Normal ranges of heart rate and respiratory rate in children from birth to 18 years: a systematic review of observational studies

Web Appendix

Web Box 1: Existing reference ranges for respiratory rate and heart rate

Respiratory rate (breaths/minute)

Age Range (years)	APLS[1] / PHPLS[2]	PALS[3]	EPLS[4]	PHTLS[5]	ATLS[6]	WHO[+7]
Neonate	30 – 40	30 – 60	30 – 40	30 – 50*	<60	
0 – 1	30 – 40	30 – 60	30 – 40	20 – 30*	<60	<50[+]
1 – 2	25 – 35	24 – 40	26 – 34	20 – 30	<40	<40
2 – 3	25 – 30	24 – 40	24 – 30	20 – 30	<40	<40
3 – 4	25 – 30	24 – 40	24 – 30	20 – 30	<35	<40
4 – 5	25 – 30	22 – 34	24 – 30	20 – 30	<35	<40
5 – 6	20 – 25	22 – 34	20 – 24	20 – 30	<35	
6 – 12	20 – 25	18 – 30	20 – 24	(12 – 20) – 30	<30	
12 – 13	15 – 20	18 – 30	12 – 20	(12 – 20) – 30	<30	
13 – 18	15 – 20	12 – 16	12 – 20	12 – 20^	<30	

* PHTLS provides separate ranges for neonates up to six weeks, and for infants between seven weeks and one year of age.
^ PHTLS does not provide ranges for adolescents over 16 years of age.
[+] WHO only provides ranges for children between two months and five years of age.

Heart rate (beats/minute)

Age Range (years)	APLS[1] / PHPLS[2]	PALS[3]*	EPLS[4]*	PHTLS[5]	ATLS[6]
Neonate	110 – 160	85 – 205^	85 – 205^	120 – 160[+]	<160
0 – 1	110 – 160	100 – 190^	100 – 180^	80 – 140[+]	<160
1 – 2	100 – 150	100 – 190	100 – 180	80 – 130	<150
2 – 3	95 – 140	60 – 140	60 – 140	80 – 120	<150
3 – 5	95 – 140	60 – 140	60 – 140	80 – 120	<140
5 – 6	80 – 120	60 – 140	60 – 140	80 – 120	<140
6 – 10	80 – 120	60 – 140	60 – 140	(60 – 80) – 100	<120
10 – 12	80 – 120	60 – 100	60 – 100	(60 – 80) – 100	<120
12 – 13	60 – 100	60 – 100	60 – 100	(60 – 80) – 100	<100
13 – 18	60 – 100	60 – 100	60 – 100	60 – 100[~]	<100

* PALS and EPLS provide multiple ranges – ranges for awake children are tabulated
^ PALS and EPLS provide separate ranges for infants up to three months, and for those between three months and two years of age.
[+] PHTLS provides separate ranges for infants up to six weeks, and for those between seven weeks and one year of age.
[~] PHTLS does not provide ranges for adolescents over 16 years of age.

Web Table 1: Search strategy used to identify included studies

Database	Age of subject	Age variation	Breathing / heart rate	Reference values
MEDLINE	adolescent/ child/ child, preschool/ infant/ infant, newborn/ (child* or adolescen* or infan* or neonate* or teenage* or newborn* or schoolchild* or pediatric or paediatric).tw.	Aging/ age distribution/ Age Factors/ Time Factors/ (age adj2 (related or range* or specific or effect or depend* or distribut*)).tw.	respiration/ respiratory mechanics/ Respiratory Physiological Phenomena/ Oximetry/ heart rate/ pulse/ Electrocardiography/ (heart rate* or pulse rate* or cardiac rate*).tw. (respirat* rate* or breathing rate* or breathing pattern*).tw. pulse oximet*.tw. (ecg or electrocardiogra*).tw.	Reference Values/ (normal adj2 (rate* or value* or limit* or range* or variab*)).tw. (reference adj2 (value* or range* or limit* or percentile or data)).tw. ((minim* or maxim* or mean or median) adj2 (rate* or value* or limit*)).tw. normative data.tw. threshold value*.tw.
EMBASE	adolescent/ child/ preschool child/ school child/ infant/ newborn/ (child* or adolescen* or infan* or neonate* or teenage* or newborn* or schoolchild* or pediatric or paediatric).tw.	Aging/ age distribution/ Age/ normal human/ (age* adj2 (related or range* or specific or effect* or depend* or distribut*)).tw.	Electrocardiogram/ breathing pattern/ breathing rate/ breathing/ heart rhythm/ pulse rate/ heart rate/ heart rate variability/ (heart rate* or pulse rate* or cardiac rate*).tw. (respirat* rate* or breathing rate* or breathing pattern*).tw. pulse oximet*.tw. (ecg or electrocardiogra*).tw.	reference value/ normal value/ (normal adj2 (rate* or value* or limit* or range* or variab*)).tw. (reference adj2 (value* or range* or limit* or percentile or data)).tw. ((minim* or maxim* or mean or median) adj2 (rate* or value* or limit*)).tw. normative data.tw. threshold value*.tw.
CINAHL	Adolescence/ Child/ Child, preschool Infant/ Infant, newborn/ (child* or adolescen* or infan* or neonate* or teenage* or newborn* or schoolchild* or pediatric or paediatric).tw.	Aging/ (age* N2 (related or range* or specific or effect* or depend* or distribut*)).tw.	Heart rate/ Heart rate variability/ Electrocardiography/ Respiration/ Respiratory Rate/ Pulse Oximetry/ (heart rate* or pulse rate* or cardiac rate*).tw. (respirat* rate* or breathing rate* or breathing pattern*).tw. pulse oximet*.tw. (ecg or electrocardiogra*).tw.	

