

## **SHORT REPORT**

# **Influence of gas density on simulated snoring**

G. Liistro, C. Veriter, D. Stanescu

*Influence of gas density on simulated snoring. G. Liistro, C. Veriter, D. Stanescu. ©ERS Journals Ltd 1999.*

**ABSTRACT:** According to a recent theoretical model, snoring is related to instability of the upper airway (UA). Factors promoting UA instability include increased gas density. The aim of this study was to test the influence of gas density on simulated snoring production and supraglottic resistance.

Supraglottic pressure and flow rate ( $V'$ ) were measured in 10 healthy seated subjects during simulated snoring. Subjects breathed three different gas mixtures: Helium–oxygen, He 79%–O<sub>2</sub> 21% (He–O<sub>2</sub>); air; and sulphur hexafluoride–oxygen, F<sub>6</sub>S 79%–O<sub>2</sub> 21% (F<sub>6</sub>S–O<sub>2</sub>) administered in a random order. Supraglottic resistance ( $R_{sg}$ ) was measured on its linear range during quiet breathing and  $V'$  was measured at the onset and middle of snoring.

Linear  $R_{sg}$  increased and  $V'$  conversely decreased with gas density. These data are in agreement with predictions of a mathematical model of the upper airway showing that snoring occurs at lower flow rates when gas density is increased.

*Eur Respir J 1999; 13: 679–681.*

Pulmonary Laboratory and Division, Cliniques Universitaires St-Luc, B-1200 Brussels, Belgium.

Correspondence: D. Stanescu, Pulmonary Laboratory and Division, Cliniques Universitaires St-Luc, Av Hippocrate 10, B-1200 Brussels, Belgium  
Fax: 32 27643703

Keywords: Airway physiology  
gas density  
snoring

Received: February 3 1998

Accepted after revision November 3 1998

Snoring is a cardinal symptom of obstructive sleep apnoea (OSA) syndrome and a frequent finding in otherwise healthy subjects [1]. Previous studies from the authors' laboratory have shown that simulated and spontaneous snoring are characterized by high-frequency oscillations of the soft palate associated with a decrease in oropharyngeal calibre. Reduction of the pharyngeal cross-sectional area increases supraglottic resistance ( $R_{sg}$ ) and is associated with flow limitation [2, 3].

The influence of gas density and viscosity on the upper airway (UA) pressure–flow relationship has not been studied before, except in animals [4].

Recently, GAVRIELY and JENSEN [5], based on a theoretical model of UA, found that among other factors, increases in UA resistance and gas density, as well as decrease in UA size promote UA instability and snoring.

In this study, the influence of gas density on supraglottic resistance and flow rate ( $V'$ ) was tested during quiet breathing and during simulated snoring.

## **Materials and methods**

Ten healthy (five females) nonsmoker subjects aged 22–30 yrs with normal spirometric data [6] and all nonobese (mean±SD body mass index, 32.4±2.9 kg·m<sup>-2</sup>), volunteered for this study. They were nonsnorers and free of any UA pathology. Written, informed consent was obtained and the experiments were approved by the Ethics Committee of the hospital.

$V'$  was measured with a Fleish No. 2 pneumotachograph (Fleisch, Lausanne, Switzerland), attached to a tightly fitting silicone face mask. Pressure drop across the pneumotachograph was measured by a ±5 cmH<sub>2</sub>O Validyne pressure transducer (Northridge, CA, USA). The airtightness of the mask was verified by measuring the helium level around

the border of the mask when the subjects were breathing a 79% He–21% O<sub>2</sub> mixture. The pneumotachograph was calibrated for the three gas mixtures: helium–oxygen, He 79%–O<sub>2</sub> 21% (He–O<sub>2</sub>); air; and sulphur hexafluoride–oxygen, F<sub>6</sub>S 79%–O<sub>2</sub> 21% (F<sub>6</sub>S–O<sub>2</sub>) by passing these gases through the pneumotachograph in series with a dry gasometer (Parkinson and Cowan CD4, Manchester, UK). An open-ended polyethylene catheter (2 mm i.d.) was placed through one nostril at the supraglottic level, 17 cm from the nares under local anaesthesia (lidocaine 10%). A similar catheter was placed into the mask at 3 cm from the nares. The proximal ends of both catheters were connected to the two sides of a differential pressure transducer (±5 cm H<sub>2</sub>O Validyne). The difference between supraglottic and mask pressure yielded supraglottic pressure ( $P_{sg}$ ). The pressure transducer was calibrated before each experiment by applying several gas pressures with a Fuess alcohol micro-manometer (Berlin, Germany). A large loudspeaker fixed to a Plexiglas box produced sinusoidal pressure oscillations. The pressure catheter, pneumotachograph and mask were connected to a port on the box. The phase angle between flow and pressure signals was <5° up to 90 Hz after adjusting the length of tubing.

