Reference ranges for respiratory rate measured by thermistry (12–84 months)

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Abstract
Previous studies of respiratory rate in children have had a number of methodological problems. The aim of this study was to construct age specific reference ranges for respiratory rate. Respiratory rate in children attending childcare centres, kindergartens, and schools was measured using a nasal thermocouple to obtain respiratory waveforms. Reference ranges were constructed using data from 293 awake children between 12 and 84 months, and from 123 sleeping children between 12 and 60 months. The mean respiratory rate declined with increasing age and was significantly lower, with lower variability, during sleep than wakefulness. Neither the awake nor sleeping reference ranges were significantly affected by sex, nor by the presence of past respiratory nor current respiratory symptoms.

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There are no widely accepted comprehensive studies that have established a reference range for respiratory rate in children older than 12 months. Despite this, clinicians rely on the respiratory rate counted at the bedside to assess children with respiratory and other illnesses. For any measured variable (such as respiratory rate) to be of clinical use, a number of conditions must be met. The range and variability in the results obtained from normal subjects must be known, and the way in which abnormal results relate to a particular disease state must be understood. In addition the method of measurement should be simple, accurate, and reproducible and it must not alter the variable being measured.

While many standard texts discuss the importance of tachypnoea as a clinical sign, they fail to define the normal range of respiratory rate. Where ranges are quoted, they appear imprecise and often no reference source is cited. For instance Barnes (1990) states that the 'newborn rate is 30 to 80; the rate decreases to 20 to 40 in late infancy and childhood and to 15 to 25 in late childhood and adolescence'.[1] Other paediatric texts[2 3] quote a study performed by Iliff and Lee in 1952.[4] These investigators published respiratory rate observations obtained at the time of performing basal metabolic rate determinations in a group of 95 boys and 93 girls aged 2 months to 18 years. Reference ranges were calculated for counting periods of at least 30 seconds. There are a number of methodological problems associated with this study. The number of children in each age group and the method of recruitment was not documented. Multiple observations were performed on some of the children and there was no record of whether respiratory symptoms or signs were present. The method of determining rate is not recorded, although it was probably based on the counting of chest wall movements. Children of different ages were measured in different arousal states. The heterogeneity of these subjects' arousal states raises doubts about the validity of the results. It is widely accepted that ventilatory control and respiratory rate are altered in both rapid eye movement and non-rapid eye movement sleep when compared with the awake state.[5 6] The utility of the quoted reference ranges remains in doubt because of these methodological problems.

Respiratory rate is traditionally measured by counting observed chest wall movements while timing with a watch. While this method is simple, and should not alter the variable being measured, its accuracy is questionable. A study comparing the counting of observed chest wall movements by nurses to respiratory inductive plethysmography in 10 mechanically ventilated adult patients found that on 34% of occasions manual counting of respiratory rate produced an error of 20% or more.[7] Another study comparing simultaneous respiratory rate counts, as determined by observation of chest wall movement and by transthoracic impedance (pneumogram), in children under 5 years of age found a wide variation between these two methods.[8] The method that produced a respiratory rate per minute that varied least from that obtained with the pneumogram, was where the counted respiratory rates for two 30 second periods were added, rather than using a single 60 second period or a single 30 second period doubled.

There have been a number of studies of the respiratory rate of infants. Morley *et al* attempted to define the normal respiratory rate of infants under 6 months of age.[9] It was difficult to count chest wall movements in small infants by observation alone. The best technique involved listening to the baby's naked chest with a stethoscope or palpating chest wall movements with a warmed hand. However, even using these methods the respiratory rate was thought to have been underestimated. Because these techniques involve some undressing of the child and close physical contact with the investigator, it is possible that the children's respiratory rate may have been altered by the measuring procedure. The measurement of respiratory rate using a nasal thermocouple has been shown to match accurately that measured by nasal pneumotachography (Marks M,

Table 1 Classification of arousal states

Quiet sleep	Sleep not associated with any spontaneous bodily movements, including no eye movements or vocalisations
Active sleep	Sleep associated with any spontaneous bodily movements, including eye movements and vocalisations
Awake and quiet	Playing quietly or listening to a story quietly with few vocalisations
Awake, unsettled, and/or crying*	Actively mobile, very frequent vocalisations, upset

*Children who were unsettled or crying could not have their respiratory rate measured. Measurements were obtained from these children only if they could be quietened.

