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*Article*

# Normal Percentiles for Respiratory Rate in Children – Reference Ranges Determined from an Optical Sensor

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**Abstract:** (1) Background: Elevated respiratory rates (RR) have been described in several disease states, such as pneumonia, asthma and bronchiolitis. There is variable methodology in how centiles for RR are derived in healthy children. Available age percentiles for RR have been generated using methods that have the potential themselves to alter the rate. (2) Methods: A newly developed optical respiratory sensor was used to measure RR which placed no restrictions on respiratory excursion. This technique enabled recording in awake children without the artefact of the observer's presence on the subject's RR. A cross-sectional sample of healthy children was obtained from maternity wards, childcare centres and schools in Brisbane, Queensland, Australia. (3): Results: RR were observed in 560 awake and 103 sleeping children of which data from 343 awake and 94 sleeping children was used to create reference ranges for healthy children from newborn to 13 years of age. The recorded RR were significantly higher when children were awake compared to asleep. During quiet sleep, RR decreased from 40 (interquartile range 7) bpm at one month to 20 (interquartile range 3) in children aged 3 years. In awake children, RR ranged from a median of 40 bpm (interquartile range 18) at 1 year to 12 bpm (interquartile range 11) at 13 years respectively. (4) Conclusions: The optical sensor was found to be an appropriate respiratory transducer, capable of measuring RR and reducing artefact by the subjective responses of alert children. The centile charts will be helpful as an aid to detecting abnormal RR in children and will contribute to further systematic reviews related to this important vital sign.

**Keywords:** respiratory rate; children

## 1. Introduction

Counting and recording respiratory rate (RR) comprises one of the fundamentals of pre-hospital, medical and nursing assessment. Marked increases in RR, or tachypnoea, have been found in respiratory (e.g. pneumonia, bronchiolitis, and acute asthma) and non-respiratory conditions (e.g. sepsis and ingestions).[1-5] RR is important in monitoring children receiving opioid analgesics and an important predictor of serious events such as cardiac arrest and admission to intensive care units. [6-8]

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While many authors and textbooks emphasise the importance of this clinical sign, recent studies have found RR is often not recorded by nursing staff or is poorly performed.[9-12] In addition, there is a variety of credible reference data of healthy ranges, especially in children. Many previously published ranges have methodological problems. This includes a small number of subjects as well as issues associated with measurement methodology and locations which can modify the RR. [13-18] Key studies described in the literature are summarised in Table 1. A systematic review of previously published studies of RR is also included. [19]. Of note, an Australian study measuring RR in healthy children and a study of RR of children presenting to an emergency department were not included in this review [16,20].

More recently, large data sets have been extracted from electronic medical records. An Australian study analysed the heart rate (HR) and RR of 111 696 children presenting to a tertiary paediatric emergency department. These children were triaged as category 5 and were afebrile (temperature < 38°C). This dataset did not include duplicates and the method of measuring RR was not stipulated. Bonafide et al. [21] also obtained 116 383 observations of RR and HR from 8894 patients from the electronic medical record of children admitted to two tertiary-care children's hospitals. The state of the child (e.g. awake or asleep) and the methodology of measuring RR and HR were not stipulated, standardised or documented within the electronic medical record or study methodology. Percentile charts based on datasets derived from the ED or ward environment is invaluable, as clinicians need to assess infants and children in these environments. The setting of care for the patient (home, pre-hospital, ED, or inpatient) is therefore an important consideration.

**Table 1. Previous studies citing reference ranges for RR in children**

| *Author* | *N* | *Age Range (years)* | *Arousal state* | *Method of measuring RR* | *Country* |
|---|---|---|---|---|---|
| Quetelet (1842)[13] | 300 | 0 – 20 | Not known | Visual Observation | England |
| Iliff and Lee (1952)[14] | 197 | 0 – 18 | Awake | Observation | United States |
| Hooker et al. (1992)[20] | 434 | 0 – 18 | Awake | Observation in ER | United States |
| Marks et al. (1993)[16] | 416 | 1 – 7 | Awake / asleep | Thermistor | Australia |
| Rusconi et al. (1994)[18] | 718 | 0 – 3 | Awake / asleep | Observation (with stethoscope) | Italy |
| Wallis et al. (2005)[22] | 1109 | 4 -16 | Awake | Observation | UK |
| Wallis et al. (2006)[23] | 346 | 5 - 16 | Awake | Observation | South Africa |
| Bonafide et al;(2013) [21] | 116 383 | 0 - 18 | Not specified | Observation | USA |
| O'Leary et al; (2015)[24] | 111 696 | 0 - 16 | Awake | Observation | Australia |

The aim of this study was to produce percentile charts of RR for healthy children from birth to 13 years of age using a methodology which was accurate, non-invasive and applicable to common clinical scenarios. Use of a computerised respiratory sensor would minimise human and observer error. Such error can relate to counting rapid or small chest wall movements, or respiratory movements masked by general body movements. RR is also sensitive to environmental conditions. States of arousal, temperature, sleep state, medications, monitoring equipment, and patient mental states will all affect RR.[25,26] Our secondary goal was to control for these various factors as much as possible.

