Obstructive sleep apnoea is a common disorder characterised by recurrent collapse of the upper airway leading to repetitive episodes of hypoaemia, hypercapnia and arousal from sleep. This disorder is associated with important consequences for affected individuals including decreased quality of life and likely adverse cardiovascular outcomes. The pathogenesis of obstructive sleep apnoea is multifactorial, but an anatomically small pharyngeal airway in combination with decrements in pharyngeal dilator muscle activity during sleep appear central to the disorder. It is therefore important to understand the effect of sleep on the mechanisms controlling the upper airway musculature.

Pharyngeal dilator muscle activity is influenced by inputs from the chemoreceptors, the brainstem central respiratory pattern generator (CPG), intrapharyngeal negative pressure and possibly vagal input from lung volume. Studies suggest that most of these mechanisms controlling the upper airway muscles are affected by sleep, with sleep generally decreasing the sensitivity or responsiveness of the control system. However, it is unclear whether wakefulness alone influences pharyngeal dilator muscle activity or whether its effect on muscle activation is mediated through brainstem respiratory neurons or other chemical/mechanical stimuli. At the transition from wakefulness to sleep, there is a decline in genioglossus (GG) and tensor palatini (TP) muscle activity accompanied by a reduction in ventilation and a rise in upper airway resistance. This decrease in upper airway muscle activity at sleep onset could result from a withdrawal of direct wakefulness stimulation of upper airway muscles, decreased muscle responses to intrapharyngeal negative pressure and/or chemostimuli, or decreased inputs from brainstem respiratory neurons. Most evidence suggests that mechanical (negative pressure) and chemo responses (oxygen and carbon dioxide tensions) are decreased during sleep.

Ventilation falls as well, suggesting decreased CPG output. However, whether loss of wakefulness has a direct effect on muscle activity not mediated through other mechanisms has not been tested.

With the application of non-invasive positive pressure ventilation (NIPPV), subjects can be passively ventilated which achieves several goals. First, expiratory positive pressure has been shown to lead to a reduction in the negative pressure reflex thereby minimising mechanoreceptor input to the upper airway muscle. Second, by adjusting inspiratory positive pressure and increasing respiratory rate to passively ventilate subjects, NIPPV can eliminate or minimise central respiratory drive to the upper airway muscles as well as to all respiratory muscles such as the diaphragm. NIPPV can also maintain ventilation and lung volume at constant levels. This should allow us to examine upper airway muscle activation during wakefulness, wake-sleep transitions, stable non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep without respiratory or mechanical inputs. Thus, pure state (sleep) influences on muscle activity should become apparent.
those who did not in terms of age, sex and body mass index. The sample size was based on preliminary data obtained in the first three subjects in the study and a previous study from our laboratory. We determined that 9 subjects would be required, using the change at the α-θ transition with mechanical ventilation to detect a 20% decrease in pharyngeal airway muscle activity with 80% power at the 5% significance level. Written informed consent was obtained from each subject and the protocol was approved by the Human Subjects' Committee of the Brigham and Women's Hospital. Women were studied during the follicular phase (days 5–11) of their menstrual cycle as determined by history.19

**Equipment and techniques**

The subjects wore a nasal mask (Respironics Inc, Murrayville, Pennsylvania, USA) connected to a heated pneumotachometer (Hans Rudolph Inc, Kansas City, Missouri, USA) and a differential pressure transducer (Validyne Corp, Northbridge, California, USA) calibrated with a rotameter for measurement of airflow. Inspiratory (TI) and expiratory (TE) times were determined from this signal and it was electronically integrated for calculation of tidal volume (VT). Minute ventilation (VE) was calculated as the sum of all VT per minute. The duty cycle (TI/TOT) was also calculated for each breath. End-tidal carbon dioxide tension (PETCO₂) was measured from expired air within the nostril using a calibrated infrared CO₂ analyser (Capnograph/Oximeter Monitor, BCI, Waukesha, Wisconsin, USA) while arterial oxygen saturation (SaO₂) was measured using a pulse oximeter probe attached to the index finger (Capnograph/Oximeter Monitor). Pressure was monitored in the mask with an open catheter attached to a pressure transducer (Validyne Corp). The subjects were instructed to breathe exclusively through the nose. This was ensured by taping the mouth and using an infrared video camera to confirm that the mouth remained closed.

