Nasal contribution to breathing with exercise: effect of race and gender

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Submitted 5 August 2002; accepted in final form 7 April 2003


Ventilation rate is a key determinant of both inhaled particle deposition and gas uptake in the respiratory tract. Ventilation rate is linked to activity, e.g., with exertion or strenuous activity, people who typically breathe through their nose will augment their nasal ventilation and also breathe through their mouth (oronasal breathing). The mode of breathing, i.e., via the mouth or nose, dramatically alters airflow dynamics in the upper respiratory tract and influences particle deposition and gas uptake. The capability of the nose to filter or condition inspired air is diminished as airflow is diverted from nasal to mouth breathing during exercise. The level of ventilation at which this switch from nasal to oronasal breathing occurs has been previously referred to as the “oronasal switching point” (21). A number of studies, however, have shown that oronasal breathing occurs at resting ventilation in some individuals (3, 7, 14). Characterizing the ventilation level and variability across individuals for the relative contribution of nasal to total breathing is critical to the construction of ventilation activity patterns for accurately constructing the airflow apportionment (nasal or mouth) at various ventilation rates associated with different activities. Ventilation activity patterns (e.g., 10-h rest, 8-h sitting, 5-h light work, and 1-h heavy exercise in a 24-h day) are beginning to be used in risk assessment to link exposure profiles to internal dose for more accurate dose-response assessment. For example, Snipes et al. (29) recently used different ventilatory patterns to illustrate that age, gender, and disease state may be important determinants of susceptibility to inhaled particles. Characterization of the variability in ventilation is an important consideration to determine the magnitude of the intrahuman variability uncertainty factor applied in inhalation risk assessment (15).

The level of exercise at which the oronasal switching point occurs and the relative contributions of oral vs. nasal breathing at rest and during exercise have been studied by a number of investigators (3, 7, 14, 21, 22, 25, 27, 31). The physiological determinants of the relative contributions to nasal and oral breathing during exercise are still not well understood. Presumably,

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nasal resistance ($R_{\text{nose}}$) to airflow should determine the relative work of breathing between nasal and mouth breathing and thus the switch from nasal to oronasal breathing during exercise (27). Schultz and Horvath (27) showed that, within an individual, nasal work of breathing was the most repeatable variable at cross-over to oral breathing in subjects and thus a potential candidate for determining the initiation of oral augmentation during exercise. Many previous studies, however, have not found good correlations between $R_{\text{nose}}$ and the switch to oronasal breathing (7, 14, 25) between individuals, perhaps because the maximal inspiratory flow through the nose (MIF$_{\text{nose}}$) may be determined by more than $R_{\text{nose}}$ as measured under resting flow conditions (5, 6, 24). Bridger and Proctor (5, 6) suggested that collapsibility of the nasal valve (referred to as alar collapse) plays a role in MIF$_{\text{nose}}$ that is independent of $R_{\text{nose}}$ downstream of the collapse point (i.e., flow-limiting segment). After noting that the few African-American subjects studied were able to achieve higher maximum nasal flow rates, they further suggested that differences in nasal structure associated with race (10, 11) may translate into different maximal flow capacities.

Similarly, modest gender differences in nasal structure have also been observed (10) and may translate into gender-dependent oronasal switching with exercise. More importantly, on average, women have lower maximal physical work capacities (PWC$_{\text{max}}$) and associated ventilation rates. Thus, at a given work effort (as %PWC$_{\text{max}}$), women might be expected to have a greater nasal contribution to breathing than men. Gender differences in these relative contributions of nasal breathing are important for assessing relative risks associated with inhaled toxicants.

The purpose of our study was to determine whether the relative contribution of nasal and oral breathing during light-to-moderate exercise is dependent on race or gender in adults. Previous studies of this type have not addressed race as a factor in oronasal breathing (7, 14, 25) in adults. Previous studies of this type have also been observed (10) and may translate into gender-dependent oronasal switching with exercise. More importantly, on average, women have lower maximal physical work capacities (PWC$_{\text{max}}$) and associated ventilation rates. Thus, at a given work effort (as %PWC$_{\text{max}}$), women might be expected to have a greater nasal contribution to breathing than men. Gender differences in these relative contributions of nasal breathing are important for assessing relative risks associated with inhaled toxicants.