## 2. Materials and Methods

**2.1 Study Design**: This was a cross-sectional study of children residing in the Brisbane area or Queensland, Australia. Brisbane was chosen for the study as it is representative of urban communities within Australia. Newborn babies were tested in maternity wards of the Royal Women's Hospital. Infants between the ages of two weeks and one year were tested at a short term residential centre which mothers attended if their babies were experiencing sleep or feeding difficulties. Children between the ages of six months and six years were tested in six different child-care centres located in four disparate geographical locations across Brisbane. Children aged five years and above were tested in four different schools, one after-school centre and several community youth groups.

**2.2 Ethical approval:** Ethical approval was granted by the ethics committees of the Royal Children's Hospital and Women's Health Sector (Protocol 94/21). Written consent was obtained from the parents of children tested within the community and those within the hospital. Information on the child's medical history, residential location and family socio-economic status was collected from parental questionnaires.

**2.3 Subjects:** The study aimed to recruit 20 children per age group. This number was determined in terms of practicality of completing the study over a 6 month period, and comparison with other similar studies of respiratory rate in children.

**2.4 Experimental protocol:**
The respiratory sensor used in this study was an angular displacement optical sensor, which had been developed for use in magnetic resonance imaging (MRI) of the abdomen and is described elsewhere.[27] The sensor is ideal for pediatric studies as there is no risk of electrical shock, it is small, simple to use, easily attached and causes minimal inconvenience to the subject. The sensor imposes no restrictions to respiratory excursions as it does not encircle the chest. A diagram of the sensor is included in Figure 1. The sensor was attached to the lower costal margin and abdomen wall and detected movement of the abdomen. Data points were sampled every 20ms. Two 30-second recordings were used for calculation of RR. The reason for using two thirty-second recordings of respiratory rate was because this is what will be most feasible in clinical practice[28,29].

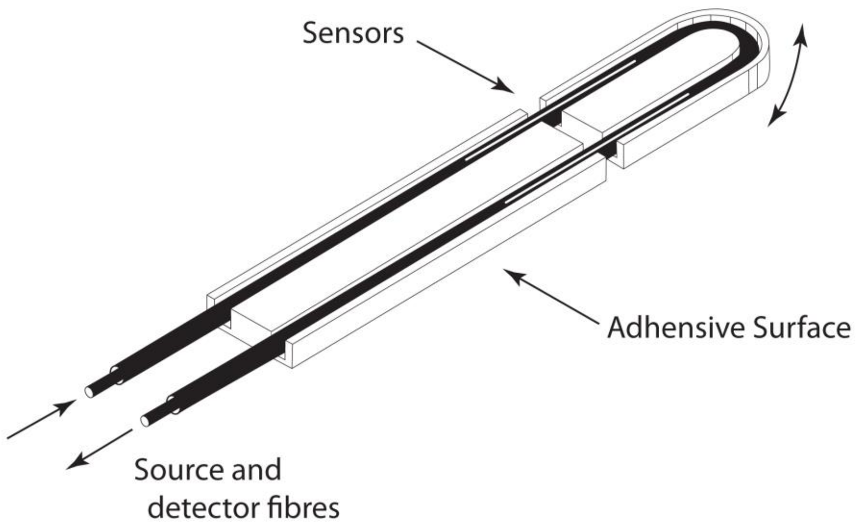


**Figure 1.** Illustration of optical respiratory sensor (the sensor is approx. 8 cm in length).

All children had their body weight, height and axillary temperature recorded at the time of testing. The ambient temperature of the room was also measured. To maximise co-operation for observation of respiratory rate, these measurements were taken after the children's RR was measured. Axillary tempeature was measured by digital thermometer (Safety 1st, Chestnut Hill, USA). Body weight was measured with bathroom scales (Salter, Kent, England). Height was measured with a measuring tape (horizontal for children < 12 months and vertical for children > 12 months). No medical examination was done on the children, since this would have increased their anxiety[16].