The genioglossal electromyogram (Ggemg) was measured with a pair of unipolar intramuscular electrodes referenced to a single ground, producing a bipolar recording. Two stainless steel Teflon-coated 30-gauge wire electrodes were inserted approximately 12–15 mm into the body of the GG muscle 3 mm lateral to the frenulum on each side using a 25-gauge needle. The needles were removed immediately, leaving the wires in place. The tensor palatini electromyogram (TPEMG) was measured in a similar manner to that of the GG muscle activity, (a) GGEMG having no inspiratory phasic activity or spontaneous breathing, no phasic activity was observed during inspiration. Hence, the GGEMG and DIAEMG were reported as the average activation across each breath. As the TP is a tonic muscle without phasic activity, the TPEMG was reported as the average activation across each breath during basal breathing and passive ventilation.

Two EEG channels (C3–A2, O2–A1), left and right electro-oculograms (EOGs) and the submental EMG were recorded to document wakefulness or sleep and score the different sleep stages by a blinded technician. Subjects were maintained in the supine posture throughout the study, verified by infrared video camera.

A microprocessor-controlled ventilator (Respironics Inc) that operates in either a continuous positive airway pressure (CPAP) mode or a spontaneous/timed (S/T) mode was used in the study. In S/T mode, this ventilator allowed control of inspiratory positive airway pressure (IPAP), exspiratory positive airway pressure (EPAP), respiratory rate, Ti and IPAP rise time. To yield the lowest Ggemg during wakefulness, CPAP mode was applied first and started at 4 cm H₂O. This pressure level was increased until the minimal level of Ggemg was obtained or to a maximum of 8 cm H₂O. If no obvious reduction in Ggemg was discernible, the subjects were studied on 6 cm H₂O. The ventilator was then switched to S/T mode and IPAP was adjusted to obtain the same or a slightly bigger VT than was observed during eupnoeic breathing. The respiratory rate was set to be the same as or slightly faster than during eupnoeic breathing, and the Ti was set based on respiratory timing in CPAP mode. IPAP rise time was set at 0.05 or 0.1 s. By adjusting the respiratory rate, Ti, IPAP rise time and the pressure difference between IPAP and EPAP, subject passivity—assessed by (a) DIAEMG having no inspiratory phasic activity, (b) GGEMG having no inspiratory phasic activity or pre-activation before onset of airflow, (c) mask pressure showing no reduction before each ventilator-initiated breath, (d) airflow pattern showing a descending ramp shape, and (e) fixed inspiratory-expiratory time ratio—could be achieved (fig 1). Recordings were stopped when there was a departure from this passive pattern until adequate passivity could be achieved or the experiment was terminated.

**Protocol**

Each subject reported to the laboratory at approximately 21:00 h having fasted for at least 4 h. After informed consent was obtained, the sleep staging electrodes and intramuscular EMG wires were placed. Subjects then assumed the supine posture in bed and the nasal mask and pneumotachograph were attached. They subsequently lay with their eyes open in this posture and were allowed to acclimatise to the equipment. Subjects were recorded during both basal breathing and passive ventilation during wakefulness for 5–10 min in each condition. After recording data during wakefulness, the subjects were allowed to fall asleep (in the supine posture) with the mechanical ventilator in place. In order to obtain multiple sleep onsets—primarily transitions from quiet wakefulness to
stage 1 sleep—subjects were awoken if they slept for 3–5 consecutive minutes without a spontaneous awakening and then were allowed to fall asleep again. This procedure was repeated until adequate data (at least 3–5 transitions) had been collected. Thereafter, subjects were allowed to fall asleep without interruption. Subjects were subsequently recorded during passive ventilation during stable NREM and REM sleep for 5–10 min in each condition.