The subjects were seated, the supraglottic catheter was placed and the face mask was adjusted. The pneumotachograph was connected to a two-way respiratory valve which permitted either connection to room air or to a bag containing one of the three gas mixtures. The subject's head was maintained in a "neutral" position, with the gaze parallel to the floor. Nasal breathing was avoided with a noseclip. He–O<sub>2</sub>, air, and F<sub>6</sub>S–O<sub>2</sub> were given in a random order. Subjects did not know the order of administration of gas mixtures. To wash out the previous gas mixture subjects were asked to perform three slow vital capacity manoeuvres, followed by 10 quiet breaths while breathing one of the three gas mixtures. Thereafter, they were asked

Table 1. – Density and viscosity of the three gas mixtures

Gas mixture [Ref.]	Density at 25°C g·L <sup>-1</sup>	Viscosity at 25°C μN·s·m <sup>-2</sup>
He–O <sub>2</sub> [7]	0.40	21.6
Air [7]	1.18	18.4
F <sub>6</sub> S–O <sub>2</sub> [8]	4.99	16.0

to simulate snoring during inspiration through the mouth. At least 10 snores were recorded while breathing each gas mixture.  $P_{sg}$  and  $V'$  were simultaneously recorded on tape (Teac R81 recorder; Tokyo, Japan).  $R_{sg}$  was calculated by dividing  $P_{sg}$  by  $V'$  and was measured on the quasilinear portion of the  $P_{sg}/V'$  relationship, *i.e.* between 0 and 0.2 L·s<sup>-1</sup> inspiratory flow, recorded on an x–y analogue plotter. To avoid any change in gas density and viscosity due to carbon dioxide and water vapour during expiration, only inspiration was studied.

Flow was measured just before the start of snoring (*i.e.* just before the  $V'$  and  $P_{sg}$  oscillations). Average flow during snoring was measured from  $V'$  versus time records. A best-fit line through the middle of  $V'$  oscillations was drawn and average flow was measured at the middle point of duration of snoring. The occurrence of flow limitations was also examined. Flow limitation was defined as a constant or decrease in inspiratory  $V'$  despite an increase in or respectively constant  $P_{sg}$ .

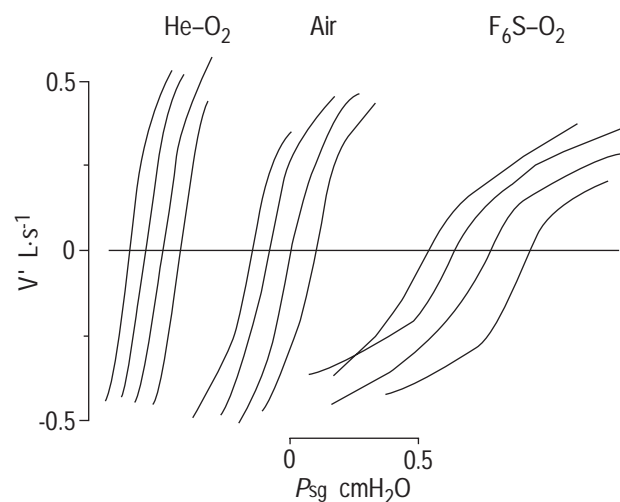
$R_{sg}$  and  $V'$  were averaged from 10 consecutive traces. Variables were compared using a two-way Wilcoxon–Wilcoxon nonparametric test for multiple comparisons of correlated samples. A p-value <0.05 was considered significant.