Awake children were sedentary for 10 minutes prior to measurement. The sensor was attached at least five minutes prior to monitoring. The sensor was small and unobtrusive and hidden under the child's clothing and attached with tape. The breathing pattern of each child was recorded for five minutes while the child was in a supine position. The children either read a set book themselves or were read to if under five years of age. Children were tested in a quiet room or corner of the childcare centre in the presence of a female assistant. Awake children were aware that there breathing was being measured. It was hoped that the story reading would distract the children from focusing on their breathing.

In sleeping children, the sensor was attached prior to sleep. Sleep state was categorised as quiet or active based on behavioural criteria.[30,31] Breathing pattern was recorded for five minutes during sleep categorised as quiet. It has been found that combing RR counted for two thirty second periods gave a more accurate RR than that counted for a single 60 second period[32].

A questionnaire administered at the same time as the observations of respiratory rate excluded children with acute or chronic respiratory illness. Children with a history of pneumonia, croup or bronchiolitis were also excluded. This questionnaire also looked at the occupations of parents of

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children who participated in the research. The Australian Standard Classification of Occupations (ASCO) was used to categorise socio-economic status[33].

**2.5 Statistical analysis**

Correlation coefficients (Pearson's *r*) were calculated to detect a relationship between RR and age; body weight; height (length); axillary temperature and ambient temperature. Centile charts were constructed using centile regression according to the method of Healy and Rasbash. [34,35] Logarithmic transformations were used to equalise standard deviations and variances across all age groups. The data were sorted into ascending order according to age and displayed on a scatter diagram. A "box" was superimposed on the left-hand side of the diagram and contained a fixed proportion of data points. For awake children, the size of this "box" was 34 and for sleeping children, 10. A least-squares regression of RR on age was calculated and fitted to the points in the box. The residual of each data point was calculated and sorted in order of size. Centiles (3, 25, 50, 75 and 97) were then plotted against the median values of the RR in the "box". The box was then moved to the right by three points and the process was repeated. Repetitions occurred until all data points had been used. Some data (half the size of the "box") were lost in the extreme age ranges.

The age range of interest was between one month and 12 years. A small number of children and young people outside of this age range were included to inform where the boxes would start and finish within the age range of study. As such, although smaller in number, the values of these children at the extremes of age assisted in guiding the centile curves in the areas of interest (0-3 years asleep and 1 – 13 years awake). Polynomial functions were fitted to the raw centiles. For sleeping and awake children, the two polynomials were joined at the ages of one and three years respectively. The smoothed centile curves and raw data were also superimposed.

It was observed that children with elevated respiratory rates had axillary temperatures greater than 37 degrees C, and these children were therefore removed from analysis. An infant on medication which could affect respiration and another child recovering from an anaesthetic were also excluded. In older awake children, however, elevated temperatures did not affect the RR and these children were not excluded from data analysis.

**3. Results**

560 awake and 103 sleeping children were measured of whom 217 awake children were excluded as they had a history of respiratory illness or cardiac disease leaving data on 343 awake and 94 sleeping children that was included in calculations of reference ranges. Table 2 shows the age and gender of children measured.

**Table 2. Age and gender of healthy children in study**

| *Awake children* | | | | *Sleeping children* | | | |
|---|---|---|---|---|---|---|---|
| Age (yr) | Boys | Girls | Total | Age (mo, yr) | Boys | Girls | Total |
| 0 | 12 | 6 | 18 | 0 - < 1 mo | 7 | 8 | 15 |
| 1 | 6 | 8 | 14 | 1 mo - < 6 mo | 7 | 12 | 19 |
| 2 | 11 | 8 | 19 | 6 mo - < 1 yr | 7 | 8 | 15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | 8 | 18 | 26 | 1 | 12 | 8 | 20 |
| 4 | 13 | 17 | 30 | 2 | 15 | 8 | 23 |
| 5 | 15 | 12 | 27 | 3-4 | 8 | 3 | 11 |
| 6 | 14 | 18 | 32 | | | | |
| 7 | 13 | 21 | 34 | | | | |
| 8 | 24 | 23 | 47 | | | | |
| 9 | 13 | 7 | 20 | | | | |
| 10 | 22 | 9 | 31 | | | | |
| 11 | 5 | 9 | 14 | | | | |
| 12 | 4 | 7 | 11 | | | | |
| 13-19 | 5 | 2 | 7 | | | | |
| 20-25 | 13 | 0 | 13 | | | | |
| Total | 178 | 165 | 343 | | 56 | 47 | 103 |

RR was highest in infants and fell rapidly until the age of three years. Two methods of measuring RR are presented in Table 3. RRs obtained by adding the respirations registered by the sensor for the first two 30-second periods of recording were calculated. RR was also measured by averaging the respirations counted over the total recording time. The mean of the differences between measuring RR using these alternative methods was 0.279 bpm, indicating there was little systematic difference (or bias) between the two methods. The standard deviation of the differences was 1.59 and the 95% limit of agreement was between -2.9 and 3.2 bpm.