Data recording and analysis
All signals (GGEMG, TPEMG, and DIAEMG (raw and MTA), flow, VT, PETCO2, Sao2, EEG, EMG and ECG) were recorded on a computer using an analogue-to-digital converter (1401plus, Cambridge Electronic Design Ltd, Cambridge, UK) and data acquisition software (Spike 2, version 5.03, Cambridge Electronic Design, Ltd). Certain signals (GGEMG, TPEMG, and DIAEMG (MTA), flow, VT, PETCO2, Sao2, EEG, EMG, ECG) were also recorded on a computer using Nihon Kohden software (Polysmith Version 4.0, Neurotronic Inc, Tokyo, Japan). The sample rate varied from 125 Hz for respiratory signals to 1000 Hz for the raw EMG. For each of the three stable conditions (relaxed wakefulness, stable NREM sleep, and REM sleep (phasic and tonic) during passive ventilation, the mean value for each variable over a 5–10 min recording time was determined.

For each subject, each breath at \( \alpha \rightarrow \theta \) transitions was assigned a value of \( \alpha \) or \( \theta \) by visual analysis of the occipital EEG signal by two of the authors (YLL, LD) independently (95% agreement) with any disagreements being resolved. A wake-sleep EEG transition required at least 1 min of \( \alpha \) activity followed by clear \( \theta \) activity lasting for at least 10 s. The transition breaths were defined as \( \alpha \) or \( \theta \) breaths based on having more or less \( \alpha \) EEG activity. An adequate \( \alpha \rightarrow \theta \) transition was defined as having at least three consecutive \( \alpha \) breaths followed by at least two consecutive \( \theta \) breaths. Each breath in the transition was then assigned a position relative to the transition from \(-5\) to \(+5\), as previously described by Worsnop et al.7 Thus, every transition had breaths \(-3\) to \(+2\), with fewer transitions having breaths in position \(-5\) and \(-4\), and \(+3\), \(+4\) and \(+5\). All ventilation and EMG parameters were calculated on a breath-by-breath basis. If the subject could not be passively ventilated within a defined \( \alpha \rightarrow \theta \) transition, the data for the transition were discarded. Thus, all ventilation and EMG parameters were calculated as the mean \( \alpha \) level \((-5\) to \(-1\)) and the mean \( \theta \) level \((+1\) to \(+5\)). Only those subjects having at least 3–5 adequate transitions were used for this analysis.

Analysis of data
All statistical analyses were performed with commercially available software (Excel 2000, Microsoft and SigmaStat + SigmaMapal; SPSS, Chicago, Illinois, USA). A paired \( t \) test was used to assess the effect of sleep onset on upper airway dilator muscle activity and ventilation. The Wilcoxon signed rank test was used if data were not normally distributed. Repeated-measures ANOVA with post hoc Student-Newman-Keuls testing was used to assess the effect of stable NREM and REM sleep on pharyngeal airway activity and ventilation. Whenever data were not normally distributed, Friedman’s non-parametric repeated measures comparisons were used. All data are presented as mean (SE) values unless otherwise stated. A p value of <0.05 was considered statistically significant.

RESULTS
Full data sets were acquired in the 10 individuals under all conditions with one exception. In one subject, no adequate TPEMG data were available because of technical problems. Thus, for TPEMG, the data presented are from 9 individuals. For the 10 subjects completing the entire study, the mean (SE) age was 33.0 (4.1) years and the mean (SE) body mass index was 24.0 (0.6) kg/m².

