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When a "wheeze" is not a wheeze: acoustic analysis of breath sounds in infants

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When a "wheeze" is not a wheeze: acoustic analysis of breath sounds in infants. H.E. Elphick, S. Ritson, H. Rodgers, M.L. Everard. ©ERS Journals Ltd 2000.
ABSTRACT: Epidemiological studies indicate that the prevalence of "wheeze" is very high in early childhood. However, it is clear that parents and clinicians frequently use the term "wheeze" for a range of audible respiratory noises. The commonest audible sounds originating from the lower airways in infancy are ruttles, which differ from classical wheeze in that the sound is much lower in pitch, with a continuous rattling quality and lacking any musical features. The aim of this study was to clearly differentiate wheeze and ruttles objectively using acoustic analysis.

Lung sounds were recorded in 15 infants, seven with wheeze and eight with ruttles, using a small sensitive piezoelectric accelerometer, and information relating to the respiratory cycle was obtained using inductive plethysmography. The acoustic signals were analysed using a fast fourier transformation technique (Respiratory Acoustics Laboratory Environment programme).

The acoustic properties of the two noises were shown to be quite distinct, the classical wheeze being characterized by a sinusoidal waveform with one or more distinct peaks in the power spectrum display; the ruttle is represented by an irregular nonsinusoidal waveform with diffuse peaks in the power spectrum and with increased sound intensity at a frequency of <600 Hz.

It is important for clinicians and epidemiologists to recognize that there are distinct types of audible respiratory noise in early life with characteristic acoustic properties.
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A number of prospective epidemiological studies have indicated that "wheeze" is an extremely common problem in early childhood. It has been suggested that as many as 48% of children "wheeze" before their sixth birthday [1–3]. Although, at one time many of these infants were labelled as "asthmatics", it has become increasingly clear over recent years that there are many subgroups of respiratory illness in infancy and early childhood [4]. A major weakness of epidemiological studies is that they simply ask whether or not a child has wheezed and do not obtain objective information regarding the noises reported by the parents as "wheeze". Classical wheeze is a highpitched whistling sound with a musical quality [5], probably generated by the oscillation of narrowed airway walls [6]. However, it has been noted that parents in a medical setting such as an outpatient clinic frequently use the term "wheeze" to describe a variety of respiratory noises [7]. Many of the children with noisy breathing described as "wheeze" instead make a coarse respiratory sound, termed locally in Yorkshire (UK) as a "ruttle". There is widespread acceptance that this is a common sound, which is much lower in pitch than a wheeze, with a continuous rattling quality and lacking any musical features. Characteristically, parents are able to feel this noise as a vibration over the baby's back in contrast to classical wheeze in which no such transmitted vibrations are evident. The source of this sound is unclear, but may reflect excessive secretions in the central and extrathoracic airways.

One study assessing the prevalence of a variety of symptoms in 298 infants <6 months of age found that noisy breathing was very common with 30% of parents reporting noisy breathing in the previous 24 h and 11% of the infants said to have had noisy breathing from birth [8]. On closer questioning, the investigators determined that stridor accounted for 1% of the total, upper airways noises 93% and classical wheeze only 2%. The vast majority of infants, therefore, had snuffly or upper airway noises; many of the latter are likely to have ruttles.

The imprecise use of the term "wheeze" by medical personnel and by parents who believe that the medical profession use the term "wheeze" to describe all audible additional respiratory noises has a number of potentially important consequences. In epidemiological studies, it is likely that "wheeze" is significantly overreported by parents when a child has ruttles or another form of noisy breathing. Thus, in clinical practice, misuse of the term has significant consequences in that the aetiology, natural history and response to therapy are all likely to be very different in young children with classical wheeze as opposed to those with ruttles.

The aim of this study was to objectively characterize the acoustic properties of the two most common audible respiratory noises of early childhood, classical wheeze and ruttles, with the hypothesis that the two noises exhibit distinct sonographic characteristics.

Methods

Infants chosen for recording were recruited from paediatric respiratory clinics, acute inpatients admitted with virally induced respiratory illness or the community (all the children were referred from inpatients or out/patients attending the Sheffield Children's Hospital). Approval for the study was obtained from the local ethics committee and informed consent was obtained from the infants' parents.