To be included, a paper had to match at least one term in each category. The CINAHL search did not include terms in the reference values category.

Web Annex 1: Kernel Regression

In our systematic review, we fitted curves showing the median and six representative centiles for the variation of heart rate and respiratory rate with respect to age. Each curve was fitted using a modified version of kernel regression, which will be discussed in more detail here.

Kernel regression is a non-parametric regression method, which allows a curve to be fitted to a set of data without specifying the form of the curve in advance.[8] To fit curves to the data on heart rate and respiratory rate in relation to age in children, it would be beneficial to have a regression method that could take into account both the different age ranges over which the measurements had been made, and would also allow weighting based on the sample size. No existing regression method was found that allowed for these variables, but it was possible to make simple alterations to the classical formulation of kernel regression to incorporate these changes.

In classical kernel regression, a kernel K(x) is centred on each data point, $x = x_i$. A popular choice for K(x) is the normal distribution with zero mean and unit variance, and this is what was used in this analysis. The kernel defines the spatial weighting given to the data point in the regression. Far away from the data point, the kernel function will have a small amplitude, and so the point will only make a small contribution to the regression curve, whereas it will make a large contribution in the region close to its location, where the value of the kernel function is larger. The width of the kernel function can be altered to control the smoothness of the final curve – this is controlled by the bandwidth h, and this can be incorporated into the definition of the kernel as shown in the equation below.

$$K_h(u) = \frac{1}{h} K\left(\frac{u}{h}\right)$$

Large values of the bandwidth will produce smooth curves, as each point will contribute to a large portion of the curve. Smaller values will produce more noisy curves, and are more likely to exhibit overfitting to the data, as each data point only affects a small portion of the curve, and does not share influence over a given section with many other points.

We use local polynomial kernel regression, which operates by fitting a polynomial at each point on the curve, weighted by the values of the kernels at that point. The degree of the polynomial fitted is denoted by p, so p=1 would fit a straight line at each point. To calculate the value of the kernel regression, m, at point x, a polynomial of order p is fitted using weighted least squares. In this analysis, we use p=1, and so the explicit formula for the local linear estimator is used:

$$m = \frac{1}{n} \sum_{i=1}^{n} \frac{\{s_2(x;h) - s_1(x;h)(x_i - x)\} K_h(x_i - x) y_i}{s_2(x;h) s_0(x;h) - s_1(x;h)^2}$$

where n is the number of data points (x_i,y_i), and s_r is defined by the equation below.

$$s_r = \frac{1}{n} \sum_{i=1}^{n} (x_i - x)^r K_h(x_i - x)$$

When fitting curves to the data on heart rate and respiratory rate in relation to age in children, each data point is associated with an age range, rather than a single age, as the measurements will have been made on groups of children. The size of the ranges can vary greatly, with some studies focusing on children grouped into year groups, while others may use 5-year groups, especially when considering older children.

One possible solution to this problem is to assign the data to the mid-point of the range, but this ignores the fact that it contains information about both older and younger children. It is therefore preferable to include the age range in the regression calculation, and this can be achieved using variable bandwidth kernel regression. In this formulation of kernel regression, h is replaced by h_i, so that the kernel centred on each data point is now able to have an independent bandwidth. The value of h_i at each data point is calculated using the following equation, where Δx_i is the age range associated with the data point, and h_c is a common multiplier which allows the overall smoothing of the curve to be manipulated.