South M, Carter B. Validation of nasal thermistry in the measurement of respiratory rate and timing (abstract). *Am Rev Resp Dis* 1993; **147** (4) part 2: A128). The thermistry method involves neither undressing of the child, nor close physical contact with the investigator. Because the method should have little influence on respiratory rate it was used for this study. The aim of this study was to establish a reference range for respiratory rate in children between 12 and 84 months of age.

Methods

Subjects were recruited from childcare centres, kindergartens, and schools. Although this sample of children was regarded as normal, it was apparent that many continue to attend childcare, kindergarten, and school while suffering mild illnesses. A structured questionnaire was used to seek symptoms of rhinorrhoea, cough, fever, sore throat, or wheeze over the preceding 24 hours, and of any past history of asthma, 'wheezy bronchitis', or 'recurrent bronchitis'. The investigator recorded any apparent symptoms at the time of respiratory rate measurement. Arousal state was classified according to behavioural criteria (table 1).

All measurements were made by a single investigator (MKM). Data were collected in awake children by adhering a thermocouple probe to the cheek so as to position the probe at the nasal orifice. Recordings were made as the children sat quietly and were read a story. Some children were unwilling to sit and have a story read to them, so no recording was attempted. If a child had marked nasal obstruction, an attempt was made to clear the nose. If this failed and the child was observed to be consistently mouth breathing the probe was positioned at the oral orifice. If the child was observed to be intermittently mouth and nose breathing the procedure was abandoned. Children were observed closely to ensure that there was no behavioural change produced by the method of measurement. If any such change occurred or if the child became upset while the thermocouple probe was adhered to their cheek the testing was abandoned. Sleep measurements were performed by placing the thermocouple probe on the children's bedding close to the nose or mouth. Sleeping data were collected only for children between 12 and 60 months because older children at kindergartens and schools did not sleep during their time at these centres.

Respiratory waveforms were obtained using a nasal thermocouple (type N). The thermocouple detected the rise and fall of temperature at the nasal (or oral) orifice produced by expiratory and inspiratory air flow respectively. The thermocouple signal was amplified, processed, and stored onto the floppy disk drive of a laptop computer. A data acquisition software package, Asyst, was adapted to save the thermistry waveform data for later retrieval. Two 30 second periods were recorded for each subject. The number of expiratory peaks recorded during the two 30 second periods were added to give the respiratory rate per minute.

STATISTICS

Mean respiratory rates when awake and asleep were compared using a two tailed Student's t test. Age specific reference ranged for awake and asleep children were constructed following the approach of Royston.[10] A logarithmic transformation was used, because variation increased with respiratory rate. Backwards stepwise selection (with inclusion criterion $p<0.05$) was used to determine the appropriate polynomial curves. Standard errors were calculated for the 2·5% and 97·5% limits of awake and asleep children at their mean ages. Following Royston,[10] with 292 subjects, evenly spread over the population sample, the standard errors in the log scale should be no greater than 10% of the corresponding standard deviations about the regression curve.

A linear modelling procedure was used to test whether the estimated reference ranges appeared to be affected by other factors, including sex, and the presence of past respiratory and current respiratory symptoms. All statistical analyses were performed using the Minitab statistics package.