## Results

Table 1 shows the density and viscosity of the three gas mixtures. Table 2 presents average values of linear  $R_{sg}$  and  $V'$  just before the start and at the middle of snoring for the three gas mixtures. Average linear  $R_{sg}$  increased significantly with gas density from  $0.5 \pm 0.37$  during He–O<sub>2</sub> breathing to  $0.65 \pm 0.47$  during air and to  $1.18 \pm 0.63$  cm-H<sub>2</sub>O·L<sup>-1</sup>·s<sup>-1</sup> during F<sub>6</sub>S–O<sub>2</sub>. Differences between He–O<sub>2</sub> and air, air and F<sub>6</sub>S–O<sub>2</sub>, and He–O<sub>2</sub> versus F<sub>6</sub>S–O<sub>2</sub> were all statistically significant (p<0.05). Average  $V'$  measured just before the start of snoring as well as  $V'$  at the middle of snoring decreased as gas density increased. All differences were significant except  $V'$  between air and F<sub>6</sub>S–O<sub>2</sub> (before snoring). During F<sub>6</sub>S–O<sub>2</sub> breathing, some subjects experienced dizziness, which resolved rapidly after returning to air breathing.

Table 2. – Average values of linear supraglottic resistance ( $R_{sg}$ ) and flow ( $V'$ ) before and at mid-snoring

	Linear $R_{sg}$ cmH <sub>2</sub> O·L <sup>-1</sup> ·s				$V'$ before snoring L·s <sup>-1</sup>				$V'$ mid-snoring L·s <sup>-1</sup>			
	He–O <sub>2</sub>	Air	F <sub>6</sub> S–O <sub>2</sub>	p-value	He–O <sub>2</sub>	Air	F <sub>6</sub> S–O <sub>2</sub>	p-value	He–O <sub>2</sub>	Air	F <sub>6</sub> S–O <sub>2</sub>	p-value
Means <sub>SD</sub>	0.50	0.65	1.18		1.19	1.00	0.73		1.26	1.06	0.70	
SD	0.37	0.47	0.63		0.65	0.61	0.59		0.63	0.44	0.41	
He–O <sub>2</sub> vs air				0.009				0.005				0.041
Air vs F <sub>6</sub> S–O <sub>2</sub>				0.005				0.059				0.012
He–O <sub>2</sub> vs F <sub>6</sub> S–O <sub>2</sub>				0.005				0.028				0.013

Fig. 1. – Supraglottic pressure–flow ( $P_{sg}$ – $V'$ ) curves in a volunteer during quiet breathing of He–O<sub>2</sub>, air and F<sub>6</sub>S–O<sub>2</sub> (redrawn from original sequential tracings).

During quiet breathing, the  $P_{sg}$  versus  $V'$  relationship was S-shaped, *i.e.* linear at flow rates <0.2 L·s<sup>-1</sup> and curvilinear at higher inspiratory  $V'$  (fig. 1). Snoring was preceded in all subjects by an increase of the curvilinearity of the  $P_{sg}$ – $V'$  relationship with respect to quiet breathing. For the group as a whole, flow limitation preceded 12% of inspiratory snores.

## Discussion

It was found that during quiet breathing, an increase in the density of inspired gas results in an increase in supraglottic resistance. During snoring, decrease of gas density was associated with increase of flow rate.

An increase in  $R_{sg}$  with gas density was previously reported in anaesthetized dogs during quiet breathing [4], but not in humans. The present data confirm previous results in animals [4] and are in agreement with predictions of aerodynamic theory [9]. The resistance to gas flow depends on airway geometry,  $V'$ , gas density, and gas viscosity. The relative contribution of density and viscosity to resistance depends on the flow regimen. Airway resistance increases with gas viscosity at low Reynolds' numbers, *i.e.* when  $V'$  is laminar. Conversely, airway resistance in a turbulent  $V'$  regimen is proportional to gas density. It is considered that UA is characterized by a fully turbulent or a transitional  $V'$  [10]. Therefore, the contribution of gas

density is expected to exceed that of viscosity. This is confirmed by the present data: linear  $R_{sg}$  increased with gas density but not with gas viscosity.

There was a large interindividual variability of  $R_{sg}$  and  $V'$  values. Scatter of  $R_{sg}$  values is well-known and has been reported by other groups [11].

