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Older individuals have increased oro-nasal breathing during sleep

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Older individuals have increased oro-nasal breathing during sleep. M.R. Madronio, E. Di Somma, R. Stavrinou, J.P. Kirkness, E. Goldfinch, J.R. Wheatley, T.C. Amis. ©ERS Journals Ltd 2004.

ABSTRACT: Breathing route during sleep has been studied very little, however, it has potential importance in the pathophysiology of sleep disordered breathing.

Using overnight polysomnography, with separate nasal and oral thermocouple probes, data were obtained from 41 subjects (snorers and nonsnorers; 25 male and 16 female; aged 20–66 yrs). Awake, upright, inspiratory nasal resistance (Rn) was measured using posterior rhinomanometry. Each 30-s sleep epoch (not affected by apnoeas/hypopnoeas) was scored for presence of nasal and/or oral breathing.

Overnight, seven subjects breathed nasally, one subject oro-nasally and the remainder switched between nasal and oro-nasal breathing. Oral-only breathing rarely occurred. Nasal breathing epochs were 55.79 (69.78) per cent of total sleep epochs (%TSE; median (interquartile range)), a value not significantly different to that for oro-nasal (TSE: 44.21 (68.66)%). Oro-nasal breathing was not related to snoring, sleep stage, posture, body mass index, height, weight, Rn (2.19 (1.77) cm $H_2O \cdot L^{-1} \cdot sec^{-1}$) or sex, but was positively associated with age. Subjects ⩾40 yrs were approximately six times more likely than younger subjects to spend >50% of sleep epochs utilising oro-nasal breathing.

Ageing is associated with an increasing occurrence of oro-nasal breathing during sleep.

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During wakefulness, changes in breathing route (*i.e.* nasal *versus* oral breathing) are most notably associated with oral augmentation of breathing during exercise. However, breathing *via* the nose or mouth, or a combination of both, is also encountered during sleep [1]. Furthermore, the breathing route may be a contributing factor in the occurrence of sleep disordered breathing (SDB). For example, it has been reported that subjects with more mouth breathing during sleep tend to experience more episodes of apnoea than those with predominantly nasal breathing [1]. In addition, nasal obstruction, which may predispose to mouth breathing, has also been linked to SDB [2]. Theoretically, a high nasal resistance should be associated with lower intraluminal pressures during inspiration, thus favouring upper airway narrowing and/or collapse. Switching breathing route from nasal to oral or oro-nasal may help to ameliorate this effect since, depending on the degree the mouth is opened, oral airway resistance can be lowered to values well below that of the nasal passages [3]. However, a switch to oral route breathing may, in itself, predispose the upper airway to collapse since a number of upper airway muscles have route-dependent respiratory-related activity [4–6]. MEURICE *et al.* [7] have also reported that opening the mouth during sleep increases upper airway collapsibility, while breathing through the mouth also has the potential to dry the upper airway mucosa, enhancing collapsibility and increasing adhesive effects [8].

There have been only two previous quantitative studies of breathing route during sleep, both using a partitioned face mask and pneumotachographs. In a study of 14 subjects, GLEESON *et al.* [1] found that, during sleep, older males breathed a greater proportion of total ventilation *via* the mouth than females and younger males. More recently, FITZPATRICK *et al.* [9] studied 10 healthy subjects (all with normal levels of awake nasal resistance values) and found an inhaled ventilation oral fraction of ∼4% during sleep. In the present study, the authors aimed to document breathing route usage during sleep in a larger group of nonsnorers and snorers of both sexes and to examine the relationship between breathing route during sleep and a range of anthropometric and sleep-related parameters.

Materials and methods

Study subjects

Breathing route during sleep was monitored in 43 adult subjects who volunteered for polysomnographic studies of breathing and/or snoring during sleep. In the course of the study, two subjects were diagnosed with obstructive sleep apnoea and were excluded, leaving 41 subjects for analysis. Seventeen of these subjects reported a history of habitual snoring. Anthropometric data, including age, height, weight, body mass index (BMI), ethnic origin and sex were obtained for all subjects. The study was approved by the Western Sydney Area Health Service Human Ethics Committee.