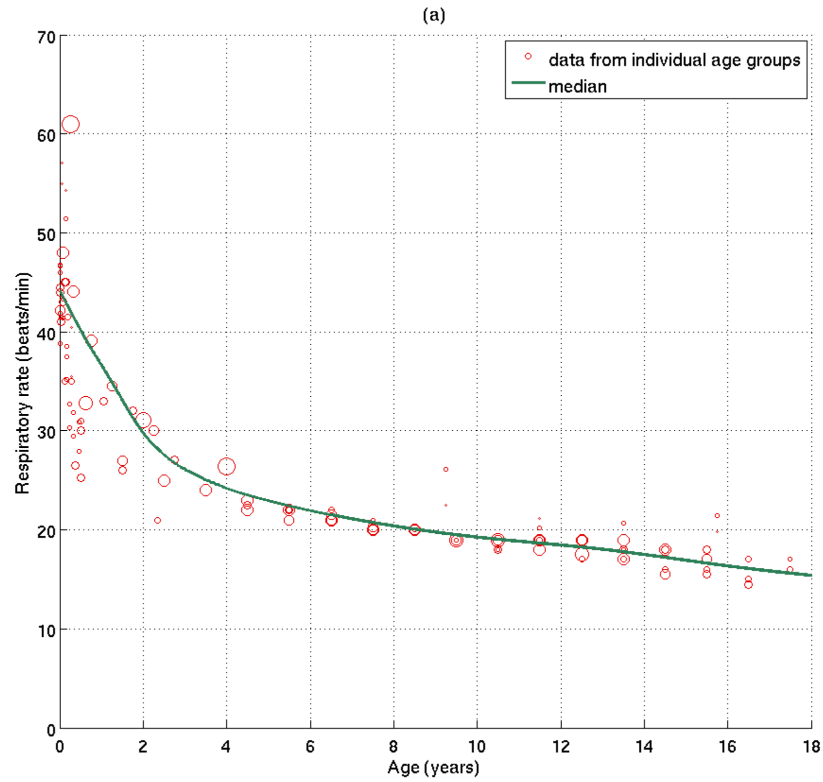
$$h_i = h_c \Delta x_i$$

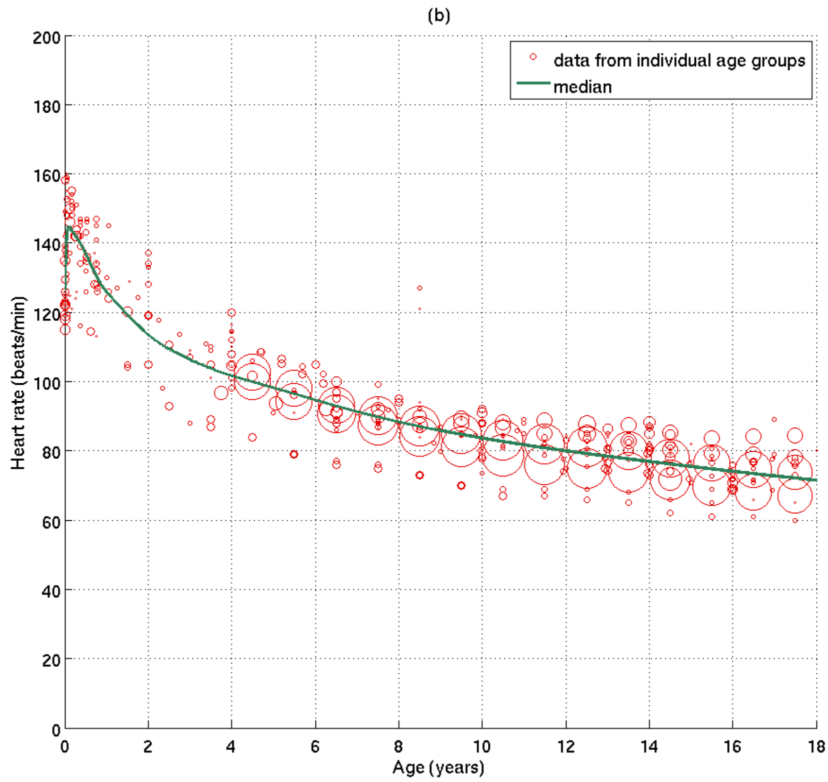
In addition to including variable bandwidths, it would also be useful to add weighting to data points to reflect the sample sizes of the measurements from which they are derived. This is achieved by adding a weighting term w_i to the kernel function, such that the resulting kernel function K_{h_i} is as shown below. The value of w_i for each data point is equal to the sample size for that point. This definition for the kernel function can then be used in place of K(h) in the local linear estimator equation.

$$K_{h_i}(u) = \frac{w_i}{h_i} K\left(\frac{u}{h_i}\right)$$

The choice of the common bandwidth multiplier, h_c, was made empirically, by trying a variety of values and choosing one that produced smooth curves with a good fit to the data across the full range of ages. For the heart rate, a value of $h_c = 2{\cdot}5$ was found to produce a good fit across all age ranges, for both the median and centile curves. For the respiratory rate data, a value of $h_c = 1{\cdot}5$ was found to produce the best fit. The choice of h_c is made empirically due to the inherent difficulty in defining an appropriate objective function for optimisation. This is because a balance needs to be struck between optimising for a close fit to the data, which will lead to a small value of h_c, and optimising for a smooth curve, which will produce a large value of h_c.