**Table 3**. Respiratory rate (RR) in awake healthy subjects calculated by two methods

| Age (yr) | *N* | RR (bpm) measured for two 30-second periods | | | RR over total test period | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Median | Mean | SD | Median |
| 0.0-0.4 | 14 | 59.3 | 9.8 | 58.5 | 58.2 | 9.1 | 57.1 |
| 0.5-0.9 | 4 | 45.5 | 18.2 | 40.0 | 47.0 | 15.6 | 42.0 |
| 1 | 14 | 31.9 | 7.2 | 29.0 | 32.3 | 7.7 | 28.9 |
| 2 | 19 | 26.7 | 2.9 | 26.0 | 26.5 | 2.5 | 26.0 |
| 3 | 26 | 25.4 | 3.4 | 25.0 | 24.9 | 3.6 | 24.6 |
| 4 | 30 | 23.5 | 4.3 | 22.5 | 23.0 | 3.6 | 22.9 |
| 5 | 27 | 22.0 | 3.6 | 22.0 | 21.9 | 3.2 | 22.0 |
| 6 | 32 | 20.4 | 3.6 | 21.0 | 20.2 | 3.4 | 20.3 |
| 7 | 34 | 20.6 | 3.6 | 20.5 | 19.6 | 3.5 | 19.5 |
| 8 | 47 | 19.7 | 3.2 | 20.0 | 19.2 | 3.0 | 19.8 |
| 9 | 20 | 20.5 | 3.3 | 21.0 | 20.1 | 3.7 | 20.2 |
| 10 | 31 | 18.7 | 3.4 | 19.0 | 19.0 | 2.9 | 18.6 |
| 11 | 14 | 16.7 | 3.7 | 17.0 | 17.7 | 3.2 | 16.2 |
| 12 | 11 | 16.9 | 4.5 | 16.0 | 17.2 | 3.9 | 16.5 |

The most significant reduction in RR occurs between birth (mean RR 41.4) and one year of age (mean RR 24.1) - see Table 4. The mean of the differences between RRs obtained for two 30-second periods and for the total time of recording was 0.34 in sleeping children. The SD of the differences was 1.22 and the 95% limit of agreement was between -2.1 and 2.8 bpm.

**Table 4**. Respiratory rate (RR) in healthy subjects during quiet sleep calculated by two methods

| Age (yr) | *N* | RR (bpm) measured for two 30-second periods | | | RR over total test period | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Median | Mean | SD | Median |
| 0 – 1 wk | 10 | 41.4 | 4.1 | 41.0 | 41.3 | 3.7 | 41.2 |
| 1 wk – 1 mo | 4 | 41.5 | 5.4 | 40.5 | 41.1 | 5.5 | 41.2 |
| 1 mo – 6 mo | 17 | 35.4 | 7.2 | 34.0 | 34.2 | 7.9 | 32.0 |
| 6 mo – 1 yr | 13 | 24.1 | 2.8 | 23.5 | 23.9 | 3.0 | 23.8 |
| 1 – 2 yr | 17 | 22.1 | 3.5 | 21.0 | 21.9 | 3.4 | 21.2 |
| 2 – 3 yr | 22 | 19.5 | 2.7 | 19.0 | 19.5 | 2.6 | 19.3 |
| 3 – 4.5 yr | 11 | 19.3 | 2.7 | 18.5 | 19.3 | 2.8 | 18.3 |

### 3.1 Centile charts

A cubic equation was fitted to the raw centiles for RR in children who were asleep, aged from birth to one year of age, and children who were awake, aged from one to three years. A quadratic equation fitted the raw centiles in sleeping children aged from one to three years, and awake children aged from three to thirteen years. Due to the method of creating the centile curves, the data at the extremes of ages are not represented (e.g. sleeping children older than three years and awake children older than thirteen years). The centile RRs calculated in awake children are summarised in Figure 2. Figure 3 summarises the RR centiles observed in children, aged from birth to 4.5 years, during quiet sleep. Details of the cubic equations characterising the data are provided in the Appendix 1.