During basal breathing, inspiratory phasic diaphragm and GG activation were observed in all subjects. Figure 1 shows an example of raw data in one individual during basal breathing and passive ventilation during wakefulness showing no active breathing with NIPPV in place. To achieve passive ventilation, the following mechanical ventilator settings were required: EPAP 6.2 (0.1) cm H2O; IPAP 12.7 (0.4) cm H2O; Tt1.2 (0.1) s; respiratory rate 17.7 (0.7) breaths/min. Muscle activity, respiratory data, ventilation, CO2 level and Sao2 during basal breathing and passive ventilation during wakefulness are shown in table 1.
Compared with basal breathing, there were significant increases during passive ventilation in \( V_E \) and \( S_aO_2 \) and decreases in \( T_I \) and \( T_I/TTOT \). No differences in \( V_T \), \( P_ETCO_2 \) and respiratory rate were observed.

### Effects of sleep onset

Figure 2 shows an example of a transition from wakefulness to sleep under passive ventilation. For the group, the mean GGEMG and TPEMG during \( \pi \) breaths were significantly higher than during \( \theta \) breaths (table 2). The individual results and group mean for the GGEMG and TPEMG during \( \pi - \theta \) transitions, stable NREM and REM sleep are shown in fig 3A and B.

There was no difference in the mean DIAEMG during \( \pi \) versus \( \theta \) breaths with NIPPV in place. There were also no significant changes in mean \( S_aO_2 \), \( P_ETCO_2 \), \( V_T \) or \( V_E \) at \( \pi - \theta \) transitions.

### Effect of sleep state

Compared with relaxed wakefulness (table 3), there were significant decreases in GGEMG and TPEMG during stable NREM sleep and REM sleep. However, post hoc testing showed that there were no statistically significant differences in GGEMG or TPEMG between stable NREM and REM sleep. DIAEMG did not differ during wakefulness, stable NREM sleep or REM sleep. Other respiratory variables are shown in table 3.

Compared with sleep onset (\( \pi \) breaths), GGEMG was significantly lower during REM sleep but not during stable NREM sleep (1.3 (0.4)% vs 1.1 (0.4)% vs 1.0 (0.3)% of maximal EMG, \( p = 0.019 \)). However, TPEMG was significantly lower during stable NREM sleep and REM sleep than at sleep onset (3.7 (2.1)% vs 3.0 (2.0)% vs 3.0 (2.0)% of maximal EMG, \( p < 0.001 \)).

### Table 1  Muscle activity and respiratory data during basal breathing and passive ventilation during wakefulness

<table>
<thead>
<tr>
<th>Muscle activity</th>
<th>Basal breathing</th>
<th>Passive ventilation</th>
<th>( p ) Value</th>
<th>Mean difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIAEMG (% max)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>12.0 (3.1)</td>
<td>6.8 (1.6)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonic</td>
<td>5.7 (1.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phasic</td>
<td>6.2 (2.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GGEMG (% max)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>5.3 (1.4)</td>
<td>1.6 (0.4)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonic</td>
<td>2.1 (0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phasic</td>
<td>3.2 (1.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPEMG (% max)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>4.4 (2.2)*</td>
<td>5.1 (2.2)*</td>
<td>&lt;0.001</td>
<td>0.4 (0.3 to 0.6)</td>
</tr>
<tr>
<td>Tonic</td>
<td>0.42 (0.0)</td>
<td>0.35 (0.0)</td>
<td>&lt;0.001</td>
<td>0.08 (0.05 to 0.10)</td>
</tr>
<tr>
<td>( T/TTot )</td>
<td>0.39 (0.0)</td>
<td>0.43 (0.0)</td>
<td>0.137</td>
<td>0.04 (0.00 to 0.10)</td>
</tr>
<tr>
<td>( V_T ) (l)</td>
<td>6.3 (0.5)</td>
<td>7.8 (0.6)</td>
<td>0.002</td>
<td>1.5 (0.8 to 2.2)</td>
</tr>
<tr>
<td>( V_E ) (l)</td>
<td>96.8 (0.2)</td>
<td>97.4 (0.2)</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>( SaO_2 ) (%)</td>
<td>42.3 (1.1)</td>
<td>40.7 (0.5)</td>
<td>0.147</td>
<td>1.6 (0.1 to 3.2)</td>
</tr>
</tbody>
</table>