Web Figure 1: Scatter plots of raw data extracted from studies reporting (a) respiratory rate and (b) heart rate in children.





Note: Data is plotted at the mean age for the group of children. The size of the marker indicates the number of children in the group.

Web Table 2: Summary of studies on respiratory rate included in the systematic review

Study, year	Setting	Age Range	Sample Size	Study Description	Method of respiratory rate measurement
Iliff, 1952[9]	Research laboratory, USA	0–18y	197	Longitudinal study of heart rate, respiratory rate and body temperature in normal children	Manual (observation)
Ashton, 1971[10]	Research laboratory, UK	44–144h	22	Cross-sectional study of heart rate and respiratory rate during consecutive sleep cycles in infants	Strain gauge^
Hoppenbrouwers, 1979[11]	Sleep laboratory, USA	0–6mths	25	Longitudinal study of circadian patterns in the respiratory rate in neurologically normal infants	Expired CO2 monitor and thermistor
Hoppenbrouwers, 1980[12]	Infant sleep laboratory, USA	0–6mths	25	Longitudinal case-control study of circadian patterns in the respiratory rate in siblings of SIDS victims (only data from control group of non-SIDS infants included in review)	Expired CO2 monitor and thermistor
Curzi-Dascalova, 1981[13]	Hospital, Paris, France	0–18wks	57	Cross-sectional study of respiratory rate in normal, full-term infants recruited from hospital nurseries	Strain gauges^
Curzi-Dascalova, 1983[14]	Hospital, Paris, France	2d–18wks	38	Case-control study of respiratory rate during sleep in siblings of SIDS victims (only data from control group of normal infants with no familial history of SIDS included in review)	Strain gauge^
Ward, 1986a[15]	Child's home, USA	0–2y	64	Case-control study of ventilatory patterns during sleep in infants with myelomeningocele (only data from control group of healthy infants included in review)	Chest wall impedance^
Ward, 1986b[16]	Medical centres, Los Angeles, USA	0–7mths	43	Case-control study of ventilatory patterns during sleep in infants born to substance-abusing mothers (only data from control group of infants born to healthy mothers included in review)	Impedance pneumogram
Antila, 1990[17]	Unspecified	2–65d	24	Case-control study of heart rate variability in infants subsequently suffering SIDS (only data from control group of non-SIDS infants included in review)	Volume expansion capsule transducer
Morley, 1990[18]	Child's home, Cambridge, UK	0–6mths	298	Cross-sectional study of respiratory rate and severity of illness in children (only data from well children recruited randomly from the birth register included in this study)	Manual (observation or auscultation)
Poets, 1991[19]	Child's home, UK	0–2y	42	Longitudinal study of breathing patterns and heart rate in full-term, healthy infants selected at random	Pressure capsule on chest
Nogues, 1992[20]	Research laboratory, France	60–75d	35	Cross-sectional study of day-time and night-time respiratory rates in normal infants	Rubber straps and thermistor^
Kahn, 1993[21]	Paediatric Sleep Clinic, University Children's Hospital, Brussels, Belgium	3mths	68	Cross-sectional study of the relationship between body position and sleep characteristics in healthy subjects referred to paediatric sleep clinic following studies confirming normal sleep behaviour, and with no history of sleep problems or apnoea	Strain gauges and thermistor^
Rusconi, 1994[22]	Day care centres or hospitals, Italy	0–3y	618	Cross-sectional study of respiratory rate in children recruited from day care centres or hospital inpatient or outpatient departments, with no chronic or severe illness, or signs of respiratory infection	Manual (auscultation)*
Bhandari, 1998[23]	Hospital, Chandigarh, India	1–8wks	50	Longitudinal study of respiratory rate of healthy infants recruited at birth (only data from normal birthweight infants included in review)	Manual (observation or auscultation)
Montgomery-Downs, 1998[24]	Community hospital and child's home, USA	0–6mths	88	Longitudinal study of quiet sleep respiratory rates in full-term normal infants recruited during childbirth classes	Capacitive pressure sensitive pad^
Rosenthal, 2000[25]	unspecified, London, UK	8–17y	106	Cross-sectional study of ventilatory variables in healthy children recruited from schools	Helium dilution mixed expired gas analysis*

