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Noise from toys and its effect on hearing

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Noise from toys and its effect on hearing

Executive Summary

Noise limits for children’s toys are to be incorporated in forthcoming European regulations and standards on toy safety. ISVR Consultancy Services were commissioned by the Consumer Safety Unit of the Department of Trade and Industry to carry out a study of noise from toys, to inform the DTI and the British Toy and Hobby Association on the key issues involved, and to provide guidance on the drafting of the standard. The purpose of this study was to provide and collate the up-to-date information necessary to allow noise limits for toys to be set on a firm scientific basis so as to protect hearing without being unnecessarily restrictive.

The objectives were as follows:

- To review the current state of knowledge concerning the relationships between noise exposure and hearing damage, and to identify national and international standards, regulations and guidelines intended to minimise the effects of noise on hearing, with particular reference to children.
- To establish appropriate noise exposure criteria for children at play, and to derive corresponding noise limits for toys, taking into account the durations of play periods and the ways in which toys may be held or operated.
- To review information concerning children’s noise exposures in their everyday environments from sources other than toys, and to make additional measurements of commonplace sources of noise, to assess whether consideration of possible noise exposures from other sources has any significance in defining noise limits for toys.
- To review existing standards and guidelines for toy noise, including the draft European Standard prEN71-1.
- To measure the noise emission from a wide range of currently available toys, and to assess the measured levels against the recommended noise limits..

Most published literature which relates noise levels and exposures to hearing damage is based on occupational noise exposures for adults. Reviewing the literature it can be concluded that, to prevent any significant measurable hearing loss in adult subjects,

- their regular daily noise exposures ($L_{EX,8h}$) should not exceed 80 dB(A) which is equivalent to a noise level of 80 dB(A) for 8 hours, and
- the peak levels to which they are exposed should not exceed 140 dB(C).

There is no compelling evidence that children are more sensitive than adults to the effects of noise on hearing, with the possible exception of new-born infants. The above exposure limits can therefore be applied to children.

Noise limits for toys need to be defined in terms of the noise emission of the toy, in the form of a maximum permitted sound level at a specified position or distance. To enable noise emission limits for toys to be derived from noise exposure limits for toy users, it is necessary to account for various factors, of which the two principal ones are:

- Daily duration of play

- The position of the toy relative to a child's ear, particularly the distance from the ear of any noise-producing component.

Published information indicates that children are unlikely to play with manufactured toys for average periods in excess of 3 hours per day, and are unlikely to be exposed to noise from toys for more than 1 - 1.5 hours per day, although wide variations are obviously possible.

Published information also shows that, except for toys designed specifically to be held close to the ear, average distances of 25 - 30 cm between the toy and a child's ear are representative of typical play, but nearly all toys might be held within 2.5 cm of the ear either during normal play or during deliberate abuse.

On the basis of the above we have formulated noise limits for toys so that

- the time average noise level, L_{eq}, at 25 cm will not cause an exposure above the exposure limit of 80 dB(A) $L_{EX,8\,h}$ assuming exposures to noise-producing toys of up to 2.5 hours per day
- the peak noise levels during occasional use or misuse as close as 2.5 cm from the ear will not exceed 140 dB(C).

The noise emissions from toys which are manually operated, such as squeeze toys and rattles, depends on the manual effort used and the frequency of repetition, which are to some extent indeterminate. For these toys, a noise limits based on the Sound Exposure Level (SEL) measured over a specified number of shakes or squeezes, are appropriate rather than the time-average noise level, L_{eq}.

Methods were investigated for assessing the noise emission from toys intended to be held close to the ear (such as telephones), or toys with headphones which couple directly to the ear canal. It was found that the noise emission from at-the-ear toys is adequately represented by a measurement of sound level at 2.5 cm from the noise-producing component of the toy.

More sophisticated measurement techniques are required to assess noise from headphones and earphones. Two methods are available: (i) using the artificial head or manikin, which has ear canals of the same geometry as a median human, with microphones at the eardrum positions, or (ii) an artificial ear, which is a device intended for audiometer calibration and which is not geometrically similar to a real ear. These methods were compared and evaluated. The manikin method provided better measurement repeatability than the artificial ear method. The manikin can be used for all types of supra-aural, circumaural or in-the-ear headphones or earphones. Artificial ears are not suitable for all types of earphone but are more widely used in test laboratories and are of much lower cost. Noise limits for headphones and earphones are therefore proposed for each device to allow either to be used when appropriate.

The following noise emission limits for toys of various types are proposed

> ***All toys including hand-held, table-top and floor toys, cot toys, excluding close-to-the-ear toys and headphones.***
> The time-averaged noise level produced by the toy in continuous use or over a cycle of use should not exceed 85 dB(A) L_{eq} at 25 cm[1]. The peak noise level should not exceed 120 dB(C) at 25 cm. Noise levels are measured in the direction giving the highest levels. Table top and floor toys should be tested on a standard table. Any

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[1] Taking into account the relatively short time for which toys are used, a noise level of 85 dB(A) L_{eq} while the toys are in use will result in a daily noise exposure of typically less than 80 dB(A) $L_{EX,8h}$. The distinction between a noise level and noise exposure is explained within this report.

hand-held toy which may also be used as a table top or floor toy should be tested on a standard table. Any toy which would always be used hand-held or away from solid surfaces should be measured hand held.

Rattles

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. (ie as above for all toys)

Or The highest achievable sound exposure level of a rattle, measured over a series of 10 shakes, shall not exceed 92 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Squeeze toys

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. (ie as above for all toys)

Or The highest achievable sound exposure level of a squeeze toy, measured over a series of 10 squeezes, shall not exceed 95 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Cap firing toys

The peak noise level should not exceed 120 dB(C) at 25 cm.

Close to the ear toys

Noise levels measured at 2.5 cm from any part of the toy should not exceed 85 dB(A) L_{eq} , the peak level should not exceed 125 dB(C).

Headphones and earphones

Either (i) the time averaged noise level measured using an artificial ear conforming to IEC 318 shall not exceed 93 dB(A), and the instantaneous peak level shall not exceed 135 dB(C). This method can only be used for types of headphone that will fit the artificial ear.

Or (ii) the undisturbed field equivalent time averaged level measured using a manikin should not exceed 85 dB(A) L_{eq} and the peak level at the manikin eardrum shall not exceed 135 dB(C). This method can be used for any type of headphone, earphone, ear insert or stethoscope which will fit the manikin in the same manner as it will fit a real person.

The above recommended noise limits were compared with those in the draft European Standard prEN71-1, allowing for differences in measurement distances where appropriate. Our recommended limits would permit time-averaged toy noise levels, L_{eq}, to be higher than the limits stated in prEN71-1; by between 1 dB and 5 dB depending on the type of toy. Our recommended limits for peak levels differ considerably from those on prEN71-1, being between 11 dB lower and 10 dB higher.

We have reviewed national regulations and standards from Canada, the USA and Taiwan, and advisory limits proposed by researchers in Scandinavia and Canada. We found these standards to be, to varying degrees, limited in their scope, and in some cases technically

inadequate. Recommendations in the literature, that noise levels from toys should not exceed 75 dB(A) irrespective of duration, are unnecessarily restrictive and not well justified.

The noise levels of 178 toys were measured. Some were supplied as samples by manufacturers and distributors, others were purchased in toy shops. Most of the toys were inherently deliberately designed to produce some noise. A few of those tested produced noise incidentally, rather than as a feature. Some of the toys tested were musical instruments or mouth-operated toys, and therefore excluded from the scope of the proposed European standard. However, such toys can generate significant noise levels, and they were included for this reason. Noise test procedures generally followed those proposed in prEN71-1, with some adaptations as necessary.

The measured noise levels were compared with the limits recommended above. Most currently available toys comply with the recommended noise limits. There are notable exceptions for headphones *when used at full volume*, some close to the ear toys, and most impulsive toys such as cap guns.

Children are exposed to many sources of noise, not just toys, during everyday life. Any consideration of permissible noise exposures from toys, and of corresponding noise emission limits for toys, needs to take these other noise sources into account. Many commonplace noise sources produce noise levels higher than the recommended limits for toys, but potential exposures to higher levels are usually short or infrequent. For example, time-averaged noise levels on underground trains can approach 90 dB(A) L_{eq}, and similar noise levels are experienced in crowds at football matches. Bursting a potato crisp packet can produce a peak sound level approaching 140 dB(C) at 50 cm.

The scientific literature shows considerable variations and uncertainties in quantifying noise exposures of children. Exposures ranging form below 60 dB(A) to above 90 dB(A) $L_{EX,8h}$ are reported in the literature. From our own noise level measurements we would expect total daily exposures between 60 dB(A) and 80 dB(A) $L_{EX,8h}$ for most young children.

The approach we have adopted in this study is to set limits which should ensure that (i) the noise from toys does not present a foreseeable risk in itself and that (ii) the noise from toys should not add significantly to any risk which may already be present from other everyday noise sources. We believe that there is an margin of safety inherent in the assumptions made in formulating the recommended limits, and that the recommended limits for toys are cautious but realistic.

Acknowledgements

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We would also like to thank Miss Wendy Harris, Headteacher, and the staff of Sinclair Infant and Nursery School in Southampton for allowing us to make noise measurements in class.

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1 Introduction

1.1 Background

The Consumer Safety Unit of the Department of Trade and Industry engaged ISVR Consultancy Services to carry out a study of noise produced by toys. As occupational noise is progressively controlled and reduced, noise from leisure activities, previously a secondary consideration, assumes increasing importance. Noise produced by toys has been identified as a safety issue and future European and International Standards on Toy Safety will impose noise limits with the aim of protecting the hearing of children.

The objective of this study was to provide and collate the up-to-date information necessary to allow noise limits for toys to be set on a firm scientific basis so as to protect hearing without being unnecessarily restrictive.

1.2 Objectives

The specific tasks identified to achieve the objective were

- To review the current state of knowledge concerning the relationships between noise exposure and hearing damage, and identify national and international standards, regulations and guidelines intended to minimise the effects of noise on hearing.
- To measure the noise emission from a wide range of toys, and assess typical resulting noise exposures, taking into account the way toys may be held and operated and the typical frequency and duration of use.
- To measure the noise levels likely to be experienced from commonplace equipment and activities inside and outside the home, and to assess typical resulting noise exposures.
- To evaluate the significance of noise from toys, in terms of the potential hearing damage risk, by comparing estimated noise exposures from toys with exposures

from other commonplace sources and activities, and with accepted damage-risk criteria.

1.3 Report Structure

The structure of this report is as follows.

Section 2 Some principles and concepts in acoustics and noise measurement.

This section provides a very brief explanation of the acoustic principles, the methods of noise measurement, and definitions of the technical terms which are used in this report.

Section 3 Effects of noise on hearing

A review of current knowledge concerning the effects of noise on hearing. Most of the information relating hearing damage to noise levels and exposures has been obtained from statistical studies of the hearing of adults exposed to occupational noise. This section therefore specifically addresses the question of whether damage-risk criteria applicable to adults are appropriate for children.

Section 4 Defining noise limits and measurement methods for toys

The significant factors which must be considered when setting noise limits for toys are identified and discussed. Specific recommendations are derived for the maximum permissible noise emissions from toys of all types. Measurement procedures and corresponding pass/fail noise limits are recommended. Any assumptions and our reasons for setting particular noise limits are explained.

Section 5 Headphones, earphones and close-to-the ear toys

Sound levels from headphones and earphones cannot be measured in the same way as other sound levels using just a sound level meter. Special techniques are needed using equipment such as artificial ears or manikin heads. This section describes these techniques, which can also be used for some close-to-the-ear toys, and specific recommendations are made to limit noise from toys with headphones.

Section 6 Comparison of our recommendations with those in existing or proposed toy safety standards

A number of existing and proposed national and international standards for toy noise are critically reviewed. The noise limits and the measurement procedures specified in these standards are compared with those which we propose in Sections 4 and 5.

Section 7 Noise levels produced by currently available toys

Noise levels produced by approximately 200 toys of various types have been measured and compared with the recommended limits. The results of these measurements are presented and discussed.

Section 8 Noise levels of everyday sources other than toys

Children are exposed to many noise sources, in addition to toys, in everyday living. The combined effect of noise from toys and noise from other sources is discussed. Noise levels have been measured in a number of locations from a number of common-place sources. These noise levels serve to provide some context for the proposed toy noise limits.

Section 9 Conclusions and recommendations

2 Some principles and concepts in acoustics and noise measurement

2.1 Sound

Sound consists of pressure fluctuations in the air which are perceived by the ear. The source of these pressure fluctuations is usually a vibrating surface or a turbulent fluid flow. The sound received at any given location is characterised by the sound pressure and the frequency. The human ear can detect sound pressures as low as about 20 µPa, and can tolerate (for short periods) sound pressures as high as 200 Pa, an amplitude range of 10^7 or 10 million times. However, the response of the ear to sound of increasing level is not linear. To take account of this, sound pressures are quantified using a logarithmic scale, the decibel (dB) scale, which is based on the ratio of the measured sound pressure to the so-called ‘reference pressure’ of 20 µPa. The result is a sound pressure level (SPL) scale: most commonplace sounds produce sound pressure levels in the range 30 dB to 100 dB. Sound pressure levels are measured using equipment comprising a pressure-sensitive microphone, an associated amplifier and an output indicator. In its simplest form, this is a small hand-held instrument called a sound level meter.

The human ear exhibits differing sensitivity to sound of different frequencies within the audible range of about 20 Hz - 20,000 Hz. To take account of this frequency response, sound level meters incorporate ‘frequency-weighting networks’ or filters which simulate the frequency response of the ear. Noise measurements relating to human reaction are generally made using the A-weighting network. These measurements are reported as A-weighted decibels or dB(A). However, for some types of measurement the A-weighting is not appropriate. This report also refers to measurements made using the C-weighting, in units dB(C), which has an almost linear frequency response.

Note that in all cases the terms ‘sound’ and ‘noise’ are interchangeable. It might be argued that the term ‘sound’ should be used when referring to the physical attributes of an acoustic source, and the term ‘noise’ (which implies an adverse subjective value judgement) when referring to the effects on people. However, no consistent attempt has been made in this report to discriminate between these terms.

2.2 Noise descriptors and units

The following quantities may be used to characterise the noise emission from a source (in this case, a toy) or the noise received at a given position. Most modern sound level meters allow these measurements to be made directly.

A-weighted sound level, L_A or L_{pA} in dB

The A-weighted sound pressure level (or SPL) in dB(A) at a point at a given time. Most sources of sound are unsteady, such that the sound level, as registered by a sound level meter, will vary with time. Where the fluctuations in sound level occur rapidly, the excursions observed on the meter will depend on the time weighting, time constant or speed of response of the meter. There are two internationally standardised settings. On older, analogue meters these were labelled Fast (F) and Slow(S). With modern digital meters the former analogue meter ballistics are simulated electronically by time-weighting ‘F’ and time weighting ‘S’.

A-weighted equivalent continuous sound level or time average sound level, $L_{Aeq,T}$, in dB

The A-weighted equivalent continuous sound level over a time period T. This is the notional continuous sound level which, over time T, contains the same amount of energy as the actual fluctuating sound being measured. It may also be defined as the average level of the fluctuating sound and is the root mean square sound pressure over a given time. The term ‘time average sound level’ is preferred in international standards though either term is acceptable. L_{Aeq} is an appropriate descriptor of the noise emission of toys which emit continuous noise, or noise which has a definable duration, such as a complete cycle of a repeating operation. For steady sounds, or sounds with a characteristic cycle it is not necessary to include the measurement time in the subscript. The ‘A’ subscript is often omitted too, as in L_{eq}, but the A-weighting is always assumed unless otherwise stated.

Sound Exposure Level, SEL, or L_{EA} in dB(A)

Sound Exposure Level (sometimes called ‘Single Event Level’) is a measure of the total sound energy associated with a noise event or series of events. Sound Exposure Level should not be confused with personal noise exposure (see below). It is that steady sound level which, if experienced for a period of 1 second, would contain the same sound energy as the event in question. SEL is an appropriate descriptor of the noise emission from toys, such as rattle and squeeze toys, which emit noise in intermittent, irregular, discrete events, rather than continuously. The time weighted average level can then be calculated from the SEL per event and the number of events in any given time period, no matter how those events are distributed within the time period.

Maximum sound level L_{Amax}

The maximum sound level, L_{Amax} is the highest sound level measured during a noise event, such as the operating cycle of a toy. For rapidly-changing noises, the measured value of L_{Amax} is dependent on the time weighting of the measuring instrument, F (fast) or S (slow). Measured levels of L_{Amax} should therefore be qualified by an indication of the measurement response setting used, eg L_{AFmax} or L_{ASmax}. Note that the term ‘maximum level’ is always used for the highest value of a running-average sound level and is not synonymous with ‘peak level’ which always refers to the highest (positive or negative) instantaneous value of a waveform.

Peak sound pressure level, L_{pk}, or L_{Cpk} in dB(C)

The peak pressure associated with a noise event or in a given time interval. This is a measure of the highest instantaneous pressure (either positive or negative relative to local atmospheric pressure), and is independent of the response time of the measuring instrument. It is usually measured with a linear frequency weighting or with the C frequency weighting which for most practical purposes can be regarded as linear. Values of L_{Cpk} are not to be confused with values of L_{max} (qv). Peak measurements are applicable to impulsive, impact or explosive noises.

Frequency bands

A noise can be characterised by the sound level in a number of frequency bands. Bands which are one-octave wide, with centre frequencies which are standardised (eg at 16, 32, 63, 125, 250, 500, 1 000, 2 000, 4 000, 8 000 Hz etc) are commonly used. Such measurements provide some information about the frequency spectrum content or ‘character’ of a noise, whereas a simple A-weighted measurement provides no such information. We consider that octave band sound levels have no specific relevance to the assessment of noise from toys. However, octave band sound levels are referred to in a draft standard which will be discussed later in this report.

2.3 Noise levels and noise exposures

The potential of noise to affect hearing depends mainly on the actual amount of noise energy received by the ear, generally termed personal noise exposure. It is important to draw a clear distinction between *noise level* and *noise exposure*. These are easily confused, since both are expressed in decibels[2].

Noise *exposure* is a combination of noise *level* and *duration* of exposure.

For the assessment of occupational noise, the concept of personal daily noise exposure, $L_{EP,d}$ or $L_{EX,8h}$ has been adopted. This is measured or calculated by integrating the total noise energy received by an individual during the course of a day (a 24-hour period), and calculating a notional noise level which, if received continuously for 8 hours (the ‘normal’ working day) would contain the same amount of sound energy as the actual exposure.

A time average noise level of 80 dB(A) L_{eq} continuing for 8 hours will cause a noise exposure of 80 dB(A) $L_{EX,8h}$. If the noise continues for twice the time, 16 hours, the time average noise level is still 80 dB(A) L_{eq} but the exposure is doubled and is now 83 dB(A) $L_{EX,8h}$. If the noise is only present for half the time, 4 hours, the time average level will still be 80 dB(A) L_{eq} but the exposure will be halved to 77 dB(A) $L_{EP,d}$.

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[2] When not expressed as a ratio in decibels, a noise *level* has units of pressure, ie pascals, Pa, or newtons per square metre, whereas noise *exposure* has units of pressure-squared and time, ie pascal-squared seconds,

A doubling of the noise duration doubles the exposure. Increasing a level by 3 dB also doubles the exposure. Increasing the level by 3 dB but halving the exposure time gives no overall change in exposure. This is sometimes referred to as the ‘3 dB exchange rate’. This 3 dB exchange rule is implicit in the concept and definition of noise exposure as used throughout Europe and in many other countries.

However, OSHA in the USA, and some Canadian provinces use a ‘5 dB exchange rate’ in occupational noise regulations [Suter, 1996]. Each doubling of time requires the sound level to be reduced by 5 dB rather than 3 dB in order to comply with a limit. The quantity measured and the noise limits are sometimes referred to as time-weighted average levels or TWA. These are not true noise exposures as defined in international standards but are sometimes referred colloquially to as ‘noise exposures’. This may lead to confusion in comparing European and North American measurements and standards concerning noise exposure. This report refers only to measurements relying on UK and European standards in which the 3 dB exchange rate is implicit.

Generally throughout this report we have placed the symbols L_{eq} or $L_{EX,8\,h}$ after a dB(A) value to indicate explicitly whether the quantity expressed is a time average noise level or a noise exposure. We have usually expressed noise exposures relative to an eight-hour reference time, ie $L_{EX,8\,h}$. We could equally well have specified noise exposures relative to a whole day, ie $L_{EX,24\,h}$. However the exposure is expressed, the total noise throughout the day is included. A noise exposure of 80.0 dB(A) $L_{EX,8\,h}$ converts to a noise exposure of 75.2 dB(A) $L_{EX,24\,h}$, the numerical difference is always 4.8, rounded to 5 for practical purposes.

2.4 Undisturbed noise fields

Noise measurements made for the purposes of evaluating loudness or hearing damage risk implicitly relate to measurements in an **undisturbed sound field**, with measurements being made at the notional position of the listener’s head in the absence of the listener. This presents difficulties in measuring noise levels associated with toys where the noise source is coupled directly to the user’s ear, by either being held close to the ear or inserted into it.

Examples are toy telephones and cassette players with headphones. The measurement of noise levels produced by these sources, and the corresponding noise exposures, requires the use of special techniques. These techniques, which are explained in Section 5, make use of ‘artificial ears’ or ‘manikins’ of varying levels of sophistication to enable the noise levels to be measured within a simulated ear canal. These measurements can then be used to derive an ‘undisturbed field equivalent’ (UFE) level, which is the level of an external undisturbed sound field which would produce the same level of sound at an ear drum as the noise source being measured.

2.5 Effect of distance

This report will refer to the measurement of noise levels at different distances and in different environments. Generally, the noise level falls as the distance from the source becomes greater, because the sound energy is distributed over a larger area. The rate of decay of sound level with distance is approximately 6 dB per doubling of distance (the inverse square law), which is equivalent to a reduction of 20 dB for each tenfold increase in distance from the source.

This relationship between noise level and distance applies only to small noise sources, and only in so-called ‘free-field’ conditions, where there are no significant reflections from objects or room boundaries. In this report, reference will be made to measurements of noise from various toys, at distances between 2.5 cm and 50 cm from the noise-emitting component. Unless otherwise stated, it is valid to assume that a noise level measured at one distance can be used to calculate the noise level at any other distance within this range by application of the inverse square law.

3 Effects of noise on hearing

Exposure to high noise levels can cause permanent damage to the structures of the ear. Such a hearing injury is most obvious as a loss of hearing sensitivity, a worsening of the hearing thresholds, so that soft sounds must be presented at a greater magnitude or strength to be just barely perceptible.

Two types of noise injury to the hearing are recognised. **Acoustic trauma** is the result of a single acoustic event, with a very high sound pressure but usually lasting only a fraction of a second. Such an event (or series of events) might be the report of a firearm or the explosion of a firework. The sound is obvious and the effect is obvious. There might be pain in the ear, sudden deafness, and possibly even disturbance of balance.

In contrast, **noise-induced hearing loss** is due to more moderate noise levels, with durations lasting minutes to hours, and possibly repeated over days to decades. The injury to the hearing is chronic, and localised to the sensory cells within the inner ear or cochlea. These sensory receptors, which change sound energy into nerve impulses which the brain can recognise, are called “hair cells”. Each cell has hair-like projections which are displaced back-and-forth in synchrony with the positive and negative acoustic pressures of the sound being sensed. When very loud sounds occur, the hair cells are simply worked too hard. In the short-term, the cells become fatigued by overstimulation. A temporary threshold shift results; this dulling of hearing sensitivity will recover after a few minutes or a few hours. If the hair cells are overstimulated for too long and too often, with insufficient recovery time, the cells will become mis-shapen, dysfunctional and eventually dead. Hair cells are a type of nerve cell and will not regenerate if destroyed. If enough of these hair cells are killed, the effect will eventually become obvious as a permanent worsening of the hearing sensitivity.

3.1 Noise limits for adults

3.1.1 Occupational noise

Considerable research was carried out in the 1960s and 1970s in Europe and the US into the relationship between occupational noise exposure and hearing loss. In the UK, the (then)

Department of Employment introduced in 1972 an advisory Code of Practice, which specified a maximum acceptable daily noise exposure of 90 dB $L_{Aeq\ (8\ hour)}$, with an overriding requirement that the unprotected ear should not be exposed to a peak sound pressure level exceeding 150 dB [Department of Employment, 1972]. The Code recognised that there were large variations between individuals' susceptibility to hearing damage from noise, and that compliance with the recommended limits did not remove all risk of such damage for susceptible persons.

Further work was carried out in the UK by the Health and Safety Commission during the 1970s and 1980s, with the aim of making regulatory limits for occupational noise exposures. Parallel activities were pursued in Europe. As a result, the European Commission issued a Directive [European Economic Community, 1986], imposing limits on workplace noise exposure which were more stringent than those put forward in the 1972 Code of Practice. The Directive was implemented in the UK by the Noise at Work Regulations 1989, which came into force in 1990 [Statutory Instruments 1989 No 1790]. These Regulations set out three "Action Levels" for noise exposure in the workplace:

> The First Action Level was considered a warning level, for individuals with a personal daily noise exposure equal to or greater than 85 dB(A) $L_{EP,d}$. A risk to hearing was implicit in this warning.
>
> The Second Action Level was set at an $L_{EP,d}$ of 90 dB(A). Noise reduction became mandatory, in response to a clear risk to hearing.
>
> The Peak Action Level, any instantaneous peak sound pressure equal to or exceeding 200 Pascals (140 dB), also placed hearing conservation duties upon both employer and employee.

Requirements for lower action levels: the effects of 'low level' noise

It is accepted that the Action Levels for noise exposure incorporated in current Regulations do not completely eliminate the possibility of a proportion of an exposed population suffering a detectable hearing loss. Considerable research has been carried out to establish the risk of hearing damage from low levels of noise, such as might be experienced in the general environment, as well as in the workplace, with the objective of defining what might be regarded as a ‘safe’ noise exposure which carries no measurable risk of hearing damage. Significant research results are discussed below.