Study design

Breathing route data during sleep were obtained for each subject from a single overnight polysomnographic study performed in a sleep laboratory (refer to Polysomnography section). Inspiratory nasal airflow resistance (Rn: 0.4 $L \cdot sec^{-1}$) in the upright seated posture was also measured during wakefulness in each subject within 24 h of the sleep study (refer to Nasal resistance section). Relationships between the occurrence of nasal, oral or oro-nasal breathing during sleep and anthropometric factors, Rn and polysomnographic variables were then examined using statistical modelling techniques (refer to Data analysis section).

Polysomnography

Routine sleep variables were recorded using standard polysomnography. Data recorded included: electro-encephalogram; electrocardiogram; electrooculogram; submental and diaphragmatical electromyograms; arterial oxygen saturation; impedance plethysmography (P/N 7000-0049-00; Compumedics, Abbotsford, Australia); body position; and nasal pressure (1600 Nasal Cannula; Salter Labs Inc., Arvin, CA, USA). The tip of the nasal cannula was modified for each study by clipping 3 mm from the tip to increase the cross-sectional area for detection of nasal pressure. The nasal cannula was inserted in the opening of the nostrils.

Breathing route was recorded using a dual-channel nasal/oral thermocouple (F-ONT2A; Grass, West Warwick RI, USA). The thermocouple was placed on top of the nasal cannula and both were taped to the sides of the face to minimise movement during sleep. Snoring was recorded using either a microphone (NL-05 Type 2; RION Co., Ltd, Tokyo, Japan) suspended 20 cm directly above the subject's mouth or an external tracheal microphone (P/N 7002-0017-03; Compumedics) attached directly to the right side of the subject's neck. All monitored parameters were recorded directly on a computer using proprietary software (W Series, V2; Compumedics). There was no cross-contamination between the oral and nasal thermocouple signals, as confirmed by having each subject perform short periods (five breaths) of exclusive nasal and exclusive oral breathing in the supine and right lateral postures immediately prior to lights out.

Nasal resistance

For each subject, Rn was measured during wakefulness in the upright, seated posture using standard posterior rhinomanometry [10] within 24 h of polysomnography.

Data analysis

Each sleep study was sleep staged for 30-s epochs using RECHSHTAFFEN and KALES [11] criteria. Respiratory events (respiratory disturbance index (RDI): number of apnoeas plus the number of hypopnoeas per hour of sleep) were identified using American Academy of Sleep Medicine criteria [12]. Epochs containing such events, as well as arousals, movements or signal artefacts were excluded from analysis (0–14% of total epochs for individuals). Route of breathing was assessed by using the nasal and oral thermocouple signals to classify each 30-s epoch as either a nasal, oral or oro-nasal breathing epoch. Nasal breathing epochs were defined as epochs containing $\geqslant 3$ consecutive phasic signals on the nasal thermocouple channel only. Oral breathing epochs were defined as epochs containing $\geqslant 3$ consecutive phasic signals on the oral thermocouple channel only. Oro-nasal breathing epochs contained $\geqslant 3$ consecutive phase linked signals on both the nasal and oral thermocouple channels. Each epoch was also classified as either a nonsnoring epoch or a snoring epoch. Snoring epochs were defined as epochs containing $\geqslant 3$ consecutive sound peaks in phase with inspiration (determined using the P-nasal signal) and with a peak amplitude of $\geqslant 5$ dB above the background sound level (~39–50 dB for individual study nights).

The occurrence of nasal breathing, oral breathing, oro-nasal breathing and snoring epochs was expressed as a percentage of the total sleep epochs (TSE) analysed. Similar data were generated for sleep stage and body position. Data for left and right lateral decubitus were combined. Minimal data were obtained for the prone posture, consequently, this body position was not included in the analysis.

Frequency histograms were developed for each measured parameter. Data were also expressed as a median and interquartile range (IR). Very little oral-only breathing (0–0.04%TSE for individuals; refer to Results section) was detected, consequently, these data were not included in any further analyses. Data were compared using the Wilcoxon signed rank test. Analysis of the relationship between breathing route and other measured parameters was expressed in terms of their association with the occurrence of oro-nasal breathing epochs (%TSE). Because of the relative absence of oral-only breathing, results for nasal-only breathing were the reverse of those for oro-nasal breathing. Statistical modelling was performed in a three-stage procedure. First, correlative analyses (Pearson's correlation coefficient, r) were performed to search for significant univariate relationships. Stepwise multivariate regression analysis was then used to test for independent relationships. Logistic regression analysis was also used to examine the extent to which age $\geqslant 40$ yrs predicted the occurrence of oro-nasal breathing epochs during sleep. A p-value of <0.05 was considered significant.