The purpose of our study was to determine whether the relative contribution of nasal and oral breathing during light-to-moderate exercise is dependent on race or gender in adults. Previous studies of this type have not addressed race as a factor in oronasal breathing. Neither have they reported data comparing gender in terms of relative contribution of nasal breathing as a function of work effort. Second, we attempted to better elucidate how parameters of nasal physiology, i.e., resistance and MIF$_{\text{nose}}$, might determine the relative contributions to nasal and oral breathing during exercise.

METHODS

A group of 11 Caucasian (6 men/5 women) and 11 African-American (5 men/6 women) healthy, nonsmoking adults, age 18–31 yr, were studied. The subjects had no smoking history, no history of lung disease, and no recent history of acute respiratory infection or viral illness within the previous 4 wk. A few subjects reported seasonal nasal allergies and associated rhinitis but were asymptomatic during the time of study. Forced expiratory volume in 1 s and forced vital capacity were determined for each subject by spirometry. Informed consent was obtained from each volunteer; the study had the approval of the University of North Carolina Committee on the Protection of the Rights of Human Subjects.

A measure of each subject’s predicted maximum exercise capacity on a cycle ergometer (2) was determined. While being monitored by a three-lead ECG, subjects performed graded submaximal exercise at three increasing workloads (in W) while maintaining a pedal rate of 60–70 rpm. Each workload trial lasted 5 min. The maximum of the three workloads did not exceed a heart rate of 170 beats/min. By linear extrapolation of the workload-heart rate relationship to each subject’s age-related predicted maximum heart rate (2, 21), the subject’s PWC$_{\text{max}}$ was determined.

On a subsequent study day, the relative contributions of oral vs. nasal breathing were measured at rest and during incrementally graded submaximal exercise on the cycle ergometer (10% increments from 0–60% PWC$_{\text{max}}$ for each subject) (21, 22). The subject was fitted with a nasal mask (Respironics, Murrysville, PA) (approximate dead space of 60 ml) that was similar to that used in pulmonary sleep laboratories and modified to allow insertion of a mass flowmeter (Korr Medical Technologies, Salt Lake City, UT) to detect nasal airflow (21, 22). Total ventilation ($V_t$) was determined by respiratory inductance plethysmography (Respitrace) (calibrated spirometer; Respirornics, Murrysville, PA) (approximate dead space of 60 ml) that was similar to that used in pulmonary sleep laboratories and modified to allow insertion of a mass flowmeter (Korr Medical Technologies, Salt Lake City, UT) to detect nasal airflow (21, 22). Total ventilation ($V_t$) was determined by respiratory inductance plethysmography (Respitrace) (calibrated spirometer; Respironics, Murrysville, PA) (approximate dead space of 60 ml) that was similar to that used in pulmonary sleep laboratories and modified to allow insertion of a mass flowmeter (Korr Medical Technologies, Salt Lake City, UT) to detect nasal airflow (21, 22). Total ventilation ($V_t$) was determined by respiratory inductance plethysmography (Respitrace) (calibrated spirometer; Respironics, Murrysville, PA) (approximate dead space of 60 ml) that was similar to that used in pulmonary sleep laboratories and modified to allow insertion of a mass flowmeter (Korr Medical Technologies, Salt Lake City, UT) to detect nasal airflow (21, 22). Total ventilation ($V_t$) was determined by respiratory inductance plethysmography (Respitrace) (calibrated spirometer; Respironics, Murrysville, PA) (approximate dead space of 60 ml) that was similar to that used in pulmonary sleep laboratories and modified to allow insertion of a mass flowmeter (Korr Medical Technologies, Salt Lake City, UT) to detect nasal airflow (21, 22). Total ventilation ($V_t$) was determined by respiratory inductance plethysmography (Respitrace) (calibrated spirometer; Respironics, Murrysville, PA)
exercise), we had subjects perform maximal inspiratory flow maneuvers via their nose by slowly exhaling to near residual volume and then rapidly inhaling through their nose at maximal effort with the nose mask and mouth plug in place (24). MIF_nose associated with these maneuvers was determined as the peak flow for each maneuver.