EPA Recommendations

In the early 1970s, the US Environmental Protection Agency was charged with a duty to develop noise criteria, in order to protect the public health and welfare with an adequate margin of safety. A review study was undertaken by Guignard [1973] to establish the state of knowledge at that time. For the case of daily exposure to continuous broadband noise without strong tonal components, a level of 75 dB(A) sustained for 8 hours (or 70 dB(A) for 24 hours) per day was thought to be the lower limiting value for detectable noise-induced permanent threshold shift (NIPTS). Exceeding this limit value would have the potential to cause NIPTS greater than 5 dB in up to 10% of exposed persons after a cumulative duration of 10 years. The hearing change was predicted for 4 kHz, the most noise-sensitive audiometric frequency.

Following on from the review by Guignard, the EPA Office of Noise Abatement and Control [1974] identified noise levels and exposure levels which would not cause measurable or significant effects upon hearing, interference with activities, or annoyance. When considering hearing effects, the authors were required to make certain basic assumptions.

1. The ability to hear frequencies above 2 kHz is important for the reception and understanding of everyday speech, in both occupational and social situations. It is known that 4 kHz is the frequency first affected by injurious noise exposure, and later most affected. Therefore, this particular frequency was selected as the single most important indicator of developing hearing injury.

2. Changes in Hearing Threshold Level less than 5 dB are generally considered not noticeable or significant.

3. There exists a range of damage susceptibility in the general population. Protecting the population up to a critical percentile (96% was chosen, leaving 4% as the most 'tender-ear' portion) would be acceptable as protecting the entire population with a margin of safety.

On the bases of these assumptions, an equivalent noise level was derived to limit hearing damage at 4 kHz to a maximum acceptable component of 5 dB, after exposure for 40 years (a working lifetime). The appropriate level was stated to be (using our current terminology)

$$L_{EX,8h} = 75 \text{ dB(A)}$$

Taking account of intermittency of the noise throughout the 8 hour averaging period, the number of working days (250) in a calendar year, and correction to a 24 hour period, the 8 hour criterion value was transformed (and rounded down slightly) to

$$L_{EX,24h} = 70 \text{ dB(A)}$$

This whole-day average noise level was considered sufficiently cautious as to protect virtually the entire population from any significant noise-induced hearing damage, at the most noise-sensitive frequency, after a working lifetime. This must be considered the most conservative criterion possible.

ISO 1999

The 'limit' value of 75 dB(A) over 8 hours, seen earlier in Guignard and the EPA, came to international notice when incorporated in the Draft of International Standard 1999 [International Organisation for Standardization 1982]. This standard set out a noise threshold for minimum predicted hearing damage. In the first section of ISO 1999 are statements which define the scope of the standard. In respect of estimating noise-induced permanent threshold shift (NIPTS) from any given noise exposure, the scope may be summarised as follows:

> Formulae are presented to calculate NIPTS, for the audiometric frequencies 0.5 kHz to 6 kHz, attributable to noise exposures over each working day of

> 8 hours, for periods of exposure lasting from 0 to 40 years. The daily exposure level $L_{EX,8h}$ permitted by the calculation method may range from 75 dB(A) to 100 dB(A). The formulae may be used to calculate the median NIPTS and the statistical distribution above and below the median. The values of NIPTS resulting from the calculation method are valid for both male and female populations.

Two points are worth mentioning here. First, NIPTS should not be confused with Hearing Threshold Level. NIPTS may combine with age-associated hearing loss and any possible pathological overlay to give Hearing Threshold Level. Second, the daily noise exposure level $L_{EX,8h}$ which appears in ISO 1999 is identical to the daily personal noise exposure level $L_{EP,d}$ known throughout the European Community.

The lower limit of applicability of the standard, that is an $L_{EX,8h}$ of 75 dB(A), is implicit in the calculation method. For noise exposure durations ranging from 10 to 40 years, the median NIPTS values, $N_{0.50}$ in dB, for both sexes are given by the equation:

$$N_{0.50} \quad = \quad (u + v \log \theta) \; (L_{EX,8h} - L_0)^2$$

where L_0 is a cut-off sound pressure level defined as a function of audiometric frequency, with values given in tabular form,

θ is the exposure time in years,

u and v are parameters tabulated as a function of frequency.

Given in the standard is a table of values for the quantities u, v and L_0 appropriate to the different audiometric frequencies. The values of L_0 have been extracted for examination here.

Values of L_0 for each audiometric frequency

Frequency, kHz	L_0, dB
0.5	93
1	89
2	80
3	77
4	75
6	77

Note that L_0 assumes a minimum value at 4 kHz, the audiometric frequency at which noise-induced hearing loss usually appears first. For an $L_{EX,8h}$ of 75 dB(A), the squared term in the equation above equals zero, therefore the median NIPTS is zero. Another equation given in the standard allows calculation of various fractiles of the NIPTS distribution; this equation also contains a multiplicative term $(L_{EX,8h} - L_0)^2$. If $L_{EX,8h}$ is less than L_0, then the squared term is deemed to be zero. This results in NIPTS at 4 kHz assuming a value of zero for all members of the population exposed to 75 dB(A).

From the values of L_0 given above, it may be seen that NIPTS at 4 kHz will be non-zero only when a threshold of 75 dB(A) is breached. For NIPTS at 3 and 6 kHz, the threshold value is 77 dB(A). For the lower frequencies, the threshold values are higher still.

Performing the calculations for $N_{0.50}$ gives a better picture. Increasing the $L_{EX,8h}$ to 78 dB(A) produces a NIPTS at 4 kHz of 1 dB (unmeasurable) after 20 years of daily exposure. An $L_{EX,8h}$ of 80 dB(A) gives a NIPTS of 1 dB after 10 years and 2 dB after 30 years exposure. On the other hand, a 4 kHz NIPTS of 5 dB would result from 85 dB(A). **The ISO 1999 calculation procedure indicates that an $L_{EX,8h}$ of 80 dB(A) will produce almost no practical effect, whereas 85 dB(A) will produce a small though measurable hearing deficit.**

A recent HSE study

Recent work in the UK has been directed towards quantifying the hearing loss which might result from exposure to lower levels than embodied in current Regulations (ie exposures below 85 dB(A) $L_{EP,d}$). Information was needed to respond to lower Action Levels proposed in a draft European Directive (the Physical Agents Directive). Robinson et al [1994] reported on the degree of noise-induced hearing loss in workers exposed at an $L_{EP,d}$ less than 85 dB(A), and also on the benefits which might follow from lower Action Levels.

The problem was approached by analysing the small amount of documentary evidence relating to hearing loss from low noise exposures. The key feature of the analysis was the separation of hearing threshold levels, in exposed populations, into components due to noise and age. Because very small threshold shifts were expected from the low-level noise exposures, the analysis concentrated on hearing data for the single, most-sensitive frequency of 4 kHz.

The data ensemble, covering a range of low-level exposures and years of occupational exposure, indicated a negligible noise-induced threshold shift at $L_{EP,d}$ value at and below 75 dB(A). Recall that daily personal noise exposure $L_{EP,d}$ is the same as equivalent A-weighted sound level normalised to 8 hours $L_{Aeq,8h}$. Above 75 dB(A), but below 85 dB(A), long-term exposure to noise has some effect, but the amount of noise-induced threshold shift is so small as to be undetectable by practical means in individual cases. Within the exposure range 75 dB(A) -85 dB(A), the effect on hearing is measurable only in the statistical sense, using groups of noise-exposed individuals.

For present purposes, the conclusion of Robinson et al [1994] will be stated as: **Noise exposures not exceeding 80 dB(A) $L_{EX,8h}$ will produce no detectable hearing threshold shift, even after years of exposure.**

3.1.2 Implications of studies of temporary hearing loss

The previous sections have dealt with consideration of noise-induced hearing loss from occupational noise. Exposure limits have been progressively reduced, over the years, with the objective of protecting more and more workers from smaller and smaller permanent hearing decrements. In defining a terminal objective for occupational noise limits, and (in the context of this report) for noise limits for social and environmental noise, it is relevant to raise the question:

Is there a noise exposure which is known to cause no permanent hearing injury?
The question may be phrased in even more extreme terms:

Is there a noise exposure known to produce no after-effects whatever, either permanent or temporary?
Research into the effect known as temporary threshold shift (TTS) is helpful in addressing these questions. Much research on TTS was conducted in the 1950s and 1960s, in an effort to understand how noise damages hearing, and to set reasonable damage risk criteria. At the time, a rule of thumb seemed appropriate and helpful: "If any particular noise produces a temporary threshold shift after an 8 hour exposure, that same noise every working day for 10 years will produce the same amount of permanent threshold shift". Although this rule of thumb, and indeed the concept of a 'black-and-white' damage risk criterion, have fallen into disregard lately, there is hidden in these concepts the idea of "**Effective Quiet**". This is a useful idea, supported by research, which bears upon the problem of noise from toys.

Effective Quiet, as an audiological concept, has two aspects in its definition. First, there is a level of sound which just **fails** to retard recovery from TTS. If an individual has a noise-induced TTS, must that individual have near-silence in order for the hearing thresholds to recover back to pre-exposure levels? No: research has shown that recovery from TTS is not significantly hindered if the noise level during the recovery period is less than or equal to 75 dB. Although helpful to hearing scientists in their attempts to understand noise-induced hearing loss, this form of Effective Quiet does not bear directly upon noise from toys.

The second aspect of Effective Quiet is much more important for present purposes. There exists a certain magnitude, in dB(A), for a broadband noise which will just **fail** to produce a TTS, no matter how long an individual is subjected to that noise. Any broadband sound falling within the range of Effective Quiet must be regarded as completely innocuous in terms of hearing damage. In respect of any noise level outside the range of Effective Quiet, the most severe criterion might be: Any noise capable of producing TTS carries a risk of producing a permanent shift of the hearing thresholds. Conversely, any noise which does not produce TTS cannot produce a permanent shift of hearing threshold.

Ward, Cushing and Burns [1976] investigated the growth and decay of TTS caused by octave bands of noise centred at 250, 500, 1 000, 2 000 and 4 000 Hz. Before any exposure, each subject gave a full pre-test audiogram. Groups of subjects then were exposed to alternating periods of high-level and then low-level bands of noise. Thresholds were then recorded, for different test series, after 2, 6 or 8 hours of noise exposure. From the data, the researchers were able to construct an octave-band spectrum for a composite broadband noise which they deduced would not retard recovery for even the most susceptible of their test subjects. The overall shape of the spectrum was generally falling from about 77 dB for the 250 Hz band to about 65 dB for the 4 kHz band: the overall level was calculated to be 76 dB(A). The authors concluded that this composite broadband noise “must be regarded as completely innocuous to nearly everyone”.

Exposure to constant-level broadband noise for very long periods, up to 48 hours, has been shown to cause TTS which grows and then remains constant. This behaviour, which is independent of exposure duration, has been termed Asymptotic Temporary Threshold Shift (ATTS). Johnson, Nixon and Stephenson [1975] reported on this phenomenon in a military context: What ATTS would be expected in US Air Force personnel exposed to continuous noise during a flight mission lasting as long as 48 hours? The threshold shift at 4 kHz, widely acknowledged as the most noise-sensitive frequency of human hearing, was used to investigate the question of a noise level which might produce no ATTS, in other words, a value of Effective Quiet. Groups of subjects were exposed to pink noise (containing equal acoustic energy per constant percentage bandwidth) at 80, 85 and 95 dB(A) for periods of 24 hours and 48 hours. TTS was measured throughout each exposure period, for comparison with each individual’s pre-test audiogram. For each exposure condition, the TTS increased rapidly over the first few exposure hours, to approach asymptotically the maximum TTS. Plotting of the ATTS values against A-weighted sound level gave a straight line, which indicated 0 dB ATTS at a sound level of 78 dB(A). A broadband sound at this level would be expected to produce no TTS, even for very long durations on the order of 1 or 2 days. This is an estimation of the maximum sound level which might be considered to be Effective Quiet.

These authors continued this line of research; see Stephenson, Nixon and Johnson [1980]. Subjects were exposed to continuous pink noise for 24 hours at levels of 65, 70, 75, 80 and

85 dB(A). TTS growth and recovery were measured at appropriate times throughout each exposure (and recovery) condition. Again, the results demonstrated that at 4 000 Hz, the most noise-sensitive frequency, the ATTS threshold was in the range 75 dB(A) -80 dB(A).

Mills, Adkins and Gilbert [1981] also examined the growth and recovery of ATTS, using broadband noise at levels of 76, 81, 87 and 91 dB(A). For the first portion of the study, exposure duration was 24 hours. The TTS was measured during the exposure and found to reach a maximum at 8 hours into the 24 hour period; thereafter, a degree of recovery appeared to take place **in spite of** the continuing noise. Further investigations concentrated on the maximum TTS after 8 hours, and recovery in quiet. Analysis of the ATTS data against the levels of the broadband noise again indicated 0 dB expected ATTS for 78 dB(A) after 8 hours.

One interpretation of the TTS studies reported above might be that, to completely eliminate any possibility of even temporary hearing loss, it is necessary to ensure that the ear is not exposed to a noise level higher than 78 dB(A). Exposure to such a level (irrespective of duration) has been shown to produce no detectable effect on hearing.

3.1.3 Damage from impulsive noise

Based upon a Damage Risk Criterion by the Committee on Hearing, Bioacoustics and Biomechanics [Kryter, 1965] and analysis of considerable experimental evidence, Coles et al [1968] proposed a noise limit for impact/impulse noise. The limit had certain assumptions at its base: 75% of exposed individuals would experience no more than a small but specified degree of TTS after a daily exposure comprising 100 acoustic events. A peak sound pressure level of 162 dB was set as the limit, with higher levels permissible for extremely short duration impulse peaks (less than one-thousandth of a second). The authors suggested certain adjustments could be made to the limit, to account for changes in the assumptions:

1. Where the exposure might be an occasional single event, the limit might be raised by 10 dB.

2. If it is desired to protect the most susceptible persons exposed (rather than only 75% of those exposed), the limit should be lowered by 10 dB.

The joint British and American work by Coles and his co-authors probably exerted some influence upon the limits expressed in the 1972 Code of Practice published by the Department of Employment. Here, levels were suggested for continuous and also impulse noise so as to minimise the incidence of hearing damage amongst workers. For impulse noise, the unprotected ear should not be subjected to instantaneous sound pressure levels exceeding 150 dB. No reference was made to the number of impulses per day associated with this overriding limit, but it seems safe to assume that an occupational impulse exposure would comprise 100-1000 events per working day. Determination of a single impulse event as equal to or greater than 150 dB would signal that all events, throughout the working day, would be at this level and thus potentially hazardous to the hearing.

Work continued to refine the limit for impulse/impact noise, culminating in a wide consensus expressed in the document by the EPA Office of Noise Abatement and Control [1974]. To protect 90% of exposed persons from an impulse-noise-induced hearing loss of 5 dB at 4 kHz, after 100 impulses per day for 10 years, the peak sound pressure level should be no more than 140 dB. Note that this more conservative 140 dB limit is found in the Noise at Work Regulations 1989.

3.1.4 Conclusions: damage risk from occupational noise

Based on the above, we are now in a position to recommend maximum noise exposures which, even if experienced for a period of many years, will result in no detectable damage to the hearing. The studies based on persons with occupational noise exposure would lead to the specification of ‘safe’ exposure limits of 80 dB(A) $L_{EX,8h}$ and 140 dB(C) peak sound level.

The results of the TTS studies might give rise to a lower limit for non-impulsive noise. The lowest possible limit would be a sound level no higher than 78 dB(A), irrespective of duration.

This would clearly be a very cautious and restrictive noise exposure limit, whether applied to toys or to any other noise source. As will be shown later in this report, people are regularly exposed to noise levels higher than 78 dB(A) in everyday life. We therefore consider that adoption of such a low limit would be both unrealistic and unjustified.

We consider that, on the basis of the available data, noise from toys should be restricted to levels which cannot forseeably give rise to noise exposures in excess of 80 dB(A) $L_{EX,8h}$ and 140 dB(C) peak level.

It is recognised that the above conclusion assumes that the outcome of research on the hearing of adults is applicable to children without correction. This assumption is examined in the following sections.

3.2 Susceptibility to noise induced hearing loss in children and teenagers

This section addresses the question of whether young children are either more or less susceptible to noise-induced hearing loss than older children or adults. If there were material differences in susceptibility, it would be necessary to apply different criteria to the various age groups in any risk assessment. If there were no material differences, criteria that have been developed from a large corpus of data from adults exposed to noise could be applied to younger people.

3.2.1 Methods of investigation

Several methods of investigation have been used in parallel to reach an overall conclusion. These have included computer-based bibliographic searching, personal knowledge of the general literature on hearing and noise-induced hearing loss, and peer-polling. The latter method has involved distributing questions via the “earmail” electronic mail reflector, e-mail contact with selected international experts and posing questions at international conferences, including the Second European Conference on Protection Against Noise, 16-19 April 1997 in London, and the 9th International Symposium on Audiological Medicine, 25-28 May 1997 in Aalborg Denmark.

3.2.2 Susceptibility to noise-induced hearing loss in children

No clear epidemiological evidence has been located to infer that young children are more susceptible to noise-induced hearing loss. Expert opinion suggests that the opposite may be the case [Axelsson, personal communication to author MEL]. Diagnosis of noise-induced hearing loss is rare [Dias, personal communication to author MEL], and when such a diagnosis is made it is inevitably presumptive. Brookhouser and Worthington [1992] identified 114 children (aged 19 and under: 90.3% males) in a clinic in the US with such a presumptive diagnosis of noise-induced hearing loss, based on history and audiometric configuration. In 42 cases the hearing loss was unilateral. The mean age of referral was 12.7 years (range 1.2 to 19.8 years), although 26% were diagnosed in children aged 10 years or younger. Such data do not permit statistical comparison with adults and hence comparison of relative risk.

Investigation of susceptibility as a function of age requires a degree of experimental control that can only be obtained in animal studies where homogeneous groups of exposed and control subjects can be compared. Several studies have identified a “sensitive period” for noise-induced hearing loss in experimental animals such as rats, guinea pigs and hamsters [Bock and Saunders, 1977; Coleman, 1976; Falk et al, 1974; Lenoir et al., 1979; Lenoir and Pujol, 1980]. These studies have been reviewed by Pujol [1991], who also assessed implications for human subjects.

The sensitive period in the rat pup extends from approximately day 16 to day 40 post-natal age. This corresponds to a period when the cochlea has reached structural and functional maturity. Studies by Henry [1984 a,b] show similar results with different strains of mice, although in one strain the early increased susceptibility only involved the lower frequency region. When these data are transferred to an equivalent developmental stage in humans, the sensitive period related to the period from 5 months gestation (hence to the unborn foetus) to a few months after birth. Hence, the main practical risk to be addressed is high levels of noise exposure in women at an advanced stage of pregnancy. Studies in pregnant ewes suggest an attenuation of approximately 20 dB for frequencies below 2 kHz for sound transmitted to an intact amniotic sac, with greater attenuation at higher frequencies [Armitage et al., 1980]. Measurements in human mothers during labour are consistent with those data [Gerhardt et al., 1988].

Two studies have shown an increased incidence of hearing loss in babies born to mothers exposed to high levels of noise during pregnancy. Daniel and Laciak [1982] investigated 75 children of mothers who had worked in a weaving factory with a noise level of 100 dB during pregnancy and found 35 to have high-frequency hearing losses of 20 dB to 55 dB. Lalande et al. [1986] examined 131 children whose mothers had worked during pregnancy in noise levels from 65 dB to 95 dB and showed a threefold raised risk of high-frequency hearing loss in those where the noise level was between 85 dB and 95 dB. Clearly, these findings raise concern over the noise environment in neonatal intensive care units where premature babies are treated: Incubator noise can reach 60 dB to 75 dB under normal working conditions [Pujol, 1991] and the sensitive period of such babies may be heightened by potentiation from ototoxic drugs or disease processes.

Despite the evidently increased susceptibility of the human foetus, premature infants and newborns, the available evidence suggests that afterwards susceptibility rapidly reaches adult values. It is difficult to conceive of a practicable experiment that could be contrived to prove or disprove the hypothesis that young children are more susceptible to noise-induced hearing loss than adults, even if such an experiment were ethically justifiable. It is well known that susceptibility in adults is variable: ISO 1999:1990 [International Organization for Standardization, 1990] gives distributions of hearing threshold levels that can be expected in populations of adults exposed to noise. Taking as an example a population of male subjects exposed to a noise level of 100 dB(A) for 10 years starting at age 20 years, the 95th and 5th percentiles of hearing threshold levels at 4 kHz are 8.2 and 56.6 dB respectively, with a median of 23.0 dB. A putative experiment might compare a group of children and a group of adults each exposed to 100 dB(A) for 8 hours per day for 10 years. Assuming that the group of adults showed a mean hearing threshold level at 4 kHz of 33 dB (standard deviation 23 dB) and the group of children showed a mean hearing threshold level of 43 dB (standard deviation 25 dB), hence 10 dB higher, a sample size calculation shows that each group would have to contain at least 75 subjects to achieve a statistical power of 80%. It is highly unlikely that such a study has been conducted, or ever will be. Hence, there is little alternative but to fall back on the scientifically parsimonious assumption that children have the same susceptibility as adults.

3.2.3 Epidemiological studies in teenagers

A carefully conducted audiometric study of young adults aged between 18 and 25 years has recently been completed by the Medical Research Council's Institute of Hearing [Smith personal communication to author MEL]. The study included subjects' reports about exposure to noise from leisure pursuits that included the teenage period. Although the prevalence of leisure noise exposure had increased sixfold compared to a previous study using similar methods conducted in the early 1980s, mainly from amplified music at night clubs, there was no audiometric evidence of noise-induced hearing loss when comparing exposed and non-exposed subgroups. According to ISO 1999, the expected median effect of the noise exposure would be in the region of 3 dB, whilst the study was sufficiently large to show significant effects between subgroups that reached 3 dB with a power of 80%. Hence, the study provides limited evidence that teenagers may be less susceptible to noise-induced hearing loss than adults. However, uncertainties in estimation of noise exposure entail caution in drawing such conclusions without further evidence.

3.2.4 Conclusions: susceptibility of children

Apart from neonates, there is no compelling body of evidence to suggest that infants and children are more susceptible than adults to noise-induced hearing loss. Therefore, methods for assessing risk that are based on adult data, such as ISO 1999:1990, may be used to assess risk in children.

4 Defining noise limits and measurement methods for toys

4.1 Introduction and general principles

Section 3 above gives us criteria for setting limits to the noise levels or exposures received by a child at the child's head or ear position. These limits are necessarily specified in terms of peak noise levels and noise exposures *received* by the child, rather than in terms of noise *emitted* by toys, as it is the noise received which affects hearing. As usual the limits or criteria are those which would be measured at the head or ear position but in the absence of the child, ie any levels are 'undisturbed field levels'.

Our criteria are, explicitly, that **the undisturbed field noise exposure for a child should not exceed 80 dB(A) $L_{EX,8h}$ and that the instantaneous peak undisturbed field noise level should not exceed 140 dB(C) or 200 Pa.**

Any practical, workable standard for setting limits on the noise from toys needs to address the noise emitted by the toys rather than the noise received by the child. We therefore need to relate the noise emitted by a toy to the noise received by a child, so that by controlling the emission of the toy we are controlling the exposure of the child.

As a general principle, a single toy, or a selection of toys used sequentially in the course of a child's play, should not cause a child to receive a noise level or noise exposure in excess of the adopted criteria, when the toy or toys is used either **as intended** or **in a manner which is reasonably foreseeable** or which might be expected. Gross misuse of a toy on a **regular** basis, eg by one child forcing an unsuitable toy very close to the ear of another, cannot reasonably be covered by a standard. But it is reasonable to expect that a standard should ensure that **isolated** occurrences should not cause lasting harm, and that parental control be exercised to prevent regular recurrences.

As a further general principle, safety criteria, expressed as noise level or exposure limits *at the child's position or ear*, should be the same for all toys without exception.

Sound levels from earphones or headphones cannot be measured directly with a sound level meter, and special measurement techniques and equipment are required, which will be described below (Section 5). The criteria we will adopt will however be shown to be the same as for other toys. For convenience close-to-the-ear toys will be considered with the earphones and headphones.

4.2 Relating noise emitted by toys to noise received by children

In relating the noise emitted by a toy to the noise received by a child we can use the classic model of a sound source (toy), a transmission path or paths, and a receiver (child). The noise at the receiver depends on the sound source and the transmission path or paths.

The noise *level* received by the child is therefore determined by

- the noise output or emission of the toy
- the orientation of the toy, if it emits noise mainly in one direction rather than uniformly in all directions
- whether the toy is used on or against a sound reflecting surface such as a table, floor or wall
- the distance between the toy and the child's head or ear when the child is playing.

The noise *exposure* for the child is determined by the above factors with the addition of

- the duration for which a child will play with toys in a day.

All these factors need to be taken account of either explicitly or implicitly when designing a standard.

The first four factors, the noise emitted by the individual toy, the directivity pattern, the presence of any surface, and the distance between the toy and the child can all be dealt with together by defining a suitable measurement technique. In general, if a toy is normally used on a surface at a certain distance then a noise measurement at that distance from the toy on a similar surface will automatically account for those factors and the noise level registered by a meter will show directly the noise which would be received by a child. In practice this is slightly oversimplified as will become apparent.

The fifth factor, the duration of play, is the ‘odd one out’. It is a behavioural factor, controlled by the child (or, in the case of infants, by an adult), dependent on the child’s interest, the child’s attention span, the child’s and family’s social, economic and cultural background, and the availability of toys to the child. The other factors are physical, geometrical or acoustical. Although more difficult to take account of in a safety standard, the duration of play is no less important.

The noise output and directivity pattern of a toy are properties of the toy to be measured. The presence and type of playing surface, the orientation of the toy, the distance between the toy and the child’s ear and the play durations are factors to be controlled or accounted for in designing a safety standard. These factors are addressed below.

Data for the following sections were obtained from a literature search using the Science Citation Index, Embase, Inspec, the Social Sciences Citation Index, UK Index to Theses, and the contents pages and indexes of important journals.

4.3 Distance from a toy to child’s ears

The distance at which the noise from a toy is measured may either be similar to the actual distance between the toy and the child’s head in normal play or else a convenient fixed distance of say 0.5 m or 1.0 m. If a fixed distance is used, an allowance must be made to the noise limits to compensate.