Results

Anthropometric data

Figure 1a–d summarises the anthropometric characteristics of the study cohort that contained 35 persons of White ethnic origin, six persons of Asian ethnic origin, 25 males and 16 females.

Nasal resistance

For the group (n=39), awake inspiratory Rn was 2.2 (1.8) cm $H_2O \cdot L^{-1} \cdot sec^{-1}$ with values ranging 0.6–6.8 cm $H_2O \cdot L^{-1} \cdot sec^{-1}$ (fig. 1e).

Polysomnographic variables

Frequency distribution histograms for polysomnographic variables *versus* number of subjects are shown in figure 1f–l. Most subjects slept reasonably well, with total sleep time ranging 148.5–386.5 min. For the group, 2.9 (4.4) %TSE was spent in nonrepetative eye movement (NREM) Stage I sleep; 57.9 (18.0) %TSE in NREM Stage II; 12.6 (7.8) %TSE in NREM Stage III; 6.4 (13.2) %TSE in NREM Stage IV; and 15.3 (10.5) %TSE in repetitive eye movement sleep. Sleep time was equally divided between the supine (45.9 (45.3) %TSE) and lateral body positions (41.2 (48.0) %TSE; p=0.51). Snoring sounds were detected in 27 subjects (fig. 1l). All subjects had an RDI $<10 \cdot h^{-1}$.