Statistical analysis. Group comparisons, i.e., Caucasians vs. African-Americans and men vs. women, for all variables reported were made by independent sample t-test. As an exploratory analysis, we also performed multivariate backward and forward stepwise regression for %nasal contribution at rest and at 20, 40, and 60% PWCmax, considering the following independent variables: race, gender, R_nose, MIF_nose, and VE at that workload. Due to our limited data set, we did not consider interactions between variables for this exploratory analysis. Statistical criteria for a variable to enter and stay in the stepwise model was set at $P = 0.15$.

RESULTS

Figure 1 shows the average total and nasal VE as a function of %PWCmax in all subjects studied. VE increased linearly with increasing workload to 60% PWCmax, whereas nasal ventilation increased more slowly with increasing workload.

Table 1 summarizes the racial comparison of subject exercise capacities, VE, and lung and nasal function. Only forced vital capacity and MIF_nose were significantly different between the two groups. There was a tendency for R_nose to be less in the African-Americans vs. the Caucasians ($P = 0.08$). R_nose tended toward a negative correlation with MIF_nose ($r = -0.41$, $P = 0.06$). Figure 2 illustrates the nasal contribution to breathing (in %VE) as a function of workload in %PWCmax for Caucasians and African-Americans. At 20 and 60% PWCmax, the Caucasians had significantly less nasal contribution to breathing than African-Americans ($P < 0.01$ and 0.05, respectively). There was also a tendency toward a racial difference at 40% PWCmax ($P = 0.06$).

Table 2 summarizes the gender comparison of subject exercise capacities, VE, and lung and nasal function. The women had a significantly less PWCmax compared with the men and, as a result, also had a lesser VE at 60% PWCmax. Figure 3 illustrates the nasal contribution to breathing (in %VE) as a function of workload (in %PWCmax) for men vs. women. At 40% PWCmax, the men had significantly less nasal contribution to breathing than women ($P < 0.05$). There was also a tendency toward a gender difference at 20% PWCmax ($P = 0.06$). Because there was a gender difference in work capacity, we also compared the men and women at a given workload. All subjects had a

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**Table 1. Racial comparisons**

<table>
<thead>
<tr>
<th></th>
<th>Caucasian</th>
<th>African-American</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men/Women, no.</td>
<td>6/5</td>
<td>5/6</td>
</tr>
<tr>
<td>Age, yr</td>
<td>22 ± 3</td>
<td>22 ± 4</td>
</tr>
<tr>
<td>Maximum work, W</td>
<td>173 ± 39</td>
<td>154 ± 68</td>
</tr>
<tr>
<td>VE at rest, l/min</td>
<td>7.6 ± 1.6</td>
<td>8.2 ± 2.7</td>
</tr>
<tr>
<td>VE at 60% maximum, l/min</td>
<td>41.0 ± 14.1</td>
<td>40.9 ± 18.7</td>
</tr>
<tr>
<td>Forced vital capacity, liters</td>
<td>5.0 ± 0.9</td>
<td>4.2 ± 0.9*</td>
</tr>
<tr>
<td>R_nose, cmH2O⋅s⁻¹</td>
<td>2.72 ± 1.81</td>
<td>1.61 ± 0.88</td>
</tr>
<tr>
<td>MIF_nose, l/s</td>
<td>2.1 ± 0.6</td>
<td>2.8 ± 1.0*</td>
</tr>
</tbody>
</table>

Values are means ± SD. VE, minute ventilation; R_nose, nasal resistance; MIF_nose, maximal inspiratory nasal flow. *Significant difference, $P < 0.05$.