It is self evident that some particular types of toy will be held closer to the ear than other types.

Axelsson and Jerson [1985] measured noise levels from toys other than cap-firing toys and firecrackers at 10 cm and at 50 cm, but did not claim that either distance was typical of normal use, and in the case of toys commented that ‘normal distances’ were greater than 10 cm.

For toys intended for children aged 3 years and under, Hellstrom et al [1992] measured noise levels at a distance of 30 cm with the toys placed on a surface. They measured noise from toy cap guns at 20 cm. For unpublished measurements by ISVR Consultancy Services [Lower 1992] a distance of 30 cm was adopted as a reasonable representation of playing distances for most toys, but additional measurements were made, where appropriate, with toys held next to the ear of a ‘Kemar’ manikin or dummy head [Burkhard and Sachs, 1975]. Bambach and Ising [1994] chose 25 cm and 2.5 cm for their measurements.

The work by Gagnon [1994] in Canada appears to be the most authoritative on the subject of the distance from toy to ear. From her data, collected within five families over a two-week period by family members acting as observers, she identified two groups of toys. The first group, ‘holding toys’ designed to be held and handled by the child, were sometimes brought as close to the ear as 2.5 cm, the distance depending upon the position of the child during play. This group included cars, rattles, squeeze toys and tape recorders. The range of distances in average or typical use was from 13 cm to 31 cm, with a mean value of 23 cm. The second group of toys were not brought closer to the ear than 15 cm. The range was 18.5 cm to 50 cm with a mean of 31.3 cm from the ear. This second group of toys included those intended to be used on a table or floor and which needed to be seen by the child. Examples included table games, ‘see and say’, ‘speak and maths’, etc. Gagnon recommended ‘worst-case’ testing distances of 2.5 cm for the first group of ‘holding’ toys and 20 cm for all others, with average-use testing distances of 20 cm (rounded from 23 cm) and 30 cm respectively for the two groups.

In our experience it is sometimes very difficult to differentiate between hand-held, table top or floor toys. The same toy may be used as a hand-held toy or as a table-top toy by different children or by the same child on different occasions. Our own recommendation would be to round Gagnon’s average distance of 23 cm for ‘holding toys’ to 25 cm rather than 20 cm, and then to use this distance not only for hand-held toys, but also for table-top and floor toys instead of Gagnon’s 30 cm distance. The distance of 25 cm is the one we would recommend for measuring noise levels typical of normal use. We would also recommend that noise levels at a distance of 2.5 cm from the ear, the closest observed by Gagnon's team, should not be sufficient to cause permanent harm to a child during occasional accidental exposure or deliberate abuse, and noise levels in a standard should reflect this also.

4.4 Playing surface and room environment

A playing surface can have two effects. Firstly the presence of a hard, flat surface acts as sound reflector. Secondly, depending on the construction and materials from which the surface is made, the surface can act as a sounding board, vibrating in its own right and radiating sound. A motorised toy may produce different noise levels when placed on a hard wooden table than when placed on a carpeted floor. Noise from a radio for example may be less influenced by the surface on which the radio is placed. Noise levels produced by a vibrating toy which bounces and impacts on a surface may be highly influenced by the surface.

The only practicable approach in a standard is to tightly specify a measurement surface so that all test laboratories will obtain the same measured levels from the same toy. A standard test table is described in ISO 7779:1988 [International Organization for Standardization, 1988] and an identical suggested design is given in ISO 11201:1995 Annex B [International Organization for Standardization, 1995 a]. The table has a surface with minimum dimensions of 0.7 m square and a minimum area of 0.5 m^2. The top is of laminated wood between 4 cm and 10 cm thick giving a well-damped solid surface to minimise the risk of vibration being induced by a machine or being re-radiated as sound from the table top.

Our experience in measuring noise from table top and floor toys shows that a 1 metre square table is about the minimum size which can accommodate a moderately sized toy and also extend below a measurement microphone placed at a horizontal distance of 50 cm from the side of the toy. It could be argued that the toy would be at the edge of a table in normal use so that the table top need not extend below the microphone position. However, this argument does not apply if the toy is on the floor rather than the table, or if a child is seated right up against the table in order to reach the toy.

Our recommendation would therefore be to place both table-top and floor toys on a table as described in ISO 7779 or ISO 11201 when measuring noise levels.

As already mentioned, it is often difficult to classify toys as hand-held, table top or floor toys. Many toys will fall into all these categories. A further recommendation, to avoid ambiguity in classifying toys, is that any toy which could be used either hand-held or on a surface should be measured on the standard table. Only those toys which are definitely not expected to be used on a table or floor should have their noise levels measured without the surface.

At normal playing distances of 25 cm to 30 cm the noise level from a toy will be affected only slightly by the acoustics of the play room, and provided the play room is not excessively reverberant and the toy is not close to a wall or other room surface (other than intentional surfaces as represented by the standard table top), then a child will experience very similar noise levels from a toy wherever they play. By the same argument many ordinarily furnished rooms will be adequate for noise measurements at 25 cm: expensive, specialist test facilities will not normally be required. (Some guidance on the suitability of a test environment may be found in the Annex to ISO 3746-1995 [International Organization for Standardization 1995 b].)

4.5 Duration of play

Duration of play is by far the most difficult factor to account for, firstly because it is likely to vary considerably from child to child, secondly because of the paucity of published information. We have seen some manufacturers’ data on the time spent playing with individual toys. In setting noise limits we should be more concerned with the total time spent playing with toys in an average day. The reason is simple - a child may put down one noisy toy only to pick up another, equally noisy toy. The child’s noise exposure from the two toys would be the same as if the child had continued to play with the first toy for the total time.

Anecdotal evidence on play durations from parents or relatives is in many instances unreliable – when asked how long children play with toys, many adults will answer unthinkingly “nearly all the time”. Only when pressed will they realise that children spend a minority of their time playing with toys. The rest of the time will be spent playing with objects which are not toys, helping or watching around the house or garden, accompanying parents on shopping trips, eating, in conversation or shared activities with parents, etc.

There are three papers or reports which we have found to be helpful in estimating play durations: Giddings and Halverson [1981], Axelsson, Dengerink, Hellstrom and Mossberg [1993] and Gagnon [1994].

Giddings and Halverson [1981] collected week-long histories of play behaviour for 17 pre-school boys and 22 pre-school girls using diaries of children’s activities kept by the mothers. The children were from white, middle-class and upper-income, professional American families. Children were aged from 22 months to 94 months with a mean of 47 months. Note that children start formal ‘school’ at a later age in the USA than in the UK. It was found that children spent about 20% of their waking time playing with manufactured toys (19% for boys, 22% for girls). This was roughly 18 hours per week or 2.6 hours per day. Children also spent about 7% of their waking hours playing with items other than toys (eg kitchen items, furniture, tools, rocks), about 13% to 16% of their time awake, or 2 hours per day, in ‘non-play’ activities (watching television, reading, records) and 58% of their waking day in other activities within or away from the home generally with adults (shopping, running errands, visiting friends and relatives, meal times, etc). About 65% of all play occurred indoors even though data were collected in midsummer. There were, as expected, differences in the types of toy chosen by girls and boys although total playing times were similar. The authors comment on how little information is available on how children spend their time and the need for further information for different social classes, for single parent families and for different age ranges. The important quantity from our point of view, however, is the 2.6 hours per day spent playing with toys.

Axelsson et al [1993] were not specifically concerned with toy play but with the more general activities affecting the ‘sound world’ of the child. We can however deduce, within limits, the amount of time spent playing with toys. In this study, 50 first, fourth and sixth grade children from a suburban school kept activity diaries for 12 weeks. Table 1 of the paper gives the average number of hours per week spent in various activities. By subtracting the time clearly spent not playing with toys from the total number of hours in a week we are left with the time which was spent playing with toys or which could been spent playing with toys but of which we are not certain. Approximately 15 hours per week are not accounted for in Axelsson's table. Taking the time which is not accounted for and adding the time spent in unspecified indoor and outdoor activities we have a total of just over 24 hours per week or just under 3.5 hours per day as an absolute maximum time available on average for playing with toys. Quite clearly we do not know how much time was spent playing with toys, but it would not have been more than 3.5 hours per day and was possibly much less than this.

Gagnon's study [1994] was limited to observing the use of a small number of noise emitting toys distributed to various families for a two-week period. It is difficult to extract any typical total play durations from the data, because play times were not recorded for all the toys which were used, just those supplied for the study. Nevertheless it was clear that "children are not exposed to noise emitting toys for long periods during a normal day". There is also an indication that children are exposed to noise from toys for less than 60 minutes in a day, although they may play with toys capable of producing noise for longer periods. Playing times for individual toys were very similar overall to playing times found by manufacturers.

The above data are limited. However such data as are available are not contradictory and some reasonable assumptions can be made in order to carry out a cursory risk assessment. Our first assumption, based on the published data, is that pre-school children will play with toys for 3 hours or less per day. It would seem reasonable to assume that some of this time would be spent playing with quiet toys, and that even the noise-producing toys would not make noise continuously. It seems likely therefore that a pre-school child would not regularly be exposed to noise from toys for more than say, 30% to 50% of the playing time, say 1 to 1.5 hours a day. Though this is not based on any strong evidence, it does seem to be consistent with Gagnon's work. Children of infant school age may play with toys as part of their schooling but will have less time outside school hours to play with toys. The total time they spend playing with toys is therefore probably similar to or slightly less than the time spent by pre-school children. Older children and teenagers will not play with toys in school and may also have homework or other chores. Consequently they are likely to have less time than the younger children to play with toys, except at weekends.

If we assume that a child will be exposed to noise from a noise-making toy for 1 - 1.5 hours a day, then a toy may produce a level of up to 87 dB(A) L_{eq} without exceeding our 80 dB(A) $L_{EX,8h}$ daily noise exposure limit. If conversely we were to set a limit of 85 dB(A) L_{eq} for toys, then a child could be exposed to this noise for 2.5 hours per day before exceeding the 80 dB(A) $L_{EX,8h}$ exposure limit. We do not, on the basis of the available evidence, expect a child to be exposed for this length of time to noise from noisy toys. We therefore recommend setting a noise limit of 85 dB(A) L_{eq} as the noise level limit for toys in the undisturbed field. We believe that there is margin of safety of at least 2 dB in this figure which will allow for the uncertainties in the play durations or in the measurement distances, and also for some exposure to noise sources other than toys.

4.6 Bringing it all together - our recommended limits and measurement techniques

Based on our estimates of normal and worst case distances and play durations as detailed above we recommend the following

4.6.1 Hand-held, table top and floor toys.

Noise level measurements for hand-held, table-top and floor toys should be measured at a distance of 25 cm from the surface of the toy in the direction of maximum noise emission. Table top and floor toys should be placed on a standard table such as that described in ISO 7779 and in ISO 11201. Toys which could be hand-held but which could also be used on a table top or floor should be measured on the standard table to avoid ambiguity. Toys which would only be used held in the hand should be measured without the table, preferably hand-held.

The time-averaged noise level produced by the toy in continuous use or over one or more complete cycles of use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

The reason for choosing the value of 120 dB(C) at 25 cm is as follows. Noise levels from small sound sources fall with distance, and sound intensity is inversely proportional to the square of the distance from the source - the inverse square law. Thus sound pressure levels reduce by 6 dB for every doubling of distance from a source, and by 20 dB for every tenfold increase in distance. Noise levels at 2.5 cm from a small source will therefore be 20 dB higher than sound levels at 25 cm from the source. The chosen peak noise level of 120 dB(C) at 25 cm equates to 140 dB(C) at a range of 2.5 cm and has been set to prevent hearing damage from occasional misuse as close to the ear as 2.5 cm. We could have specified the peak limit as 140 dB(C) at 2.5 cm, but it is more convenient and no less accurate to measure the peak level at the same distance as the time-average level.

The time average level of 85 dB(A) at 25 cm would equate to 105 dB(A) at 2.5 cm. The daily exposure limit of 80 dB(A) $L_{EX,8h}$ would therefore be reached in just under 5 minutes, if the toy were held close to the ear. However, we believe that such a high level would be most unpleasant and would not be endured for more than a second or two, so occasional misuse should not cause permanent harm. It is sufficient to rely on a peak limit to protect against the occasional misuse of toys too close to the ear.

4.6.2 Rattle and squeeze toys

For rattle and squeeze toys used by the child, the limits should be the same as above for hand-held toys. The time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. We recommend that measurements should be made over a 10 to 30 second period, and the toy operated so as to produce the highest levels achievable.

We note that the draft European Standard prEN71-1 [CEN 1996] specifies Sound Exposure Levels measured over a number of shakes of a rattle or a number of squeezes of a squeeze toy. This method does have some practical advantages, as will be discussed below. We can, with some assumptions, express our recommended time-average limits as SEL values.

If we assume a squeeze toy can be squeezed once per second, then to keep the time-averaged level over the period of use of the toy to 85 dB(A) L_{eq} the Sound Exposure Level of a single, average squeeze must be 85 dB(A) SEL or less. (The numerical equivalence between the L_{eq} and SEL occurs because one squeeze occupies one second, and the SEL has a reference time period of 1 second).

It is more convenient to measure over more than one squeeze. The measured levels will be more repeatable over a number of squeezes and more representative of average use. The SEL over a series of ten squeezes must be 95 dB(A) or less. This is equivalent to an average of 85 dB SEL per squeeze for 10 squeezes. One squeeze per second is a fast rate and difficult to maintain with some of the stiffer squeeze toys, especially those which ‘stick’ in their squeezed state and need to be manipulated until they pop back into shape. Therefore our SEL limit of 95 dB for a series of ten squeezes is cautious.

If we assume a rattle can be shaken twice per second, then to keep the time-averaged level over the period of use of the toy to 85 dB(A) L_{eq} the Sound Exposure Level of an average shake must be 82 dB(A) SEL or less. The SEL over a series of ten shakes must therefore be 92 dB(A) or less.

Our alternative recommendations for squeeze toys and rattles therefore are as follows.

The Sound Exposure Level of a squeeze toy, measured over a series of 10 squeezes, shall not exceed 95 dB(A) at 25 cm. The Sound Exposure Level of a rattle, measured over a series of 10 shakes, shall not exceed 92 dB(A) at 25 cm. The peak noise level from a rattle or squeeze toy should not exceed 120 dB(C) at 25 cm.

4.6.3 Cap guns

The peak noise level limit of 120 dB(C) at 25 cm should also apply to toy weapons and cap guns. Our own measurements show that cap guns producing peak levels of 144 dB(C) give single shot SELs of around 110 dB(A). A cap gun producing a peak level of 120 dB(C) is likely to produce SELs of 90 dB(A) or less, in which case at least 2800 shots would be needed to exceed a daily exposure of 80 dB(A) $L_{EX,8\,h}$. We can safely assume this number of shots will not normally occur in a day. Accordingly limiting the peak level of cap guns should be sufficient: a time average noise level or SEL limit is not needed.

4.7 Summary of our recommended noise limits for all toys except close-to-the-ear toys and headphones

4.7.1 Hand-held, table-top and floor toys, cot toys

The time-averaged noise level produced by the toy in continuous use or over a cycle of use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. Noise levels are measured in the direction giving the highest levels. Table top and floor toys should be tested on a standard table. Any hand-held toy which may also be used as a table top or floor toy should be tested on a standard table. Any toy which would always be used hand-held or away from solid surfaces should be measured without the table, preferably hand held.

4.7.2 Rattles

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Or The highest achievable Sound Exposure Level of a rattle, measured over a series of 10 shakes, shall not exceed 92 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

4.7.3 Squeeze toys

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Or The highest achievable Sound Exposure Level of a rattle, measured over a series of 10 shakes, shall not exceed 95 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

4.7.4 Cap guns

The peak noise level should not exceed 120 dB(C) at 25 cm.

5 Headphones, earphones and close-to-the-ear toys

5.1 Introduction

The normal criteria for assessing the risk of hearing damage relate to noise from machinery, equipment or loudspeakers rather than from headphones. We have applied similar criteria to toys. These criteria are expressed in terms of the sound levels measured at the work place, or in our case, at the child’s position. Care is taken when measuring these levels to place the measuring equipment, usually a sound level meter, so that the meter operator and anyone else present do not unduly influence the reading by causing reflections or sound shadows. The reading is therefore representative of an unobstructed or undisturbed sound field. European Directive 86/188/EEC [European Economic Community, 1986] and the UK national implementation in the Noise At Work Regulations 1989 [Statutory Instruments 1989; No. 1790] specify maximum sound levels in terms of undisturbed field levels.

There is at present no specific criterion or method for assessing noise levels from devices held against, inserted in or coupled to the ear, and then relating these levels to the risk of hearing damage or the noise regulations. Such devices may include toys, headphones or telephones. To estimate risk we must convert the toy or headphone sound levels to their equivalent unobstructed field levels. Again there is no standard procedure for this at present. However Rice et al [1987] have suggested a method based on the use of a manikin, or artificial head and torso. The manikin, known as 'Kemar' (**K**nowles **E**lectronics **M**anikin for **A**coustic **R**esearch), incorporates microphones to measure sound levels at the eardrum positions [Buckhard and Sachs, 1975]. The manikin has been designed to be geometrically and acoustically representative of a median human. Noise levels measured at the eardrum of Kemar are representative of noise levels which would be present at a median adult human eardrum under the same conditions.

The rationale behind Rice's method is as follows. A given noise level and spectrum at the ear drum will give a certain risk of hearing impairment whether that noise level is produced by an external undisturbed sound field (from machines or loudspeakers) or by a noise source close to or coupled to the ear. We can measure the noise levels and spectrum produced at Kemar's ear drum by the coupled noise source. We can also calculate what spectrum and levels of a notional external, undisturbed sound field would be necessary to duplicate the spectrum and levels produced at the eardrum by the close or coupled noise source. The notional external noise field and the actual close noise source would produce the same sound levels at the ear drum, therefore both carry the same risk to hearing. Rice et al provide the necessary frequency-dependent transfer function to convert eardrum sound levels to the equivalent unobstructed external field levels. Because an ear canal is a resonant tube it amplifies sound and the noise level at the ear drum is generally higher than the sound level of an equivalent external sound field. The amount of amplification provided by the ear canal varies with frequency. Low frequency sounds are hardly amplified at all while sounds with a lot of energy around 3 kHz are amplified most, by about 15 dB. The amplification for any particular sound therefore depends on its spectrum, the amount of sound energy in each frequency region.

5.2 Procedure for calculating an equivalent undisturbed sound level

First the spectrum of the sound from the close-up noise source must be determined at the eardrum. This is difficult with real heads outside the controlled conditions of a laboratory, but easy using an artificial head or manikin such as Kemar, which has been shown to be acoustically very close to the median or average real adult. The spectrum is measured by dividing the frequency range into separate bands each one-third of an octave wide and the sound level in each one-third octave band is measured.

Once the headphone sound level has been measured in each band, each band level is modified by subtracting a specific value. The value differs from band to band, but for each band is always the same. The new modified levels in each component band are summed to give an overall sound level which is the equivalent unobstructed sound level.

5.3 Justification for using the manikin to represent children

There are various aspects of test procedures which need to be justified. These are discussed in Sections 5.3.1 - 5.3.3 below.

5.3.1 Can an adult-size manikin represent a child?

The manikin used here was designed to be representative of an adult rather than a child. Keefe et al [1994] found that a child's ear canal changes considerably in the first 24 months from birth and is not fully adult-like at 24 months. However Hellstrom et al cite work by Kruger and Ruben [1987] who studied the development of the ear canal and report that the acoustics (transfer function) of the earcanal of a 3 year old resembles that of an adult. Newborn children however have earcanals which amplify sounds most in the frequency range between 6 kHz and 8 kHz, whereas adults and children over 3 years have earcanals which amplify sound most between 2 kHz and 3 kHz. Accordingly the manikin would appear to be reasonably representative of children aged 3 years or more, though not babies. The manikin method is therefore reasonable for toys used by children of 3 years and upwards. More fundamentally, the use of the A-weighting curve will be as valid for children of 3 years or more as it is for adults.

An important point needs to be made here. There are two aspects to the use of the manikin. The first aspect is the measurement of sound levels at the eardrum, the second is the use of the manikin to derive undisturbed field equivalent levels. If the manikin is not representative of a very young child then the sound levels at the manikin's eardrum will not be representative of those at the young child's eardrum. However, when the manikin is used to derive undisturbed field equivalent levels, we measure the eardrum sound levels which are amplified by the adult-sized earcanal compared to the undisturbed field then estimate undisturbed field levels by subtracting the amplification of the adult-sized earcanal. If we had a baby manikin the measured eardrum levels would be higher than the undisturbed field equivalent levels by an amount determined by a baby-sized earcanal, but we would then subtract the amplification appropriate to the baby-sized earcanal. The undisturbed field level predicted in each case would be the same. Thus many of the errors in using an adult-sized manikin rather than a baby-sized manikin are self-cancelling when predicting undisturbed field levels, though not when predicting noise levels at the baby's eardrum. The manikin method is therefore far more robust than might be expected from comparing the acoustics of babies' ears to those of adults' ears.

5.3.2 Susceptibility of children compared to adults

There is the question of whether children's ears are more susceptible than an adults. The different acoustics of a baby ear canal compared with an adult ear canal are more important here. This point has already been fully addressed in Section 3.

5.3.3 Is there a less complicated method?

There is the question of whether a manikin is necessary or whether a simpler device would be suitable, such as the standard artificial ear conforming to IEC 318 [International Electrotechnical Commission, 1970] which is used mainly for calibrating audiometer headphones.

There are several good reasons for using the manikin in preference to an artificial ear. Firstly the manikin is geometrically similar to a real person, and has flexible rubbery ears similar to a human's. Any device, toy, headphone, earpiece, telephone or whatever can be held against or inserted in the manikin's ear in exactly the same way as on a real ear. The artificial ear is not geometrically similar to a real ear, so how a headphone should be placed on the artificial ear is not at all well-defined. The artificial ear is designed specifically to fit audiometric earphones and telephones which have a limited variation in shape and standard; it does not fit insert earphones, in-the-ear or in-the-concha earphones, or toy telephones. Supra-aural earphones with foam pads can be placed on the artificial ear but the measurements are not particularly repeatable unless the foam pads are very large. Secondly the manikin's ear is acoustically as well as geometrically similar to a real ear so the sound level at the manikin's eardrum is similar to that at a real eardrum and the manikin's ear provides a realistic load impedance to the toy or earphone. Because the artificial ear is designed to fit audiometric earphones it can present an appropriate load impedance to an earphone, but it will not present an appropriate load to any device which it does not fit. The artificial ear's microphone does not correspond to a real eardrum in its position, it vaguely corresponds to a point in a real ear near the earcanal entrance, but only when used to measure noise from earphones or telephones. Thus there is therefore no unique transfer function for adjusting sound levels from the microphone to a notional undisturbed field. The artificial ear has a definite role in the calibration of earphones for audiometry or production testing of telephones, but is not designed for, and nor suited to the measurement of some other types of headphone.

Despite the above arguments an artificial ear is cheaper than a manikin, and is in far more widespread use. Purchase of a manikin would be difficult to justify by a toy-testing laboratory for toy-testing alone, although many specialist acoustic laboratories carrying out research already have access to manikins. If the artificial ear could be used for measuring noise from earphones and headphones with sufficient accuracy, and if any inaccuracy could be countered by setting a lower noise limit to include a built-in tolerance for the uncertainty, then the artificial ear would be acceptable for measuring supra-aural and circumaural earphones, though a manikin would still be preferred. It must be stressed that the IEC 318 artificial ear **cannot** be used for in-the-ear or in-the-concha styles of earphone.

We have therefore compared measurements of undisturbed field levels made with a Kemar manikin with measurements on an artificial ear for a limited number of toys with supra-aural earphones.

5.4 Comparison of headphone output levels measured on an Artificial Ear with undisturbed field levels derived from a manikin

One-third octave band spectra and A-weighted levels were measured for the toys with earphones on a Kemar manikin and on an IEC 318 artificial ear (Brüel & Kjær Type 4153). The undisturbed field equivalent level was calculated from the Kemar measurements in each case. The results are shown in Table 1.

The Undisturbed Field Equivalent level is the important level related to the risk of hearing damage and our limits for noise levels from toys are expressed as UFE levels. The above results indicate that noise levels measured on an artificial ear overestimate the undisturbed field equivalent levels by about 11 dB on average, with a standard deviation of nearly 3 dB. Consequently if we wish to limit the undisturbed field equivalent level from toys and headphones to 85 dB(A) L_{eq} we need to limit the noise levels measured on an artificial ear to 93 dB(A) L_{eq}. We have added the mean difference between the artificial ear and the UFE level (10.7 dB) to our UFE criterion level (85 dB(A)) and then subtracted one standard deviation (2.7 dB) to allow for the measurement uncertainty (85 + 10.7 - 2.7 = 93 dB(A)). By taking one standard deviation we are implying that for 84% of headphones the measured level will be below the UFE of 85 dB(A) as intended, but 16% of headphones could produce true UFE levels slightly above our criterion of 85 dB(A) without this showing in the measurements. We should however point out that our measured data was limited to four sample items.

We have not compared undisturbed field levels of impulsive or impact noises from ‘distant’ sources as measured with a sound level meter with the corresponding levels measured at a manikin’s ear drum. By ‘distant’ we mean noise sources other than those close to or covering the ear, and would include hand claps, door slams, gun shots, the clink of bottles, hammering, etc. The manikin’s head related transfer function suggests that peak levels measured at the eardrum would be higher than levels measured in the undisturbed field, by as much as 15 dB in some cases. In some cases, with some head orientations relative to the source, the level at the eardrum could be similar to or less than the level in undisturbed space. Nevertheless, an instantaneous peak level from a distant source registering as 140 dB(C) peak at a sound level meter, could produce higher levels at a human eardrum or at a manikin’s eardrum. Therefore if we set a limit of 140 dB(C) at a manikin’s eardrum, this should be more protective than a limit of 140 dB in the undisturbed field. Examination of Table 1 shows that time averaged A-weighted levels measured at the microphone of the artificial ear were within ± 4 dB of those measured at the manikin’s eardrum microphone. If we *assume* that C-weighted, instantaneous levels as measured on the artificial ear are also within ± 4 dB at the manikin’s eardrum, we would conclude that an instantaneous level of 136 dB should be imposed when headphones are measured on the artificial ear. In view of the limited information on which this argument is based, we tentatively recommend an over-riding instantaneous peak limit of 135 dB(C) peak, whether measured on the artificial ear or at the manikin’s eardrum.

