

Measurements and Assessment of Sound Emitted by Toys Intended for Children under the Age of Three Years Old

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Toys emitting sounds are classified as significant sources of noise found in the children environment. Impulse and continuous noise emitted by toys, used in close to the child's ear, acting directly on the organ of hearing, can lead to serious adverse health effects. This is especially true for children under the age of three, in which the state of the hearing organ determines their intellectual development.

The current level of safety of sound emitting toys intended for children in this age group is insufficient. This is confirmed by the reports from the control of market surveillance authorities.

A new approach to the assessment of children's exposure to noise generated by toys, included in EN 71-1:2011 + A2:2013 Standard, based on the permissible values applicable to the workplaces, requires further tests and verification.

The paper presents the results of the research work and assesses the level of sound emitted by toys in the light of current standard requirements, carried out using the author's methodology. Toys intended for children under the age of 3 years, commercialized on the European market by Polish manufacturers and importers were tested. The results of the tests allowed us to determine the impact of duration of the sound pressure level measurement on the final result.

Keywords: toys, sound level, noise, hazards, safety of use.

Notations

- L_p – emission sound pressure level,
 L_{pA} – A-weighted time averaged emission sound pressure level,
 $L_{pAF\max}$ – A-weighted FAST time constant averaged maximum emission sound pressure level,
 $L_{pC\text{peak}}$ – C-weighted peak emission sound pressure level,
 L_{pA1s} – A-weighted single event emission sound pressure level.

1. Introduction

Toys play an important role in the mental and physical development of children. Thanks to them, they acquire knowledge, skills, mobility, and shape their imagination. Children playing with toys, from a simple manipulation of rattles by infants, to complex reactions, when using interactive toys, experience different stimuli, including the acoustic ones (GRYNKIEWICZ-BYLINA, 2013). The sounds generated by the electronic and mechanical toys interact with the ear of the child, which is responsible for the development of speech and thinking processes (SULKOWSKI,

2009). Among them are undesirable and annoying sounds defined as noise (ENGEL, 2001). They negatively affect health, especially regarding children. Noise can cause fatigue, lack of concentration, disorientation, irritability, increased blood pressure, headache, dizziness, and in the worst case, temporary or permanent hearing loss (ABAS AI ALI, 2013; CROMBIE *et al.*, 2011; DOBRUCKI *et al.*, 2013; JAROSZEWSKI, JAROSZEWSKA, 2001; JAROSZEWSKI, 2001; VAN KEMPEN *et al.*, 2010; STANSFELD *et al.*, 2005; SULKOWSKI, 2009). In Poland every sixth child has hearing problems (DWORAK *et al.*, 2004). In young children under the age of three, noise causes anxiety, uncertainty, confusion, and tears, which negatively affects the development of their psycho-physical functions (FREUDENTHAL *et al.*, 2013; HARAZIN, 2010; MORRONGIELLO, SANDRA, 1987).

To protect children from the noise emitted by toys, the European Union Directive 2009/48/EC (Directive, 2009), which specifies the requirements for the acoustic parameters, was established. According to the directive, the maximum impulse and continuous sound levels emitted by toys should not lead to damage of

children hearing. The limit values of sound pressures are specified in the EN 71-1:2011 Standard “Safety of toys. Mechanical and physical properties”, harmonized with the above Directive. This standard does not cover all kinds of toys available on the market, and does not include the time of sound emission. The EN 71-1:2011 + A2:2013 Standard complements this issue by a new approach to the assessment of children’s exposure to the hazard associated with using the acoustic toys, basing on the Directive 2003/10/EC (Directive, 2003). The standard specifies the limits of emission sound pressure levels for toys based on the values applicable for the workplaces which do not require the use of personal protective equipment.

Research work on the assessment of risks associated with emission of sound from toys, conducted in many of the world scientific centers (BISTRUP *et al.*, 2006; GESHANI *et al.*, 2005; JOUBERT, 2012; MCLAREN *et al.*, 2014; SEGAL *et al.*, 2003; SLEIFER *et al.*, 2013; YAREMCHUK *et al.*, 1997), as well as the results of the inspection (Department of Market Surveillance, 2009), indicate for insufficient safety of sound emitting toys sold on the market. This particularly applies to electronic toys intended for children under the age of three, which emit sound at high levels of frequency, which are in resonance with the outer ear channel, and which is best received by the child’s ear (HARAZIN, 2010). The authors

of the published studies emphasize the need to continue research work on improving the methods for measuring the parameters recreating the real usage of toys by children. This applies in particular to sound emission time of the toy and its distance from the child’s ear. Unfortunately, the results of the published studies do not refer to the standard acoustic requirements for toys, which are in force in the European Union.

In the work entitled: “Testing the parameters of acoustic toys”, carried out in KOMAG in the years 2014–2015, the level of sound emitted by toys intended for children under the age of three (GRYNKIEWICZ-BYLINA, RAKWIC, 2015) was identified and assessed in the light of the current requirements. The impact of the testing method on the result of the acoustic emission level of toys, including measurement time, the parameter dependent on the method of toys’ use by children, was analyzed.