Results

Approximately 50% of children between 12 and 24 months either refused to have the procedure performed or became upset during testing; therefore data were not collected from these subjects. Above this age the procedure was generally well tolerated. Data were successfully collected from approximately 75% of those children above 36 months who agreed to have the thermocouple attached to their cheek. Respiratory rate measurements were taken from 293 subjects when awake (mean age 52·0 months, range 15·7–83·8) and 123 subjects when asleep (mean age 34·9 months, range

Table 2 Characteristics of subjects (awake and quiet); values are number (%)

Age grouping (completed months)	Girls	Boys	Respiratory symptoms Past	Respiratory symptoms Current
13–24	7 (41·2)	10 (58·8)	5 (29·4)	14 (82·3)
25–36	24 (53·3)	21 (46·7)	11 (24·4)	22 (48·9)
37–48	33 (55·9)	26 (44·1)	17 (28·8)	30 (50·8)
49–60	26 (38·2)	42 (61·8)	39 (57·4)	41 (60·3)
61–72	23 (43·4)	30 (56·6)	14 (26·4)	19 (35·8)
73–84	24 (47·1)	27 (52·9)	27 (52·9)	19 (37·3)
Total	137 (46·8)	156 (53·2)	113 (38·6)	145 (49·4)

Table 3 Characteristics of subjects (asleep); values are number (%)

Age grouping (completed months)	*Quiet sleep*	*Active sleep*	*Girls*	*Boys*	*Respiratory symptoms*	
					Past	*Current*
13–24	20 (74·0)	7 (26·0)	13 (48·1)	14 (51·9)	10 (37·0)	16 (59·3)
25–36	32 (82·1)	7 (17·9)	21 (53·8)	18 (46·2)	8 (20·5)	21 (53·8)
37–48	34 (91·9)	3 (8·1)	19 (51·4)	18 (48·6)	12 (32·4)	19 (51·4)
49–60	17 (85·0)	3 (15·0)	8 (40·0)	12 (60·0)	8 (40·0)	8 (40·0)
Total	103 (83·7)	20 (16·3)	61 (49·6)	62 (50·4)	38 (30·9)	64 (52·0)

12·6–59·9). Sixty three children had both awake and asleep recordings. The characteristics of the awake and sleeping subjects are described (tables 2 and 3 respectively). No more than one measurement was made from each child in each arousal state. These measurements were used to construct awake and asleep reference ranges (figs 1 and 2 respectively). Table 4 gives expected respiratory rates with reference ranges in yearly age groupings. For children aged 12–60 months respiratory rates were, on average, significantly lower when asleep than awake ($p<0.001$).

The regression equations for our subjects were:

$$\text{Awake: } \log_e rr = 3{\cdot}15 - 0{\cdot}00616\ (\text{age}-50) + 0{\cdot}000078\ (\text{age}-50)^2$$
$$\text{Asleep: } \log_e rr = 2{\cdot}97 - 0{\cdot}00194\ (\text{age}-50),$$

where age is expressed in months. The 95% confidence intervals for the limits of the reference ranges for wakeful and sleeping children, calculated at the mean ages, were ±3·3% and ±4·2% respectively.

Neither the wakeful nor sleeping reference ranges were significantly affected by sex, nor by the presence of past respiratory or current respiratory symptoms ($p>0.1$, for each factor considered separately in the general linear model). The arousal state for sleeping subjects (active and quiet sleep) also did not significantly affect the sleeping reference range.

Discussion

The reference ranges constructed indicate that the mean respiratory rate declines with age in both sleeping and wakeful children. The decline is much more marked for children when awake. Between 18 and 54 months the mean respiratory rate declines by 7·9

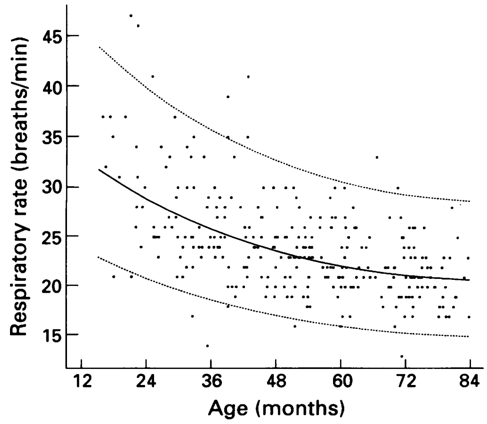

Figure 1 Age specific 95% reference range for respiratory rate in children when awake.