5.4.1 Recommendations for specifying noise limits from headphones or earphones

Based on the above our best recommendations for specifying noise limits for toys with headphones are as follows.

Any volume control or other settings shall be set to produce the maximum sound output.

Either (i) the time averaged noise level measured using an artificial ear conforming to IEC 318 shall not exceed 93 dB(A), and the instantaneous peak level shall not exceed 135 dB(C). This method can only be used for types of headphone that will fit the artificial ear.

or (ii) the undisturbed field equivalent time averaged level measured using a manikin should not exceed 85 dB(A) L_{eq} and the peak level at the manikin eardrum shall not exceed 135 dB(C). This method can be used for any type of headphone which will fit the manikin in the same manner as it will fit a real person.

Additional comment: we would recommend using a standardised CD or Cassette Tape for all measurements on CD players and tape players. We would recommend tuning to an FM pop music station, or the strongest AM pop music station receivable, for measurements on radios (assuming that specialist RF test equipment will not often be available in toy testing laboratories).

5.5 Use of a manikin to measure close to the ear sources other than earphones

The manikin can also be used to measure noise levels from sources other than headphones or earphones which may be held close to the ear or against the ear. Examples of such sources are real or toy telephones. These devices may have an earphone or musical sounder in the earpiece held against the ear, but in many toy telephones the sounder is on the back of the earpiece away from the ear, or even in the mouthpiece or in the back of the mouthpiece. These sounder positions are intended to discourage children from placing the sounder directly against the ear.

Again although a manikin is useful for such measurements a simpler method would be to use a regular microphone close to the sound source. The draft standard prEN71-1 recommends measurements at 2.5 cm from a toy classified as a close-to-the ear-toy. To evaluate this procedure we have measured a small number of close to the ear toys including toy telephones using the Kemar manikin and have calculated the UFE level. We have done this with the toy held as intended and also with the toy held so that its sounder is against the manikin's ear. We have also measured these toys using a sound level meter at 2.5 cm from the sound output port for comparison.

The levels measured these methods are given in Table 2. The sound levels measured at 2.5 cm were, for the four sample telephones tested, 3 dB lower, 1 dB lower, 3 dB higher and 6 dB higher than the undisturbed field equivalent levels derived from the manikin. The variation can be explained by the position of the sounder on the telephone handset. The use of a sound level meter at 2.5 cm therefore appears to indicate sound levels reasonably representative of UFE levels for toy telephones held as normal telephones, although our sample size is too small to claim that this will always be the case.

When a sounder port is pressed very tightly against the ear, which is likely to be rare but possible during normal play, the UFE level is typically 7 dB to 8 dB higher than the level at 2.5 cm, but in one instance was up to 14 dB higher. If we wish to prevent an UFE level of 140 dB(C) peak arising from a sounder sealed to the ear, but wish to measure at 2.5 cm using a sound level meter, we would need to limit the peak level at 2.5 cm to about 126 dB(C) - 132 dB(C), depending on the toy. Accordingly we suggest a 'round number' limit of 125 dB(C) peak at 2.5 cm

5.5.1 Recommendations for specifying noise limits for close to the ear toys other than headphones or earphones

Based on the above, our recommendations for specifying noise levels for close-to-the-ear toys other than earphones or headphones are as follows.

Noise levels measured in free field at 2.5 cm from any part of the toy should not exceed 85 dB(A) L_{eq} , the peak level should not exceed 125 dB(C).

5.6 Summary of our recommended noise limits for close-to-the-ear toys and headphones

5.6.1 Close to the ear toys

Noise levels measured at 2.5 cm from any part of the toy should not exceed 85 dB(A) L_{eq} , the peak level should not exceed 125 dB(C).

5.6.2 Headphones and earphones

Either (i) the time averaged noise level measured using an artificial ear conforming to IEC 318 shall not exceed 93 dB(A), and the instantaneous peak level shall not exceed 135 dB(C). This method can only be used for types of headphone that will fit the artificial ear.

Or (ii) the undisturbed field equivalent time averaged level measured using a manikin should not exceed 85 dB(A) L_{eq} and the peak level at the manikin eardrum shall not exceed 135 dB(C). This method can be used for any type of headphone, earphone, ear insert or stethoscope which will fit the manikin in the same manner as it will fit a real person.

6 Comparison of our recommendations with those in existing or proposed toy safety standards

Various national standards exist to limit the noise from toys. European and International standards either exist in draft or are in preparation. Furthermore some researchers have put forward proposals which would restrict the noise from toys quite considerably. The UK Toy (Safety) Regulations do not specifically cover noise but are automatically covered by Schedule 2 (the Essential Safety Requirements for Toys) which require that the users of toys as well as third parties must be protected against health hazards and risk of physical injury when the toys are used as intended or in a foreseeable way. Any changes to the European Standard will automatically be adopted as a British Standard. In this section we compare the noise limits which we propose with limits in existing and draft standards and with limits proposed in the literature.

6.1 Canadian Hazardous Products Act

The Hazardous Products Act [Canadian Government, 1980] prohibits "the advertising, sale and importation of hazardous products". Schedule I, Part I of the Act lists 'prohibited products' and includes, as Clause 10 (a),

> "Toys, equipment and other products for use by a child in learning or play that ... make or emit noise exceeding one hundred decibels measured at the distance that the product ordinarily would be from the ear of the child using it..."

The Act does not specify whether the noise level is a peak or average level nor whether it is weighted or un-weighted, nor any details on measurement procedure. Without further guidance the clause is unusable.

If the intention of the Act is to limit peak levels to 100 dB then it is highly restrictive, in fact 20 dB more restrictive than our recommendations. If the intention is to limit average levels or L_{eq} to 100 dB then it is very lax, allowing levels up to 15 dB more than our recommendations.

6.2 American National Standard ASTM F 963 - 96 Standard Consumer Safety Specification on Toy Safety

The most recent revision of this American Standard, Standard Consumer Safety Specification on Toy Safety, was published in 1996 under the auspices of the American Society for Testing and Materials [ASTM 1996].

Clause 4.5 states:

> "4.5 *Impulsive Noise* - Toys shall not produce impulsive noise with an instantaneous sound pressure level exceeding 138 dB (20 µN/m^2) when measured at any position 25 cm from the surface of the toy. The sound levels shall be measured using the equipment described in 16 CFR 1500.47. When determining sound levels, both the toy and the test equipment shall be at least 1 m from any wall, ceiling or other large obstruction. As specified herein, the sound levels shall not be exceeded after the toy is tested in accordance with procedures contained in 8.5 through 8.10. The sound pressure levels for toy caps must not exceed 138 dB when measured as described in 16 CFR 1500.47 16. The warning statements and notifications to the CPSC, as required by 16 CFR 1500.86 (a) (6), must be observed if the sound pressure level of toy caps exceeds 138 dB when measured using that method."[3]

"Impulsive noise" is defined as "one in which the variations in noise level involve maxima at intervals greater than 1 s" (Clause 3.1.15). Table A3 of the standard indicates that the impulsive noise requirement applies to mouth-actuated toys, musical toys, toy guns and projectiles, and mechanical games.

The limit on impulsive noise is very similar to current EU limits for industry of 140 dB and, as such, is adequate for average use assuming a toy is not used closer than 25 cm to the ear. Our recommendation is 18 dB lower on the assumption that 140 dB must not be exceeded even if a toy is occasionally misused as close as 2.5 cm to the ear.

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[3] Notes: (i) the 20 µN/m^2 in parentheses, more usually written as 20 µPa, is the reference sound pressure corresponding to 0 dB and does not equate to 138 dB, (ii) the CPSC is the US Consumer Product Safety Commission, Washington DC20402, (iii) 16 CFR 1500 is the American Hazardous Substances Act Regulations in various sections of the Code of Federal Regulations.)

The ASTM standard does not give any limits for time-average noise levels.

6.3 Chinese National Standards CNS 4797-3, CNS 4798-32 (Taiwan)

CNS 4798-32 [National Bureau of Standards, Taiwan, 1987] gives the measurement procedure for noise producing toys. CNS 4797-3 Section 5.3 [National Bureau of Standards, Taiwan, date unknown] gives the noise limits.

The test procedure in CNS 4798-32 requires a room with a reverberation time of 0.5 s or less (Clause 2.3). The microphone of the required sound level meter is placed 250 mm from the noise producing mechanism of the toy (Clause 4.2). The meter is set to time weighting ‘F’ (fast) if the toy is designed to produce a continuous noise, and time weighting ‘S’ if the toy is designed to produce an impulsive noise (Clause 4.3). The toy is oriented to produce the maximum level at the microphone, and is activated so as to emit the loudest sound level. The highest sound level reading is taken (clauses 4.4, 4.5). It is recommended that 10 measurements are made on each of 10 samples of toy and the average sound level is obtained by arithmetic averaging if the range of levels is less than 10 dB, or by logarithmic averaging if the spread of readings is wider (Clause 4.8).

The relevant clauses of the English language version of CNS 4797-3 giving the noise limits are as follows:

> “5.3 Noise-Producing Toys
>
> 5.3.1 General
> Except for toy whistles, toy wind musical instruments, into which a child must blow air to obtain sounds, and toy or toy components percussion instruments (e.g. a toy drum), any toy that is designed to produce continuous or impulsive noise shall comply with the relevant requirements of Paras. 5.3.2 - 5.3.4.
>
> 5.3.2 Toys That Produce Continuous Noise
> Where a toy is designed to produce a continuous noise, when tested in accordance with CNS 4798-32, Method of Test for Toy Safety (Measurement of Noise Level)

> average noise level shall be 100 dB or less, (an instantaneous sound pressure level shall be less than 135 dB)
>
> 5.3.3 Toys that Produce Impulsive Noise ([2])
> Where a toy is designed to produce an impulsive noise, when tested in accordance with CNS 4798-32, that the average noise shall be less than 135 dB.
> Note: ([2]) Impulsive noise means produced at regular and at long variations. (e.g. a cap pistol, that produces an impulsive sound 100 times within a period of 5 min.)
>
> 5.3.4 Handhold rattles or other handhold toys that are designed to produce sound when shaken:
> A handhold rattle or other handhold toy that is designed to produce a continuous or impulsive noise when shaken shell comply with the requirements of Paras. 5.3.2 and 5.3.3 as appropriate.....”

The average noise level limit for toys producing continuous noise is 100 dB, presumably unweighted. This level is higher than our recommended level of 85 dB(A) by of the order of 15 dB. The instantaneous limit of 135 dB is similar to the ASTM Standard and again is satisfactory for average use but, we submit, too lax for occasional misuse.

For toys producing impulsive noise it would appear that the average noise level measured with time-weighting ‘S’ (slow response) is required to be less than 135 dB. No instantaneous limit is given for toys producing impulsive noise, only for toys producing continuous noise. This is wholly inadequate, and in practice will give no protection whatever against impulsive noise.

6.4 Draft European Standard prEN71-1.

The most recent draft of the European Standard to which we have access is identified as N 300, prEN71-1:1996, Safety of toys - Part 1: Mechanical and physical properties [CEN, 1996]. This draft contains some ambiguities and we have already submitted extensive comments in a separate report [Lower and Lawton, 1997] at the request of the DTI. Our understanding of the prEN71-1 noise limits is given in Table 3(a). It must be stressed that these are our interpretations and may not be as intended by the working group. Note also that in prEN71-1 Sound Exposure Level is referred to as the ‘A-weighted single event emission sound pressure level, L_{pA1s}’, and the time-averaged or equivalent continuous sound level, L_{eq} , is referred to as the ‘A-weighted emission sound pressure level, L_{pA}’.

The noise limits we have quoted in Table 3(a) are those which are proposed to come into effect 3 years after the publication of EN71-1, and higher noise limits are proposed in the standard for the initial 3 year period. In principle, it is not acceptable to have higher limits in force for three years before the reduced limits are enforced. Either the limits for the first three years are safe and there will be no need to change them later, or else the limits for the first three years are not safe and should not be condoned. In the case of toys firing percussive caps we understand that the 3 year transition period has been permitted because manufacturers need to overcome problems of flash and flying debris before introducing quieter caps.

The differences between our recommended noise limits and those given in the draft of prEN71 1 are summarised in Table 3(b). A more detailed comparison is given in the following paragraphs.

In the draft prEN71-1 noise limits are given for ‘close-to-the-ear’ toys as time-averaged levels, L_{eq}, and as peak levels at 2.5 cm from the microphone. The limits (after 3 years) are 80 dB(A) L_{eq} and 125 dB(C) peak. The 80 dB(A) L_{eq} value is 5 dB lower than our proposed limit of 85 dB(A) L_{eq} at 2.5 cm, while the 125 dB(C) peak at 2.5 cm is the same as our own recommendation.

The draft of prEN71-1 recommends instantaneous peak levels of 125 dB(C) at 50 cm for all toys except rattles, squeeze toys and close to the ear toys. This limit equates to 131 dB(C) at 25 cm. This limit is 11 dB above our recommendation and does not allow for reasonably foreseeable use of toys as close as 2.5 cm to the ear; it allows only for toys which are at least 70 mm from the ear.

For cap guns only, prEN71-1 proposes a higher peak limit of 140 dB(C) at 50 cm (equivalent to 146 dB at 25 cm) during the three-year transitionary period. This higher limit is **unacceptable** and will result in peak levels exceeding even the current industrial limit (or peak action level) of 140 dB if cap guns are used at normal distances of approximately 25 cm from the ear.

For rattles and squeeze toys the instantaneous peak level is 110 dB(C) at 50 cm. This equates to 116 dB(C) at 25 cm which is 4 dB lower than our recommended limit but not excessively restrictive. We do not know why the peak limit for these toys should differ from those of other toys, unless there is evidence that these toys are used closer to the ears than other toys. This is not explained in the draft.

No time-averaged level, L_{eq}, is given for rattles and squeeze toys. Instead prEN71-1 specifies a limit as a Sound Exposure Level (called the single-event emission sound pressure level in the draft) of 85 dB. Taking the standard literally the SEL limit applies to either 10 shakes of a rattle or 10 squeezes of a squeeze toy. In which case the SEL limit for the average single shake or squeeze would be 75 dB. However the draft standard is ambiguous and could be taken to imply that the SEL limit 85 dB(A) applies for a single shake or squeeze. The ambiguity arises in the following two sentences (the comments in square brackets are our own)

> “For rattles and squeeze toys the result is the average of the SEL-levels [measured for 10 squeezes or shakes] and the highest of the peak levels. Subtract 10 dB from the L_{pA1s} [our note: the SEL] to get the value for one.”

The second sentence requires us to subtract 10 dB but ‘the result’ has already been defined in the first sentence as the value before the 10 dB is subtracted. This ambiguity will we hope be eliminated in future drafts. Expressing the limit as an SEL is unusual though acceptable and may have advantages of being more repeatable in practice: a time-averaged level for continuous shaking or squeezing would be equally acceptable provided the measurement is repeatable.

If the SEL limit of 85 dB(A) at 50 cm in prEN71-1 refers to a series of ten shakes or squeezes, then it equates to a limit of 91 dB(A) SEL at 25 cm. This is 4 dB more stringent than our recommendations of 95 dB(A) SEL at 25 cm for ten squeezes of a squeeze toy but similar to our limit of 92 dB(A) SEL at 25 cm for ten shakes of a rattle. (If the prEN71-1 limit of 85 dB(A) SEL at 50 cm is for a single shake or squeeze, then the draft standard is less stringent than our recommendations by 6 dB for squeeze toys and by 10 dB for rattles.)

The draft prEN71-1 also limits the high frequency sound levels from squeeze toys. The sum of the band sound pressure levels in the 4 kHz and 8 kHz octave bands (symbol L_{HF}) is limited to 65 dB. We do not consider this limit to be justified in any way. The reason for this limit and our arguments against it are given in the Appendix to this report.

The draft prEN71-1 implies that the time-averaged sound levels, L_{eq}, should be measured for hand-held, table top and floor toys, but the draft fails to give any limits for comparison. We understand that earlier versions of the draft specified a limit of 97 dB(A) L_{eq} at 50 cm. We do not know why this limit has been dropped from the more recent version, nor do we know whether there was any intention to reduce this level after 3 years. A level of 97 dB(A) L_{eq} at 50 cm is equivalent to 103 dB(A) at 25 cm. This is a very high limit, 18 dB above our own recommendation and in our view unacceptable. If this level were to be reduced by 12 dB, which is the reduction proposed for close to the ear toys after 3 years, it would reduce to 85 dB at 50 cm, equivalent to 91 dB at 25 cm. This would be closer to, but still higher than, our recommendation of 85 dB(A) at 25 cm or 79 dB(A) at 50 cm. Perhaps the limit has been omitted from the current draft to allow further consideration.

The current draft of prEN71-1 is also ambiguous in specifying a noise limit for the ‘pass by’ or ‘passing by’ test for pull and push toys and for spring propelled toys. The current draft appears to require a measurement of the maximum C-weighted level rather than the maximum A-weighted level as in previous drafts. There is no rational reason for this other than a drafting error. The noise limit is set as an instantaneous or peak C-weighted level, which is a different quantity.

6.5 Other standards

We are aware from discussions with a manufacturer that there is an Australian Standard, but we do not have details of the noise limits at the time of writing. We have seen in confidence a manufacturer's list of toy noise levels that implies the Australian Standard is more strict than the American Standard, as some toys were classified as not for sale in Australia.

Leroux and Laroche [1991a] state that there are 'applied recommendations' on noise limits for toys in Norway and Sweden. They quote that toys producing continuous or quasi-continuous noise are limited to 90 dB(A) at 50 cm, measured with a sound level meter with time-weighting 'F'. For toys emitting impulse noise the limit is 135 dB peak at 50 cm, or 95 dB(A) measured with time-weighting 'F' if a peak reading is not available. These limits are higher than those we have recommended.

Although other countries have legislation or regulations concerning toy safety, we are not aware of any which contain noise limits.

6.6 Noise limits proposed by Canadian researchers

Leroux and Laroche [1991a, 1991b, 1992] have criticised the Canadian Hazardous Products Act for not sufficiently protecting the hearing of children. Their recommendation [Laroux and Laroche 1991a] is that...

> "Noisy toys should not emit any continuous or quasi-continuous noise or any combination whatsoever of these noises whose levels exceed 75 dB(A) for one or other of these distances: at the ear, at 10 cm, at 30 cm and at 1 m. One of these distances, the most representative, is chosen according to the use usually made of the

> toy. In order to take the special features of a child’s auditory system into account, this level, which corresponds to the limit proposed by the WHO (1980), should not be exceeded at any time regardless of the producer’s estimated normal time of use.
>
> Noisy toys producing impacts or impulses should not emit any noise of this kind at levels exceeding 95 dB(A) [sic] peak for one or other of these distances: at the ear, at 10 cm, at 30 cm and at 1 m. One of these distances, the most representative, is chosen according to the use usually made of the toy. This level was established according to the criterium [sic] judged to be safe for adults (Laroche et al, 1990a and Laroche et al 1990b.)”.

We consider these proposed limits far too restrictive and not justified on the evidence available.

Elsewhere in their report, Leroux and Laroche [1991a] state that “in the adult population, it is a well known fact that an eight-hour exposure leading to a dose exceeding 75 decibels A (dB(A)) will produce a significant hearing impairment hazard (WHO, 1980)”. In fact the World Health Organisation document cited [WHO, 1980] states, on page 18, that “for the working environment, there is no identifiable risk of hearing damage in noise levels of less than 75 dB(A) L_{eq} (8 h). For higher levels there is an increasing predictable risk and this must be taken into account when setting occupational noise standards”. On page 82 the WHO document states that “Recent research and analysis of most of the available data has provided a statistical basis for predicting the degree of hearing loss likely to be experienced by people exposed to steady noise during an 8-h working day, for periods up to 40 years. The risk is negligible for $L_{eq}(8\ h) \leq 75$ dB(A). Above this limit, the risk of noise-induced permanent threshold shift increases with increase in noise level. If the significant noise exposures are concentrated over shorter periods during the day, this basic criterion implies that the risk would also be negligible with a 4-h exposure to 78 dB(A), a 2-h exposure to 81 dB(A), or a 1-h exposure to 84 dB(A)”. Thus we consider that Leroux and Laroche have misinterpreted the text of the WHO booklet and have overstated the risk. Elsewhere however they appear to accept the various higher noise levels are equally safe for the shorter durations. In other publications Leroux and Laroche moderate their claims to asserting that 75 dB(A) is a “world wide accepted safe limit”. This is quite different from claiming that levels above 75 dB(A) are not safe.

Another reason why Leroux and Laroche specify a very low limit irrespective of exposure duration is their assertion that “It is illusory to rely on time of use to effectively regulate the limit to be imposed on noise levels produced by toys. This parameter presents variations too large to be adequately controlled.” We would agree that there are likely to be large variations, but would disagree that these cannot be taken into account. There are limits to a child’s playing time and a worst case can be estimated. If we assume that a child is exposed to noisy toys for a maximum of 2 hours a day on average, but in reality the time is 6 hours on average, ie three times as long, then our proposed noise limits will be 5 dB too high. We do not consider that we could be this far adrift, but even if we were, a noise limit set 5 dB too high because of an underestimate in exposure time will be more protective and better founded than limits currently in force. Further research on playing times would then permit confirmation or refinement of the limits proposed here.

7 Noise levels produced by currently available toys

Noise levels were measured for a large number of current toys representing a broad cross section of the market. Some of these toys were supplied by manufacturers, mostly members of the BTHA, as samples specifically for this study. Other toys were purchased locally from two large specialist toy shops and from a very low cost down-market general store. Some items are included which are not classified as toys in prEN71-1 or European Directive 88/378/EEC.

7.1 Methods and equipment

Because we needed to start making measurements before finalising our own recommendations, the draft European Standard methods were used as the basis for most measurements. The draft European Standard methods were also used so that the measured levels could be given to co-operating manufacturers. We have, in addition, converted measured levels from the table-top, floor and hand-held toys from the European specified 50 cm to our preferred 25 cm distance by adding 6 dB. The European draft standard does not cover mouth-actuated toys so we have used our own simple methods for toy musical wind instruments and similar toys.

The noise measurements were made using a Brüel and Kjær (B&K) Type 2236 precision integrating sound level meter, unless otherwise stated. This meter can simultaneously measure the A-weighted time averaged noise level L_{eq}, the highest instantaneous C-weighted (or unweighted) peak level, and the Sound Exposure Level as well as other noise descriptors.

Measurements on headphones were made using two systems. The first was a B&K Type 4153 artificial ear conforming to the IEC 318 standard used with a B&K Type 4134 microphone, a B&K Type 2639 preamplifier, and a B&K Type 2133 dual channel frequency analyser. The second system was a Knowles Electronics Kemar manikin fitted with Knowles Electronics Zwislocki 4-branch ear simulators, B&K Type 4134 microphones, B&K Type 2639 microphone preamplifiers, and a B&K Type 2133 dual channel frequency analyser.

All measurement systems were checked before and after use with a B&K Type 4231 sound level calibrator.

Calibration of equipment is traceable to UKAS/NAMAS laboratories through microphones, pistonphones, a digital voltmeter and a frequency meter which are maintained at ISVR Consultancy Services as laboratory standards. Calibration certificates are available for inspection.

7.2 Hand-held, table-top and floor toys, cot or crib toys.

The majority of toys tested were included in this group.

Time average and peak sound levels of hand held, stationary and self-propelled table-top and floor toys were measured at 50 cm in various directions as specified in the draft prEN71 procedures. Measurements on rattles, squeeze toys and cap guns are treated separately as described below (Section 7.3). Musical electronic keyboard instruments were tested with other musical instruments and are included in Section 7.9, although they could also have been included here. Most measurements were carried out in an anechoic room, some measurements were also carried out in a large normally furnished room. Table-top and floor toys were placed on a one metre square table. This table was constructed following the design in ISO 7779:1988 for measurements of noise from business machines or computers [International Organization for Standardization, 1988].

Measured levels at 50 cm are given in Table 4 together with levels calculated at 25 cm by adding 6 dB to the measured levels. The general type of toy is indicated: the manufacturers' names and toy names are not given here to maintain commercial confidentiality.

Figures 1 and 2 show cumulative distributions of the time-averaged and peak levels respectively.

It is evident from Figure 1 that 85% of the toys tested in this group satisfy our recommendation that the time average level should not exceed 85 dB(A) at 25 cm. There is no criterion given in the most recent draft which we have seen of prEN71-1.

Figure 2 shows that all the toys tested in this group had instantaneous peak levels below 120 dB(C) at 25 cm and therefore satisfy our recommendation. All the toys also meet the peak-level requirement of the draft prEN71-1, which is 125 dB(C) at 50 cm.

7.3 Rattles and squeeze toys

Rattles and squeeze toys were measured at 50 cm as specified in the draft of prEN71-1. The results are given in Table 5 for rattles and Table 6 for squeeze toys, together with levels calculated for a distance of 25 cm.

The Sound Exposure Level for a series of 10 shakes of each rattle are shown in Figure 3, and the peak levels in Figure 4. All measured SELs were below our recommended limit of 92 dB(A) for a series of 10 shakes at 25 cm. All peak levels were below our recommended limit of 120 dB at 25 cm.

The Sound Exposure Level for a series of 10 squeezes of each squeeze toy are shown in Figure 5, and the peak levels in Figure 6. All peak levels were below our recommended limit of 120 dB at 25 cm. Eleven of the thirteen squeeze toys, had measured SELs below our recommended limit of 95 dB(A) for a series of 10 squeezed at 25 cm.

7.4 Pull-push toys

Four pull along toys were tested. Each toy was pulled along by on our standard test table. The maximum A-weighted sound level with time weighting ‘F’ (L_{AFmax})was measured at the microphone positions recommended in prEN71-1, essentially 50 cm from the toy at its closest approach. Peak levels were low and not recorded. The levels at 25 cm were calculated from the levels at 50 cm by adding 6 dB, and are shown in Table 7. The time-average noise level over longer periods will not exceed the highest noise level at the toys closest approach and therefore noise from all four toys was below our limit of 85 dB(A) L_{eq} at 25 cm.