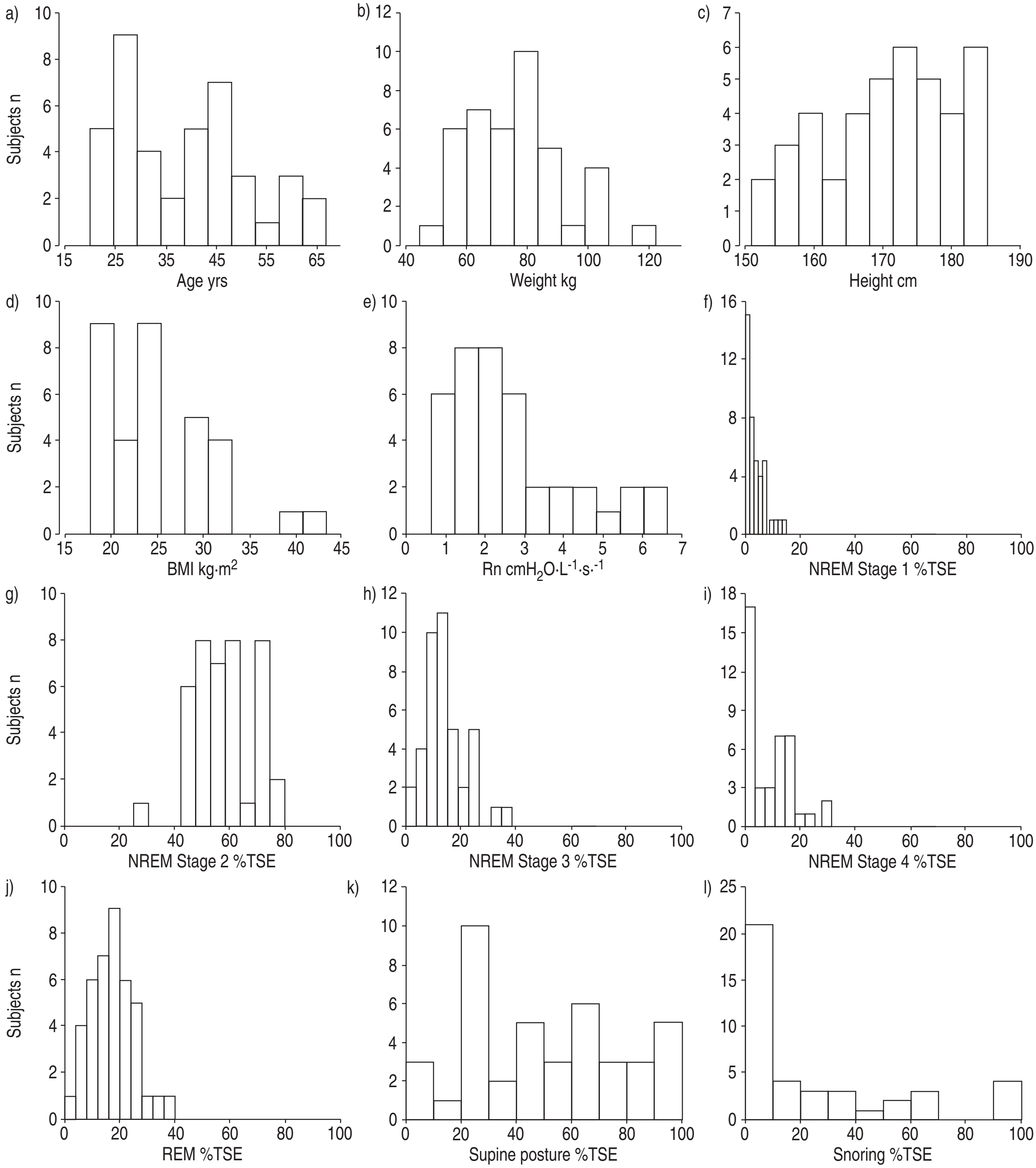

Fig. 1. – Frequency distribution histograms in 41 subjects for a–d) anthropometric factors, e) nasal resistance, f–j) sleep architecture, k) supine sleep posture and l) occurrence of snoring epochs. Note the frequency distribution histogram for lateral posture is the exact reverse of that for the supine posture and is not shown. TSE: total sleep epochs; Rn: nasal resistance at 0.4 $L \cdot s^{-1}$; BMI: body mass index; REM: rapid eye movement sleep; NREM: nonrapid eye movement sleep.

Breathing route during sleep

Figure 2 shows the raw data demonstrating nasal and oro-nasal breathing signals during different periods of NREM sleep in one subject. Figure 3a–c summarises the occurrence of nasal, oral and oro-nasal breathing epochs for the group. During sleep, 11 subjects breathed exclusively or almost exclusively *via* the nasal route throughout the night, while six subjects breathed exclusively or almost exclusively oro-nasally all night. The remaining subjects switched their breathing route between nasal-only breathing and oro-nasal breathing throughout the night. There was no fixed pattern associated