2. Testing methodology

The sound emitting toys intended for children below three years old were tested. Eighty toy items commercialized on the European market by Polish manufacturers and suppliers were tested.

The tests were carried out according to the following algorithm (Fig. 1).

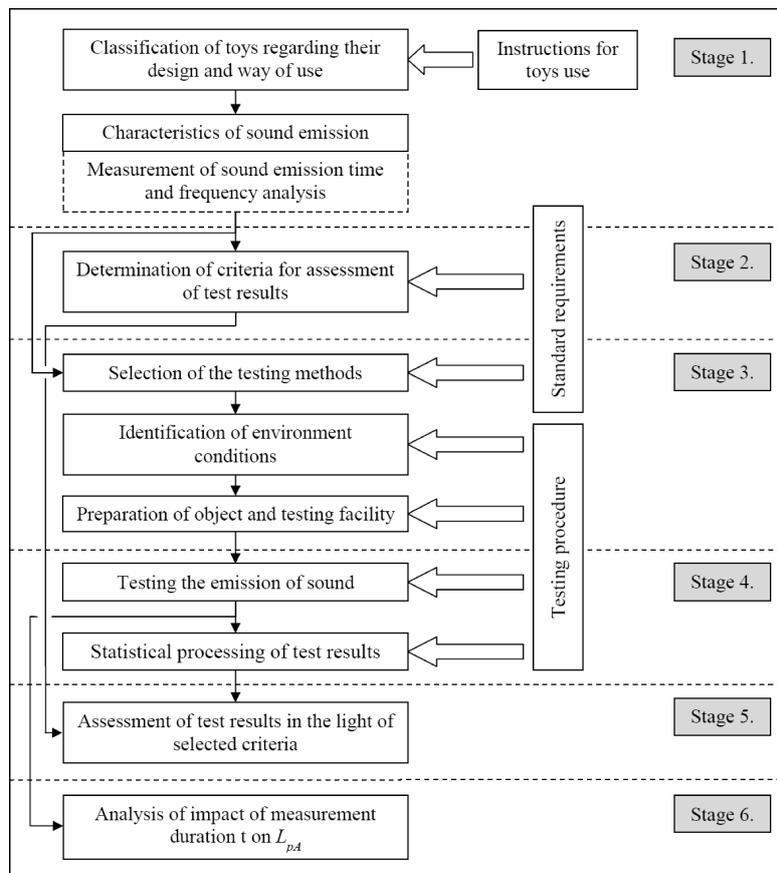


Fig. 1. Algorithm for the testing methodology.

Table 1. Classification of toys regarding their design and way of use.

Group symbol	Toy type	Structure of sound emitting source	Method of sound generation
A	Rattles	casing with rattling components made of plastic, metal, or wood	hit of rattling elements on the enclosure, when shaken by a child's hand
B	Close-to-the-ear toys	battery supplied electronic system in the toys enclosure put against child's ear	sound emitted from a loudspeaker in the casing after pressing the button
C	Hand-held toys	battery supplied electronic system in the toys handle held by a child	sound emitted from a loudspeaker in the casing after pressing the button
D	Large toys	battery supplied electronic system in one of the toy components	sound emitted from a loudspeaker in the toy component after pressing the button or tuning the knob
E	Musical box toys	battery supplied electronic system in the enclosure of a toy to be hung over child's head or to hold in a hand	sound emitted from a loudspeaker in the casing after pressing the button
F	Vehicles to be set into motion by a child	mechanical and pneumatic systems in toy components	hitting plastic toy components, after turning the knob or as a result of violent air flow when pressing / squeezing a toy component with the child's hand
G	Push toys	mechanical system in a toy component	hitting plastic toy components in the result of toy's movement

At the Stage 1 the toys were classified into the groups from A to G, considering their design and way of use (Table 1). The instructions of use, attached to toys as separate documents or placed on their packaging, were analyzed.

Percentage share of each type of toy groups among the tested toys is given in Fig. 2.

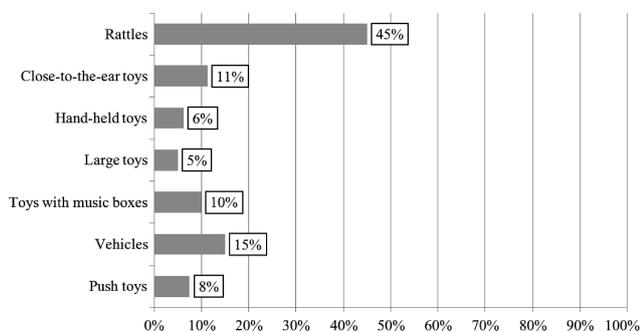


Fig. 2. Percentage share of each type of toy groups among the tested toys.

Rattles, belonging to group A, commonly used by youngest children make the most popular group among the tested toys. Close-to-the-ear toys – group B – are the important toys due to the risk of damage of hearing organ due to their vicinity with the ear.

To characterize the sound emission from each toy, the duration of emission was measured and frequency analysis was made. Sound emission of all tested toys was cyclical. Time of sound emission in one cycle varied from 3 to 240 seconds for toys with electronic systems. In the case of toys that generate sound by mechani-

cal knobs, sound emission time in one cycle did not exceed 5 s. There were no toys with continuous sound emission among the tested toys.