7.5 Toy cap guns and other toys producing impulsive noise

Some of the items tested here may not be classified as toys for the purposes of prEN71-1 or the UK Toy (Safety) Regulations. It proved difficult to obtain cap guns locally. One gun was not tested because we were unable to obtain the necessary strip caps even from specialist toy shops. The two cap guns tested were purchased locally from a specialist toy shop which had them in a store room but not on open display.

Levels were measured at 50 cm in accordance with prEN71-1 for all toys except the cap guns and ‘bomb bags’. The cap guns were measured at 1 metre to prevent overloading of the measurement equipment and the level at 50 cm was calculated by adding 6 dB to the measured levels. The ‘bomb bags’ were measured at 1 metre using a B&K Type 4136 ‘quarter-inch’ microphone with a preamplifier and measuring amplifier. Bomb bags are flat, plastic-foil envelopes containing sodium bicarbonate and a small sealed bag of citric acid. When the bag of citric acid is broken by squeezing, the acid reacts with the bicarbonate to produce carbon dioxide gas. The foil pack inflates and bursts with a loud bang.

The measured levels and levels calculated at other distances are given in Table 8. Apart from the ricochet gun, which did not fire caps and could also have been classified as a regular hand-held toy, all the toys exceeded our recommended limit of 120 dB(C) at 25 cm. A toy drum which exceeded our limit would have been below the limit of 125 dB(C) at 50 cm proposed in prEN71-1. However, as a child-actuated toy, a drum is excluded from the scope of prEN71-1.

7.6 Close to the ear toys other than headphones

It is often difficult to decide which toys should be classified as close-to-the-ear. We have included toy mobile telephones where the sound comes from the handset but not toy table telephones with a silent handset nor telephone-shaped squeeze toys. We have also included musical teethers. A toy-walkie talkie radio was tested as a close to the ear toy but was also tested using the procedure for headphones

Time average and peak sound levels produced by the close-to-the-ear toys were measured at 2.5 cm from the toy surface, at the position of maximum sound output, as specified in the draft prEN71 procedures. This position is not always the obvious one. For example, two similar toy telephones had a pattern of holes, apparently for sound emission, on their back surface, but their sound output was at its maximum close to the front surface, at the push keys.

The measured levels are given in Table 9 and shown in Figures 7 and 8. Roughly 40%, just 5 out of 13 of the close-to-the-ear toys met our requirement of 85 dB(A) at 2.5 cm. Only 3 out of 13 toys emitted noise below the limit of 80 dB(A) at 2.5 cm given in the draft of prEN71. Eleven out of thirteen, 85%, of the close to the ear toys produced peak levels below our recommended limit of 125 dB(C). The two toys which exceeded the peak noise limit were both toy loud-hailers with sound effects. We were not certain whether this category was appropriate. Had these been classed as hand-held toys they would still have exceeded the relevant limit.

7.7 Headphones and earphones

A-weighted noise levels at maximum volume settings are given in Table 10. All the samples exceeded our recommended limit of either 93 dB(A) on an artificial ear or 85 dB(A) undisturbed field equivalent derived from the manikin measurements. Peak levels were not measured but were expected to be below our limit of 135 dB(C) on the artificial ear or at the manikin’s eardrum.

7.8 Musical wind instruments and toys operated by blowing

This category of mouth actuated toys is outside the scope of prEN71-1. With this type of toy, the distance between the ear and the toy is determined by the toy’s dimensions and by the distance from the child’s mouth to the ears. We therefore measured levels alongside the ear of the person blowing. We also measured noise levels at 50 cm, as a bystander's position. We have taken the greater of these two levels. The levels measured were the highest L_{eq} and highest peak level which could be obtained over the relatively short measurement time of 15 to 20 seconds. This is not necessarily representative of normal use and a more controlled and more representative procedure will need to be developed if noise levels are to be measured from this type of toy. In particular it was noted that the sound levels obtained could not be maintained over extended periods without the (possibly unfit) adult experimenter becoming dizzy. An adult's capabilities will differ from a child's, and there may be large variations from child to child.

The measured levels are given in Table 11 and the cumulative distribution are shown as Figures 9 and 10. As the test method is not wholly satisfactory we have not attempted to compare these levels with any particular noise limits. Given a satisfactory test procedure it would be reasonable to measure alongside the ear and at 50 cm and at both positions the measured levels should be below a limit of 85 dB(A) L_{eq} and 120 dB(C) peak.

7.9 Musical instruments other than those operated by blowing.

Some of the toys included in this section, eg electronic keyboards, could also be classified as hand held or table top toys and this grouping is essentially a subset of the hand-held, and table top category. We have adopted the same noise limits and therefore the classification is not critical.

Noise levels are shown in Table 12, and their cumulative distributions presented in Figures 11 and 12. Thirty percent of the instruments tested had time averaged sound levels below our recommendation of 85 dB(A) at 25 cm, although another 40% were less than 5 dB above the limit, and all toys were within 8 dB of the limit. Peak noise levels did not exceed our recommendation of 120 dB(C) at 25 cm, except for one toy only, a tambourine.

8 Noise levels of everyday sources other than toys.

8.1 Noise exposures from toys and their contribution to the total noise exposure for the child.

So far in this report we have not mentioned noise from sources other than toys, except as an aside in Section 4.5, but we have nevertheless taken other noise sources into consideration. There are many sources of noise in a child's every day life at home, at school, in the garden, travelling, shopping or playing. The risk to a child's hearing depends on the total noise exposure from all sources of noise, not just the noise from toys. We could recommend an upper limit for a child's daily noise exposure, and this would have to be 80 dB(A) $L_{EX,8h}$ ie the same limit we have used for toys alone, arrived at from the same data.

But this is too simplistic and overlooks an important point: we do not have any control over the noise from the many and various sources which are not toys. We cannot, in a toy safety standard, protect a child's hearing against noise from all these other sources. We can, however ensure that toys do not present a risk in themselves and do not significantly add to any risk which may already be present from other everyday sources.

We need to consider three possible situations, (i) where the noise exposure from all other sources is much less than that from toys, (ii) where the noise exposure from all other sources is about the same as that from toys, and (iii) where the noise from all other sources is much greater than noise from toys. These three situations cover all possibilities.

If a child's noise exposure from all other sources combined is less than the child's noise exposure from toys, then the noise from toys dominates the total noise exposure. If the combined exposure from all other sources is 70 dB(A) $L_{EX,8h}$ and the noise exposure from toys is 80 dB(A) $L_{EX,8h}$ then the total exposure is, by decibel addition, 80.4 dB(A) $L_{EX,8h,}$ This is virtually the same as the contribution of the toys alone, effectively there is no additional risk from the other sources, and no significant risk to hearing.

At the other extreme, if a child's noise exposure from all other sources combined is more than the child's noise exposure from toys, then the noise from other sources dominates the total noise exposure. If the combined exposure from all other sources is 90 dB(A) $L_{EX,8h}$ and the noise exposure from toys is 80 dB(A) $L_{EX,8h}$ then the total exposure is 90.4 dB(A) $L_{EX,8h}$. The contribution of the noise from toys to the total exposure is minimal. The total noise exposure is potentially damaging if repeated frequently over a long period, but the contribution from the toys does not significantly increase the risk. Taking the toy noise away completely would not significantly reduce the risk. To remove the risk, the dominant noise sources, those other than toys, must be reduced in level.

The middle situation, where a child's noise exposure from all other sources combined is equal to the child's noise exposure from toys, is the most interesting. If the combined exposure from all other sources is 80 dB(A) $L_{EX,8h}$ and the noise exposure from toys is also 80 dB(A) $L_{EX,8h}$ then the total exposure is 83 dB(A) $L_{EX,8h}$. The contribution of the toys and the contribution of all other sources are equal, and when this is so, the total exposure is 3 dB higher than the noise of toys alone, or 3 dB higher than the combination of all other sources. There may be some effect on hearing for repeated regular exposures at 83 dB(A) $L_{EX,8h}$ over many years, but any effect on hearing will be small.

From the three situations above we can see that, if we set the maximum possible noise exposure from toys to 80 dB(A) $L_{EX,8h}$ then the total noise exposure can exceed 83 dB(A) $L_{EX,8h}$ but only if and when the noise from all other sources is dominant. The toys can still contribute to exposures above 83 dB(A) $L_{EX,8h}$ but only as a minor contributor.

The 80 dB(A) $L_{EX,8h}$ noise exposure from toys in the above examples was not arbitrary. It is the noise exposure which would occur if a child played with a toy or series of toys for 152 minutes per day if each of the toys produced an average noise level of 85 dB(A) L_{eq} at the child's position. From the indications in the literature, we expected a maximum of about 90 minutes exposure to noise from noise-producing toys per day. This would have allowed a noise level of 87 dB(A) L_{eq} at the child, but in rounding the noise limit down to 85 dB(A) L_{eq} we are building in a 2 dB safety margin. If our assumption of a 90 minutes maximum exposure to noise from toys is correct, we would effectively have an upper limit of

78 dB(A) $L_{EX,8h}$ to our noise exposure from toys. In practice too, not every noise-producing toy will produce noise right up at the limit, many will be below the limit to varying degrees. Thus in practice, given the limits we have recommended for toys, and as far as we or anyone can be certain, the noise exposure from toys will usually be below 78 dB(A) $L_{EX,8h}$.

In summary, if our recommendations on noise limits are adopted, we do not expect toys to present a significant risk to hearing in their own right, nor do we expect toys to contribute significantly to any risk which may already be present from everyday noise sources.

8.2 Noise levels from various everyday sources

Noise levels were measured in several common environments from several common sources both in the home and away from the home. Measurements or recordings were made using either a hand-held B&K 2236 sound level meter, a B&K 2236 meter semi-concealed in such a way as to not compromise the noise measurements, or a high quality miniature microphone and DAT tape recorder worn on or carried unobtrusively about the person so as not to attract attention.

The noise levels measured are presented in Table 13. Most of these noise levels were obtained by the authors especially for this project, but two entries are recent measurements made by colleagues for other purposes.

In addition to the time-averaged noise levels and peak levels already used in this report, Table 13 shows some other noise descriptors, such as the L_1, L_{10} and L_{90} which are the noise levels exceeded for 1%, 10% and 90% of the measurement period. The L_1 and L_{10} show the highest levels reached during the period, the L_{90} indicates the lowest levels. The bigger the difference between the L_{10} and the L_{90}, the more variable the noise level. This variability is not evident from the average level alone.

Noise in the home from domestic appliances and normal domestic activities are generally too low in level or else too short in duration to cause concern.

The noise levels measured in a school room are also sufficiently low not to cause concern. This class in which measurements were made was a reception class in an infant and nursery school and was generally acknowledged to be the noisiest class in the school. There were about 50 children, aged 4 to 5 years, with two teachers team teaching and one assistant. Noise levels during play time (when children were outside) were not recorded. A significant noise source in a child's everyday activities when playing outdoors is likely to be the shouts and sounds of other children at play.

Shops and supermarkets are generally satisfactorily quiet. Noise levels in a record shop reached 84 dB(A) at some positions very close to loudspeakers, but the average throughout the shop was about 75 dB(A).

Cars, buses and trains are generally satisfactory for passengers. Car radios generally add 5 dB - 6 dB to the time-average noise level for most car passengers, though some drivers clearly choose far higher volumes. Noise levels in London Underground trains can exceed 90 dB(A) and averaged over a journey between stations can reach 89 dB(A).

Noise levels at a football (soccer) match averaged a high 90 dB(A) L_{eq} over the game. Noise levels in an electronic and video games arcade were also high at some machines, with short term levels close to three machines of 85 dB(A), 87 dB(A) and 88 dB(A) L_{eq} over short periods. Most of the machines produced levels nearby between 74 dB(A) and 84 dB(A). Peak levels up to 122 dB(C) were measured near some machines.

Peak levels in everyday life can be quite high. A 120 dB(C) peak was recorded in a supermarket and caused by impacts between wine bottles while shelves were being restocked rapidly. Peak levels of 115 dB(C) to 125 dB(C) frequently occur when car doors are slammed even if the slam is not particularly hard. With a deliberately loud hand clap at 50 cm we obtained a peak of 124 dB(C) though peaks of 117 dB(C) - 120 dB(C) are more typical for hand clapping. Peak levels from 'party poppers' and bursting balloons were included with our toy measurements: party poppers produce peaks of about 127 dB(C) at 50 cm, balloons bursting are between 130 dB(C) and 140 dB(C) at 50 cm.

8.3 Noise levels and noise exposures from published documents.

As well as making our own measurements we have collected some data from the scientific literature.

A comprehensive list of levels of various noise sources in the lives of children and teenagers is given by Axelsson et al [1993] in their Table 1. They include the sound levels at movies and discos of 87.5 and 92.5 dB(A) respectively.

Jackson and Leventhall [1985] give many examples of typical noise levels from sources in and around the home. The range of levels of kitchen appliances range from 44 dB(A) to 89 dB(A). Stating the range may be misleading as most appliances are towards the middle and bottom of the range. The two highest levels are for a food liquidiser (89 dB(A)), and whistling kettle (81 dB(A)) which are used for short times only. None of the appliances listed is cause for concern. Noise levels from living room, bedroom and bathroom appliances are equally harmless with everyday exposures. Electric drills are quoted at 91 dB(A), presumably for the operator rather than a bystander. As appliances are made quieter, lists such as these will slowly become out of date.

Truchon-Gagnon and Hétu [1988] measured the noise levels in Canadian day-care centres for children and found levels between 72 dB(A) and 80 dB(A) $L_{eq,8\,h}$ with an average of 76.5 dB(A) L_{eq}.

Perego et al [1996] measured noise levels in Italian kindegartens attended by children aged three to five years. The average noise levels over the school day at 10 such schools ranged from 77 dB(A) to 84 dB(A) L_{eq} with an average of 80 dB(A) L_{eq}.

Clark [1991] published noise levels from leisure activities in the USA, some of which are applicable to children as well as adults.

Electronic arcade games have also received some attention from Plakke [1983] and from Mirbod et al [1992]. Plakke found noise levels averaged over 30 seconds ranging from

73 dB(A) to 92 dB(A) in one arcade and levels between 83 dB(A) and 92 dB(A) for most machines in a second arcade, with one particular machine reaching 111 dB(A). Mirbod et al found noise levels averaged over one hour periods of 86.5 dB(A) to 89.8 dB(A) $L_{eq,1h}$ (sufficient they estimate to cause 4 dB - 8 dB TTS at 4 kHz). Noise levels over eight hour periods were between 80.3 dB(A) and 87.5 dB(A). The authors were more concerned with the employees' than with the players' noise exposures and hearing.

Axelsson [1996] reports noise levels recorded at several pop and rock concerts. Average levels were from 97 dB(A) to 110 dB(A) L_{eq} with an average of 101 dB(A). In some cases concerts lasted several hours. Peak levels were between 124.5 dB and 139.5 dB.

The MRC Institute of Hearing Research [MRC 1985] reviewed the literature on damage to hearing arising from leisure noise. This was mainly concerned with adult activities but has much of relevance to children especially older ones. Several common noise sources are listed. The MRC authors were disappointed in the general quality of the work published in the literature, but were able to conclude that the major source of auditory hazard was amplified music. Discotheques and personal cassette players were identified as real risks for the individual.

8.4 Whole-day exposures for children

Von Gierke [1975] cites data from the US Environmental Protection Agency which estimated typical 24-hour average noise levels ($L_{eq,24\,h}$) as follows:

	Suburban	Urban
Preschool child	60	69
School child	77	77
Housewife	64	67
Office worker	72	70
Factory worker	87	87

These estimates were based on assumptions of typical life-style patterns and noise levels. Converting these average levels to noise exposures gives values of 65 dB(A) $L_{EX,8h}$ for suburban preschool children, 74 dB(A) $L_{EX,8h}$ for urban preschool children and 82 dB(A) $L_{EX,8h}$ for urban and suburban school children. Whether these noise exposures are still typical, 25 years later, is not known. It is not certain how levels in other countries would compare.

Siervogel et al [1982] attempted to measure whole-day noise exposures of children directly using noise dosemeters (body-worn meters) with microphones attached to children's collars. They found average levels of 76.7 dB(A) to 83.8 dB(A) $L_{eq,\,24\,h}$ with some children receiving above 90 dB(A) $L_{eq,24\,h}$. These levels give typical exposures of 81 dB(A) to 89 dB(A) $L_{EX,8h}$ with some exposures above 95 dB(A) $L_{EX,8h}$. We consider that these measured noise levels may be misleading and do not show the true exposures of the children concerned to the noise in their environment. Siervogel et al. used dosimeters (body worn meters) with microphones at the children's collars. This microphone position is only about 10 cm from the mouth. Normal adult speech at this distance can easily reach 80 dB(A) - 82 dB(A). A child's playful shouts and screams will produce even higher levels at the collar position. The authors claim that their measurements include sound from all sources, which is true. But their measured levels may be attributable to the child's own voice at least in part, and give a misleading impression of the surrounding noise environment.

Axelsson et al. [1993] calculated noise exposures for school children from diaries of their activities over a 12-week period and the typical noise levels of those activities. They calculated a value of 51 dB(A) which we take to be a 24-hour average. This translates into a noise exposure of around 56 dB(A) $L_{EX,8h}$. The more noisy activities of the children were also the more infrequent ones. They concluded that school children have relatively little noise exposure during their normal daily activities.

8.5 Summary of information on children's every day noise exposures.

Overall the literature cited in this section shows considerable variations and uncertainties in quantifying noise exposures of children. Exposures ranging form below 60 dB(A) to above 90 dB(A) $L_{EX,8h}$ are claimed. From our own noise level measurements we would estimate exposures probably between 60 dB(A) and 80 dB(A) $L_{EX,8h}$ for most young children, most of the time, but we have not confirmed this by measurements, and we do not have sufficient information on children's lifestyles to calculate it. Nevertheless, the noise limits we have recommended for toys have been chosen to ensure that toys do not present a risk in themselves and do not significantly add to any risk which may already be present from other everyday noise sources.

9 Conclusions and recommendations

9.1 There is an extensive body of published literature which relates noise levels and noise exposures to hearing damage in adults. It can be concluded that, to prevent any significant measurable hearing loss in adult subjects,

- their regular daily noise exposures should not exceed 80 dB(A) $L_{EX,8h}$ which equivalent to a noise level of 80 dB(A) for 8 hours, and
- the peak levels to which they are exposed should not exceed 140 dB(C).

9.2 There is no compelling evidence that children are more sensitive than adults to the effects of noise on hearing, with the possible exception of new-born infants. Hearing risk damage criteria derived from adult studies can therefore be applied to children. Accordingly, we recommend that noise limits for toys should be set so that children do not suffer noise exposures or peak levels higher than those stated above.

9.3 Noise limits for toys must be defined in terms of their noise emission, in the form of a maximum permitted sound level at a specified position or distance. To enable noise emission limits for toys to be derived from noise exposure limits for toy users, it is necessary to account for various factors, of which the two principal ones are:

- Daily duration of play
- The position of the toy relative to a child’s ear, particularly the distance from the ear of any noise-producing component

9.4 Published information indicates that children are unlikely to play with manufactured toys for average periods in excess of 3 hours per day, and are unlikely to be exposed to noise from toys for more than 1 - 1.5 hours per day, although wide variations are obviously possible.

9.5 Published information shows that, except for toys designed specifically to be held close to the ear, ‘toy to ear’ distances of 25 - 30 cm are representative of typical, average play, but nearly all toys might occasionally be held within 2.5 cm of the ear either during normal play or during deliberate abuse.

9.6 Accordingly we have formulated noise limits for toys so that

- the time average noise level, L_{eq} at 25 cm will not cause an exposure above the exposure limit of 80 dB(A) $L_{EX,8h}$ even for extreme playing times of 2.5 hours and
- the peak noise levels during occasional use or misuse as close as 2.5 cm from the ear will not exceed 140 dB(C).

9.7 The noise emission from toys which are manually operated, such as squeeze toys and rattles, depends on the manual effort used and the frequency of repetition, which are to some extent indeterminate. For these toys, a noise limits based on the Sound Exposure Level (SEL) measured over a specified number of shakes or squeezes, are appropriate.

9.8 Methods of assessing the noise emission from toys which are intended to be held close to the ear (such as telephones), or toys with headphones which couple directly to the ear canal, have been investigated. It is found that the noise emission from at-the-ear toys is adequately represented by a measurement of sound level at 2.5 cm from the active component of the toy.

9.9 More sophisticated measurements are required to assess noise from headphones and earphones. Two methods are available: (i) using the artificial head or manikin, which has ear canals of the same geometry as a median human, with microphones at the eardrum positions, or (ii) an artificial ear, which is a device intended for audiometer calibration and which is not geometrically similar to a real ear. Both methods have been evaluated.

9.10 The use of a manikin provides better measurement repeatability and can be used for all types of supra-aural, circumaural or in-the-ear headphones or earphones. Artificial ears are not suitable for all types of earphone but are more widely used in test laboratories and are of much lower cost. Noise limits for headphones and earphones are therefore proposed for each method to allow either method to be used when appropriate.

9.11 The following noise emission limits for toys of various types are proposed

All toys including hand-held, table-top and floor toys, cot toys, excluding close-to-the-ear toys and headphones.

The time-averaged noise level produced by the toy in continuous use or over a cycle of use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. Noise levels are measured in the direction giving the highest levels. Table top and floor toys should be tested on a standard table. Any hand-held toy which may also be used as a table top or floor toy should be tested on a standard table. Any toy which would always be used hand-held or away from solid surfaces should be measured hand held.

Rattles

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. (ie as above for all toys)

Or The highest achievable sound exposure level of a rattle, measured over a series of 10 shakes, shall not exceed 92 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Squeeze toys

Either The highest achievable time-averaged noise level produced by the toy in continuous use should not exceed 85 dB(A) L_{eq} at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm. (ie as above for all toys)

Or The highest achievable sound exposure level of a rattle, measured over a series of 10 shakes, shall not exceed 95 dB(A) at 25 cm. The peak noise level should not exceed 120 dB(C) at 25 cm.

Toy cap guns

The peak noise level should not exceed 120 dB(C) at 25 cm.

Close to the ear toys

Noise levels measured at 2.5 cm from any part of the toy should not exceed 85 dB(A) L_{eq} , the peak level should not exceed 125 dB(C).

Headphones and earphones

Either (i) the time averaged noise level measured using an artificial ear conforming to IEC 318 shall not exceed 93 dB(A), and the instantaneous peak level shall not exceed 135 dB(C). This method can only be used for types of headphone that will fit the artificial ear.

Or (ii) the undisturbed field equivalent time averaged level measured using a manikin should not exceed 85 dB(A) L_{eq} and the peak level at the manikin eardrum shall not exceed 135 dB(C). This method can be used for any type of headphone, earphone, ear insert or stethoscope which will fit the manikin in the same manner as it will fit a real person.

9.12 The above recommended noise limits have been compared with those in the draft European Standard prEN71-1, allowing for differences in measurement distances where appropriate. Our recommended limits would permit time-averaged toy noise levels, L_{eq}, to be higher than the limits stated in prEN71-1; the differences are between 1 dB and 5 dB for different toy types. Our recommended limits for peak levels differ considerably from those on prEN71-1, being between 11 dB lower and 10 dB higher. We have submitted other comments on the draft prEN71-1 as a separate report.

9.13 We have reviewed national regulations and standards from Canada, the USA and Taiwan, and advisory limits proposed by researchers in Scandinavia and Canada. We find these other standards to be, to varying degrees, limited in their scope, and technically inadequate. We particularly disagree with the recommendations of Leroux and Laroche [1991, 1992], who recommend upper noise level limits for toys of 75 dB(A) regardless of duration, or 95 dB(A) peak. We consider that such limits are unnecessarily restrictive and not well justified.

9.14 The noise levels of 178 toys have been measured. Some were supplied as samples by manufacturers and distributors, others were purchased in toy shops. The toys were almost all of an inherently noisy design, in that noise-generation was obviously their primary function. A small number of toys tested were of a type where noise-generation could be described as incidental.

9.15 Some of the toys tested would be described as musical instruments or mouth-operated toys, and therefore excluded from the scope of the proposed European standard. However, such toys can generate significant noise levels, and they were included for this reason. Noise test procedures generally followed those proposed in prEN71-1, with adaptations as necessary. The measured noise levels have been compared with the limits recommended above with the following findings:

Hand-held table top and floor and cot toys

16 % (17 out of 105) exceeded the time average noise level of 85 dB(A) L_{eq} at 25 cm

None of the toys exceeded the peak limit of 120 dB(C) at 25 cm

Rattles

None of the 9 toys (0 out of 9) exceeded the SEL limit of 92 dB(A) for 10 shakes

None of the toys (0 out of 9) exceeded the peak limit of 120 dB(C) at 25 cm

Squeeze toys

21% (3 out of 14) exceeded the SEL limit of 92 dB(A) for 10 squeezes

None of the toys (0 out of 14) exceeded the peak limit of 120 dB(C) at 25 cm

Pull and push toys

None of the toys (0 out of 4) exceeded the time average noise level of 85 dB(A) L_{eq} at 25 cm

None of the toys (0 out of 4) exceeded the peak limit of 120 dB(C) at 25 cm

Toys producing impulsive noise

The cap guns, bursting balloons, party poppers and a toy drum exceeded the peak limit of 125 dB(C) at 25 cm

Close-to-the-ear toys

60% (7 out of 13) exceeded the limit of 85 dB(A) at 2.5 cm

15% (2 out of 13) exceeded the limit of 125 dB(C) at 2.5 cm

Headphones and earphones

100% (4 out of 4), when used at full volume, exceeded our limit of 93 dB(A) on an artificial ear or 85 dB(A) UFE level measured on a manikin.

Muical instruments other than those operated by mouth

69% (9 out of 13) had time average levels exceeding 85 dB(A) at 25 cm, although exceedances were generally less than 5 dB

7% (1 out of 13) exceeded the peak limit of 120 dB(C)

9.16 It is concluded that for many types of toy, most currently available toys comply with the recommended noise limits. There are notable exceptions for headphones *when used at full volume*, close to the ear toys, and impulsive toys such as cap guns.