Sleep is associated with an increased UA resistance. This has been reported in healthy subjects [12], as well as in heavy snorers [2] and OSA patients [2, 13]. Inspiratory flow limitation during quiet breathing and snoring has been found in apnoeic and nonapnoeic snorers during sleep [2, 13]. These changes have been attributed to a sleep-related decrease in muscle tone resulting in reduction of the cross-sectional area of UA. In the present study as well in a previous one [3], flow limitation was not a prerequisite for simulated snoring. Why is there  $V'$  limitation during spontaneous snoring but not during simulated snoring? During simulated snoring, activation of UA muscles increases wall stiffness and stabilizes the airway, preventing flow limitation. This is in agreement with the model of GROTBORG and GAVRIELY [14] on flutter generation in collapsible tubes.

Recently, GAVRIELY and JENSEN [5] in a mathematical model of snoring generation emphasized different factors facilitating snoring. In their model, a decrease in airway calibre, as well as increases in inspiratory flow, UA compliance, resistance and gas density promote instability of the airway and result in snoring production. The model also predicts that an increase in gas density decreases  $V'$  required to produce snoring. The present data agree with these predictions. Their model also predicts a complete collapse of the airway during snoring. However, in a figure included in this work [5], flow rate during simulated snoring was not shown to reach zero flow. Furthermore, UA closure during either simulated or spontaneous snoring has not been shown using both fibroscopy and cineradiography [2, 3].

In conclusion, it was found that during simulated snoring, the flow rate (preceding snoring, as well as during snoring) decreased with gas density. During quiet breathing, linear supraglottic resistance increased with gas density.

## References

1. Lugaresi E, Cirignotta F, Coccagna G, *et al.* Clinical significance of snoring. *In: Saunders N, Sullivan C, eds. Sleep and Breathing.* New York, Marcel Dekker, 1984; pp. 283–298.
2. Liistro G, Stanescu DC, Veriter C, Rodenstein DO, Aubert Tulkens G. Pattern of snoring in obstructive sleep apnea patients and in heavy snorers. *Sleep* 1991; 14: 517–525.
3. Liistro G, Stanescu D, Veriter C. Pattern of simulated snoring is different through mouth and nose. *J Appl Physiol* 1991; 70: 2736–2741.
4. Series F, Series I, Atton L, Blouin A. Influence of airway resistance on hypoxia-induced periodic breathing. *J Appl Physiol* 1992; 72: 2128–2133.
5. Gavriely N, Jensen O. Theory and measurements of snores. *J Appl Physiol* 1993; 74: 2828–2837.
6. Jouasset D. Normalisation des epreuves fonctionnelles respiratoires dans les pays de la C.E.C.A. *Poumon Coeur* 1960; 16: 1145–1159.
7. Johns DP, Pretto JJ, Stretton JA. Measurement of gas viscosity with a Fleisch pneumotachograph. *J Appl Physiol* 1982; 53: 290–293.
8. Anonymous. Sulfur hexafluoride  $F_6S$ . *Gas encyclopaedia.* Amsterdam, Elsevier, 1976; p. 863.
9. Drazen JM, Loring SH, Ingram RH Jr. Distribution of pulmonary resistance: effects of gas density, viscosity, and flow rate. *J Appl Physiol* 1976; 41: 388–395.
10. Ferris BGJ, Mead J, Opie LH. Partitioning of respiratory flow resistance in man. *J Appl Physiol* 1964; 19: 653–658.
11. White DP, Lombard RM, Cadieux RJ, Zwillich CW. Pharyngeal resistance in normal humans: influence of gender, age, and obesity. *J Appl Physiol* 1985; 58: 365–371.
12. Hudgel DW, Hendricks C, Hamilton HB. Characteristics of the upper airway pressure–flow relationship during sleep. *J Appl Physiol* 1988; 64: 1930–1935.
13. Smith PL, Wise RA, Gold AR, Schwartz AR, Permutt S. Upper airway pressure–flow relationships in obstructive sleep apnea. *J Appl Physiol* 1988; 64: 789–795.
14. Grothberg JB, Gavriely N. Flutter in collapsible tubes: a theoretical model of wheezes. *J Appl Physiol* 1989; 66: 2262–2273.