Infants for entry into the study were carefully selected by one of the investigators (M.L. Everard). Only infants with clear auscultatory characteristics of either classical wheeze or a coarse rattling sound associated with vibrations on palpation were selected as it was wished to include only typical examples for the purpose of defining the noises.

Infants with any other lung sounds, or a combination of sounds, were excluded from the study.

Lung sound recording and analysis was carried out by a second investigator (H.E. Elphick).

In total, 15 babies (age 7–10 months) were selected, seven with wheeze (four male, three female) and eight with ruttles, (two male, six female).

Recording of lung sounds was performed using a small sensitive piezoelectric accelerometer (EMT 25C; Siemens, Iselin, NJ, USA) attached to the skin of the chest *via* a double-sided adhesive ring. The sound sensor was a contact transducer weighing 15.4 g, with a height of 13 mm and diameter of 28 mm. The transducer allows measurements of as low as 20 dB. A flat frequency response of this transducer has been documented in the range 60–500 Hz, a gain of ~4 dB in the range 500–1,000 Hz and a 15-dB/octave roll-off at >1,200Hz [9]. Lung sounds were recorded anteriorly from the right upper zone of the chest with the baby breathing normally. Signals from the chest and abdomen were monitored by uncalibrated inductive plethysmography (Respitrace; Studley data systems, Oxford, UK) in order to identify the phase of respiration. The recording on each occasion lasted for ~1 min of tidal breathing, with the baby quiet or asleep. Recordings were made in a quiet room with background noise kept to a minimum and the quality of the recording was monitored by listening through headphones.

Segments suitable for analysis were identified and edited by listening to the lung sounds on headphones whilst simultaneously checking the respiration trace. Artefacts from movement of the baby or external background noise were eliminated from the recordings prior to analysis. The sound signal was band-pass filtered between 50 Hz (to attenuate heart sounds) and 2,500 Hz (to avoid aliasing during analogue-to-digital conversion) using a sixth order Butterworth filter.

The signals were amplified and transmitted to an IBM-compatible personal computer *via* a 16-bit analogue-to-digital converter using a sampling rate of 10,240 Hz·channel-1. The power spectrum display was produced by performing a 2,048-data-point fast fourier transformation at 100-ms intervals. A 200-ms overlapping window was used, resulting in 50-ms overlaps either side of each 100-ms segment, allowing a Hanning window to be applied without any loss of information. At a sampling rate of 10,240 Hz·channel^{-1}, this resulted in a 5-Hz frequency resolution for each segment. The sound recording, analysis and display process was performed using the computer programme Respiratory Acoustics Laboratory Environment (RALE) (Pixsoft, Winnipeg, Canada) [5].

Any particular 100-ms segment could be highlighted and viewed in detail, both in the time and frequency domain. Examples from each subject selected for use in the definition of wheeze and ruttles.

Results

The acoustic images clearly illustrated differences between wheezes and ruttles and these differences were