9.17 Children are exposed to many sources of noise, in addition to toys, during everyday life. Any consideration of permissible noise exposures from toys, and of corresponding noise emission limits for toys, needs to take these other noise sources into account. Many commonplace noise sources produce noise levels higher than the recommended limits for toys, but potential exposures to higher levels are usually short or infrequent. For example, time-averaged noise levels on underground trains can approach 90 dB(A), and similar noise levels are experienced in crowds at football matches. Bursting a potato crisp packet can produce a peak sound level approaching 140 dB(C) at 50 cm.

9.18 Published literature shows considerable variations and uncertainties in quantifying noise exposures of children. Exposures ranging form below 60 dB(A) to above 90 dB(A) $L_{EX,8h}$ appear in the literature, though we question the validity of the study reporting the highest exposures. From our own noise level measurements we would expect exposures probably between 65 dB(A) and 75 dB(A) for most young children, most of the time, but we have not confirmed this by measurements, and we do not have sufficient information on children's lifestyles to calculate it.

9.19 No firm conclusions can be drawn from the available information about children's exposure to noise from sources other than toys, except that exposures will be variable and opinions are divided. The approach we have adopted is to set noise limits for toys which should ensure that the noise from toys does not present a foreseeable risk in itself and should not add significantly to any risk which may already be present from other everyday noise sources. We believe that there is an margin of safety inherent in the assumptions we have made in formulating the recommended limits and the recommended limits for toys appear to be cautious but realistic.

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Table 1

Comparison of headphone noise levels measured on an artificial ear with undisturbed field equivalent levels derived from measurements on a manikin

Description of toy with headphone	A-weighted levels, dB(A) L_{eq}			Differences in A-weighted levels, dB	
	on artificial ear	at Kemar's eardrum	Undisturbed field equivalent level, (UFE)	artificial ear-UFE	Kemar's eardrum - UFE
Headphones with a radio built into the earpieces (#69)	104.1	100.3	93.4	10.6	6.8
Radio with optional headphones (#120)	99.8	102.6	91.3	8.5	11.3
Cassette player with headphones (#67)	101.0	102.0	91.0	10.0	11.0
Toy walkie- talkie radio (#130)	122.1	120.6	108.3	13.8	12.3
mean difference				10.7	10.4
standard deviation of difference				2.7	0.7

Table 2

Comparison of sound levels at 2.5 cm from a toy with undisturbed field equivalent levels derived from measurements on a manikin

Description of toy	Sound levels, dB(A)		
	at 2.5 cm in free field	Undisturbed field equivalent	
		sounder held tightly, sealing to the ear	toy held normally to ear
Soft rubbery telephone (#22)	93.0		96
Hand Held Recorder (#27)	95.1	103	
Telephone (#25)	90.0	97	84
Musical Teething Ring (#70)	69.6	78	52
Musical telephone (#75)	81.1	81	
Musical teether (#82)	68.7	77	49
Telephone (#83)	84.3	99	81
Soft rubbery telephone (#148)	99.0		100

Table 3(a)

Apparent sound level requirements of draft prEN71-1.

Category of toy	Quantity to be measured and requirement to be met*				
	Time averaged A-weighted SPL, L_{Aeq}	Sound Exposure Level, SEL, L_{EA}	C-weighted peak SPL $L_{pC\ peak}$	Maximum A-weighted SPL with time weighting 'F' L_{AFmax}	Sum of the pressure levels in the 4 kHz and 8 kHz octave bands L_{HF}
Close-to-the-ear toys	**4.20 a*** 80 dB(A) L_{eq} @2.5 cm		**4.20 f** 125 dB(C) pk @2.5 cm		
Earphones	**4.20 a** 90 dB(A) L_{eq} on artificial ear		**4.20 f** 125 dB(C) pk on artificial ear		
Toy using percussion caps			**4.20 e** 125 dB(C) pk @50 cm		
Rattles		**4.20 b** 85 dB(A) SEL @50 cm	**4.20 d** 110 dB(C) pk @50 cm		
Squeeze toys		**4.20 c** 85 dB(A) SEL @50 cm	**4.20 d** 110 dB(C) pk @50 cm		**4.20 c** 65 dB(A) L_{HF} @50 cm
Other hand held (hand held toys except rattles, squeeze toys and cap guns)	✓		**4.20 f** 125 dB(C) pk @50 cm		
Stationary and self-propelled table-top and floor toys	✓		**4.20 f** 125 dB(C) pk @50 cm		
Pull and push toys, hand activated spring propelled toys			**4.20 f** 125 dB(C) pk @50 cm	✓ (pass by test)	

Notes

* Where a measurement is required and a noise limit is given in the standard, the clause specifying the requirement is stated, eg '4.20 a'

✓ Measurement required, but no maximum limit given?

‡ Requirement 4.2 f applies to 'any type of toy excluding toys using percussion caps', and therefore includes rattles and squeeze toys, but Requirement 4.2 d applies a lower limit to rattles and squeeze toys. Requirement 4.2 f should therefore be modified to exclude rattle and squeeze toys.

Table 3 (b)

Our recommendations compared with our interpretation of the sound level requirements in the draft prEN71-1.

Category of toy	Quantity to be measured and requirement to be met*				
	Time averaged A-weighted SPL, L_{Aeq}	Sound Exposure Level, SEL, L_{EA}	C-weighted peak SPL $L_{pC\ peak}$	Maximum A-weighted SPL with time weighting 'F' L_{AFmax}	Sum of the pressure levels in the 4 kHz and 8 kHz octave bands L_{HF}
Close-to-the-ear toys, measured in free-field at 2.5 cm	**5 dB higher**		**same**		
Earphones measured on artificial ear	**3 dB higher**		**10 dB higher**		
Toy using percussion caps			**11 dB lower**		
Rattles		**1 dB higher**	**4 dB higher**		
Squeeze toys		**4 dB higher**	**4 dB higher**		no limit specified by ISVR
Other hand held (hand held toys except rattles, squeeze toys and cap guns)	no limit specified in prEn71-1		**11 dB lower**		
Stationary and self-propelled table-top and floor toys	no limit specified in prEn71-1		**11 dB lower**		
Pull and push toys, hand activated spring propelled toys	no limit specified in prEn71-1		**11 dB lower**		

Notes

1. 'Higher' indicates that our recommended maximum limit is higher than the comparable limit in prEN71-1
2. Differences in measurement distances have been taken into account, eg 85 dB(A) at 25 cm would be considered to be the same as 79 dB(A) at 50 cm

Table 4

Noise levels from hand-held, cot, table-top and floor toys, except musical instruments

Ref	Description	Type	Sound levels measured at 50 cm		Sound levels calculated at 25 cm	
			Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)	Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)
1	Electronic space communicator	hh	73.9	89.6	79.9	95.6
2	Laser gun with sound	hh	68.9	78.3	74.9	84.3
3	Talking action figure	hh	66.9	80.7	72.9	86.7
4	Talking motorcycle	hh	66.2	84.5	72.2	90.5
5	Talking motorcycle	hh	56.5	78.3	62.5	84.3
6	Racing car with radio control	tt&f	78	91.7	84	97.7
9	Remote control walking car	tt&f	70.5	93.6	76.5	99.6
10	Musical house	tt&f	63.6	94.3	69.6	100.3
11	Music box with lights	tt&f	62.4	81.6	68.4	87.6
12	Roundabout with ringing bells	tt&f	59.7	94.6	65.7	100.6
13	Musical pop-up animal	tt&f	58.3	94.9	64.3	100.9
15	Boat game with sound	tt&f	77.1	103.1	83.1	109.1
17	Cosmetic box with sound	hh	65.0	78.5	71.0	84.5
18	Telephone	hh	58.2	77	64.2	83
19	Ball with electronic sound	tt&f	71.8	86.7	77.8	92.7
20	Meowing cat	hh	61.4	77.3	67.4	83.3
21	Windup musical TV	tt&f	63.0	77.2	69.0	83.2
23	Table telephone with sound	tt&f	72.4	93.3	78.4	99.3
24	Musical keyboard	tt&f	71.5	83.3	77.5	89.3
25	Train - mobile with sound	tt&f	68.6	83.5	74.6	89.5
26	Talking keyboard	tt&f	71.1	89.5	77.1	95.5
27	Recorder (handheld)	hh	73.5		79.5	
29	Talking doll	hh	64.2	80.7	70.2	86.7
30	Plastic figure plays tune	hh	62.7	84.7	68.7	90.7
31	Fire engine sound/movement	tt&f	75.9	89.6	81.9	95.6
32	Megaphone - electronic	hh	89.6	105.9	95.6	111.9
33	Megaphone - electronic	hh	86.4	101.1	92.4	107.1
34	Cot mobile musical	hh	59.7	76.6	65.7	82.6
35	Bus with sounds	tt		109		115
36	Music jukebox	tt&f	71.8	100.9	77.8	106.9
37	Megaphone - battery operated	hh	98.6	110	104.6	116
39	Doll with feeding bottle	hh	53.4	66.9	59.4	72.9
40	Spot racing set	tt&f	70.1	87.2	76.1	93.2
43	Talking soft toy	hh		91.1		97.1
44	Action figure with animal sounds	tt&f/ hh	64.7	83.9	70.7	89.9
45	Train roundabout with bell	tt	69.3	97.1	75.3	103.1
46	Activity frame with sound	hh	61.8	89.9	67.8	95.9

Table 4 Continued

Ref	Description	Type	Sound levels measured at 50 cm		Sound levels calculated at 25 cm	
			Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)	Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)
47	Soft motorised squeeze toy	tt&f	63.8	76.2	69.8	82.2
48	Music box - battery operated	tt	58.9	75.4	64.9	81.4
49	Board game with animal noises	tt	67.3	92.2	73.3	98.2
50	Rotating game with electronic animal noises	tt	74.2	91.3	80.2	97.3
52	Battery operated vacuum cleaner	tt&f	65.2	79.1	71.2	85.1
53	Space gun with electronic sound	hh	79.2	90.9	85.2	96.9
56	Fire engine battery operated	tt&f	82.0	91.6	88.0	97.6
58	Sword with sound	hh	70.9	86.2	76.9	92.2
64	Plastic electronic musical toy	hh	53.2	65.0	59.2	71.0
65	Plastic plane with sound	hh	71.4	87.7	77.4	93.7
66	Toy sewing machine	tt&f	77.4	98.9	83.4	104.9
74	Motorised car with sound	tt&f	73.6	92.6	79.6	98.6
79	Activity centre with music	tt&f	59.7	107.3	65.7	113.3
80	Activity centre with sound	tt&f	70.4	85.3	76.4	91.3
81	Music box with pop-up figure	hh	61.0	76.5	67.0	82.5
84	Table telephone with bell and squeak	tt&f-bell	76.7	93.0	82.7	99.0
85	Motorised bouncing ball	tt&f	69.4	100.7	75.4	106.7
86	Shake and squeak character		68.3	85.6	74.3	91.6
88	Shake and squeak character		69.0	87.5	75.0	93.5
89	Pinball with electronic sound	tt&f	87.8	112.8	93.8	118.8
90	Space gun with sound	hh	77.8	89.8	83.8	95.8
91	Soft animal with sound and action	tt&f	71.7	93.4	77.7	99.4
92	Head with sound and action	hh	68.8	88.9	74.8	94.9
93	Soft animal with sound and action	tt&f	64.4	82.8	70.4	88.8
94	Laser torch with sound	hh	80.3	91.3	86.3	97.3
95	Soft animal with sound	hh	67.9	86.1	73.9	92.1
96	Soft animal with sound	tt&f	70.4	86.2	76.4	92.2
97	Soft animal with sound	tt&f	55.5	72.5	61.5	78.5
98	Space gun	tt&f	78.3	89.6	84.3	95.6
99	Soft animal with sound	hh	64.2	84.7	70.2	90.7
100	Soft animal with sound	hh	68.5	83.3	74.5	89.3
101	Soft animal with sound	tt&f	66.0	84.7	72.0	90.7
102	Soft toy with sound and action	tt&f	73.6	86.4	79.6	92.4
103	Activity phone musical	tt&f	70.1	86.4	76.1	92.4
104	Activity set sound and action	hh?	54.9		60.9	
104	Activity set sound and action	hh?		97.8		103.8
105	Cot mobile - musical	Cot	55.7	86.8	61.7	92.8
106	Musical keyboard	tt&f	65.4	87.8	71.4	93.8
107	Activity set musical	tt&f	68.5	86.7	74.5	92.7
108	Activity set music and sounds	tt&f	64.8	84.8	70.8	90.8
108	Activity set music and sounds		74.1	95.8	80.1	101.8
116	Wind-up musical TV	tt&f	63.2	78.9	69.2	84.9
117	Musical soft toy	hh	52.6	64.2	58.6	70.2

Table 4 Continued

Ref	Description	Type	Sound levels measured at 50 cm		Sound levels calculated at 25 cm	
			Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)	Time average noise level, dB(A) L_{Aeq}	Peak level, dB(C)
118	Sword with electronic sound	hh	76.8	88.7	82.8	94.7
119	Activity centre with sound	tt&f	73.3	97.3	79.3	103.3
120	Radio	tt&f	85.8	96.0	91.8	102.0
121	Radio alarm clock	tt&f	80.4	101.2	86.4	107.2
122	Cassette recorder	tt&f	82.3	98.2	88.3	104.2
122	Cassette recorder	tt&f	90.6	102.6	96.6	108.6
141	Toy car with driver	tt&f	76.2	91.9	82.2	97.9
145	Musical mobile	cot	51.5	71.1	57.5	77.1
146	Jukebox	tt&f	84.9	100.0	90.9	106.0
147	Mobile car	tt&f	74.1	96.8	80.1	102.8
149	Book with sound effects	tt&f	71.0	85.7	77.0	91.7
150	Puzzle with sound	tt&f	61.9	84.1	67.9	90.1
151	Talking doll	hh	68.4	87.9	74.4	93.9
152	Space monster sound and action	hh	77.1	94.1	83.1	100.1
153	Spacecraft with sound	hh	65.4	89.9	71.4	95.9
154	Action figure with sound	hh	79.1	95.9	85.1	101.9
155	Electronic laser game	tt&f	75.8	92.2	81.8	98.2
156	Action figure with sound	hh	65.6	78.2	71.6	84.2
157	Talking action figure	hh	67.2	84.6	73.2	90.6
159	Electronic motorcycle	tt&f	68.2	84.9	74.2	90.9
161	Police car	tt&f	88.1	98.1	94.1	104.1
162	Action figure with sound and motion	tt&f	77.3	94.9	83.3	100.9
163	Action figure with sound	hh	69.2	83.8	75.2	89.8
164	Cash register with speech	tt&f	80.0	103.6	86.0	109.6
165	Electronic cash register	tt&f	76.3	103.2	82.3	109.2
166	Game with buzzer	tt&f	81.6	83.7	87.6	89.7
167	Remote control car	tt&f	79.0	93.6	85.0	99.6
171	Aeroplane with sound and motion	tt&f	86.7	100.0	92.7	106.0

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 5

Sound levels produced by rattles

Ref No	Description	Sound levels measured at 50 cm				Sound levels calculated at 25 cm	
		SEL, dB(A)		Peak level, dB(C)		SEL, dB(A)	Peak level, dB(C)
		1st operator	2nd operator	1st operator	2nd operator	average of 2 operators	average of 2 operators
46	Activity frame with sound	75.4	77.8	92.2	91.2	82.6	97.7
54	Teething rattle	84.9	84.6	105.6	102.2	90.8	109.9
57	Chime rattle	61.2	63.0	74.6	74.6	68.1	80.6
62	Rattle	80.9	85.4	97.9	104.3	89.2	107.1
73	Rattle	72.1	70.9	93.5	91.6	77.5	98.6
140	Rocking toy with sound	83.8	81.0	101.9	95.0	88.4	104.5
142	Soft toy with bell	69.0	71.4	90.1	94.5	76.2	98.3
143	Soft toy with bell	68.6	73.7	88.4	94.8	77.2	97.6
144	Socks with sound	68.1	68.8	84.8	84.3	74.5	90.6

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 6

Sound levels produced by squeeze toys

Ref No	Description	Sound level measured at 50 cm							Sound level calculated at 25 cm	
		SEL, dB(A)		Peak level. dB(C)		4 kHz octave band level	8 kHz octave band level	L_{HF}	SEL, dB(A)	Peak level. dB(C)
		1st operator	2nd operator	1st operator	2nd operator					
28	Squeeze toy	70.5		83.1		57.3	54.4		76.5	89.1
42	Squeeze toy	92.4		100.0					98.4	106.0
42	Squeeze toy	99.3		102.9		81.9	72.2		105.3	108.9
46	Activity frame with sound	80.8		91.7		72.5	75.1		86.8	97.7
47	Soft motorised squeeze toy	77.8		89.2		71.8	75.7		83.8	95.2
51	Bicycle horn	104.0		112.7		102.8	99.0		110.0	118.7
63	Plastic squeeze toy	88.4		97.3		73.3	91.0		94.4	103.3
71	Telephone with sound	76.4		90.2		68.8	59.4		82.4	96.2
76	Squeaking ball	88.1	84.8	97.1	100.6	79.8	69.9		94.1	103.1
84	Table phone with squeak	69.0	73.4	88.0	94.9	66.8	66.4		75.0	94.0
87	Squeeze doll	84.1		92.9		80.3	69.6		90.1	98.9
110	Squeaking ball	87.0		96.8		79.7	89.9	90.0	93.0	102.8
111	Animal squeaker	82.9		91.6		68.1	84.9	84.9	88.9	97.6
139	Squeeze toy	84.4		98.8				92.8	90.4	104.8

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 7

Noise levels from pull and push toys

Ref No	Description	Maximum A-weighted sound level. L_{AFmax}	
		Measured at 50 cm	Calculated at 25 cm
7	Plastic pull along with sound and action	73.9	79.9
8	Plastic pull along with sound and action	77.5	83.5
16	Plastic pull along with sound and action	77.1	83.1
14	Plastic push along dumper truck	71.7	77.7

NB: Manufacturers' names and toy names appear in the master copy of this report but have been omitted from the published version

Table 8

Sound levels from hand held toy cap guns and other toys producing impulsive noise

Ref	Description	Toy type	Peak level, dB(C)	
			at 50cm	at 25 cm
60	Drum	impulsive	119.1	125.1
61	Gun with sounds	impulsive	102.3	108.3
68	Party poppers	impulsive	127.7	133.7
169	Cap gun - roll caps	cap gun	140.9	146.9
170	Cap gun - plastic caps	cap gun	144.5	150.5
177	Explosive bags	impulsive	147	153
178	Balloons	impulsive	130 - 144	136 - 150

NB: Manufacturers' names and toy names appear in the master copy of this report but have been omitted from the published version

Table 9

Noise levels from close to the ear toys

Ref No	Description	Measured sound levels	
		Time average level, dB(A) L_{eq}	Peak level, dB(C)
22	Telephone with musical sounds	93.0	105.0
27	Miniature recorder and playback	95.1	112.0
32	Megaphone electronic	115.0	128.1
37	Megaphone electronic	121.3	132.6
55	Musical telephone	90.0	102.1
70	Musical teething ring	69.6	79.8
75	Musical telephone	81.1	88.9
82	Musical teething ring	68.7	88.1
83	Mobile phone	84.3	98.5
117	Musical soft toy	71.6	86.8
130	Audio walkie talkie	91.0	102.0
148	Telephone with musical sounds	99.0	98.2
168	Rifle with electronic sound	93.3	109.2

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 10

Noise levels from headphones

Ref	Description	Time average A-weighted noise level, dB(A) L_{eq}		
		On artificial ear	At manikin’s eardrum	Undisturbed Field Equivalent
67	Cassette player with headphones	101	102	91
69	Radio headphones	104	100	93
120	Radio	100	103	91
130	Audio walkie talkie	122	121	108

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 11

Wind instruments and other toys operated by blowing

Ref No	Description	Noise level close to ear or at 50 cm, whichever is greater	
		Time average level, dB(A) L_{eq}	Peak level, dB(C)
112	Party Tickler	87.0	102.5
113	Party plastic horn	89.7	100.1
114	Party paper horn	95.1	111.6
115	Balloon squeaker	92.5	112.4
72	Saxophone	88.9	107.9
77	Party squeaker	92.5	108.4
78	Party tickler	97.1	114.3
79	Party squeaker	92.2	108.9
129	Recorder	95.2	106.1
172	Mouth piano	83.0	99.1
173	Harmonica	83.0	99.9
174	Recorder	93.5	104.1
175	Flute	92.1	104.0
176	Kazoo	77.7	97.5
135	Trumpet	87.9	102.9

NB: Manufacturers’ names and toy names appear in the master copy of this report but have been omitted from the published version

Table 12

Musical instruments other than wind instruments

Ref No	Description	Sound levels measured at 50 cm		Sound levels calculated at 25 cm	
		Time average level, dB(A) L_{eq}	Peak level, dB(C)	Time average level, dB(A) L_{eq}	Peak level, dB(C)
123	Electronic keyboard	83.3	99.2	89.3	105.2
124	Electronic keyboard	81.3	97.4	87.3	103.4
125	Electronic keyboard	83.6	94.2	89.6	100.2
126	Electronic keyboard	75.2	90.4	81.2	96.4
127	Electronic keyboard	80.0	100.5	86.0	106.5
128	Guitar	76.5	100.4	82.5	106.4
131	Mini keyboard	87.5	99.8	93.5	105.8
132	Accordion	86.4	102.9	92.4	108.9
133	Piano	80.2	101.1	86.2	107.1
134	Guitar	72.1	94.2	78.1	100.2
136	Xylophone	85.6	111.0	91.6	117.0
137	Tambourine	87.9	117.2	93.9	123.2
138	Maracas	76.6	100.9	82.6	106.9

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Table 13

Noise levels from sources other than toys

Source description	Noise level						Measurement duration
	dB(A)					dB(C)	
	L_{eq}	L_1	L_{10}	L_{90}	Max L_F	Peak (Max P)	
In the home and garden							
Washing machine - Hoover 1000 wash - measured in centre of room	50	60	56	--	62	88	00h 37m 00s
Washing machine - Hoover 1000 spin - measured in centre of room	68	70	69	67	62	88	00h 03m 55s
Vacuum cleaner - Hoover Compact - operator's posn	75	80	78	72	88	107	00h 05m 00s
Vacuum cleaner - Henry - operator's position	77	85	79	73	93	103	
Hair dryer - Braun 4425, 30 cm	71	75	73	69	75	85	00h 01m 00s
Alarm beep - Sony Digicube clock radio at 1m	70	75	72		75	85	
Alarm beep (progressively increasing) Roberts R617 radio	59	67	64		68	79	
TV	55	63	59	43	71	89	02h 08m 00s
Washing up by hand	64	76	61	45	90	105	
Kettle	60						
Microwave oven	57	58	58	56	59	78	
Electric can opener	67	68	68	66	68	80	
Telephone ringing , 1 metre (BT Duet low setting)	58		62			74	00h 00m 25s
Telephone ringing , 1 metre (BT Duet High setting)	78		83			94	00h 00m 25s
Telephone ringing , 1 metre (BT Tremolo High setting)	73		78			88	00h 00m 25s
Smoke alarm on ceiling, Black & Decker, underneath at head height	93	100	97		100	103	00h 00m 11s

Source description	Noise level						Measurement duration
	dB(A)					dB(C)	
	L_{eq}	L_1	L_{10}	L_{90}	Max L_F	Peak (Max P)	
Lawn mower - electric cylinder - operator position	73	77	76	69		101	00h 05m 00s
Lawn mower - electric hover - operators position	83	86	85	81		105	00h 08m 00s
Jig saw - 12 mm MDF - 1 m away	84	88	87		89	101	
Electric drill - 12 mm MDF - 1 m away	82	88	87		88	102	
Child's shout or scream at 1.2 m (during an ISVR Open Day competition)	106						00h 00m 08s
Adult hand clap at 50 cm						120-124	
Bursting empty potato crisp packets at 50 cm						136-139	
School							
In reception class for youngest children - morning (approx 50 children, 2 teachers, 1 assistant)	74						
In reception class for youngest children - afternoon	73						
Transport and outdoors							
Car: Rover Metro 1.1, radio off, windows closed, suburban driving	64	72	68	53	86	125	00h 23m 20s
	64	71	68	54	80	116	00h 25m 00s
Car motorway journey Manchester to Southampton	79						
London railway terminus (Waterloo)							
Concourse, 9 am	73	80	77	66	83	103	00h 10m 00s
Concourse, between announcements, approx 9 am	67						
Concourse, during announcements, approx 9 am	77						
Concourse, with music,1.30 pm	73				77		00h 03m 00s
Concourse during announcements, midday	88						

Source description	Noise level						Measurement duration
	dB(A)					dB(C)	
	L_{eq}	L_1	L_{10}	L_{90}	Max L_F	Peak (Max P)	
Platform sweeping machine passing at approx 7 m	81				90		00h 01m 00s
Outdoor railway platform (Southampton Airport Parkway) (max level from Virgin HS125 Cross Country Service departing from opposite platform)	79				102	114	00h 05m 00s
Inside railway train (Southampton-London)	67						
Inside railway train (London - Southampton)	67	70	68	65	73	102	01h 00m 00s
Inside railway train (Southampton-London)	71						
Inside double deck bus (small windows open) (Leyland “Atlantean”)	74						00h 04m 00s
Inside double deck bus (small windows open) (Leyland “Atlantean”)	76						00h 16m 00s
Inside double deck bus (small windows open) (Leyland “Atlantean”)	76						00h 19m 00s
Inside underground trains: various journeys of 1 to 4 stops							
Northern line	86				94	111	
Northern line	89				94		
Piccadilly line	79				92		
Northern line	78				89		
Underground station platform - no train	65					109	
Underground station platform - no train	74						
Underground station platform - trains entering					98		
Underground station - traversing ticket areas escalators and corridors (Waterloo)	73						00h 03m 00s
Underground station - traversing ticket areas escalators and corridors (Leicester Square)	72						
Underground station - foyer Piccadilly	72						