Wallis, 2005[26]	Schools, Plymouth, UK	4–16y	1,109	Cross-sectional study of heart rate and respiratory rate in children attending primary or secondary schools	Manual (observation)*
Balasubramanian, 2006[27]	Children's Hospital, Chennai, India	1mth–5y	626	Cross-sectional study of heart rate, respiratory rate and oxygen saturation in healthy children attending outpatients department for immunization and/or well-baby check-ups as patients or siblings, or posted for elective surgery	Manual (observation)*
Wallis, 2006[28]	School, Langa Township, Cape Town, South Africa	5–16y	346	Cross-sectional study of heart rate and respiratory rate in children attending school	Manual (observation)*

Notes:
Age is given in years (y), months (mths), weeks (wks), days (d), or hours (h).
* data from awake children was used in constructing the centile charts.
^ data from asleep children was used in constructing the centile charts.
Absence of the above markings indicates that it is not possible to differentiate between data from awake and asleep children.
SIDS - sudden infant death syndrome
CO_2 - carbon dioxide

Web Table 3: Summary of studies on heart rate included in the systematic review

Study, year	Setting	Age Range	Sample Size	Study Description	Method of heart rate measurement
Iliff, 1952[9]	Research laboratory, USA	0–18y	197	Longitudinal study of heart rate, respiratory rate and body temperature in normal children	Manual (palpation or auscultation)
Ashton, 1971[10]	Research laboratory, UK	44–144h	22	Cross-sectional study of heart rate and respiratory rate during consecutive sleep cycles in infants	ECG^
Bradfield, 1971[29]	Primary School, Cambridge, UK	7–10y	54	Cross-sectional study of body build, heart rate and energy expenditure of boys attending primary school	Electrode-based heart rate monitor*
Betau, 1980[30]	Veterans General Hospital, Taiwan	0–1y	302	Longitudinal study of ECG parameters from randomly chosen normal newborns in hospital nursery	ECG
Davignon, 1980[31]	unspecified, Montreal, Canada	0–16y	2,141	Cross-sectional study of normal ECG parameters from healthy white children recruited from obstetric clinic, well-child clinics, and public schools	ECG
De Caprio, 1981[32]	unspecified, Italy	5–25y	46	Cross-sectional study of the effect of age on heart rate and systolic time interval in healthy young people recruited during normal check-ups	ECG
Hediger, 1984[33]	unspecified, Philadelphia, USA	12–17y	621	Longitudinal study of blood pressure in black adolescents, recruited from a large birth cohort study	Manual (radial palpation)*
Pereira, 1984[34]	Home visits, Philadelphia, USA	18–19mths	21	Cross-sectional study of the relationship between heart rate, activity, and energy expenditure in healthy male infants recruited from a large longitudinal study	ECG*
Lindner, 1985[35]	unspecified, Germany	0–4wks	30	Longitudinal study to determine the influence of heart rate on systolic time intervals in healthy term neonates	ECG and echocardiogram
Ward, 1986a[15]	Child's home, USA	0–2y	64	Case-control study of ventilatory patterns during sleep in infants with myelomeningocele (only data from control group of healthy infants included in review)	ECG^
Ward, 1986b[16]	Medical centres, Los Angeles, USA	0–7mths	43	Case-control study of ventilatory patterns during sleep in infants born to substance-abusing mothers (only data from control group of infants born to healthy mothers included in review)	ECG
Egger, 1987[36]	Outpatient clinic or child's home, Switzerland	10–16y	43	Cross-sectional study of the normal range of 24-hour ambulatory blood pressure in healthy children recruited from schools	Blood pressure monitor*
Palatini, 1987[37]	Normal daily activities, Italy	10–14y	30	Case-control study of the effect of endurance training on Q-T interval and cardiac electrical stability (only data from control group of healthy normotensive boys randomly selected from school included in review)	ECG
Berard, 1988[38]	Day nurseries, Nice, France	6–45mths	264	Cross-sectional study of blood pressure and heart rate in normal children measured during routine check-ups	Blood pressure monitor*
Peirano, 1988[39]	Child's home, France	5 – 24wks	28	Case-control study of night sleep heart rate patterns in infants at risk for SIDS (only data from control group of clinically and neurologically normal infants included in review)	ECG^
Romano, 1988[40]	Normal daily activities, Italy	6–11y	32	Cross-sectional study of ECG parameters in healthy children recruited as volunteers or after requesting examination prior to undertaking sporting activity	ECG
Gemelli, 1989[41]	Hospital nursery, Italy	4d	21	Cross-sectional study of circadian blood pressure patterns in full-term infants delivered after spontaneous labour	Blood pressure monitor
Mimura, 1989[42]	Private kindergarten, Japan	4–6y	1,069	Cross-sectional study of physical fitness in young children recruited from a kindergarten	Pen-oscillograph*