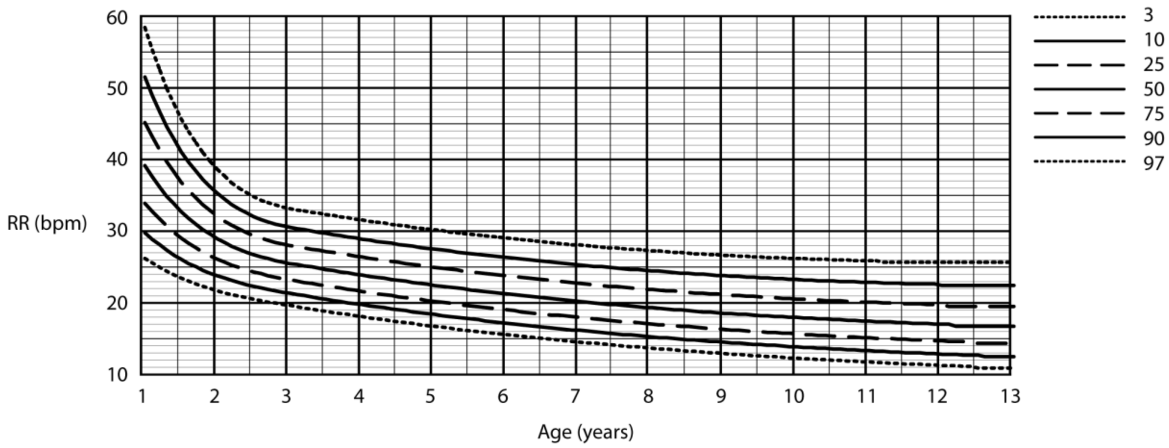


**Figure 2.** Respiratory Rate centile chart in awake children (centiles – 3rd, 10th, 25th, 50th, 75th, 90th, 97th)

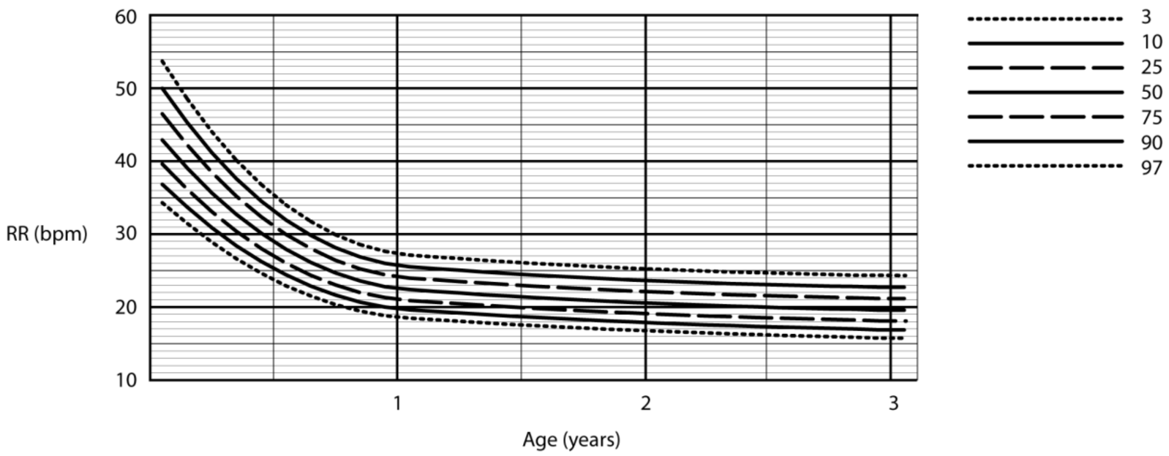


**Figure 3.** Respiratory Rate centile chart in asleep children (centiles – 3rd, 10th, 25th, 50th, 75th, 90th, 97th)

**3.2 Representativeness of Population**

A comparison of the occupations of parents within a small sub-group of children who participated in the study with those who did not was undertaken. In both groups, parents came from managerial / administrator and professional groups. Sixty-seven percent of the parents who allowed their children to participate were from the professional compared with 44 % who did not allow their children to participate (not significant, Chi square test with Yates correction). Questionnaires were also issued to a sample of the children who participated in the project for further analysis. This included 53 responses from 62 pre-school children and 55 responses from 73 school age children. Amongst, pre-school children there was an over-representation of parents in professional and para-professional groups. Amongst school age children, there was a better distribution of parent's occupation of children in this study compared to the general population.

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Children tested in the community with a history of respiratory disease were excluded from the data used to create centile curves for RR in healthy children. This included 217 children with a history of respiratory diseases such as asthma, pneumonia, croup, bronchiolitis and chronic neonatal lung disease. These children were excluded because data on children, free from even minimal lung disease, is vital if it is to be used as a baseline for studying sick children [36].

## 4. Discussion

### 4.1 Comparison with Similar Studies

Most clinicians would agree that RR is a useful and important sign to measure.[37] Various factors need to be considered when reviewing studies of RR. This includes age, number of participants, setting (community versus clinical), country, sate of the child (awake versus asleep) nature of study (cross-sectional versus longitudinal) and method of measurement (manual versus automated).