The frequency range of the sound emitted by the tested toys varied from 500 to 20,000 Hz. Examples of the frequency spectrum in one-third octave bands recorded for the following toys: rattle, phone, and vehicle are shown in Fig. 3.

The highest emission sound pressure levels in the third octave frequency were recorded for the following bands: 2500 Hz, 3150 Hz, 4000 Hz, 5000 Hz, 6300 Hz, 8000 Hz, 10000 Hz, and 12500 Hz for a toy in group A, 3150 Hz for a toy in group B, as well as 800 Hz and 1000 Hz for toys in group F.

At the next stage of the project, the criteria for assessment of the measurement results, depending on time of sound emission by the toy, were developed. The limit values specified in the EN 71-1:2011 + A2:2013 standard were the basis for the following emission sound pressure levels: L_{pA} , $L_{pAF\max}$, and $L_{pC\text{peak}}$. They include duration of sound emission and a distance of the toy from the microphone of the sound level meter with the related corrections K_t and K_l . Correction K_t , taking into account the impact of emission duration on the results of sound pressure level, was calculated according to the following relationship (National Institute for Occupational Safety and Health, 1998, p. 2):

$$K_t = -10 \log \frac{t}{t_0}, \quad (1)$$

where t is the time of continuous sound emission, in seconds, t_0 is the assumed time of using the toy by a child during one day, which is 7200 s.

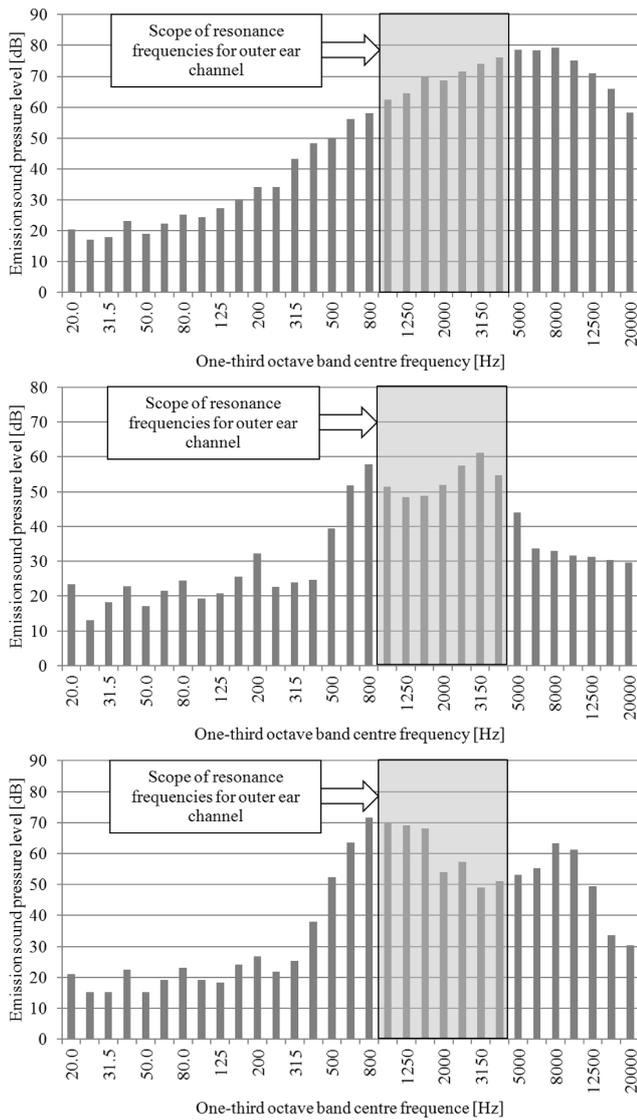


Fig. 3. One-third octave bands of sound emitted from toys of groups A, B, and F.

Correction K_l , taking into account the impact of measurement distance on emission sound pressure level, was calculated according to the following relationship (KOTARBIŃSKA, 1997):

$$K_l = -20 \log \frac{l}{l_0}, \quad (2)$$

where l is the measured distance between the toy and the microphone of the sound level meter in metres, l_0 is the distance of a toy from child's ear, in metres.

The criteria for assessment of the test results are given in Table 2.

At the stage 3 of the project, proper testing methods, specified in EN 71-1 + A3:2013 Standard, were selected for each group of toys, basing on toys' sound emission characteristics and taking into account the actual conditions as well as the way of using the toys by children. The methods take into account the distance of a toy from the child's ear, (2.5 cm for close-to-the-ear toys – group B – close contact with the ear, and 25 cm for other toys – length of child's arm). In the case of toys from groups B, C, D, E, and F, different positioning of the child's ear (direction of sound emission) was also taken into account. For toys belonging to the group D, E, F, G, the methods provided sound reflections from the horizontal surfaces on which they are used (table, floor). The method selected for toys from group G included the tests of emission sound pressure levels during toys' movement. To increase the reproducibility of the test results for the toys from group A, where sound emission levels depend on the force shaking the toy, participation of adults had been planned.