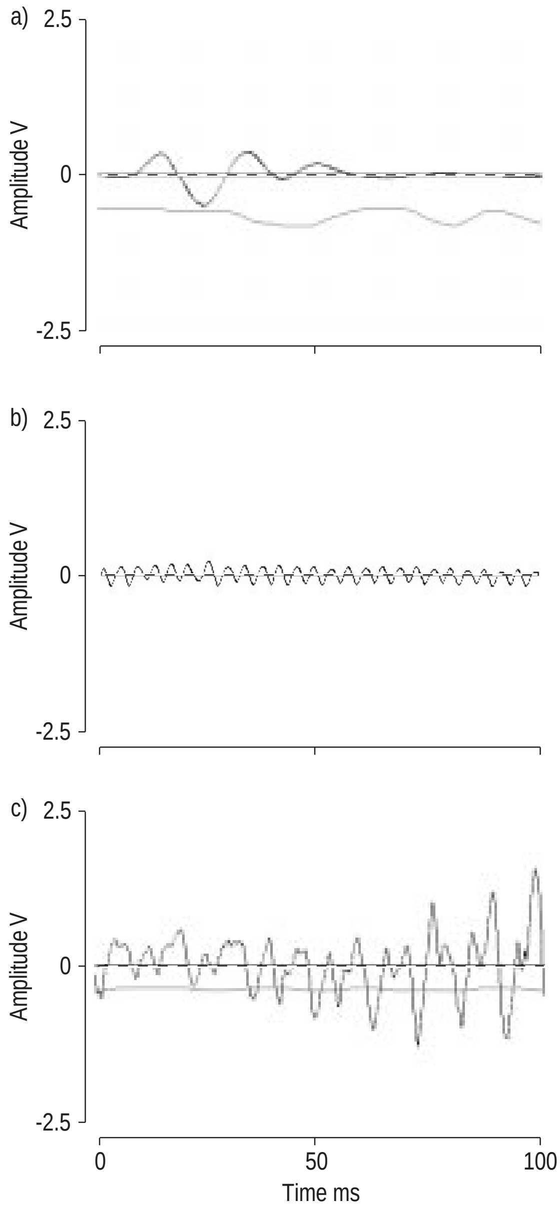

Fig. 1. – Waveform display: a) normal recording; b) wheeze with characteristic sinusoidal pattern; and c) ruttles, with nonsinusoidal irregular waveform pattern. ——: waveform; ——: flow.

apparent in all three display modalities (figs. 1–3). The analysis produced consistent results within both of the groups. All infants with wheeze or ruttles could be clearly identified by a blinded observer on the basis of the acoustic analysis.

The waveform represents the amplified output (in volts) from the contact sensor as a function of time (in milliseconds). Figure 1 shows a 100-ms segment of time during expiration. The authors have found that the waveform pattern for the wheezy baby has a very characteristic regular sinusoidal pattern, which contrasts with the non-sinusoidal, irregular and variable pattern noted in infants with rattles.

The Fourier power spectrum display is the plot of the log scale of the signal output, *i.e.* the signal intensity (in decibels) as a function of frequency (in hertz) as calculated using a fast fourier transformation technique (fig. 2). The normal power spectrum shows an exponential decay in intensity with increasing frequency. The power spectrum for the wheezy baby is characterized by distinct sharp narrow peaks of intensity at high frequencies with a width of ~10 Hz superimposed on the normal spectrum. The dominant peak occurred at a frequency of 125–375 Hz (mean 201.45 Hz) during inspiration and 212–303 Hz (mean 239.9 Hz) during expiration. Again, the recordings obtained from infants with ruttles, although there was a degree of individual variation, all showed a different pattern from those obtained from wheezing infants. As with the wheezing infants, there are abnormal peaks superimposed on the normal curve but, in the case of ruttles, these peaks are multiple, diffusely distributed and variable in size and shape. The dominant peak frequency was 70–190 Hz (mean 124.2 Hz) during inspiration and 87–238 Hz (mean 123.5 Hz) during expiration. This was significantly different from the infants with wheeze during expiration ($p<0.05$, Mann-Whitney U-test). The most striking feature of this pattern is that it occurs in the lower frequency range, *i.e.* <600Hz, where there is overall increased sound intensity compared to wheeze (fig. 2).

The sonogram is a plot of frequency as a function of time. Figure 3 shows a single example of a 5-s period of recording. The intensity of the sound is displayed as a colour spectrum with dark colours representing quiet sounds, light green to yellow medium intensity sounds and orange-red loud sounds. The characteristic features of the sonogram of a wheezy infant are horizontal bars, which correspond to the peaks of intensity in the power spectrum. The sonogram of the ruttly child has a less distinct pattern but is of generally increased intensity throughout the lower frequency range.