Muller, 1989[43]	Medical centres, France	4–18y	101,259	Cross-sectional study of ECG parameters in children	ECG*
Park, 1989a[44]	Medical Center Hospital, San Antonio, USA	5–149h	219	Cross-sectional study of arm and calf blood pressure in healthy full-term infants recruited at birth	Blood pressure monitor
Park, 1989b[45]	Pediatricians' offices and well-baby clinics, San Antonio, USA	0–5y	1,554	Cross-sectional study of oscillometric blood pressure in patients and accompanying siblings attending paediatricians' offices or well-baby clinics, who were completely healthy or had only minor complaints without fever	Blood pressure monitor
Von Bernuth, 1989[46]	Normal daily activities, Germany	0–14y	141	Cross-sectional study of heart rate and rhythm in healthy children	ECG
Antila, 1990[9]	unspecified	2–65d	24	Case-control study of heart rate variability in infants subsequently suffering SIDS (only data from control group of non-SIDs infants included in review)	ECG
Gemelli, 1990[47]	unspecified, Italy	0–1y	514	Longitudinal study of blood pressure during the 1st year of life in infants born consecutively at the Policlinic of the University of Messina	Blood pressure monitor*
Poets, 1991[19]	Child's home, UK	0–2y	42	Longitudinal study of breathing patterns and heart rate in full-term, healthy infants selected at random	ECG
Durant, 1992[48]	Normal daily activities, USA	3–5y	190	Cross-sectional study of reliability and variability of heart rate monitoring in young children. Participants recruited from longitudinal study into cardiovascular disease risk factors in families of young children	Electrode-based telemetry heart rate monitor*
Alpay, 1993[49]	Military Academy of Medicine, Ankara, Turkey	3–10d	25	Cross-sectional study of heart rate and rhythm patterns in healthy newborn infants	ECG
Barron, 1993[50]	Clinical neurophysiology laboratory, Haifa, Israel	15–17y	40	Case-control study of neurocardiovascular function in young people who had episodes of syncope under conditions of emotional stress (only data from control group of healthy volunteers included in review)	ECG*
Kahn, 1993[21]	Paediatric Sleep Clinic, University Children's Hospital, Brussels, Belgium	3mths	68	Cross-sectional study of the relationship between body position and sleep characteristics in healthy subjects referred to paediatric sleep clinic following studies confirming normal sleep behaviour, and with no history of sleep problems or apnoea	ECG^
Krull, 1993[51]	Normal daily activities, Germany	6–10y	105	Cross-sectional study of 24-hour ambulatory blood pressure monitoring in healthy children recruited from a school	Blood pressure monitor*
Harshfield, 1994[52]	Normal daily activities, USA	10–18y	300	Cross-sectional study of ambulatory blood pressure monitoring in healthy, normotensive children recruited by advertisement for a study on cardiovascular risk factors in youth	Blood pressure monitor*
Macfarlane, 1994[53]	General and children's hospital, postnatal clinics, preschools and schools, Glasgow, Scotland	0–18y	1,782	Cross-sectional study of ECG parameters in healthy, normally developed children, and children hospitalised for problems that did not affect the cardiovascular system	ECG
Regecová, 1995[54]	Kindergartens, Bratislava, Slovak Republic	3–7y	1,542	Cross-sectional study of the association between urban traffic noise and blood pressure in healthy children recruited from kindergartens	Manual (radial palpation)*
Andrásyová, 1996[55]	Gynaecological Clinic of university faculty of medicine, Bratislava, Slovak Republic	1–7d	83	Cross-sectional study of the pattern of circulatory response to head-up body tilting in full-term newborns	Blood pressure monitor*