Before testing the electronic toys, the batteries charge levels were checked and in the case of any doubts they were replaced with new ones.

Table 2. Criteria for assessment of test results.

Group/toy type	Type of sound emission		Permissible emission sound pressure levels		
	continuous	cyclic	L_{pA} [dB (A)]	$L_{pAF \max}$ [dB (A)]	$L_{pC \text{ peak}}$ [dB (C)]
	Duration t [s]				
A/Rattles	–		85	–	110
B/Close-to-the-ear toys	$t > 2400$	$t > 30$	60		
	$720 < t \leq 2400$	$5 < t \leq 30$	65		
	$t \leq 720$	$t \leq 5$	70		
C/Hand-held toys D/Large toys E/Musical box toys F/Vehicles	$t > 2400$	$t > 30$	80		
	$720 < t \leq 2400$	$5 < t \leq 30$	85		
	$t \leq 720$	$t \leq 5$	90		
G/Push toys	$t > 2400$	$t > 30$	–	80	
	$720 < t \leq 2400$	$5 < t \leq 30$		85	
	$t \leq 720$	$t \leq 5$		90	

The tests were carried out in a laboratory, with a limited impact of reflected and absorbed sounds on the sound pressure level on the tested surface. For this purpose, the K_{2A} environmental correcting factor, determined on the basis of sound absorption in the room, which did not exceed 2 dB, was entered. In addition, the environmental conditions regarding temperature and humidity as well as barometric pressure were checked in the aspect of meeting the requirements for measuring instruments put to their manufacturers.

Then, a testing facility with a SON-50 integrating-averaging sound level meter of the first class accuracy according to PN-EN 61672-1:2005 Standard and a WK-21 sound surround microphone were constructed. According to the testing procedure (GRYNKIEWICZ-BYLINA *et al.*, 2014), the sound level meter was calibrated using KA-50 acoustic calibrator of the first class accuracy, according to PN-EN 60942:2005 Standard.

For each group of toys the location of measuring points, taking into account toy geometrical parameters, was determined. The distance of the sound level meter's microphone from the toy at each measuring point was assumed as equal to (50 ± 1) cm. The difference between the above distance and the real distance, resulting from the position of the toy with respect to the child's ear is included in the evaluation criteria (Table 2). Toys and measuring points were arranged in such a way as to minimize the sound wave reflections from the laboratory walls.

At the stage 4, tests of sound emission were carried out for the seven groups of toys using the measurement methods which vary in position of the measuring points and in the number of operators taking part in measurements.

For the toys from A group (rattles) measurements were taken at one point located over the reflecting surface, during shaking the rattle by an operator. Three adults repeated the measurements.

Measurement of emission sound pressure level from B (close-to-the-ear toys) and C (hand-held toys) toy groups were taken at six measuring points located as in Fig. 4 (EN 71-1, 2013).

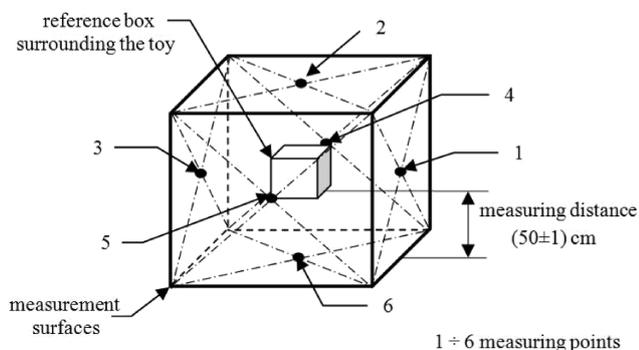


Fig. 4. Arrangement of measuring points 1–6 for toys from B and C groups.

For toys from groups D, E, F (large toys, music box toys, and vehicles) the emission sound pressure level was measured in five points, located identically as in the case of the previous toy groups. Due to use of such toys on a floor or on a table, which are reflecting surfaces, point No. 6 was not taken into account in the measurements.

In the case of G group of toys (for pushing) measurements of sound pressure level were taken in two measuring points located on both sides of the movement track.

Duration of measurements depended on the time of sound emission by the tested toy. All emission cycles were considered. In the case of emission cycle shorter than 15 s, it was repeated until reaching the above time. At each measuring point, the test was repeated three times. Operators taking part in the measurements – turning on/off sound emission using buttons or knobs in the case of toys from groups B to G and shaking the rattles (group A) – acted in a way that minimizes the impact of their hands on the level of the emitted sound.

For the selected toys from group A, which is characterized by the shortest duration of one cycle of sound emission, the measurements of emission sound pressure level for a single event (one shake of a rattle of duration 1 s) L_{pA1s} , were also taken.

During tests, also the impact of a background noise was measured in the selected points.

Each measurement was recorded in the form of sound emission time curves. An example of time curves from the measurement of sound emission is presented in Fig. 5.

Time curves, recorded during the measurements, were analyzed using Son-50 Monitor ver. 2.13 computer programme. For each curve, the highest levels of L_{pA} , $L_{pAF\max}$, and $L_{pC\text{peak}}$ were determined. To average L_{pA} , duration of the shortest sound emission cycle was assumed as equal to (15 ± 1) s.