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**Table 2. Gender comparisons**

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Age, yr</td>
<td>22 ± 2</td>
<td>22 ± 4</td>
</tr>
<tr>
<td>Maximum work, W</td>
<td>125 ± 37</td>
<td>201 ± 42*</td>
</tr>
<tr>
<td>VE at rest, l/min</td>
<td>6.9 ± 0.9</td>
<td>8.9 ± 2.6*</td>
</tr>
<tr>
<td>VE at 60% maximum, l/min</td>
<td>30.7 ± 7.4</td>
<td>51.2 ± 16.3*</td>
</tr>
<tr>
<td>Forced vital capacity, liters</td>
<td>4.0 ± 0.8</td>
<td>5.2 ± 0.8*</td>
</tr>
<tr>
<td>R_nose, cmH2O⋅s⁻¹</td>
<td>1.89 ± 1.32</td>
<td>2.44 ± 1.69</td>
</tr>
<tr>
<td>MIF_nose, l/s</td>
<td>2.2 ± 0.8</td>
<td>2.7 ± 0.9</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. Significant differences: *$P < 0.001$; †$P < 0.05$, ‡$P < 0.005$. 

J Appl Physiol • VOL 95 • AUGUST 2003 • www.jap.org
workload at or near 50 W during their exercise (a workload associated with ~20% PWC\textsubscript{max} in men and 40% PWC\textsubscript{max} in women), at which women and men had a \( \dot{V}_E \) of 22.1 ± 2.4 (SD) and 23.5 ± 5.3 l/min respectively [not significant (NS)]. At this workload, women had a nasal contribution to breathing of 79 ± 21% compared with 67 ± 28% for men (NS).

The results of multivariate stepwise regression analysis for %nasal contribution to breathing at rest showed no significant variables at the \( P = 0.15 \) level. The same analysis at 20% PWC\textsubscript{max} showed significance for 1) \( \dot{V}_E \) at this workload (\( P = 0.001 \) and 2) race (\( P = 0.007; r^2 = 0.62 \) for the regression). Similarly, at 40% PWC\textsubscript{max}, the regression analysis showed significance for 1) \( \dot{V}_E \) at this workload (\( P < 0.001 \) and 2) race (\( P = 0.028; r^2 = 0.62 \) for the regression). Finally, at 60% PWC\textsubscript{max}, the regression analysis showed %nasal contribution to breathing dependence on 1) \( \dot{V}_E \) at this workload (\( P < 0.001 \) and 2) race (\( P = 0.003; r^2 = 0.59 \) for regression). Neither \( R_{nose} \) nor MIF\textsubscript{nose} was a significant predictor of %nasal contribution to breathing at any exercise level.

Figure 4 illustrates the relationship between \( \dot{V}_E \) and the %nasal contribution at 40% and 60% PWC\textsubscript{max}. For comparison to previous work, the “switching point” reported by Niinimaa et al. (21), \( \dot{V}_E = 35 \) l/min, is delineated. Below \( \dot{V}_E = 35 \) l/min, there is considerable variation in %nasal contribution to breathing (30–100%), with African-Americans clearly having a greater nasal contribution than Caucasians. Above \( \dot{V}_E = 35 \) l/min, the %nasal contribution drops to <40% in all of the Caucasians, whereas four of the African-Americans maintain %nasal contributions of >40%.

**DISCUSSION**

As in previous studies (3, 7, 14, 21, 22, 25, 31), our laboratory has shown that the nasal contribution to breathing decreases with increasing exercise (Fig. 1). Consequently, the air entering the lower respiratory tract is less conditioned and filtered of inhaled toxicants than it is otherwise (1, 9), thus subjecting the lower respiratory tract to potential insult. Others have also shown an average 50% nasal contribution to \( \dot{V}_E \) at a mean \( \dot{V}_E \) of 40 l/min (7, 22, 31). Whereas our data and that of others suggest that the %nasal contribution plateaus as total \( \dot{V}_E \) increases, absolute nasal ventilation rates may continue to rise, reaching mean peak values of 40 l/min (25). Unlike some previous findings (21, 22), we did not find a distinct switching point for a change from nasal to oronasal breathing; rather, subjects generally tended to gradually increase their oral contribution to breathing as exercise levels increased. Nevertheless, a comparison of the switching point of Niinimaa et al. (21) (35 ± 10 l/min) with our nasal contributions and ventilation rates (Fig. 4) shows that, for ventilation rates >30 l/min, all subjects had nasal breathing that falls <90% of total. It is also true that, above the switching point of 35 l/min (Fig. 4), except for two outliers, all subjects’ nasal contribution to breathing fell <50%. However, below that ventilation rate there was considerable variability in the nasal contribution to breathing (i.e., 30–100%). Other studies (7, 14) have also found a more variable switching between nasal and oronasal breathing as we have found here. Some of the differences between studies may be due to different measurement techniques but also may be due to the “blindedness” of the subjects toward the test’s objectives. We found in pilot studies that, if subjects thought we wanted them to breathe through their nose (based on posttest questioning), they were more likely to maintain nasal breathing solely until reaching a switching point, where, despite their best efforts, they needed to orally supplement their breathing. In fact some subjects who were less fit than others never achieved ventilation rates where switching occurred.