Abdurrahman, 1998[56]	Children's Hospital Medical Centre, Cincinnati, USA	1wk–24y	43	Cross-sectional study of pulmonary venous flow Doppler velocities in normal children referred for echocardiographic evaluation of murmur, in normal sinus rhythm, and with no evidence of structural or functional heart disease	Echocardiogram
Compagnone, 1999[57]	Elementary schools, San Francisco, USA	7–10y	174	Cross-sectional study of cardiovascular reactivity in elementary school children	Blood pressure monitor*
Oberlander, 1999[58]	Biobehavioural Research Unit, Centre for Community Child Health Research, Vancouver, Canada	4–8mths	24	Longitudinal study of cardiac autonomic responses to acute noxious events in healthy infants recruited at birth	ECG*
Rogachevskaia, 1999[59]	Secondary school, Siktivkar, Russia	7–16y	726	Cross-sectional study of blood circulation and gas exchange in secondary school children	Manual (radial palpation)*
Logan, 2000[60]	Daytime monitoring during normal daily activities, Scotland	3–4y	20	Cross-sectional study of apparent levels of physical activity in young healthy children	Telemetry heart rate monitor*
Rijnbeek, 2001[61]	unspecified, Rotterdam, the Netherlands	0–16y	1,912	Cross-sectional study of normal ECG parameters in healthy children recruited from child health centres, primary and secondary schools	ECG
Rabbia, 2002[62]	Schools, Turin, Italy	12–18y	2,230	Cross-sectional study of resting heart rate in randomly selected children recruited from schools	Manual (radial palpation)*
Bernaards, 2003[63]	unspecified, the Netherlands	13y	410	Longitudinal study to assess the association between smoking and cardiovascular fitness in subjects recruited from secondary schools. Smoking prevalence at age 13 was approximately 1%	ECG*
Rekawek, 2003[64]	Normal daily activities, Poland	4–18y	372	Cross-sectional study of heart rate variability indices in healthy children	ECG
Hadtstein, 2004[65]	Normal daily activities, Germany	5–18y	938	Cross-sectional study of physiological circadian and ultradian rhythms of blood pressure and heart rate in healthy school children	Blood pressure monitor*
Pivik, 2004[66]	Research laboratory, USA	8–10y	39	Case-control study of the cardiovascular response to morning nutrition (only data from non-fasting group of healthy children recruited from local community included in review)	ECG*
Makan, 2005[67]	unspecified, UK	14–18y	250	Case-control study of left ventricular volume in trained adolescent athletes (only data from control group of healthy adolescents recruited from large secondary education boarding schools included in review)	Echocardiogram*
Massin, 2005[68]	Normal daily activities, Belgium	0–16y	264	Case-control study of cardiac rate and rhythm patterns in ambulatory and hospitalised patients (only data from control group of healthy ambulatory children included in review)	ECG
Wallis, 2005[26]	Schools, Plymouth, UK	4–16y	1,109	Cross-sectional study of heart rate and respiratory rate in children attending primary or secondary schools	Finger probe*
Balasubramanian, 2006[27]	Children's Hospital, Chennai, India	1mth–5y	626	Cross-sectional study of heart rate, respiratory rate and oxygen saturation in healthy children attending outpatients department for immunization and/or well-baby check-ups as patients or siblings, or scheduled for elective surgery	Manual (auscultation)*
Cui, 2006[69]	Children's Hospital, Illinois, USA	0–18y	289	Cross-sectional study to determine the normal range of left ventricular Tei index in paediatric patients with normal echocardiograms	Echocardiogram

Niboshi, 2006[70]	unspecified, Japan	9–18y	970	Cross-sectional study of brachial-ankle pulse wave velocity in healthy Japanese children recruited from school or after doctor's consultations for functional murmur (patients and healthy siblings)	ECG*
Wallis, 2006[28]	School, Langa Township, Cape Town, South Africa	5–16y	346	Cross-sectional study of heart rate and respiratory rate in children attending school	Finger probe*
Yamanaka, 2006[71]	Hospital, company or school, Japan	6–19y	279	Cross-sectional study of the effects of aging on the cardiovascular response to postural change in healthy Japanese subjects	ECG*
Mason, 2007[72]	unspecified, worldwide	10–19y	1,345	Cross-sectional study of ECG parameters in normal healthy volunteers screened for enrolment in pharmaceutical company-sponsored clinical trials	ECG
Roberson, 2007[73]	Children's Hospital, Illinois, USA	0–18y	308	Cross-sectional study of right ventricular Tei index in paediatric patients with normal echocardiograms	Echocardiogram
Wyller, 2007[74]	Outpatient clinic, Hospital paediatric department, Oslo, Norway	12–18y	57	Case-control study of abnormal thermoregulatory responses in chronic fatigue syndrome (only data from control group of healthy volunteers from local schools included in review)	ECG*
Salameh, 2008[75]	Normal activity, unspecified location	0–20y	616	Cross-sectional study of normal heart rate in healthy children referred with palpitations or suspected paroxysmal supraventricular tachycardia, in whom a full clinical and echocardiographic examination failed to confirm the suspected problem, and did not find any evidence of structural cardiac disease, significant arrhythmia or other serious illness	ECG
Semizel, 2008[76]	unspecified, Bursa, Turkey	0–16y	2,241	Cross-sectional study of ECG parameters in healthy children recruited from nursery, primary and secondary schools, child health centres, and a maternity hospital	ECG
Sung, 2008[77]	Schools, Hong Kong	6–18y	14,842	Cross-sectional study of blood pressure in Chinese children recruited from primary and secondary schools	Blood pressure monitor*