DIAEMG, diaphragm electromyogram; GGEMG, genioglossus electromyogram; TPEMG, tensor palatini electromyogram; \( T/I \), inspiratory time; \( T/TTot \), duty cycle; \( RR \), respiratory rate; \( V_T \), tidal volume; \( V_E \), minute ventilation; \( SaO_2 \), oxygen saturation; \( P_ETCO_2 \), end-tidal carbon dioxide tension.

*Average muscle activity of each breath.

†Wilcoxon signed rank test.

Figure 2  Example of a transition from wakefulness to sleep under passive ventilation in one individual. There are substantial decreases in muscle activity in both the genioglossus and tensor palatini across the wake-sleep transition. DIA, diaphragm; EEG, electroencephalography; GG, genioglossus; MTA, moving time average; PMASK, mask pressure; TP, tensor palatini; \( V_T \), tidal volume.
DISCUSSION

This is the first study, to our knowledge, to assess the effect of sleep (loss of isolated wakefulness drive) as well as the different sleep states on upper airway dilator muscle activity while minimizing the influences of respiratory and mechanical inputs. The results indicate that, at the wake-sleep transition, there are moderate reductions in mean GG and TP muscle activity and, during stable NREM and REM sleep, both GG and TP muscle activity are lower than during relaxed wakefulness.

Compared with sleep onset (0 breaths), there were further decreases in the activity of TP during stable NREM and REM sleep but for GG only during REM sleep. Thus, wakefulness has an important independent effect on upper airway dilator muscle activity that is unlikely to be mediated through the respiratory or mechanical control systems.

Immediate effect of sleep on upper airway muscle activity

At sleep onset (0 breaths), a consistent decrement in pharyngeal dilator muscle activity has previously been demonstrated by Mezzanotte and Worsnop, together with a reduction in VE and a rise in upper airway resistance. However, they observed that there was a subsequent recruitment in muscle activity after the initial fall in Ggemg during the first two 0 breaths. By the fifth breath after the transition, Ggemg had largely recovered to stable waking levels. They speculated that GG is recruited in response to increasing negative upper airway pressure and/or rising CO₂. By applying CPAP to diminish intrapharyngeal negative pressure, Fogel et al reported a similar reduction in Ggemg over the first two 0 breaths following a transition, but CPAP prevented the rise in upper airway resistance at the transition and eliminated the subsequent recruitment of Ggemg. It was therefore suggested that the initial reduction in upper airway muscle activity at sleep onset is due to loss of a “wakefulness” stimulus rather than to loss of responsiveness to negative pressure. However, the changes in the upper airway dilator muscle control that occur during sleep onset are complex. Shea et al reported that GGEMG responses to brief pulses of negative pressure were minimally reduced (not significantly) in the first five breaths after an α–θ transition compared with stable wakefulness. Nonetheless, it is unclear how chemoreceptive inputs influence Ggemg at sleep onset, as such studies would be difficult to conduct and interpret. Thomson et al also reported that, at α–θ transitions, there are prolongations in breath duration and expiratory time in the absence of changes in airway resistance or fluctuations in ventilation and CO₂ tension. These observations suggest that there is an abrupt reduction in ventilatory motor output at the wake-sleep transition. As the GG muscle receives inputs from the CPG, it is possible that the change in CPG activity at sleep onset could influence GG muscle activation. Taken together, it is likely that the decrement of Ggemg during sleep onset is a combination of a loss of the wakefulness drive, a mildly decreased negative pressure reflex and a minimally reduced respiratory (CPG) input (fig 4).