In the case of measurements where difference between the measured sound pressure level and background noise exceeded 10 dB, correction K_1 was added, determined from the following relationship (PLEBAN, AUGUSTYŃSKA, 2000):

$$K_1 = -10 \log(1 - 10^{-0.1\Delta L}), \quad (3)$$

where ΔL is the difference between the measured sound pressure level and background noise, in dB.

The following values were calculated on the basis of the test results:

- for A group toys, the arithmetic mean of L_{pA} from the measurements taken by three operators,
- for B–G groups toys, the arithmetic mean of L_{pA} from three repetitions of the measurements taken in the point at which the highest values were obtained,

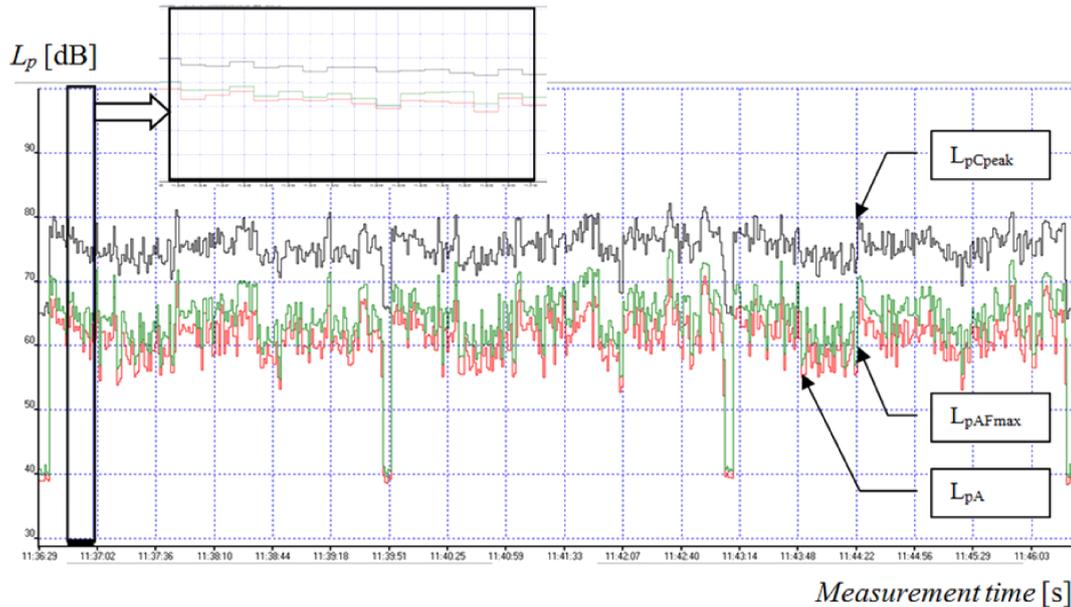


Fig. 5. Time curves from sound emission measurement for close-to-the-ear toy from group A.

- for G groups toys, the highest $L_{pAF\max}$ from three repetitions of the measurements,
- for all toys the highest L_{pCpeak} from three repetitions of the measurements.

In the case of measurements of L_{pA} in A group toys, the standard correction of -5 dB (A), associated with participation of adults in the measurements, was included.

Measurements' uncertainty was also estimated, according to the requirements of testing procedure (GRYNKIEWICZ-BYLINA *et al.*, 2014). In calculation of uncertainty of sound emission measurements, the following parameters were taken into account:

- accuracy of the measuring instruments,
- imperfection of the measuring method,
- impact of meteorological conditions and background noise,
- acoustic absorptivity and geometric parameters of the laboratory, in which the tests were conducted,
- instability of sound emission by the tested object,
- measurements repeatability,
- competences of the personnel.

Sources of uncertainty as well as the associated factors affecting the measurement results is given in Fig. 6 in the form of an Ishikawa diagram.