Source description	Noise level						Measurement duration
	dB(A)					dB(C)	
	L_{eq}	L_1	L_{10}	L_{90}	Max L_F	Peak (Max P)	
Shopping and entertainment							
Out-of town supermarket	68		71	59		114	00h 20m 00s
Edge of town supermarket	67		70	60		121	00h 24m 00s
Shopping mall (midday) first	72						00h 09m 00s
Shopping mall (midday) second	69						00h 06m 00s
Stationers newsagent book and record shop	59						00h 04m 00s
Large record shop with music playing - average throughout shop	75						00h 05m 00s
Large record shop with music playing - approx 2 m from loudspeakers					84		
Second large record shop with music	67						00h 08m 00s
Shopping precinct/lightly used roads: Southampton	69-74						
Oxford St London lunchtime	75				94	113	00h 07m 00s
Regent Street	77				94		00h 10m 00s
Round trip Waterloo to Waterloo Undergrd+Roads+Shops	78				102		01h 20m 00s
Football match: Southampton - v - Coventry	90	100	92	77	119	127	01h 30m 00s
Electronic games arcade - near various machines	74 - 88					122	

Notes:

L_1 is the noise level exceeded 1% of the time (with -frequency weighting ‘A’ and time weighting ‘F’)
L_{10} is the noise level exceeded 10% of the time (with -frequency weighting ‘A’ and time weighting ‘F’)
L_{90} is the noise level exceeded 90% of the time(with -frequency weighting ‘A’ and time weighting ‘F’)
Max L (with -frequency weighting ‘A’ and time weighting ‘F’)

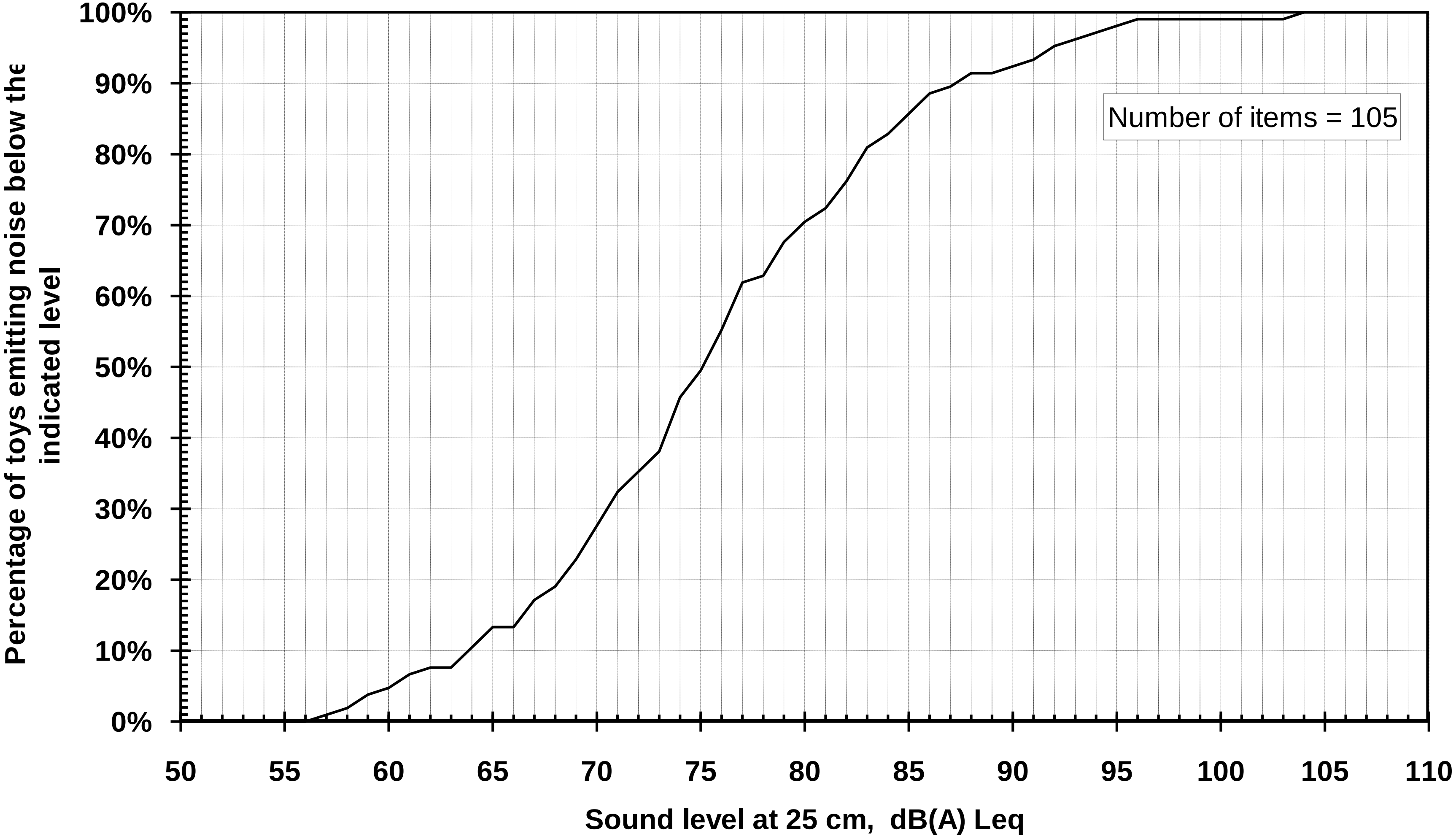

Figure 1 Cumulative distribution of A-weighted sound levels of hand-held, table-top, floor and cot toys

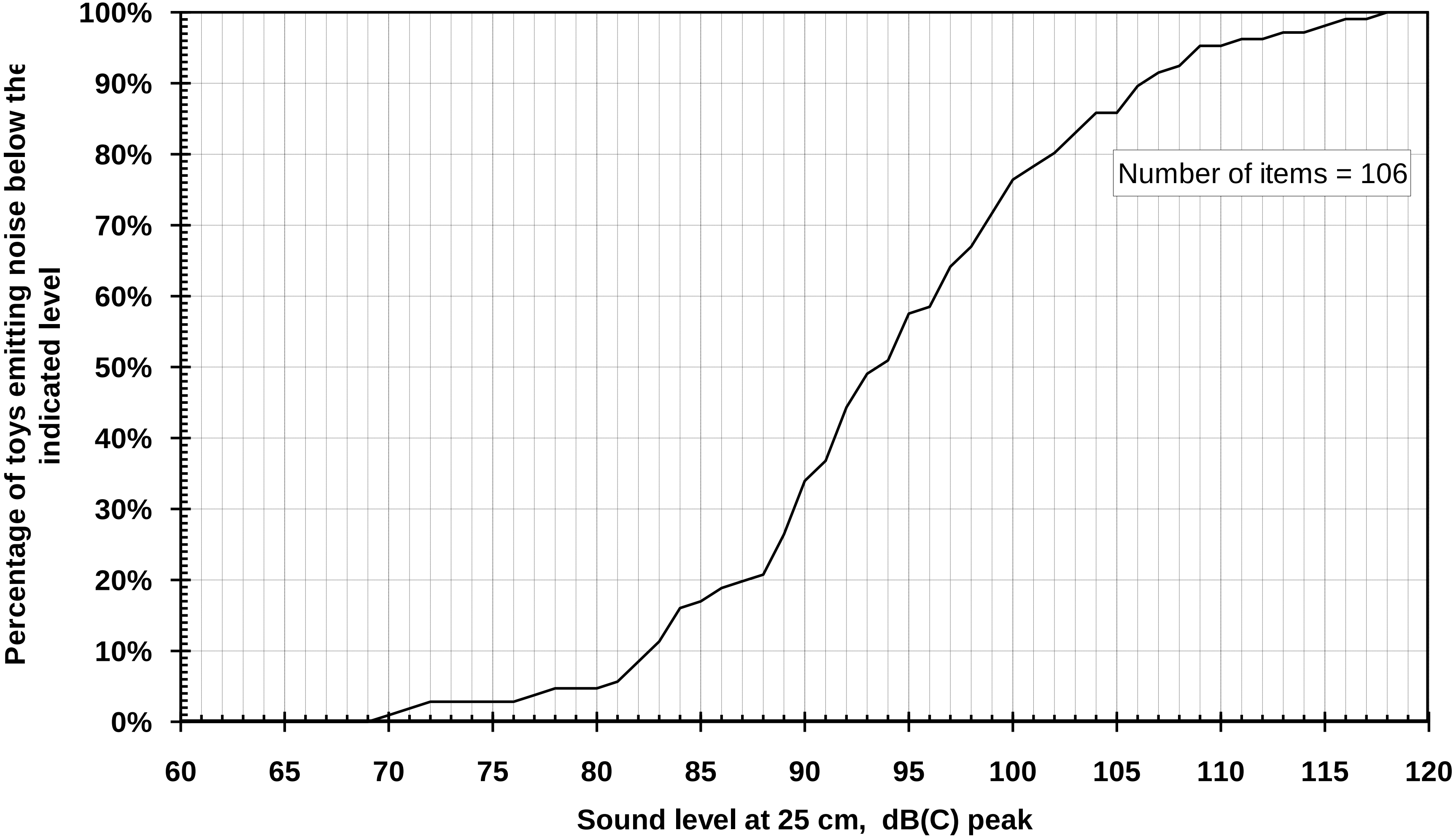

Figure 2 Cumulative distribution of peak C-weighted sound levels of hand-held, table-top, floor and cot toys.

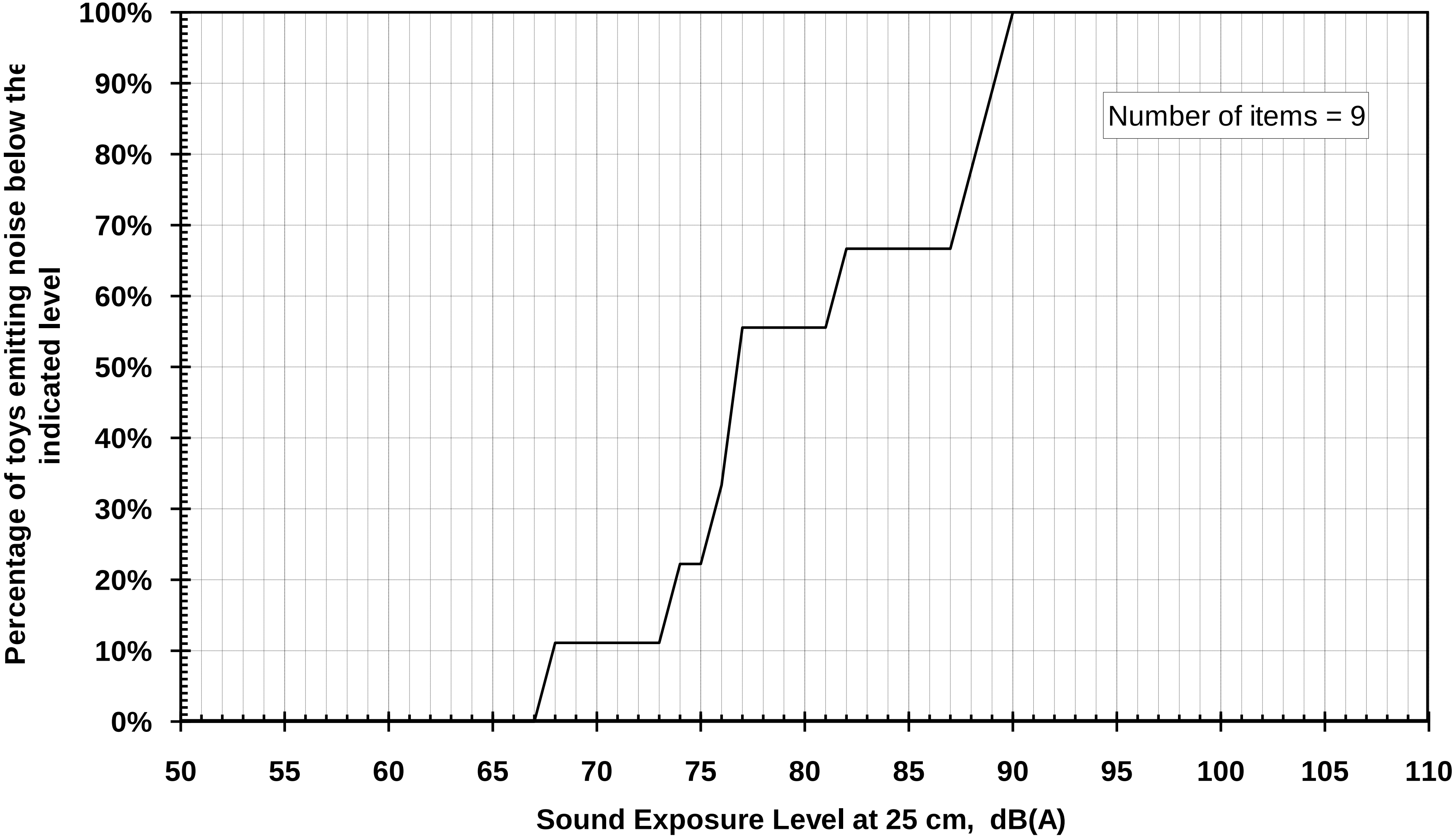

Figure 3 Cumulative distribution of A-weighted Sound Exposure Levels over a series of 10 shakes of rattles

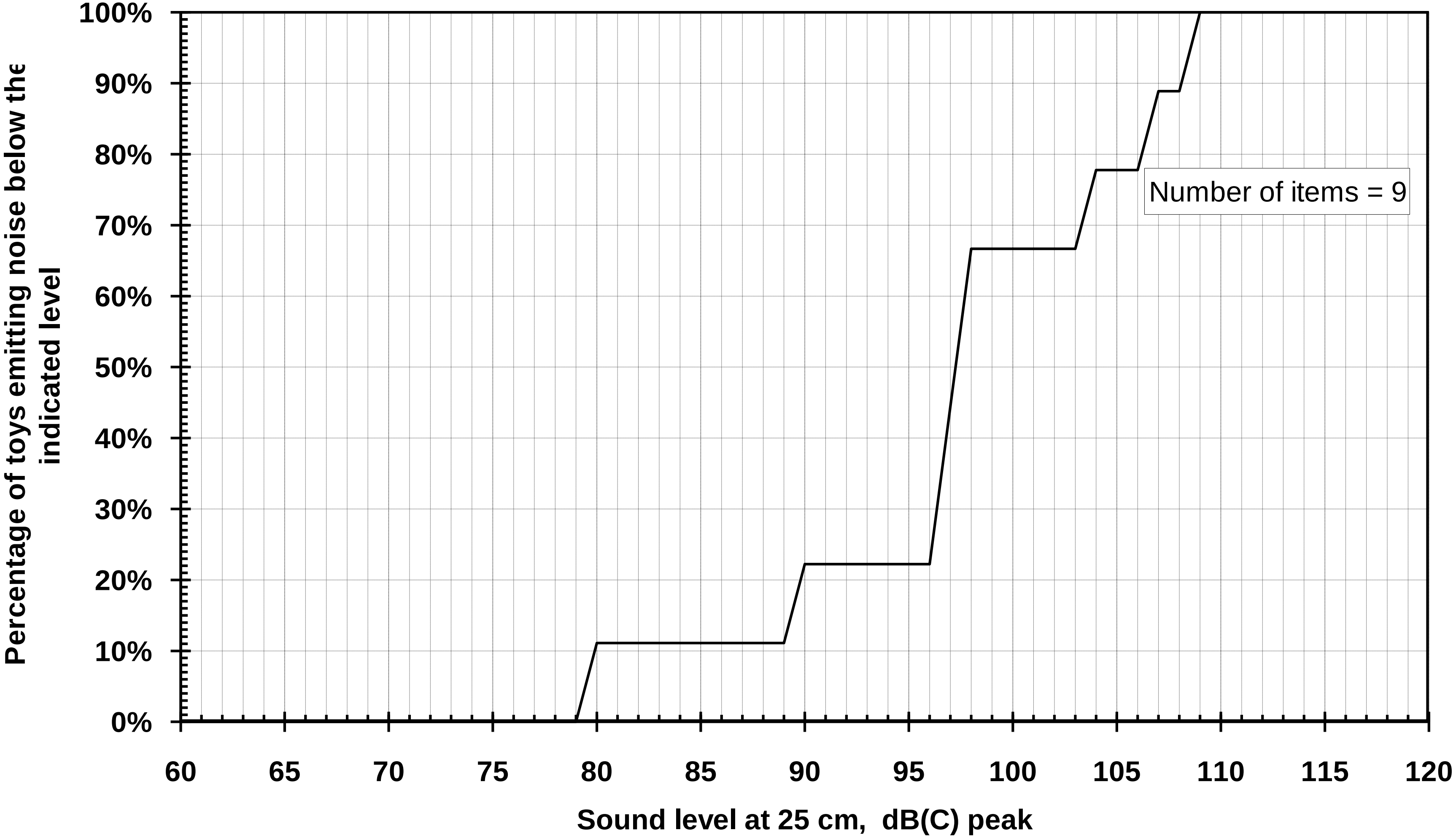

Figure 4 Cumulative distribution of peak C-weighted sound levels of rattles

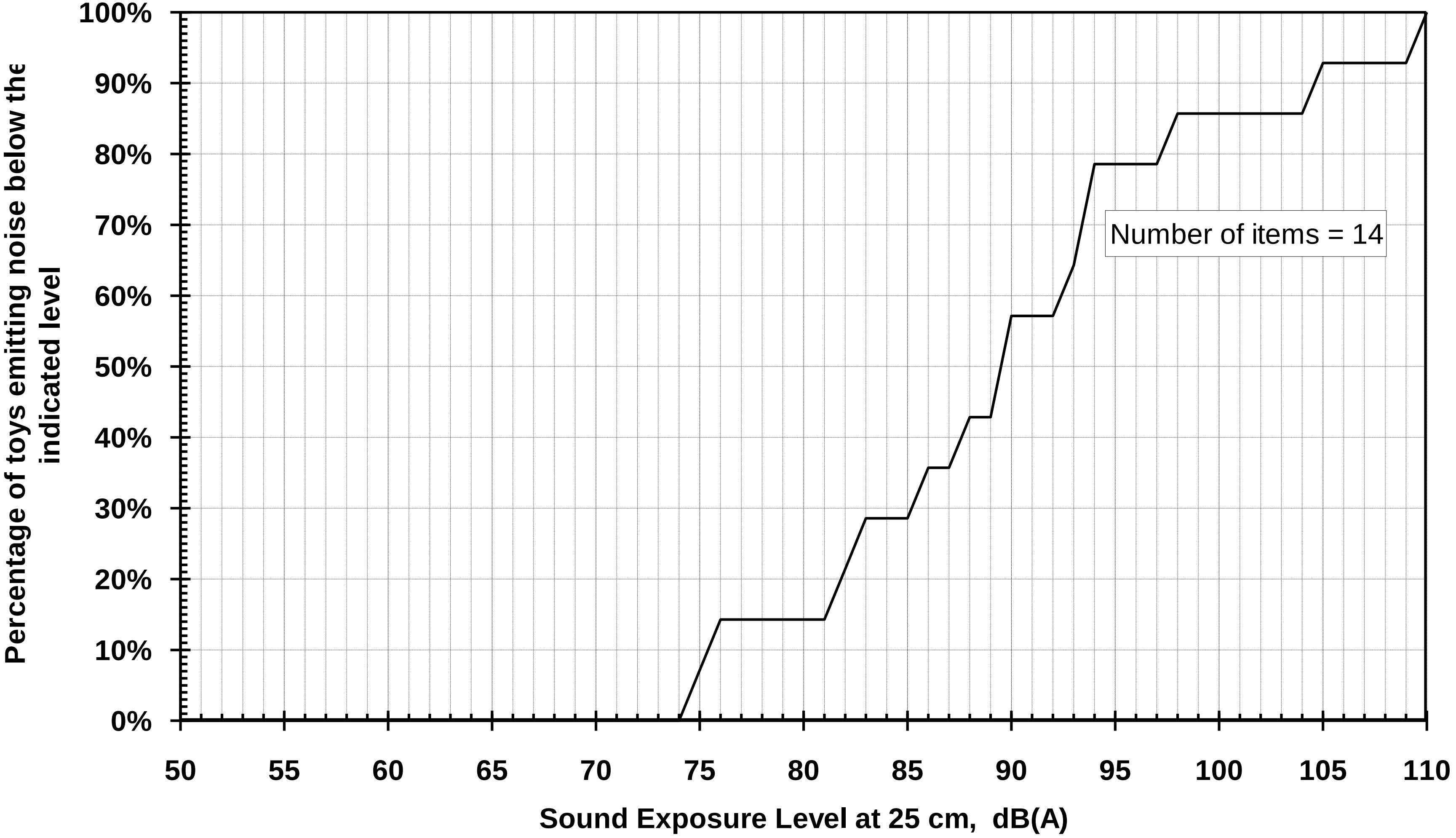

Figure 5 Cumulative distribution of A-weighted Sound Exposure Levels over a series of 10 squeezes of squeeze toys

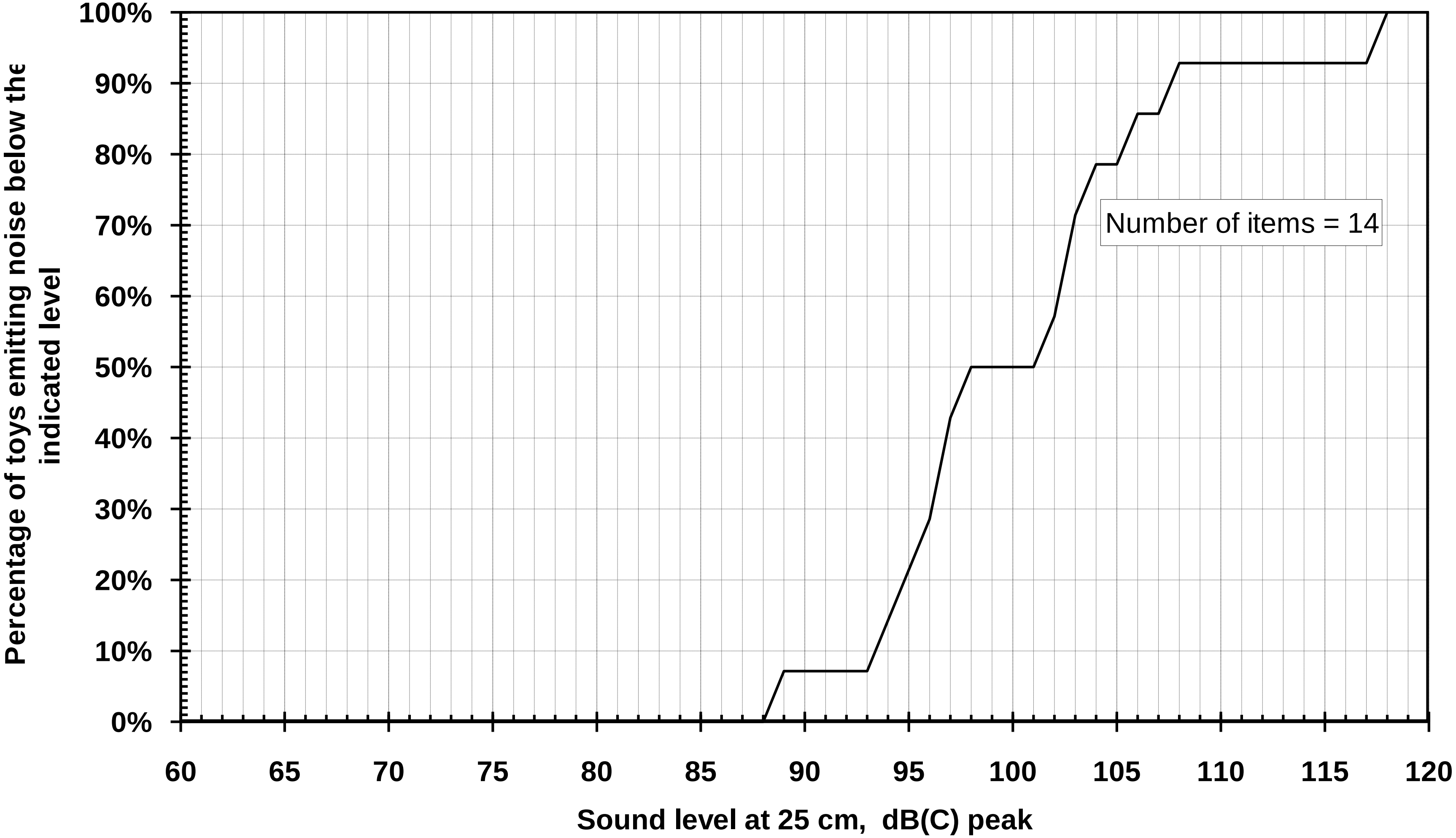

Figure 6 Cumulative distribution of peak C-weighted sound levels of squeeze toys

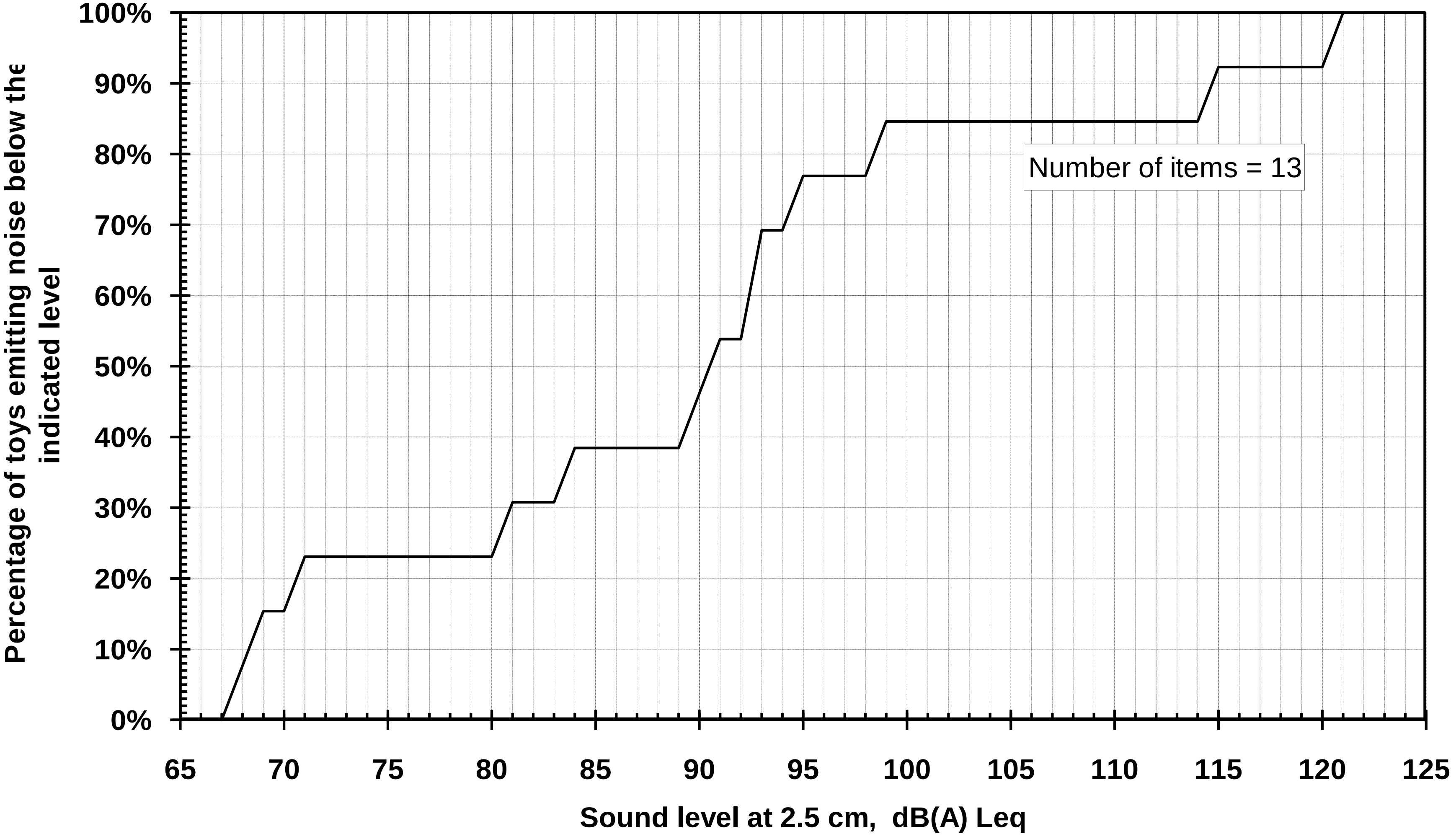

Figure 7 Cumulative distribution of A-weighted sound levels of close-to-the-ear toys.