A systematic review of 20 studies by Fleming et al has identified respiratory rate data for 3881 children.[19] Not all studies of RR in children were included in this review. [38,39] This review included three large and sentinel studies of RR in children. The largest sample of children studied where the method for counting RR was stipulated was that by Wallis et al who studied 1109 awake children aged between 4 and 16 years in Plymouth, UK. RR was measured by direct observation of the clothed chest wall for 60 seconds[22]. A second study of younger children by Rusconi et al measured RR by direct auscultation with a stethoscope for one minute in 618 infants and children, aged 15 days to 3 years[18]. This study presented RR reference ranges for both awake and asleep children.

The third study in this review was that by Iliff and Lee which was a longitudinal study of 95 boys and 93 girls with a total of 3318 measurements of RR[14]. This study is often quoted quoted in textbooks *(E.G. Nelson's Textbook of Pediatrics[40]* and the *Harriet Lane Handbook* [41]. Children under 18 months of age were tested while they were sleeping. Between 18 months and three years of age, respirations were counted when children were either awake or asleep with no differentiation made between these two states. In addition, the children in this study lived an altitude of 1564 metres (Denver, Colorado) and the lower oxygen partial pressure may have affected their breathing patterns.[18] Despite having "Measurements taken at heights greater than 1000 m above sea level" as an exclusion criteria, this study was still included in the review by Fleming et al. [19]

The observational studies in the systematic review by Fleming et al are therefore quite heterogeneous[19]. In some studies RR was measured by observation and in other studies it was measured with a stethoscope. RR measured with stethoscopes or respiratory monitors are usually higher than that compared with observation alone.[18,26] This may be due to the detection of small breaths not appreciated when observing chest or abdominal movements. It is also possible that touching an infant with a stethoscope or hand may cause an increase of agitation that raises the respiratory rate.[26] Also there is no discrimination between awake and asleep states in the centile charts presented in this study. Further, subgroup analysis of RR data showed no significant differences on the basis of the wakefulness of the child.

Table 5 shows RR obtained from current study alongside RR derived from Fleming et al[19]. Median RR are quite similar with the average of the difference in median RR for the different age groups just 0.6. For the 1$^{st}$ centile, RR was higher in the current study up until age 4 where it then became lower. One explanation for this difference could be the presence of lower RR for sleeping children within the data presented in the systematic review. Most observations of RR in sleeping children will occur under the age of 4 years[42]. For the 99$^{th}$ centile, except for ages 1.6 to 3 years, the RR from the current study was generally higher than in the study by Fleming et al, with the average of the difference in RR for the 99$^{th}$ centile being -1.6.

Studies of RR of children in ED and inpatients in the wards has found higher RR for children aged older than 3 years [21,24]. It is possible one reason for this is the anxiety associated with a visit to an ED, or alternatively the impact of illness for hospital inpatients. O'Leary et al. found lower RR in children aged less than 3 years compared to the study by Fleming et al. and Bondafide et al. [21,24] Children aged less than 3 years of age are more likely to sleep during the day, and this is one important consideration when measuring RR in this age group. [42] This can't fully explain the differences between various study results as it would be unlikely a young child would sleep during the triage assessment or presentation to an emergency department [24]. Nevertheless, wherever possible, it would seem important to note whether the RR is taken during sleep or when the child is awake.

**Table 5.** Comparison of awake RR data from current study and study by Fleming et al.[19] (1$^{st}$ Centile, Median and 99$^{th}$ centile)

| Age | RR 1 | RR 1 current | Δ | Median RR | Med RR current | Δ | RR 99 | RR 99 Current | Δ |
|---|---|---|---|---|---|---|---|---|---|
| 1 - 1.5 | 21 | 22 | -1 | 35 | 35 | 0 | 53 | 55 | -2 |
| 1.6 - 2 | 19 | 21 | -2 | 31 | 30 | 1 | 46 | 44 | 2 |
| 2.1 -3 | 18 | 19 | -1 | 28 | 27 | 1 | 38 | 37 | 1 |
| 3.1 - 4 | 17 | 18 | -1 | 25 | 25 | 0 | 33 | 35 | -2 |
| 4 - 6 | 17 | 16 | 1 | 23 | 23 | 0 | 29 | 32 | -3 |
| 6 - 8 | 16 | 14 | 2 | 21 | 20 | 1 | 27 | 30 | -3 |
| 8 - 12 | 14 | 11 | 3 | 19 | 18 | 1 | 25 | 29 | -4 |
| 12 - 15 | 12 | NA | NA | 18 | NA | NA | 23 | NA | NA |
| Mean Δ | | | 0.1 | | | 0.6 | | | -1.6 |

Δ denotes the difference between RR in current study and RR in referenced study for a given centile.