In this study, with the application of NIPPV to eliminate or minimise inputs from local mechanical stimuli (negative pressure) and CPG and to maintain ventilation and CO₂ levels across wake-sleep transitions, there was a moderate decrement in Ggemg which suggests that the muscle is independently controlled by the wake/sleep state. However, the baseline

Table 2  Muscle activity and ventilation during α-θ transition

<table>
<thead>
<tr>
<th></th>
<th>Wakefulness (α)</th>
<th>Sleep (θ)</th>
<th>p Value</th>
<th>Mean difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average muscle activity (% max)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIAEMG</td>
<td>6.5 (1.5)</td>
<td>6.4 (1.6)</td>
<td>0.324</td>
<td>0.0 (0.0 to 0.1)</td>
</tr>
<tr>
<td>Ggemg</td>
<td>1.6 (0.5)</td>
<td>1.3 (0.4)</td>
<td>0.016</td>
<td>0.3 (0.1 to 0.5)</td>
</tr>
<tr>
<td>TPMEG</td>
<td>4.3 (2.3)</td>
<td>3.7 (2.1)</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>VT (l)</td>
<td>0.42 (0.0)</td>
<td>0.41 (0.0)</td>
<td>0.079</td>
<td>0.01 (0.00 to 0.03)</td>
</tr>
<tr>
<td>VT (l/min)</td>
<td>7.8 (0.7)</td>
<td>7.7 (0.8)</td>
<td>0.253</td>
<td>0.2 (–0.1 to 0.4)</td>
</tr>
<tr>
<td>SaO₂ (%)</td>
<td>97.2 (0.3)</td>
<td>97.2 (0.3)</td>
<td>0.755</td>
<td>0.0 (0.0 to 0.3)</td>
</tr>
<tr>
<td>PetCO₂ (mm Hg)</td>
<td>40.3 (0.8)</td>
<td>40.6 (1.0)</td>
<td>0.287</td>
<td>0.3 (–0.3 to 0.9)</td>
</tr>
</tbody>
</table>

DIAEMG, diaphragm electromyogram; Ggemg, genioglossus electromyogram; TPMEG, tensor palatini electromyogram; VT, tidal volume; PETCO₂, end-tidal carbon dioxide tension.

Wilcoxon signed rank test.
Table 3  Muscle activity and ventilation during wakefulness, NREM sleep and REM sleep during passive ventilation

<table>
<thead>
<tr>
<th></th>
<th>Wakefulness</th>
<th>NREM sleep</th>
<th>REM sleep</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average muscle activity (%) max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIAEMG</td>
<td>6.8 (1.6)</td>
<td>6.4 (1.6)</td>
<td>6.4 (1.6)</td>
<td>0.273</td>
</tr>
<tr>
<td>GGEMG</td>
<td>1.6 (0.4)</td>
<td>1.1 (0.4)</td>
<td>1.0 (0.3)</td>
<td>0.003</td>
</tr>
<tr>
<td>TPEMG</td>
<td>5.1 (2.2)</td>
<td>3.0 (2.0)</td>
<td>3.0 (2.0)</td>
<td>-0.001</td>
</tr>
<tr>
<td>Vt (l)</td>
<td>0.43 (0.0)</td>
<td>0.41 (0.0)</td>
<td>0.42 (0.0)</td>
<td>0.278</td>
</tr>
<tr>
<td>Vt (l/min)</td>
<td>7.8 (0.6)</td>
<td>7.5 (0.4)</td>
<td>7.8 (0.5)</td>
<td>0.569</td>
</tr>
<tr>
<td>SaO2 (%)</td>
<td>97.4 (0.2)</td>
<td>96.7 (0.3)</td>
<td>96.9 (0.4)</td>
<td>0.014</td>
</tr>
<tr>
<td>PETCO2 (mm Hg)</td>
<td>40.7 (0.5)</td>
<td>41.4 (0.7)</td>
<td>42.1 (0.9)</td>
<td>0.055</td>
</tr>
</tbody>
</table>

NREM, non-rapid eye movement; REM, rapid eye movement; DIAEMG, diaphragm electromyogram; GGEMG, genioglossus electromyogram; TPEMG, tensor palatini electromyogram; Vt, tidal volume; Vs, minute ventilation; SaO2, oxygen saturation; PETCO2, end tidal carbon dioxide tension.

