes in respiratory mode and posture, the authors observed that under more challenging conditions, such as severe hypoxia, the capacity of the GH muscle to maintain force output during high activation levels may be negatively impacted.[28] In summary, the EMG activity of the GG muscle was more efficient than that of the GH muscle in maintaining proper upper airway function.

In a related study, the impact of the respiratory pathway on the GG and NDM muscles during cycling exercise in an upright position was investigated.[29] The findings revealed that NDM EMG activity was markedly elevated during NB, whereas GG-EMG activity was not influenced by NB or OB. Moreover, the EMG activity of the NDM muscle exhibited significantly greater sensitivity to nasal ventilation than to oral or total ventilation during both upright and supine exercise.

The primary limitation of this review is that the material retrieved was heterogeneous because it included studies conducted both in healthy individuals and patients and with high variance in age because of the presence of children and adults. Therefore, the results reported here should be considered with caution because they cannot be extended to a wider context. Furthermore, given that most participants were healthy individuals, extending the findings of the present review to a clinical context is difficult.

CONCLUSION

The present review confirms that the nasal and OB elicit different brain areas and heterogeneously influence respiratory muscle function. Knowledge of the underlying mechanisms could be beneficial, for example, in personalizing respiratory and manual techniques when rehabilitating individuals with neurological or respiratory impairments. Additionally, changes in posture, respiratory muscle EMG activity, and respiratory function resulting from different breathing modes are clinically significant, as they can affect rehabilitation components in individuals with respiratory impairments. To enhance the generalizability of the findings, future research should conduct randomized controlled trials involving a broader range of pathologies and patients from various age groups. This approach would increase the applicability of the results in clinical contexts.

Footnotes

Authorship Contributions

Concept: Ö.B., E.P., Design: Ö.B., M.P., E.P., Data Collection or Processing Ö.B., M.P., Analysis or Interpretation: Ö.B., M.P., E.P., Literature Search: Ö.B., M.P., Writing: Ö.B., M.P., E.P.

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