A study of 293 awake and 123 asleep Australian children by Marks et al. was not included in the systematic review by Fleming et al[19]. It is possible that this was due to the exclusion factor "Children with illnesses likely to affect the cardiac or respiratory system". While Marks et al. did include children with past or current respiratory symptoms, they found this did not impact on RR. This study is most similar to the current study in terms of design and results, and an omission from the systematic review by Fleming et al.[19]. The current study and that by Marks et al. [39] were performed in Australia, with a single investigator and used a respiratory sensor and automated counting technique. Marks used a nasal thermistor which did not involve undressing the child, nor close physical contact with the investigator. However, it is possible a nasal thermistor may stimulate trigeminal receptors which are known to lower RR. This could account for the lower RR

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observed in awake children at younger age ranges in the current study. However, limitations include not being able to record RR on mouth breathers and 50 % of children aged between one and two years of age refusing to participate or becoming upset during the study. RR for both studies was quite similar, although Marks had a larger age range for the asleep children.

**4.2 Clinical Utility of Centiles for Respiratory Rate**

Centile charts for RR should assist in differentiating between children with health and disease. Traditionally centile charts are to monitor growth in the same child over time. There may therefore be some limitations in using a centile chart to categorise a respiratory rate measured at one particular point in time.[43] However, it may be possible to observe a baseline respiratory rate in a child with a chronic disease (such as cystic fibrosis or a neuromuscular condition) and see how this changes over time. The reduction in baseline RR with growth and development may be less than that seen for healthy children.

It may also be possible to monitor changes in a child's respiratory rate during the one acute episode of care. For example, an increase in respiratory rate may indicate worsening asthma, while a reduction may indicate response to treatment. Alternatively, a reduction in respiratory rate may indicate a deterioration in a child's condition (e.g. in a child with a brain injury or alternatively a child receiving excessive analgesia with an opioid infusion). RR can be combined with other observations (e.g. HR and blood pressure) to determine an overall assessment of the severity of a child's acute illness. Such a composite score, or Early Warning Score, can be a sensitive indicator or warning of early deterioration in an unwell child.[44,45] Using pulse oximetry as another "vital" sign can result in important changes in the treatment of some children. [46]

This study and the study by Marks et al[16], contrary to the systematic review[19], suggest that sleeping RR in younger children may be a more specific and sensitive indicator of disease than RR in awake children. Figure 4 demonstrates the difference in RR for younger children during both awake and asleep states. Younger children do spend more time in the day sleeping, and there would be opportunity to observe sleeping RR in short stay wards or during overnight admissions[42].

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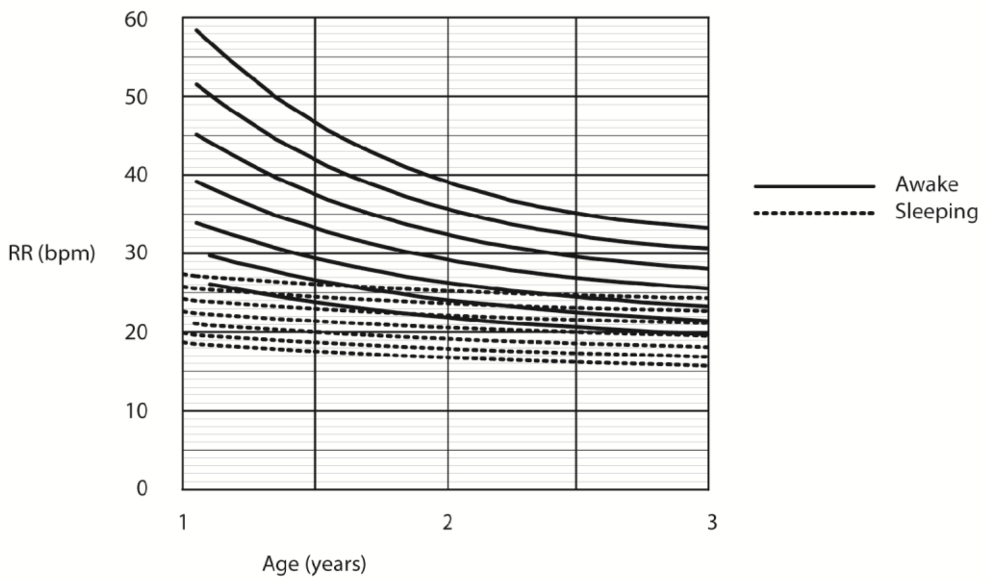


**Figure 4.** Respiratory Rate centile chart in asleep and awake children (centiles – 3rd, 10th, 25th, 50th, 75th, 90th, 97th)

Another area of interest relates to what centile to use for the upper limit of health e.g. 97 or 99 centile. In the current study we have used the 97th centile based on the precedent of growth charts[47]. We also feel it preferable to assign abnormality based on a lower centile or RR and rule out disease based on other physical signs and observations, investigations, and changes in the child's condition over time.