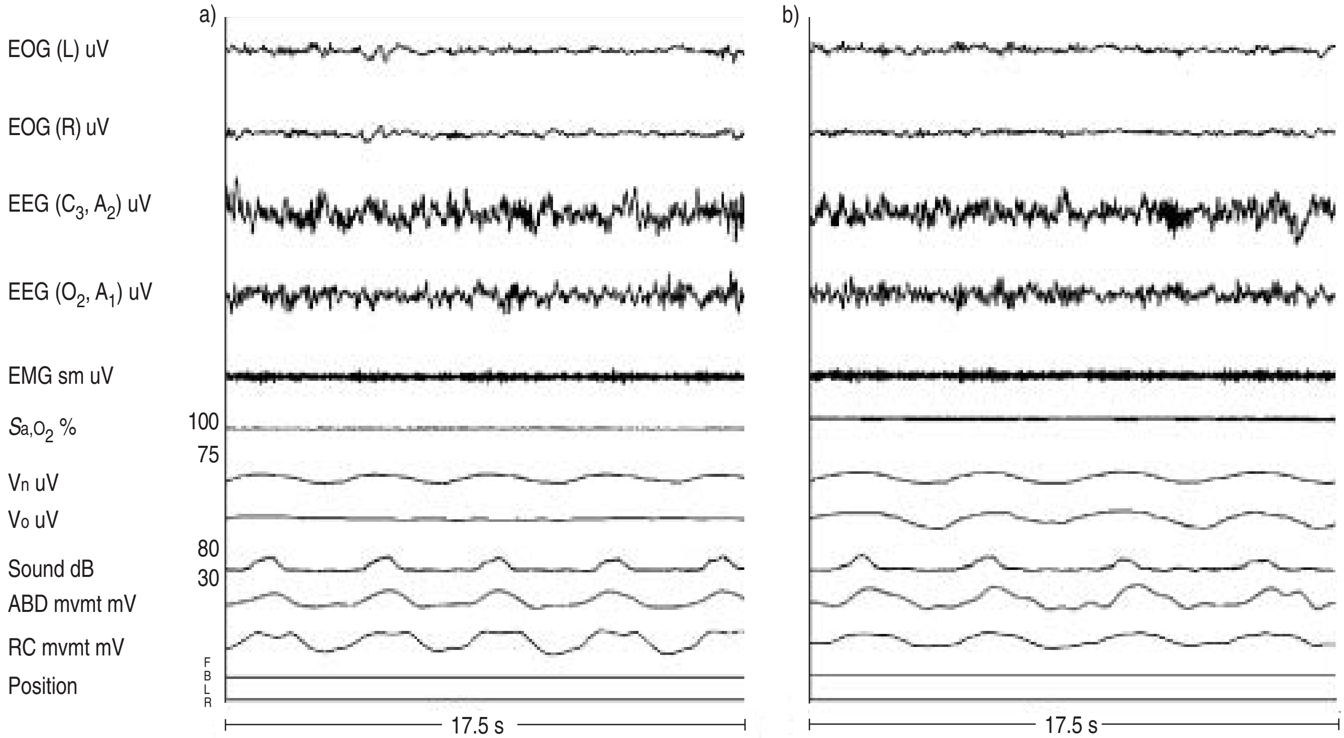

Fig. 2. – Raw data recorded during nonrapid eye movement sleep in the supine posture in one subject during a) nasal-only breathing and during b) oro-nasal breathing. Note that snoring occurs during both nasal-only breathing and oro-nasal breathing. EOG: electrooculogram; L: left; R: right; EEG: electroencephalogram; EMG sm: submental electromyogram; S_{a,O_2}: arterial oxygen saturation; Vn: nasal airflow; Vo: oral airflow (thermocouple); Sound: microphone; ABD mvmt: abdominal movement (impedance plethysmography); RC mvmt: chest movement (impedance plethysmography); Position: body position; F: front; B: back. Inspiration is upwards in Vn, Vo, ABD and RC mvmt. EEG electrodes named according to position: C: central; O: occipital; A: auricular; even number: right side; odd number: left side.

with breathing route changes with considerable intra- and inter-subject variability in the duration (every few minutes to ~20–40-min intervals) of nasal or oro-nasal breathing periods before a switch to the alternate pattern was initiated. Exclusive oral breathing was rare, occurring in only three subjects (0.003–0.04 %TSE). Indeed, of the 26,498 epochs classified for breathing route, only 27 of these were oral-only breathing epochs. For the group, the occurrence of nasal breathing (55.8 (69.8) %TSE) was not significantly different to that for oro-nasal breathing (44.21 (68.66) %TSE; p=0.14).

Breathing route during snoring

Both nasal and oro-nasal breathing occurred during snoring epochs (fig. 2), however, the relative occurrence rates varied widely for individuals. For the group, 56.5 (80.7) % of snoring epochs were also oro-nasal breathing epochs.

Univariate analysis

When the data were examined for univariate relationships, the occurrence of oro-nasal breathing epochs during sleep (*i.e.* oro-nasal breathing epochs %TSE) correlated positively with age ($r=0.42$; $p<0.01$) and BMI ($r=0.33$; $p=0.03$), tended to correlate positively with the occurrence of snoring epochs ($r=0.29$; $p=0.06$), and correlated negatively with the occurrence of nonsnoring epochs ($r=-0.34$; $p=0.03$).

Multivariate regression analysis

Stepwise multivariate regression analysis revealed that the only independent predictor for the occurrence of oro-nasal breathing epochs during sleep was age (oro-nasal breathing epochs: %TSE=1.17 yrs -2.71; adjusted $r^2=0.15$; $p<0.01$; fig. 4).

Logistic regression analysis

Table 1 shows the occurrence of oro-nasal breathing epochs > and <50 %TSE for subjects with age ⩾40 yrs and <40 yrs. Logistic regression analysis confirmed that an age of ⩾40 yrs was a significant predictor for an occurrence of >50 %TSE for oro-nasal breathing epochs during sleep ($p=0.01$; odds ratio=5.8; 95% CI: 1.5–22).