We also found that the degree of nasal breathing at rest was correlated with %nasal contribution to breathing during exercise. The best simple regression be-
 tween resting nasal contribution and nasal contribution during exercise occurred at the 20% PWC_{max} level ($r = 0.51, P < 0.05$) and diminished by 60% PWC_{max} ($r = 0.38, \text{NS}$). So while there may have been some effect of subject’s baseline nasal contribution at rest, this effect or relationship was not significant at the higher workloads and thus could not explain the racial differences seen as exercise progressed. Furthermore, there was no significant racial difference in nasal contribution to breathing at rest ($P = 0.20$). We chose to characterize nasal contribution to breathing as a function of relative (14, 21, 22) rather than absolute (7, 25) workload for reasons associated with risk assessment. Because individuals have variable fitness levels, they will generally exercise at their own capacities (or fraction of their PWC_{max}). Thus the breathing patterns for these relative workloads should be considered when attempting to model and/or assess risk associated with inhaled toxicants. Using relative workloads to compare nasal contribution to breathing as a function of race did not affect our findings, because the PWC_{max} and V_{E} at any relative workload were similar between African-Americans and Caucasians. However, the same comparison between men and women was affected because the latter had significantly lower PWC_{max} and thus lower ventilation rates at a given %PWC_{max}.

Previous investigators have not distinguished their subjects by race and their associated differences in nasal function. We have shown here that African-Americans have a greater nasal contribution to breathing with exercise compared with Caucasians. This difference was greatest as exercise level increased. Whereas there was only a tendency for R_{nose} to be less in the African-Americans compared with Caucasians (Table 1), there was a clear difference in the MIF_{nose}, with African-Americans able to achieve 33% higher maximal nasal flows. This was true, despite their having significantly smaller vital capacities (Table 1) than Caucasians (18). Figure 4 shows that, after switching to oronasal breathing, most African-American subjects were maintaining higher levels of %nasal contribution than most of the Caucasians. Two African-Americans had nasal contributions of 75% at V_{E} as high as 40 l/min (Fig. 4).

A clear relationship between either MIF_{nose} (which differed by race) or R_{nose} and nasal contribution to breathing was not evident in our study. This may be due, in part, to the fact that both MIF_{nose} and R_{nose} were measured immediately postexercise, at rest. Whether or not we obtained a true reflection of R_{nose} during the exercise period is open to question. First, we measured an average R_{nose} (inspiratory and expiratory) over the flow range of ±0.5 l/s postexercise. The resistance at different phases of the breathing cycle may vary and be important for determining maximal nasal ventilation during exercise. For example, Shi et al. (28) showed hysteresis in the inspiratory resistance during hyperpnea, i.e., lesser R_{nose} during increasing vs. decreasing inspiratory flow. They further showed that voluntary flaring of the nostrils reduced the hysteresis and overall R_{nose}. The degree to which their results with voluntary hyperventilation can be extrapolated to the exercise condition is not clear, however. Second, total R_{nose} at a given flow rate is known to be reduced with exercise, depending on the workload (12). We tried to capture the R_{nose} associated with each subject’s exercise state by measuring it immediately postexercise, in each case within 15 min. However, it is not known how much change in R_{nose} occurred for each subject in association with the exercise protocol. Nor were we able to ascertain the degree to which each subject maintained nasal dilatation postexercise. We chose not to measure preexercise R_{nose} and MIF_{nose} so that subjects would be as naive as possible with regard to oronasal breathing during the exercise protocol (discussed in METHODS). Future studies using other measures or indexes of R_{nose} that do not require use of the nasal mask, e.g., acoustic rhinometry, may allow for these pre- and postmeasures while also not biasing subjects with regard to their oronasal breathing during the exercise protocol.