Caution must also be exercised in relation to directly imputing findings from studies of healthy children to the management of sick children[43]. For example, RR might be raised by various factors such as a stressful clinical environment, fever and pain. It is also possible such effects may vary between ages. The study of reference ranges undertaken by Hooker et al. and O'Leary et al. in an emergency department and by Bonafide et al. in an inpatient setting has some appeal therefore in this context.[20,21,24] The study by Hooker et al. was also not included in the systematic review by Fleming et al. [19]

While not having the power of larger studies derived from electronic medical records [21,24], or a systematic review, smaller studies such as the current study do contribute to the knowledge and understanding of RR in terms of their focus on the physiology and method of measurement of RR. The state of the child (awake and asleep) and method of measuring RR are important in this context. Further, for neonates and infants differentiating between active and quiet sleep may also be an important consideration. [48,49] Based on the current study, and other recommendations in the literature, we suggest measuring RR for two separate 30 second intervals, as the preferred method of measuring RR. [32] It may be helpful for institutions to suggest how RR is measured, and when documenting RR to note the state of the child (sleep or awake). This could further enhance the value of the excellent percentile charts obtained from large data sets from electronic medical records.

### 4.3 Limitations

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The findings of this study were limited somewhat by the population that volunteered to participate in the study. Examination of the occupations of parents of children involved in the study does show that there is an over-abundance of certain occupational groups and a lack of other groups. Obtaining children from childcare centres and private schools accounts for this.

While the number of subjects in this study is similar to that of Marks et al[16], more subjects in each age group would have been helpful. This is particularly in the context of using a log transformation to obtain a normal distribution and using polynomial equations to smooth the centile charts. There are also alternative ways of determining centile charts. The current study used the method of Healy et al[35]. Another method proposed by Cole et al[50], also allows any centile to be quantified. Further, data at the extremes of ages (ie youngest and oldest children) may have more of a contribution to the centile chart[50].

Awake children were also informed about certain aspects relating to the breathing study before their respirations were observed. This may have caused the children to alter their breathing patterns. This is a limitation of any study that observes breathing patterns in children unless the experiments are performed without telling the subject that their breathing is being monitored.

## 5. Conclusions

Respiratory rate must be counted in the context of a child's overall condition and also monitored over time. Medical textbooks vary in their reference values and often make no mention of where their values have been obtained. Having accurate reference ranges or percentile charts of respiratory rate for healthy children would make defining abnormal or clinically significant respiratory rates easier. The need for detailed studies of respiratory rate with sound research methods has been highlighted.[51] This study provides reference ranges of RR for healthy infants and children from birth to 13 years. This data is specific for Australian children and is particularly useful for sleeping infants less than 3 years of age. Some strengths of this study include the carefully designed methodology and close observation of whether children were asleep or awake. It is important to differentiate between sleeping and wakeful states when measuring RR in younger children.

**Author Contributions:** For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, S.W. and J.P.; methodology, A.H, J.P. and S.W.; software, S.W.; validation, A.H. and S.W.; formal analysis, A.H., S.W. and J.P.; investigation, A.H., S.W. and J.P.; resources, J.P. and S.W.; data curation, A.H.; writing—original draft preparation, A.H.; writing—review and editing, A.H., S.W. and J.P; supervision, J.P. and S.W.; project administration, J.P. and S.W.; funding acquisition, J.P. and S.W. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A - Cubic equations characterising the data

The fitted equation for sleeping children, aged from birth to one year, and awake children, aged from one to three years:

$$\log_{10}RR_i = a_{0,i} + a_{1,i} + a_{2,i}t^2 + a_{3,i}t^3$$

where t denotes age in years and $\log_{10} RR_i$ the smoothed curve for the *i*th percentile.

The fitted equation for awake children, aged from three to thirteen years, and sleeping children, aged one to three years:

$$\log_{10}RR_i = a_{0,i} + a_{1,i} + a_{2,i}t^2$$

where t denotes age in years and $\log_{10} RR_i$ the smoothed curve for the *i*th percentile.

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