Discussion

The major finding in this study was that snorers and nonsnorers utilised both nasal and oro-nasal breathing during sleep. Furthermore, most subjects used nasal breathing throughout the night, but added oral breathing intermittently, such that, for the group, the occurrence of oro-nasal breathing sleep epochs was not significantly different to that for nasal-only breathing. Pure oral breathing during sleep occurred rarely. Snoring occurred with both nasal and oro-nasal breathing. Age was the only independent predictor for

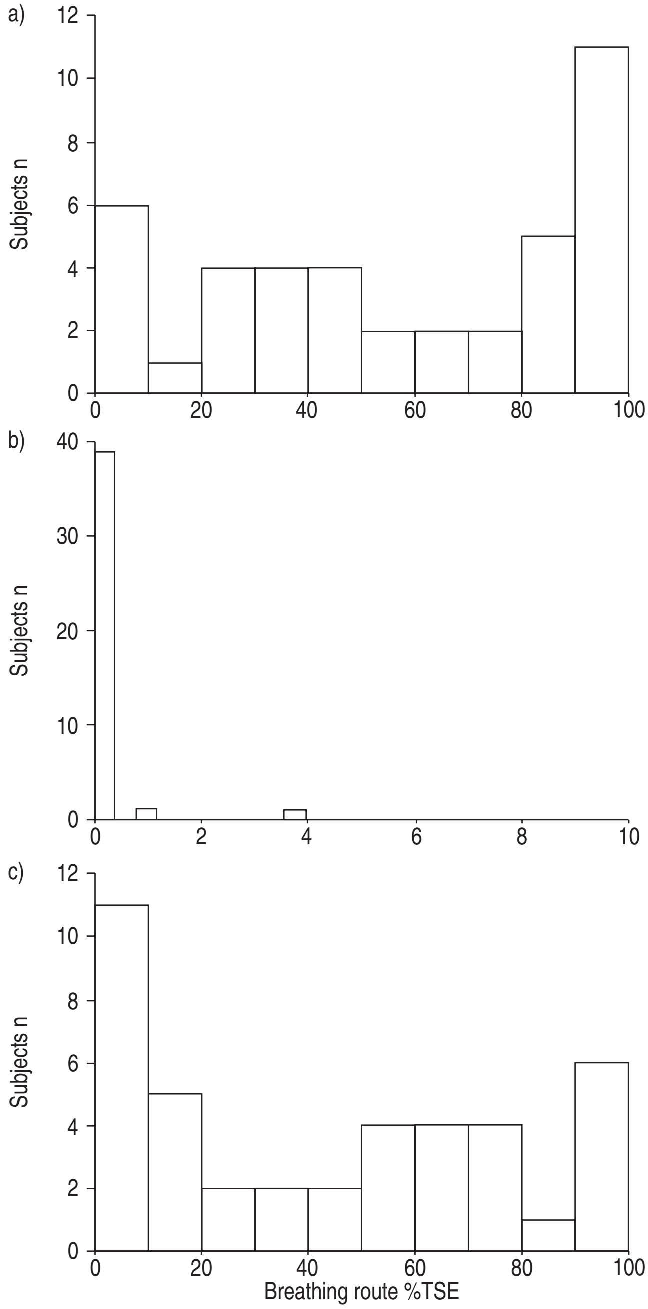

Fig. 3. – Frequency distribution histograms for a) occurrence of nasal-only, b) oral-only and c) oro-nasal breathing epochs during sleep in 41 subjects. TSE: total sleep epochs.

breathing route during sleep. Subjects ⩾40 yrs of age were approximately six times more likely than younger subjects to spend >50% of the night utilising oro-nasal breathing.

The authors monitored breathing routes using a dual channel thermocouple device that sensed nasal and oral airflow separately. Such devices have been used extensively for monitoring airflow during sleep [13–15]. Potential disadvantages associated with the use of these devices include failure to sample airflow adequately because of inappropriate positioning of sensors or dislodgment during sleep, cross-contamination from the alternate pathway, and poor sensitivity to changes in airflow because of nonlinear response characteristics [15]. In the present study, the thermocouple leads were supported by hooking them behind the ears and taping them to the subject's cheeks. The absence of cross-contamination was verified at the commencement of each study by having the subject voluntarily breathe *via* the nasal and oral routes separately and ensuring that no signal was detected for the opposite route. Changes in sensor position during the night, however, remain a potential complication.