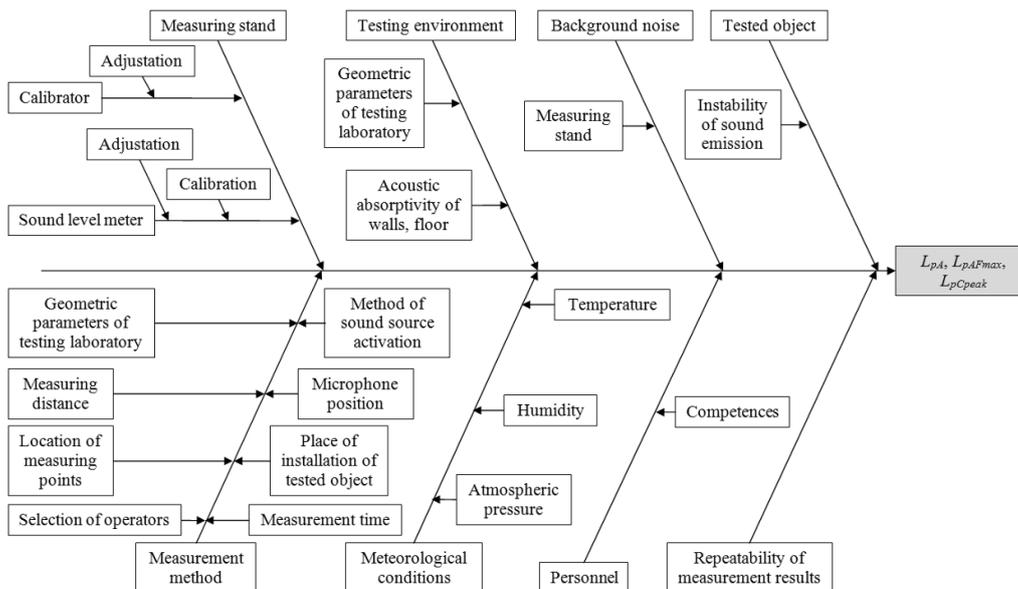


Fig. 6. Sources of uncertainty in measurements of sound emission from toys.

The method for estimation of uncertainty was based on the rules presented in the guides (Committee for Guides in Metrology, 2010; European Co-operation for Accreditation, 2013; ELLISON, WILLIAMS, 2012). In the result of the calculations, it was determined that the expanded uncertainty of sound emission measurements is within the range (3.2–3.7) dB, which makes 4% to 7% of the measured amount.

At the stage 5, the measurement results were assessed in the light of the criteria formulated at the stage 2.

The results of L_{pA} and L_{pA1s} measurements, taken for A group toys, were compared, and basing on this information, the impact of measurement duration on the result of emission sound acoustic pressure was determined at the stage 6.

3. Test results

Results of emission sound pressure level for each toy group are given in Table 3 (GRYNKIEWICZ-BYLINA, RAKWICZ, 2015).

The recorded emission sound pressure levels were within the following ranges:

- from 43.7 to 82.1 dB (A) for L_{pA} ,

- from 78.2 to 80.1 dB (A) for $L_{pAF\max}$,
- from 69.5 to 123.8 dB (C) for $L_{pC\text{peak}}$.

The highest L_{pA} and $L_{pC\text{peak}}$ levels were recorded in the case of rattles, belonging to A group and the lowest levels were recorded for toys with music boxes from E group and vehicles from F group.

The highest differences between the maximal and minimal L_{pA} and $L_{pC\text{peak}}$, exceeding 30 dB, were reported in rattles (group A) and close-to-the-ear toys (group B). Different solutions of the sound source, including placing the hitting elements inside toy enclosures (sound dumping) or outside it, undoubtedly affected the tests of rattles. Low emission sound pressure levels in the case of close-to-the-ear toys could be the result of using elements dumping the sound generated by electronic toys.

Levels of L_{pA} , $L_{pAF\max}$, and $L_{pC\text{peak}}$ were compared with the criteria for assessment of the results given in Table 2 and are shown in Fig. 7.

The analysis of the results has shown some exceedances in permissible levels of $L_{pC\text{peak}}$ in rattles of group A and L_{pA} in close-to-the-ear toys of group B.

The results of $L_{pC\text{peak}}$ measurements for rattles are given in Fig. 8, and specification of L_{pA} for close-to-the-ear toys in Fig. 9.

Table 3. Results of emission sound pressure level for toys.

Group/Toy type	Number of toys	Statistical parameters	L_{pA} [dB (A)]	$L_{pAF\max}$ [dB (A)]	$L_{pC\text{peak}}$ [dB (C)]
A/Rattles	36	x_{\min}	46.3	–	78.3
		x_{\max}	82.1	–	123.8
		x_{av}	64.6	–	96.6
B/Close-to-the-ear toys	9	x_{\min}	48.4	–	69.5
		x_{\max}	77.7	–	102.6
		x_{av}	60.8	–	85.4
C/Hand-held toys	5	x_{\min}	61.9	–	76.4
		x_{\max}	80.2	–	93.0
		x_{av}	72.3	–	85.3
D/Large toys	4	x_{\min}	64.9	–	72.3
		x_{\max}	71.0	–	97.1
		x_{av}	68.1	–	85.3
E/Toys with music boxes	8	x_{\min}	43.7	–	76.5
		x_{\max}	50.6	–	83.0
		x_{av}	47.4	–	79.5
F/Vehicles	12	x_{\min}	63.1	–	85.7
		x_{\max}	79.2	–	106.5
		x_{av}	74.9	–	97.5
G/Toys for pushing	6	x_{\min}	–	78.2	85.2
		x_{\max}	–	80.1	106.7
		x_{av}	–	79.3	94.4