Our findings suggest that Caucasians may be at greater risk for inhalation of toxic gases and particles than African-Americans because of their lower nasal contribution to overall breathing. However, it may also be that there are racial differences in nasal efficiencies for removing these gases and particles. Some recent studies suggest that this may in fact be the case for inhaled particles. Kesavanathan et al. (16, 17) attempted to link specific nasal characteristics with total and regional particle deposition in the adult nose. They showed that nasal particle deposition efficiency for 2–6 μm was increased with decreased minimal cross-sectional area of the nasal passages and increasing ellipticity of the nostrils, with the latter being significantly greater in Caucasians than in African-Americans. Others have shown that the minimal cross-sectional area of the nasal passages is significantly larger in African-Americans than Caucasians as well (10). So the advantage of greater nasal contribution to breathing observed by us may be offset by a less efficient nasal filtering capacity in African-Americans. Differences in nasal efficiency associated with race require further study, especially for gaseous pollutants and conditioning of inspired air.

Our finding of lesser nasal contribution to breathing with exercise for men vs. women is likely due to the different ventilation rates (due to different workloads) at each level of exercise (Table 2). The regression analysis showed that, at each level of exercise, %nasal contribution to breathing was most significantly associated with V_{E}. From a risk assessment perspective, the men may be at greater risk (i.e., more susceptible) to inhalation of toxic gases and particles compared with women exercising at similar effort levels. On the other hand, when we matched workload (at ~50 W) and V_{E} between men and women, there was not a significant gender difference in nasal contribution to breathing. We also found no gender difference in nasal function (Table 2), which is supported by other measures of internal nasal structure as well (10).
A few models have incorporated values for nasal ventilation fractions to predict particle deposition in the lower respiratory tract (13, 20, 26). In each case, model inputs were based on the previous study of Niinimaa et al. (22) and do not take into account racial or gender differences discussed here. For example, the most recent International Commission on Radiological Protection model (13) incorporated fixed fractions of nasal ventilation for all adults, either “normal augmenters,” i.e., those who breathe nasally at rest, or “habitual mouth breathers,” depending on their type of activity (e.g., sleep, sitting, light exercise, and heavy exercise). For the light-exercise condition, normal augmenters and habitual mouth breathers were predicted to have a nasal ventilation fraction of 1.0 and 0.4, respectively. Our data (e.g., Figs. 2 and 3) may provide input of more realistic average nasal ventilation fractions in the adult population that will vary as a function of race and gender. For example, a comparison of the light-exercise condition (20% PWCmax) in African-Americans vs. Caucasians shows nasal fractions of 1.0 and 0.7 (Fig. 2) that can be used to predict respiratory tract deposition differences between these two groups. However, to be accurate, these models must also consider the relative scrabbling efficiency of the noses as a function of race and gender.

**Conclusion.** Like others, we have shown that the contribution of nasal breathing to \( V_e \) diminishes with increasing exercise effort. However, we have also found that nasal ventilation during exercise varies as a function of both race and gender. African-Americans have a greater nasal contribution to breathing during exercise than Caucasians. It may be that this inter racial difference is due to the former’s ability to achieve greater maximal flow rates through their nose, although this dependence requires further investigation. At relative exercise efforts (i.e., as a %maximum work capacity), the women also had a greater nasal contribution to breathing during exercise than men. This gender difference is explained by the fact that the women achieved lower \( V_e \) than men at a given percentage of their maximum work capacity. Because oral augmentation during exercise was shown to be a function of \( V_e \), the women did not need to augment their breathing orally until much later in their relative work effort. These racial and gender-related differences in route of breathing during exercise may be important for determining relative risks of individuals to environmental or occupational exposures of potentially toxic gases or particulate matter.

**DISCLOSURES**

This study was supported by US Environmental Protection Agency Cooperative Agreement 824915/829522.

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**REFERENCES**