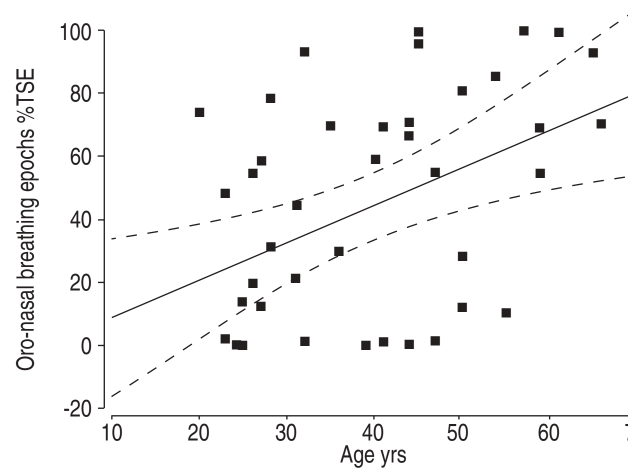

Fig. 4. – Relationship between age and occurrence of oro-nasal breathing epochs during sleep. ——: regression line; - - -: 95% CI limits for prediction equation.

It is well established that thermocouple devices have limitations for the detection of airflow because of their nonlinear response characteristics [12]. However, the principal problem here is poor sensitivity to changes in airflow at higher airflows [15]. In fact, these devices have high sensitivity for detecting the presence (or absence) of airflow [14]. Thermocouple signals were used in the present study only for this latter purpose and no attempt was made to quantitate the level of airflow present. Thermal-based devices for the detection of respiratory airflow sense changes in temperature associated with exposure to inhaled or exhaled gas. Therefore, should inspiration and expiration take place *via* different breathing routes the interpretation of a thermocouple signal as representing breathing *via* a single route may be confounded. Thus, in the context of the present study, breathing patterns that involved, for example, inhalation *via* the nose and exhalation *via* the mouth, would be classified as oro-nasal breathing if a nasal and oral route signal was present or oral only if there were only an oral signal. This latter possibility is unlikely since oral-only breathing was encountered rarely. The former pattern, however, would have been included in the present occurrence rate for oro-nasal breathing.

Instrumentation with nasal cannulae has been shown to increase nasal resistance in some individuals, particularly those with a high baseline nasal resistance [16]. Consequently, it is possible that the breathing route in the present study was

Table 1. – Subject age and occurrence of oro-nasal breathing epochs during sleep

Oro-nasal breathing epochs %TSE	Number of subjects n	
	Age <40 yrs	Age ⩾40 yrs
⩽50%	16	6
>50%	6	13
Total number of subjects	22	19

%TSE: per cent total sleep epochs.

influenced by the presence of the nasal pressure cannulae and thermocouple probes. However, this would seem unlikely in the current study's subject group since baseline nasal resistance did not emerge as a significant predictor of breathing route during sleep.

The present authors found that most subjects used the nasal route for breathing while asleep, either exclusively or in combination with oral breathing. These findings are in general agreement with other studies on this topic [1, 9], using a dual compartment face mask with attached pneumotachographs to monitor nasal and oral airflow during sleep. While the authors have demonstrated an ~44 %TSE occurrence of oro-nasal breathing during sleep, findings reported by FITZPATRICK *et al.* [9] suggest that the magnitude of the oral fraction of minute ventilation associated with this pattern of breathing may be relatively small (~4 %), *i.e.* although oro-nasal breathing occurs frequently during sleep most of the minute ventilation remains *via* the nasal route. In the study by GLEESON *et al.* [1] they found that nasal breathing always contributed a minimum of one third of the total ventilation during sleep but the contribution of oral breathing varied. GLEESON *et al.* [1] did not observe any oral-only breathing. Since their subjects were encumbered by a face mask the issue remains as to the extent to which this instrumentation altered the breathing route. However, the present study has now demonstrated a similar finding based on the occurrence of nasal and oro-nasal breathing epochs, and achieved this without instrumentation of the face, beyond the attachment of sensors to the skin.

The current authors were interested in examining what factors might be associated with the oral augmentation of nasal breathing during sleep and, therefore, analysed the current data for significant associations between both anthropometrical and polysomnographical variables, and the occurrence of oro-nasal breathing epochs. Positive univariate relationships were found between oro-nasal breathing epochs during sleep and both age and BMI, while a negative association with nonsnoring epochs, and a borderline significant positive association with snoring epochs, were also demonstrated. Weight and height, each considered separately, and ethnic origin (White or Asian), together with sleep stage and sleeping posture (back *versus* side) all showed no association with breathing route. Multivariate regression analysis demonstrated that age was the only identified independent predictor of oro-nasal breathing during sleep. The univariate associations with BMI and nonsnoring reflected the tendency for older individuals in the current study's cohort to have higher levels of BMI and for younger individuals not to snore. The association between age and oro-nasal breathing explained only ~15% of the variance. Consequently, while there was a significant positive association between age and oro-nasal breathing during sleep, the effect was relatively weak and clearly there must be other influences that were not measured in the present study. Nevertheless, the relationship demonstrated in fig. 4 predicts an increase in the occurrence of oro-nasal breathing epochs during sleep of ~1 %TSE for each age year.