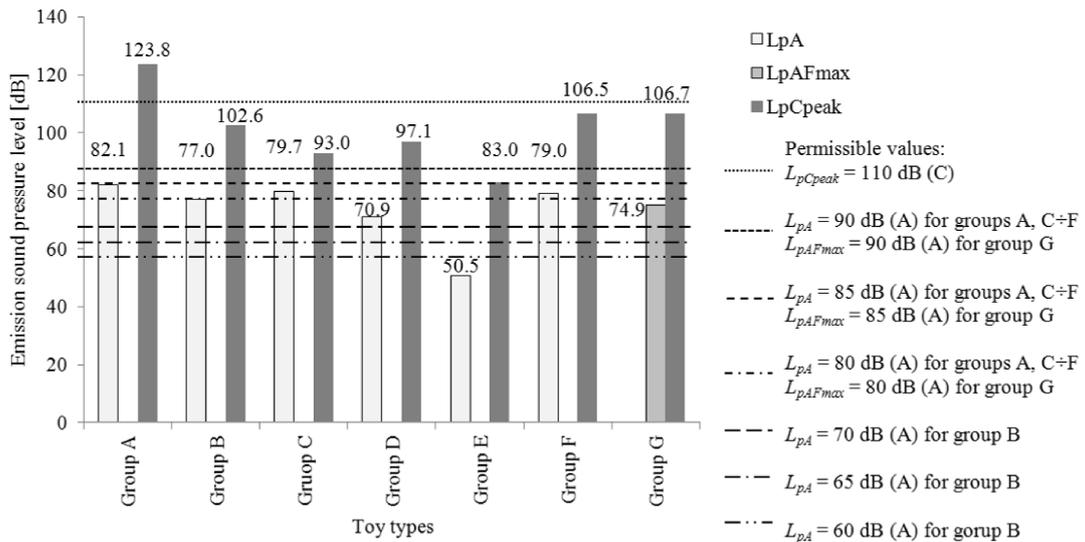


Fig. 7. Highest levels of L_{pA} , L_{pAFmax} , and L_{pCpeak} in relation to the permissible values in all toy groups obtained.

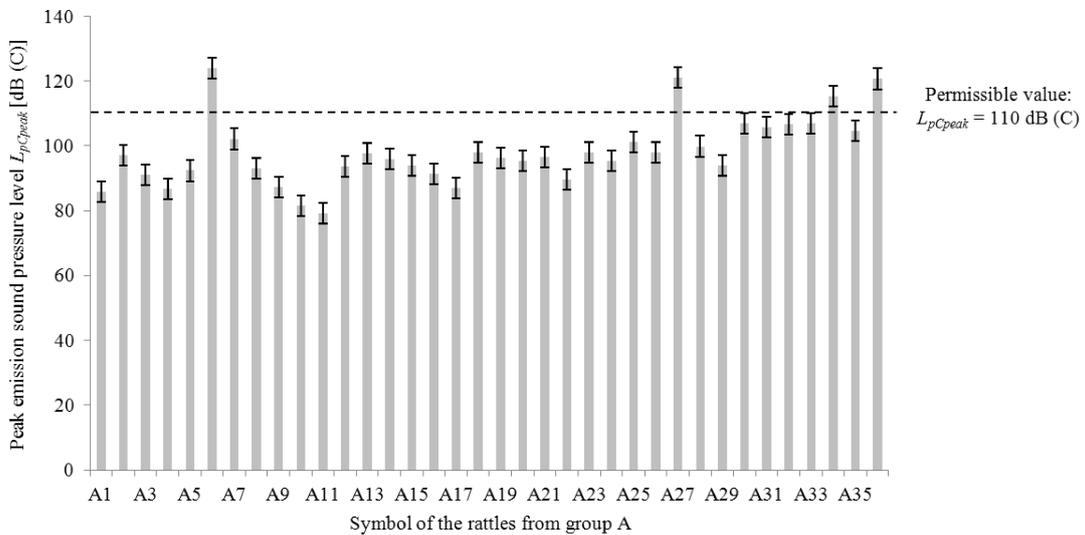


Fig. 8. Results of L_{pCpeak} measurements for rattles (group A).

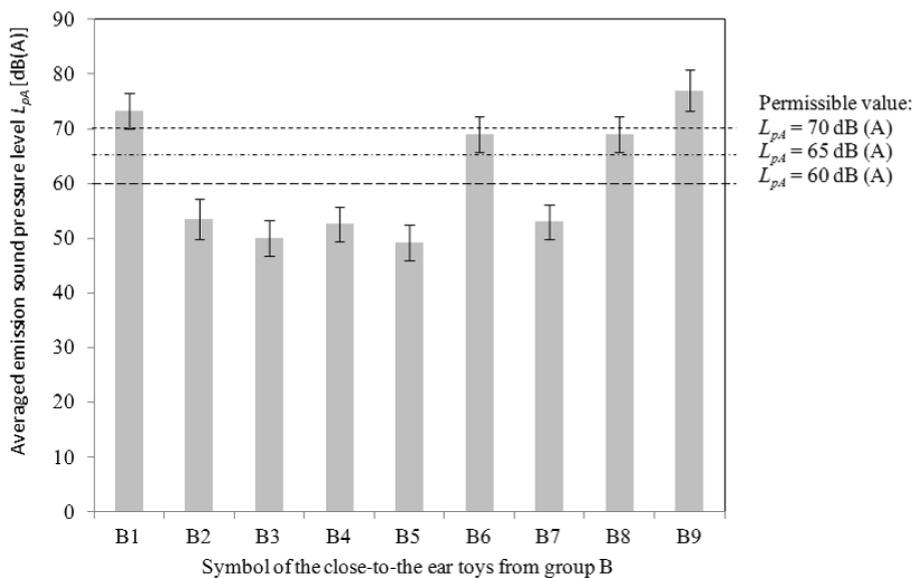


Fig. 9. Results of L_{pA} measurements for close-to-the-ear toys (group B).