Figure 4  Simplified scheme illustrating three potential major sources of neural inputs involved in genioglossus muscle control across wake-sleep states: (1) mechanoreceptor reflexes (negative pressure), (2) phasic respiratory inputs, and (3) wake-sleep sensitive neural systems. We believe that (1) and (2) were eliminated by non-invasive positive pressure ventilation. Ach, acetylcholine; CPG, central pattern generator; SHT, serotonin; Hist, histamine; NE, norepinephrine; NTS, nucleus solitary tract.

3. Wake-sleep sensitive neural systems

2. Phasic respiratory inputs

1. Mechanoreceptor reflexes

Effect of stable sleep on upper airway muscle activity

Our findings that, with minimal respiratory and mechanical inputs, both GGEMG and TPEMG during stable NREM and REM sleep were lower than during relaxed wakefulness further confirm that the wakefulness drive can modulate upper airway dilator muscle control. However, when compared with sleep onset, both stable NREM and REM sleep led to further TPEMG decrements, but only REM sleep was associated with further GGEMG reductions. This difference could result from the loss of wakefulness input having a different effect on these two muscles. However, it is also possible that our inability to find a difference in GGEMG between sleep onset and stable NREM may have been due to a relative lack of power, given the small number of subjects studied. If such a difference exists, it is likely to be less robust than was seen for TPEMG.

The lack of observed difference in muscle activity between stable NREM and REM sleep deserves comment. Most studies, including protocols in animals and humans, indicate that GGEMG is reduced more during REM than during NREM sleep.30–31 However, one study by Wiegand and colleagues reported no difference in GGEMG between REM and NREM sleep in normal subjects when tonic REM sleep was considered.32 Nonetheless, none of these studies was designed to evaluate the isolated loss of wakefulness on upper airway dilator muscle activity. In this study we observed that, after losing the wakefulness drive to these upper airway dilator muscles, there is consistent tonic muscle activity in both the GG and TP across stable NREM and REM sleep and that this tonic muscle activity is not different between NREM sleep and REM sleep in these two muscles. However, this change in muscle activity may be complicated by a floor effect. Larger changes might have been observed during spontaneous breathing.
Limitations of the study
Several methodological considerations must be examined when assessing our conclusions. First, $\text{SaO}_2$ was lower during sleep and there was a trend towards an increased $\text{PETCO}_2$ level which suggests that all subjects may not have been completely passively ventilated during NIPPV at all times. However, we believe any active ventilation was minimal as our criteria for passive ventilation were strict. We showed that, with NIPPV in place, active ventilation was minimal as our criteria for passive ventilation were strict. We showed that, with NIPPV in place, active ventilation was minimal as our criteria for passive ventilation were strict.

suggests that all subjects may not have been completely passively ventilated, a very small decrease in respiratory muscle activity by sudden negative airway pressure in man. J Physiol 1991;143:15–29.


Influence of wakefulness on pharyngeal airway muscle activity

Yu-Lun Lo, Amy S Jordan, Atul Malhotra, Andrew Wellman, Raphael A Heinzer, Matthias Eikermann, Karen Schory, Louise Dover and David P White

Thorax 2007 62: 799-805 originally published online March 27, 2007
doi: 10.1136/thx.2006.072488

Updated information and services can be found at:
http://thorax.bmj.com/content/62/9/799

These include:

References
This article cites 35 articles, 11 of which you can access for free at:
http://thorax.bmj.com/content/62/9/799#BIBL

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections
Airway biology (1100)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/