In the study by GLEESON *et al.* [1], a much stronger positive correlation ($r=0.83$) between oral breathing during sleep and age in males only was found. While differences in correlation strength between the two studies might reflect differences in study size and subject characteristics, in the present study sex was not associated with breathing route during sleep. This discrepancy between the two studies may relate to the fact that the study by GLEESON *et al.* [1] contained only seven males and seven females and had a wider range of ages and more individuals >40 yrs of age in the male group than in the female group. Since multivariate analysis was not performed in the study by GLEESON *et al.* [1] this finding may, in fact, reflect an age, rather than a sex effect.

The mechanisms linking age and oro-nasal breathing during sleep are not known. GLEESON *et al.* [1] suggested that the effect may be related to an increased Rn in males. However, in the present study there was no association between awake Rn values and breathing route during sleep. The median value for inspiratory Rn in the present study group was 2.19 cm $H_2O \cdot L^{-1} \cdot sec^{-1}$, a value within the normal range for the current authors' laboratory. The lack of a relationship between Rn and breathing route would, however, not be likely to apply at high Rn levels. In addition, Rn in the upright posture and during wakefulness was measured and this value may not be reflective of that occurring in the supine posture and during sleep. However, for subjects with a relatively normal Rn, breathing route during sleep is not predicted by awake upright Rn. Therefore, Rn does not appear to explain the relationship between breathing route and age, and other mechanisms must play a role. Such effects might include ageing effects on jaw and upper airway muscle activity during sleep and/or loss of skeletal muscle strength. It should be noted, however, that the relationship is weak and clearly there are other factors involved that are not (at least not tightly) related to age.

Mouth opening during sleep has been associated with increased upper airway collapsibility even in healthy subjects [7]. This effect is thought to be mediated *via* a combination of upper airway narrowing and decreased efficiency of upper airway dilator muscle action [7]. In the present study the occurrence of snoring epochs tended to correlate with the occurrence of oro-nasal breathing epochs, while there was a negative relationship between nonsnoring epochs and oro-nasal breathing (*i.e.* absence of snoring was associated with the absence of oro-nasal breathing). However, both these relationships were not significant when corrected for the effect of age and, thus, probably reflect a tendency for the snorers to be older than the nonsnorers.

Mouth breathing and snoring have been previously linked temporally and an association between the two postulated [1]. However, it has also been recognised for some time that both nasal and oro-nasal snores occur [17]. The present study suggests that oro-nasal breathing is not a prerequisite for snoring and that while the occurrence of oro-nasal and nasal snoring varies widely between individuals, on a group basis, nasal and oro-nasal snoring occur with approximately equal frequency.

The presence of snoring in the current study's subjects suggests that some breaths may have been characterised by inspiratory flow limitation (IFL) and increased upper airway resistance (UAR). The extent to which this occurred was not assessed in the present study. However, the lack of a demonstrated relationship between snoring and breathing route makes it unlikely that IFL or UAR influenced breathing route in the study's subjects since the snoring epochs are more likely to be characterised by IFL and increased UAR.

This study, along with previous investigations [9, 16], demonstrates that the oral breathing route is utilised during sleep in some subjects. Consequently, the use of nasal breathing monitoring (*e.g.* P-nasal) alone to monitor sleep disordered breathing may be potentially confounded by the occurrence of oral route breathing.

To summarise, the authors demonstrated that snoring and nonsnoring subjects utilise both nasal and oro-nasal, but rarely oral-only, breathing during sleep. The occurrence of oro-nasal breathing sleep epochs increases with increasing age and is not related to: sex; White or Asian ethnic origin; height; weight; body mass index; awake nasal resistance (within the normal range); sleep stage; sleeping position or the occurrence of snoring. The authors conclude that ageing is associated with an increased oro- nasal breathing during sleep.

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