An analysis of measurements for toys from A and B groups has shown exceedances of permissible values in 4 rattles and 4 close-to-the-ear toys. A detailed specification of the measurement results for the above toys is given in Table 4.

The mentioned exceedances varied from 5.3 to 13.8 dB (C) in the case of the rattles (group A), and from 4.0 to 13.2 dB (A) in the case of the close-to-the-ear toys (group B).

The measurement results of L_{pA} and L_{pA1s} for rattles – samples A30–A33 taken within $t = 1$ s and within 15 s – were compared to determine the im-

portant of measurement duration on the result of emission sound pressure levels, see Table 5.

The comparative analysis of the results presented in Table 5 has shown a significant impact of extension of the measurement duration from 1 s to 15 s on the result of L_{pA} level. The sound level increased by 10 times. The obtained result justifies taking into account the time of sound emission by the toy. That also indicates the necessity of improvement of the method to consider the real time of using the toy, which in majority of cases exceeds 15 s.

Table 4. Specification of measurement results for toys with over-standard sound emission.

Toy type	Symbol of the tested sample	Assessment criteria [dB (A)]/[dB (C)]	Measurement results [dB (A)]/[dB (C)]						
			Measur. No.	L_{pCpeak}			L_{pA}		
				x	x_{max}	U^*	x	x_{av}	U^*
Rattle	A6	$L_{pCpeak} \leq 110$ dB (C)	1	122.3	123.8	± 3.2	-		
			2	123.8					
			3	120.1					
	A27		1	119.9	121.0	± 3.2			
			2	121.0					
			3	118.6					
	A34		1	113.6	115.3	± 3.2			
			2	113.6					
			3	115.3					
	A36		1	120.6	120.6	± 3.2			
			2	116.6					
			3	114.8					
Telephone	B1	$L_{pA} \leq 60$ dB (A)	1	-			73.4	73.2	± 3.2
			2				73.1		
			3				73.2		
	B6	$L_{pA} \leq 65$ dB (A)	1				70.5	69.0	± 3.7
			2				69.1		
			3				67.4		
	B8	$L_{pA} \leq 65$ dB (A)	1				69.3	69.0	± 3.2
			2				68.8		
			3				68.8		
	B9	$L_{pA} \leq 70$ dB (A)	1				76.3	77.0	± 3.3
			2				77.1		
			3				77.7		

^{/*} expanded uncertainty at 95% confidence level and coverage factor $k = 2$.

Table 5. Measurement results of L_{pA} and L_{pA1s} for rattles.

Toy name	Toy symbol	Measurement results [dB (A)]		$L_{pA} - L_{pA1s}$
		L_{pA1s} ($t = 1$ s)	L_{pA} ($t = 15$ s)	
Rattle	A30	67.1	76.3	9.2
	A31	65.2	75.6	10.4
	A32	66.6	77.7	11.1
	A33	66.7	77.0	10.4

4. Summary

Toys that emit sound pose a threat to the environment of children's life, especially of those in the age of three years old, when the hearing organ is at the early stage of development and is sensitive to noise.

The risk associated with the adverse, not related to hearing, effects to children, affecting their intellectual development, is intensified by high-level sounds of long-time emission. The design of the sound emission sources in toys is diversified, ranging from simple mechanical solutions, as in the case of rattles to complex mechatronic systems (interactive toys, recreating popular equipment such as mobile phones, applied to the ear). There is sound emission of high level in the frequency range, which is best received by the child's ear and could cause damage to the hearing organ. This range of sound frequencies was identified at the stage of the characteristics of objects for testing. The obtained results confirm the values obtained by HARAZIN (2010), JOUBERT *et al.* (2012), SLEIFER *et al.* (2013), and YAREMCHUK *et al.* (1997).

The procedure accepted for testing, based on the author's algorithm of testing methodology allowed determining the sound emission levels for numerous groups of toys, diversified in designs and ways of usage.

The results of the tests confirmed the presence of the toys with over standard acoustic emission on the European market. They also drew attention to some toys, for which it is necessary to take appropriate actions aiming at their withdrawal from the market. Among 80 samples of the tested toys, about 10% emitted sound exceeding acceptable values of averaged (L_{pA}) and peak emission sound pressure level ($L_{pC_{peak}}$). The test results have shown that use of rattles and close-to-the-ear toys, where exceedances up to 14 dB were reported, is especially dangerous for children under age of three.

In the case of toys emitting sound cyclically, the test results also indicated a significant impact of extension of measurement time on the results of emission sound pressure level. For the tested samples, an increase of the measured values by 10 dB was observed, when increasing the number of measuring cycles from one lasting 1 s to multiple cycles lasting 15 s. That fact indicates that further improvement of the methods for testing the sound emission from toys is needed for better recreation of real conditions of using the toys.

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