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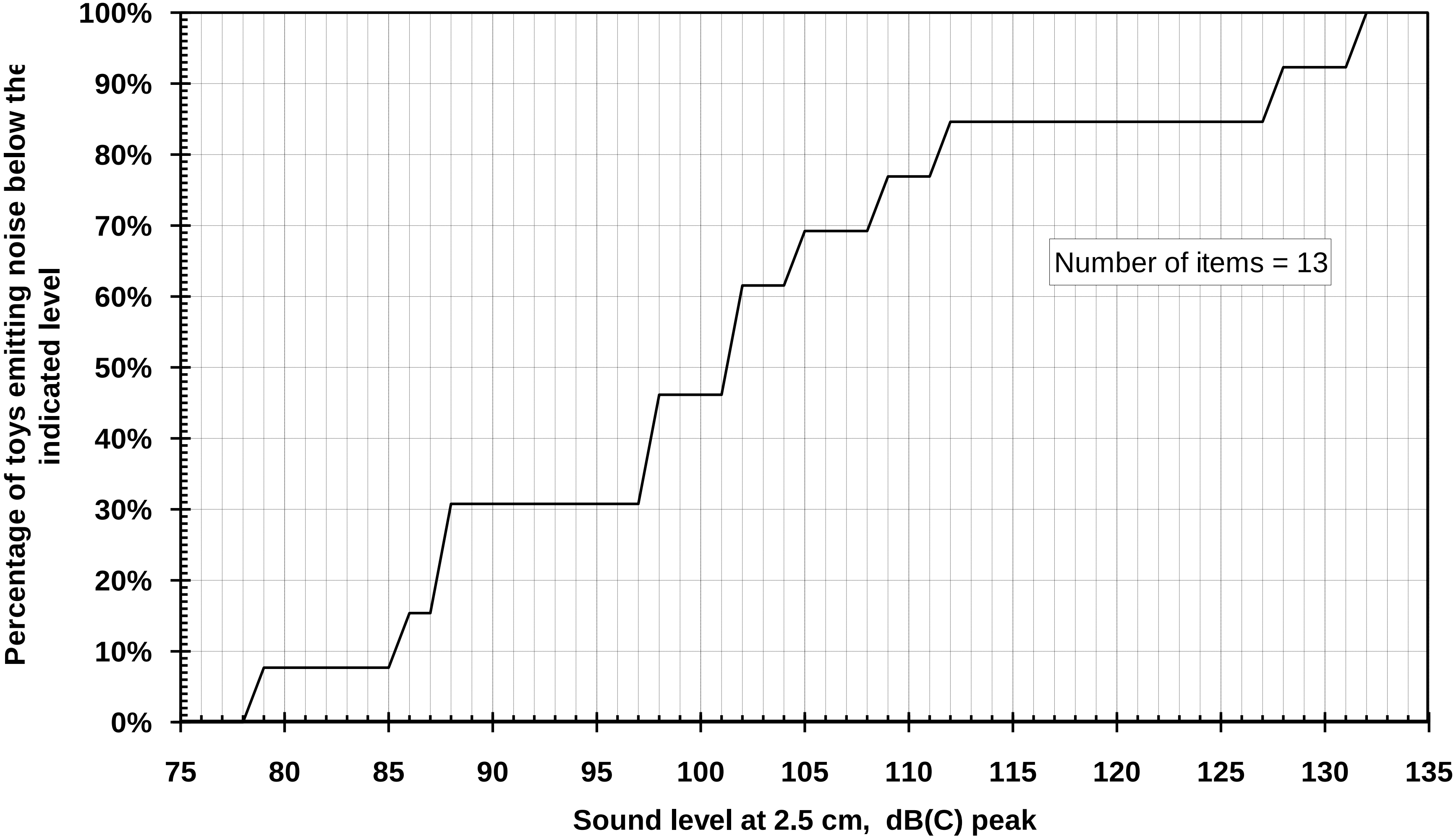

Figure 8 Cumulative distribution of peak C-weighted sound levels of close-to-the-ear toys.

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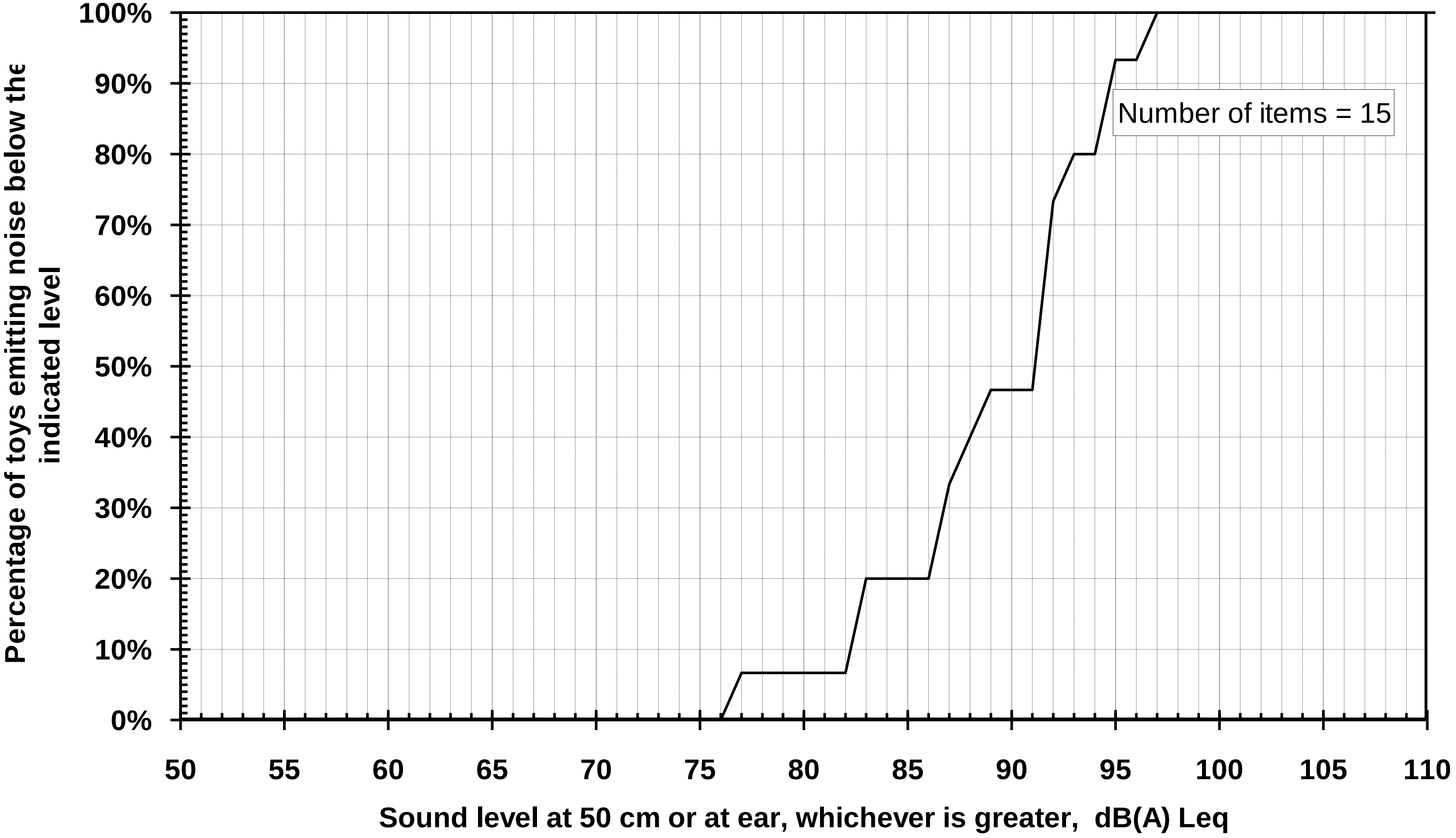

Figure 9 Cumulative distribution of A-weighted sound levels of wind instruments and toys operated by blowing.

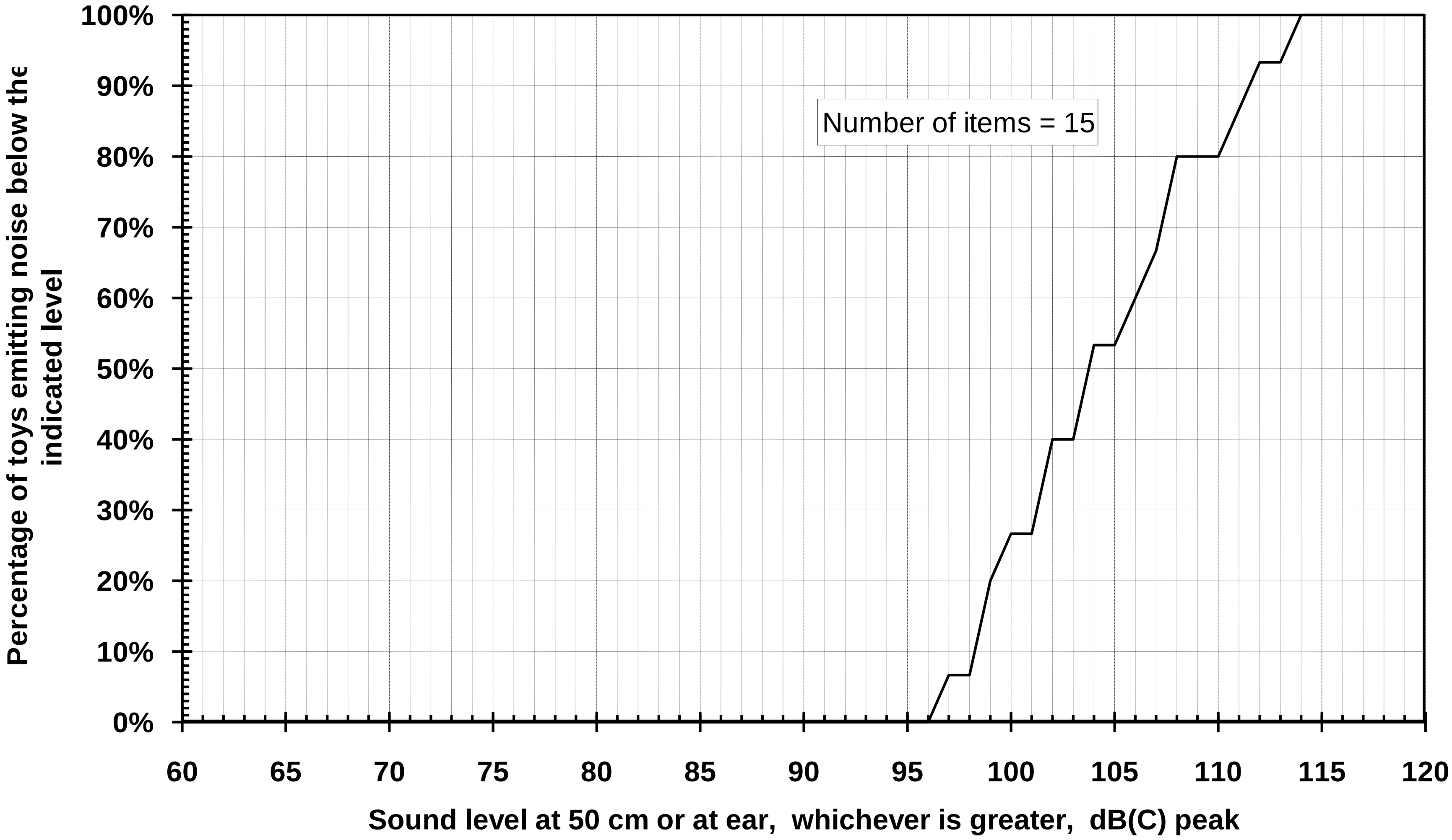

Figure 10 Cumulative distribution of peak C-weighted sound levels of wind instruments and toys operated by blowing.

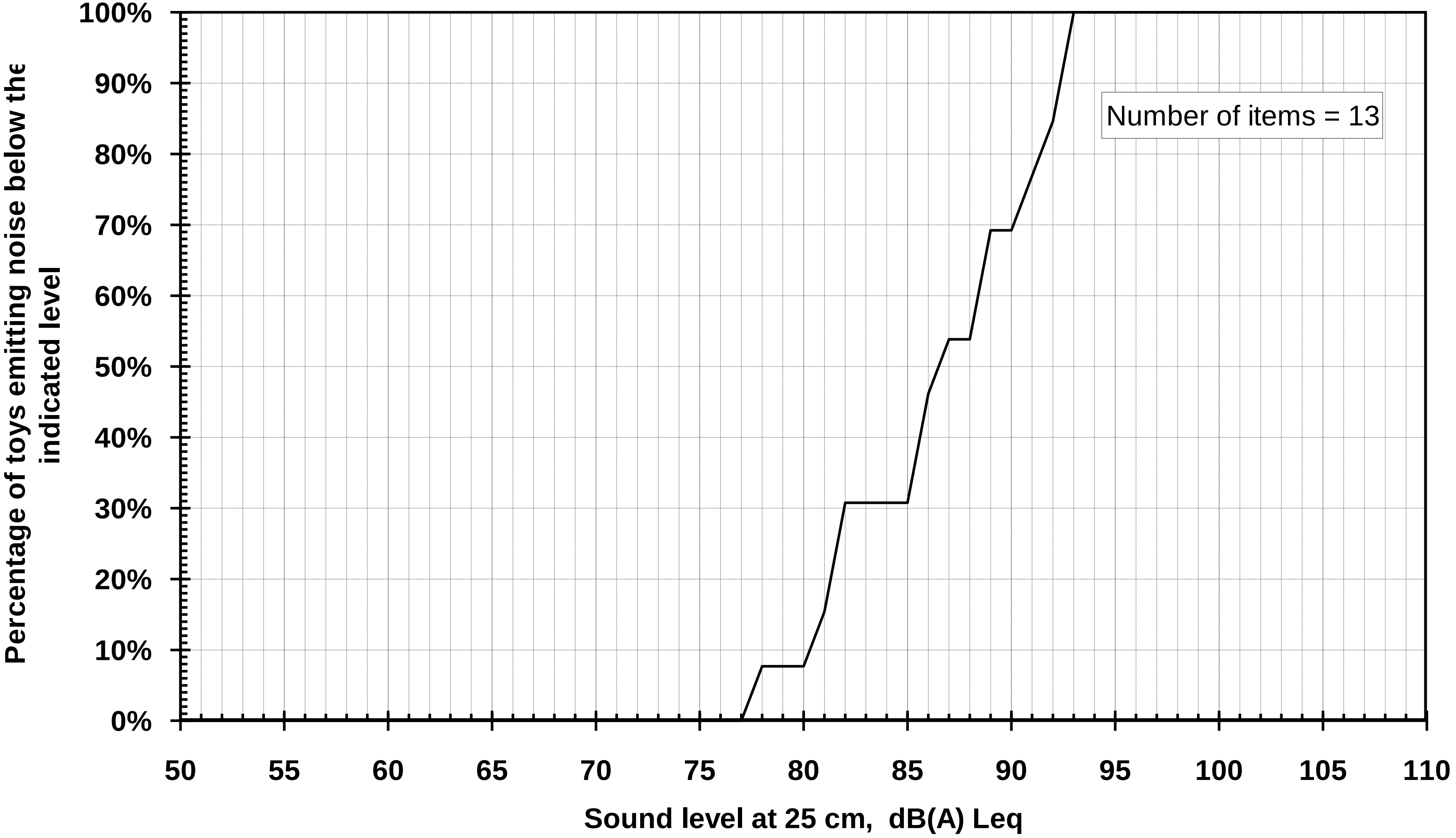

Figure 11 Cumulative distribution of A-weighted sound levels of musical instruments other than wind instruments.

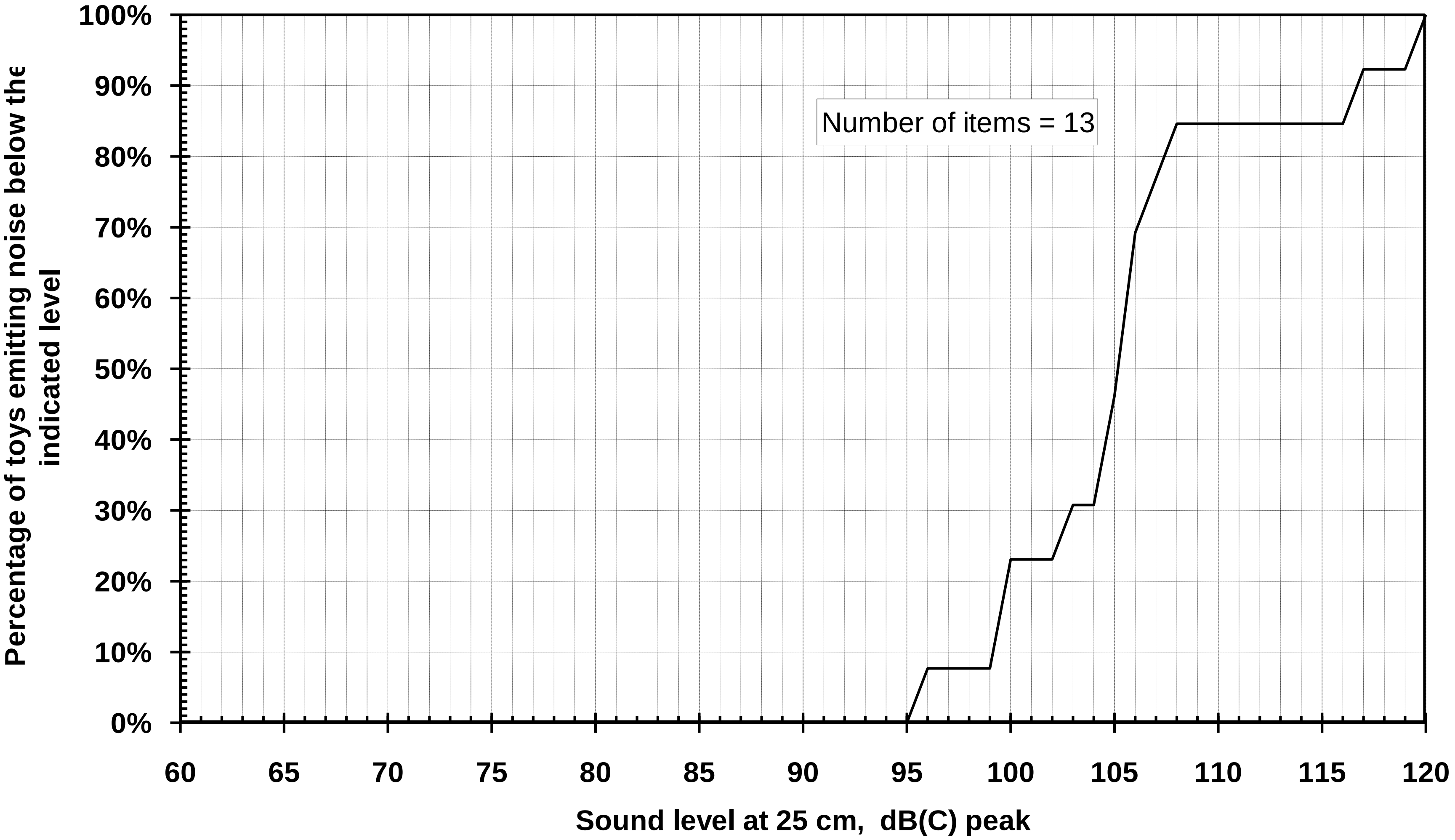

Figure 12 Cumulative distribution of peak C-weighted sound levels of musical instruments other than wind instruments.

Appendix
Limits to high-frequency noise from squeeze toys

A.1 Limit proposed in the draft prEN71-1.

The draft of prEN71-1 imposes a limit on the high-frequency noise emitted by squeeze toys: the sum of the band pressure levels in the 4 kHz and 8 kHz octave bands has to be 65 dB or less.

The reason for this high-frequency limit arose from the different sizes of the adult and the very young infant ear canals. The size and shape of the ear canal in the very young infant cause an acoustic resonance within the ear canal giving a peak in the ear canal transfer response in the range from 5 kHz to 8 kHz. The ear canal of an adult is longer and the resonance in an adult ear canal will be at a lower frequency, in the range from 2 kHz to 4 kHz. An adult may also have a dip, or anti-resonance, in the ear canal response at high frequencies where an infant may have a peak.

The magnitude of the primary resonant peak will be of the order of 15 dB, whether in adults or infants, and the dip or anti-resonance may be of the order of -15 dB. In other words, at resonance the sound level at an eardrum might be 15 dB *above* the sound level outside the ear, while at anti-resonance the sound level at an eardrum could be 15 dB *below* the level outside the ear. If a toy were to generate a high-pitched tone at a frequency which corresponded to a resonance in an infant ear, but an anti-resonance in an adult ear, it would be possible for that tone to give rise to a sound pressure at the eardrum in an individual infant which might be 30 dB greater than the sound pressure at the eardrum of an individual adult. It has been argued that an adult would perceive this tone to be relatively quiet, whereas to the infant it might be far louder. The adult could unwittingly expose the infant to high noise levels, and therefore a limit to high frequency noise was proposed to prevent this.

A.2 Our arguments against the proposed limit.

In assessing the risk of damage to hearing in adults we measure noise levels in the undisturbed sound field. We do not measure noise levels at the ear drum, and it would be impracticable and inconvenient to do so. We also use the A-weighting circuit in the measuring equipment to simulate the response of the ear. This A-weighting circuit is effectively a tone control which reduces the low frequencies and extreme high frequencies in the noise signal. The A-weighting curve is a reasonable, but highly stylised, approximation to the relative sensitivity of the whole adult ear (not just the ear canal) at different frequencies. The A-weighting does not and cannot mimic the detailed response differences of individual ears. The A-weighting curve **does** follow the trend of emphasising the 2 kHz to 4 kHz range where the adult ear is most sensitive but it does **not** have dips around 6 kHz to represent the anti-resonances.

Consider two tones, one at 2.5 kHz and the other at 6 kHz, but with identical sound pressure levels at a given point in space. If measured with a sound level meter at that point, without the A-weighting in circuit, the indicated sound levels of the two tones would be identical. With the A-weighting switched in, these two tones at 6 kHz and 2.5 kHz, would differ by less than 1.5 dB, which is a very small difference.

The sound level at an infant's eardrum produced by the 6 kHz tone would be similar to the sound level at an adult's ear drum produced by the 2.5 kHz tone, but the sound level at the adult's eardrum would be much lower at 6 kHz. Although an adult might perceive a 6 kHz tone as far quieter than a 2.5 kHz tone, the sound level meter with the A-weighting will indicate that the 2.5 kHz and the 6 kHz tone have very similar levels. The adult might underestimate the level of a 6 kHz tone as perceived by a child, but the meter with the A-weighting would not. Therefore, as we set noise limits in terms of an A-weighted sound level measured away from the head, there is no need to measure or apply separate noise limits to levels in the 4 kHz and 8 kHz octave bands.

As further background information, the noise limits or action levels in the UK *Noise at Work Regulations*, equivalent national legislation in other EU countries, and similar regulations and standards in other countries, are predicated on the assumption that noise levels are measured in free space, undisturbed by the presence of a person, not at an eardrum. The ear canal resonance has been allowed for, implicitly and on a statistical basis, because the noise limits or action levels were originally derived by correlating degrees of hearing loss against the noise levels measured in undisturbed space, not noise levels measured at eardrums. Further explicit allowances should not be necessary.

We would also point out that there are wide variations in the frequency of the resonance and antiresonances among adults and among children, and published information suggests that by the age of 3 to 5 years, the frequency of a child’s ear canal resonance falls within the range of frequencies typical of adults.