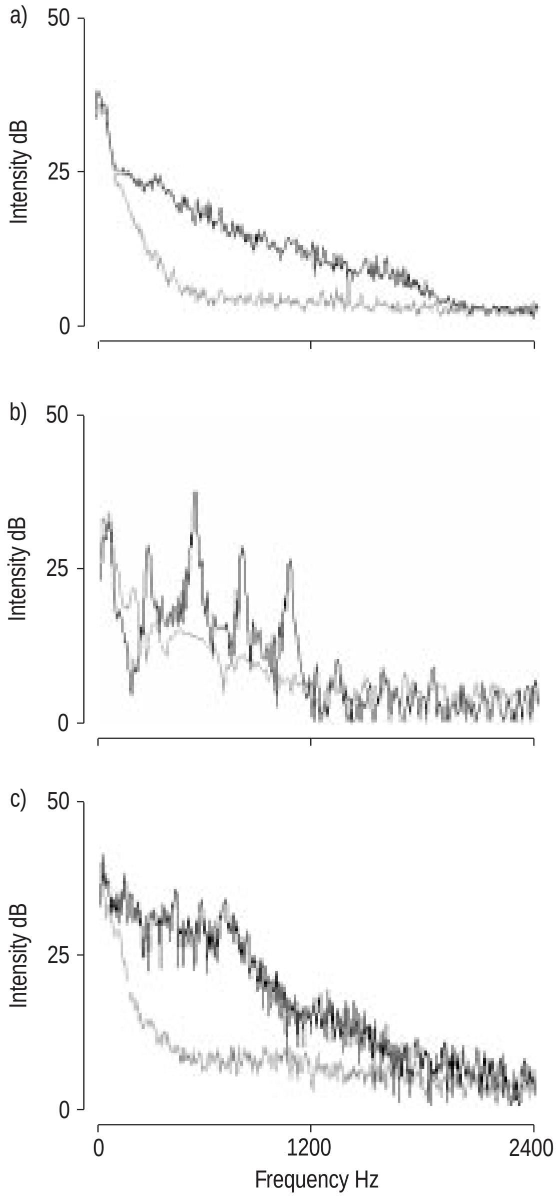

Fig. 2. – Power spectrum display: a) normal recording; b) wheeze with sharp narrow distinct peaks; and c) ruttles, with diffuse variable peaks with increased intensity at <600 Hz. ——: breath sound; ——: background noise.

Discussion

Using acoustic analysis, it is possible to clearly distinguish two distinct groups of infants with audible noises that appear to originate from the lower airways. Analysis of recordings from infants with classic wheeze indicated that the acoustic properties were very similar to those described in adults [10] whereas recordings from infants with ruttles confirmed the clinical impression that these are two distinctive respiratory sounds.

The term ruttle is used commonly in this part of the North of England (North Trent/South Yorkshire) to describe respiratory sounds that are much lower in pitch than a wheeze, with a continuous rattling quality and lacking musical features. Characteristically parents are able to feel this noise as a vibration over the baby's back in contrast to classical wheeze in which no such transmitted vibrations are evident. The authors have observed that ruttles are common in the first year of life but rarely heard after 15–18 months of life. The underlying mechanism is unclear but the authors speculate that they may reflect excessive secretions in central and extrathoracic airways or be related to airways tone; further research is needed to clarify this. Since wheeze and ruttles are both common in early life, they occasionally coexist in the same child.

It is important to recognize that ruttles are distinct from classical wheeze for a number of reasons. It has been

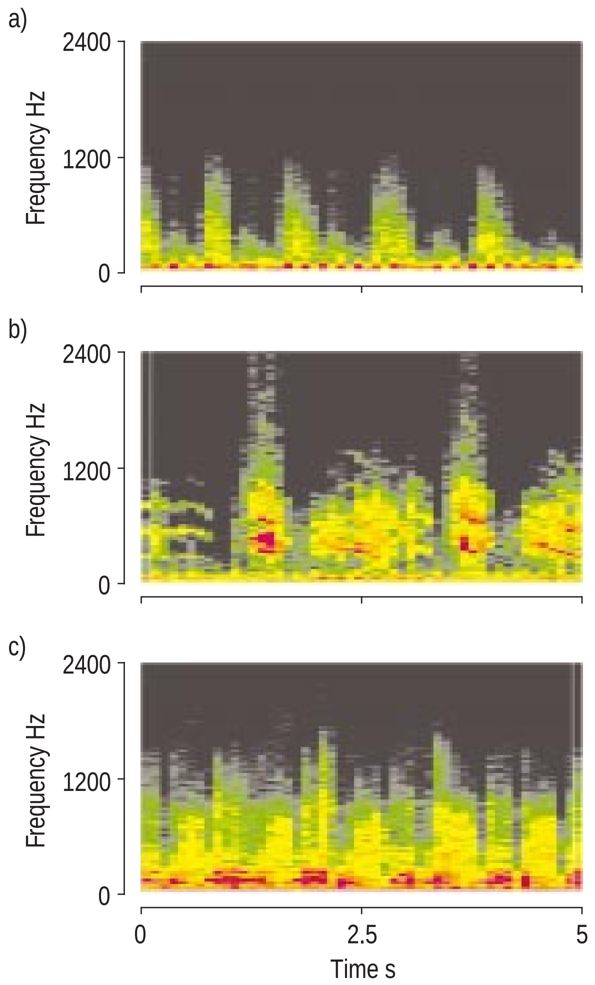

Fig. 3. – Sonogram: a) normal recording; b) wheeze, horizontal bars of intensity corresponding with peaks in the power spectrum display; and c) ruttles, with increased intensity in the low frequency range. Dark colours represent quiet sounds, light green to yellow medium intensity sounds and orange-red loud sounds.