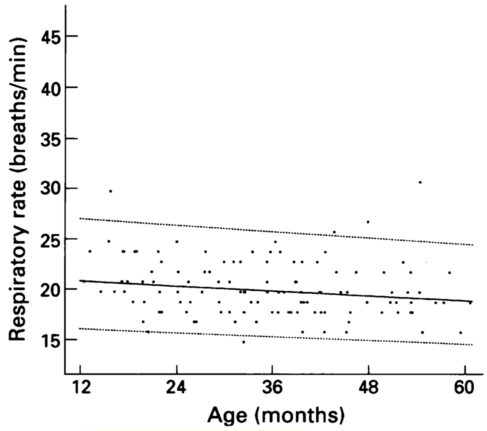

Figure 2 Age specific 95% reference range for respiratory rate in children when asleep.

breaths/minute when awake and by just 1·4 breaths/minute when asleep. The variability of respiratory rate was greater while awake than asleep (figs 1 and 2). While awake the younger children demonstrate a slightly greater variability in respiratory rate than do older children; in contrast, the variability is similar for all ages when asleep. The mean respiratory rate during sleep was lower at all ages than during wakefulness. It is likely that there will be situations where such differences in respiratory rate and variation during different arousal states are of clinical significance.

It is difficult to compare these data with those previously published,[4] because the latter data were collected from children in variable arousal states. It would appear, however, that our data indicate slightly higher mean respiratory rates for awake children aged 12–24 months (31 *v* 26 breaths/minute) and 24–36 months (27 *v* 25 breaths/minute). The rates are similar for children aged 36–84 months. The mean respiratory rates and the variability of respiratory rates of sleeping children appear considerably lower than those previously reported at all ages.

Neither a history of recent upper respiratory tract symptoms, nor a past history consistent with airways obstruction had any apparent effect on the respiratory rate. A clinical examination of all subjects may have been more reliable than the structured questionnaire in the detection of current respiratory symptoms (and signs), but it may have decreased the number of subjects willing to undergo the procedure. Our data regarding a past history of

Table 4 Expected respiratory rate and reference range for yearly age groups

	Awake		*Asleep*	
Age grouping (completed months)	*Expected respiratory rate**	*2·5%–97·5%*	*Expected respiratory rate**	*2·5%–97·5%*
13–24	31	22–43	21	16–27
25–36	27	20–38	20	16–26
37–48	25	18–34	20	15–26
49–60	23	17–32	19	15–26
61–72	22	16–30	N/A	N/A
73–84	21	15–29	N/A	N/A

N/A=not applicable.
*The values for the expected respiratory rate, the 2·5% and the 97·5% limits, were calculated from the regression equations using the median age of each of the groupings listed (that is 18, 30, 42, 54, 66, and 78 months respectively).

one or more of asthma, wheezy bronchitis, and chronic bronchitis are consistent with a recent estimate for the prevalence of asthma history in Melbourne children at age 7 years.[11]

Children aged between 12 and 24 months were the most difficult to collect data from with the nasal thermistry method. This was due to stranger shyness rather than an inherent difficulty in the technique. Once the thermocouple probe had been adhered to the cheek most children could be distracted adequately by reading a story while respiratory rate measurements were collected.

An attempt was made to differentiate the respiratory rate during quiet and active sleep using behavioural criteria. However, it is difficult to judge sleep state from behavioural criteria alone, because muscle arousals evident on an electromyogram may be present without producing recognisable body movements.[12] Sleep marked by gross bodily movements was likely to have been under represented in this study because the subjects had to be relatively still during respiratory rate measurement.

The reference ranges constructed in this study enable clinicians to assess changes in respiratory rate occurring in disease. While nasal thermistry does have some advantages over traditional techniques of respiratory rate measurement, we do not suggest that it should replace careful clinical observation.

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