Notes:
Age is given in years (y), months (mths), weeks (wks), days (d), or hours (h).
* data from awake children was used in constructing the centile charts.
^ data from asleep children was used in constructing the centile charts.
Absence of the above markings indicates that it is not possible to differentiate between data from awake and asleep children.
SIDS - sudden infant death syndrome
ECG - electrocardiograph

Web Table 4: Proposed respiratory rate cut-offs (breaths/minute) based on centile charts

Age Range	1st centile	10th centile	25th centile	Median	75th centile	90th centile	99th centile
0 – 3m	25	34	40	43	52	57	66
3 – 6m	24	33	38	41	49	55	64
6 – 9m	23	31	36	39	47	52	61
9 – 12m	22	30	35	37	45	50	58
12 – 18m	21	28	32	35	42	46	53
18 – 24m	19	25	29	31	36	40	46
2 – 3y	18	22	25	28	31	34	38
3 – 4y	17	21	23	25	27	29	33
4 – 6y	17	20	21	23	25	27	29
6 – 8y	16	18	20	21	23	24	27
8 – 12y	14	16	18	19	21	22	25
12 – 15y	12	15	16	18	19	21	23
15 – 18y	11	13	15	16	18	19	22

Age ranges given in years (y) and months (m).

Web Table 5: Proposed heart rate cut-offs (beats/minute) based on centile charts

Age Range	1st centile	10th centile	25th centile	Median	75th centile	90th centile	99th centile
Birth	90	107	116	127	138	148	164
0 – 3m	107	123	133	143	154	164	181
3 – 6m	104	120	129	140	150	159	175
6 – 9m	98	114	123	134	143	152	168
9 – 12m	93	109	118	128	137	145	161
12 – 18m	88	103	112	123	132	140	156
18 – 24m	82	98	106	116	126	135	149
2 – 3y	76	92	100	110	119	128	142
3 – 4y	70	86	94	104	113	123	136
4 – 6y	65	81	89	98	108	117	131
6 – 8y	59	74	82	91	101	111	123
8 – 12y	52	67	75	84	93	103	115
12 – 15y	47	62	69	78	87	96	108
15 – 18y	43	58	65	73	83	92	104

Age ranges given in years (y) and months (m).
“Birth” refers to the immediate neonatal period.

Web Annex 2: Investigation of heterogeneity

Heart rates measured in community settings were significantly higher than those measured in clinical or laboratory settings. This may be because many of the studies carried out in community settings involved ambulatory monitoring during normal daily activities, which might include physical exertion, although exercise studies were excluded from the review. In contrast, children studied in more controlled clinical and research settings are more likely to be resting during measurement, resulting in lower heart rates.

We also found that heart rates were significantly higher when measured using automated devices (e.g. ECGs) compared to manual measurements (e.g. auscultation or palpation). Electronic devices may cause anxiety in children, resulting in elevation of heart rate, particularly if they are uncomfortable (as might be the case with inflating blood pressure cuffs) or unfamiliar. On the other hand, manual methods may underestimate true heart rates owing to difficulty in counting the rapid rates seen in young children. This has previously been reported to account for underestimation of the heart rate by between 15 and 20 beats/minute in young infants.[78] Heart rates measured in developing countries were found to be significantly higher than those measured in developed countries. This may be due to lower levels of general health in developing countries even among "healthy children", although a similar increase was not observed in the respiratory rate.

A small but significant trend in heart rate was observed with the date of publication, with more recent publications tending to report higher heart rates. However, it is likely that much of this variation is due to the higher prevalence in recently published papers of automated measurement methods, and measurements made in community settings or developing countries, all of which were shown to be associated with higher reported heart rates. Although our search spans the period from 1950 to 2009, over 75% of the included studies were carried out after 1988, with only 6% being carried out before 1980. Heterogeneity due to gender was not investigated, although some studies report a small but significant difference in heart rate of between 3 and 11 beats/minute at some age ranges.[42,52,61,62,75] The age ranges at which these differences are significant are not consistent between studies, and so further investigation may be required on this subject.

The increase in heart rate in the first month of life observed in our centile chart is unlikely to be due to modelling artefact, as a similar peak is observed in all six primary studies that reported multiple measurements on infants under one year of age.[30,31,35,47,53,76] All of these studies used automated measuring equipment, with five using ECG, and one using an automated blood pressure monitor,[47] making measurement error unlikely.

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