shown that, in a medical setting such as an outpatient department, and in the community, parents frequently use the term "wheeze" to describe ruttles [7]. This is of relevance to epidemiologists in that the tendency to call audible respiratory noises "wheeze" may lead to significant over-reporting of wheeze when parents are completing questionnaires as part of an epidemiological study. The authors suggest that ruttles are likely to have a different aetiology, natural history and, probably, response to therapy compared to wheeze, which will influence both clinical practice and the outcome of clinical trials.

Subjective evaluation of breath sounds is variable and intra observer agreement on lung sound terminology has been found to fall somewhere between chance and total agreement despite attempts to standardize nomenclature [11]. Objective analysis of breath sounds has received relatively little attention over the years and there have been very few studies in young children. Practical difficulties including the complexity of the apparatus currently used and the necessity to eliminate artefactual noise due to movement and vocalization of the baby, as well as from the external environment, have contributed to this. Standardization of methodology is important in the interpretation of acoustic studies. The site of recording may determine characteristics of the sound pattern obtained [5]. In the present study, lung sounds were recorded anteriorly from the right upper zone of the chest in all infants in order to standardize the analyses as the majority of the babies were asleep in the supine position during recording. The relationship between detection of wheeze and airflow is complex. Flow can be easily measured in adults, however, as an alternative, respiration signals were derived from thoracic impedance so that the two phases of respiration be analysed separately. The development of sophisticated analytical packages such as the RALE software developed by H. Pasterkamp is likely to lead to more interest in this area of research in the future.

The American Thoracic Society (ATS) [12] and the 10th International Conference on Lung Sounds [13] have attempted to standardize the nomenclature of breath sounds based on previous studies in adults. These position statements define wheezes as high-pitched musical sounds and bronchi as low-pitched continuous sounds. The waveform pattern for classical wheeze has been described previously by MURPHY *et al.* [10] as "continuous undulating sinusoidal deflections" replacing the normal waveforms of lung sounds. The wheeze is continuous, which means a duration of >250 ms [14]. In the power spectrum display, wheezes produce a well-defined number of peaks, the dominant frequency being ≥400Hz, according to the ATS Committee on pulmonary nomenclature [12], and the higher peaks being harmonics of the dominant peak frequency. The peak frequencies are highly variable, as noted by PASTERKAMP *et al.* [15] and others, and this is one of the difficulties encountered when attempting to quantify wheeze analysis.

The above characteristics refer to studies involving adults and older children. However, the present findings for wheezy infants were in general agreement with them, the sinusoidal waveform patterns having a duration of >250 ms. The power spectrum patterns in the present infants were also similar to those in adults, although the mean dominant frequency was 225.5 Hz during expiration compared with a mean frequency of >400 Hz in the ATS consensus definition for adults.

In a recent study involving a mixed group of infants with "bronchiolitis", the only acoustic study of abnormal respiratory noises in infants to date, TAL *et al.* [16] described complex repetitive waveforms that were different from wheeze. To the listener, they were less musical and more "raspy" than the typical wheeze. It is possible that they were describing the noise that the present authors term ruttles.

The present study has provided objective evidence to support the clinical impression that there are at least two common types of audible respiratory noises in infancy originating from the lower respiratory tract, classical wheeze and ruttles. As shown by THORNTON *et al.* [8], the majority of babies in the community with noisy breathing do not wheeze and recognition of this is important for all those involved in the care of young infants. Clear and unambiguous descriptions of wheeze are clearly vital if clinical and epidemiological studies are to be valid. The failure of epidemiological studies to distinguish between these two distinct types of respiratory noise will result in significant overestimation of the prevalence of wheeze in the community.

It is hoped that the present work will serve as a starting point in the application of acoustic analysis to noisy breathing in infants. Further research is clearly needed to establish the long-term consequences of ruttles, and the authors′ definitions of these two noises can now be applied to assess the accuracy of the terminology used by parents and doctors in clinical practice.

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