Title
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Journal
International journal of pediatric otorhinolaryngology, 79(12)

ISSN
0165-5876

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Publication Date
2015-12-01

DOI
10.1016/j.ijporl.2015.09.018

Peer reviewed

International Journal of Pediatric Otorhinolaryngology 79 (2015) 2086–2089

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Loudness and acoustic parameters of popular children's toys☆

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ARTICLE INFO

Article history:
Received 28 June 2015
Received in revised form 5 September 2015
Accepted 13 September 2015
Available online 25 September 2015

Keywords:
Toys
Hearing loss
Noise induced hearing loss

ABSTRACT

Objective: This project was conducted to evaluate the loudness and acoustic parameters of toys designed for children. In addition, we investigated whether occluding the toys' speaker with tape would result in a significant loudness reduction; thereby potentially reducing the risk of noise induced hearing loss.
Methods: Twenty-six toys were selected after an initial screening at two national retailers. Noise amplitudes at 0.25, 0.5, 1, 2, 4, and 8 kHz were measured using a digital sound level meter at a distance of 0 and 30 cm. The toys' speakers were then occluded using adhesive tape and the same acoustic parameters were re-measured.
Results: Mean maximum noise amplitude of the toys at 0 cm and 30 cm was 104 dB A (range, 97–125 dB A) and 76 dB A (range, 67–86 dB A), respectively. Mean maximum noise amplitude after occlusion at 0 cm and 30 cm distances was 88 dB A (range, 73–110 dB A) and 66 dB A (range, 55–82 dB A), respectively, with a p-value <0.001.
Conclusions: Proper use of the loudest toys at a distant of 30 cm between the speaker and the child's ear will likely not pose a risk of noise-induced hearing loss. However, since most toys are used at closer distances, use of adhesive tape is recommended as an effective modification to decrease the risk of hearing loss.

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1. Introduction

Noise-induced hearing loss (NIHL) is a major cause of hearing impairment in the United States. It results from a permanent change in hearing thresholds secondary to recurrent or prolonged exposure to loud sound levels [1,2]. Although aging and genetics are major risk factors, children, teenagers, and young adults are increasingly at risk of tinnitus and hearing loss from recreational noise exposure [3]. It has been suggested that noise exposure in children may induce damage that would otherwise not occur in older individuals [4,5].

Hearing loss in children can lead to academic, psychosocial, and developmental problems [6,7]. Some suggest that even a unilateral hearing loss and mild bilateral hearing loss can lead to stunted psychoeducational development [8]. Currently, NIHL is not curable, thus preventive methods such as early recognition of the insults, and behavior modifications, are used to delay the onset of hearing impairment [9].

In the last decade, the adverse effects of toy noise exposure has been increasingly recognized by the United States, European Union, as well as by International Organization of Standards (ISO), leading to the creation of new safety standards (ASTM, E.U., Canada, ISO) [10–13]. The standards are relatively similar; and, studies reveal that there are still toys in the market that do not comply with them. For example, McLaren in New Zealand found that 21% of toys they tested did not conform to the acoustic criteria in the ISO standard. Similar findings were noted in the United States [14–17].

This study was conducted to evaluate the efficacy of sound modulation of many of the popular children's toys available at major national retailers. The peak sound pressure levels and their corresponding frequencies in popular toys were measured. Thereafter, we investigated the possibility of significant reduction in the peak sound pressure level (SPL) and frequency by occluding the toys' speaker.

2. Methods and materials

This study was performed during the months of November and December 2013 to screen for the peak SPL of commercially

☆ Presented at the American Society of Pediatrics Otolaryngology (ASPO), Las Vegas, NV (May 14–18, 2014).

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http://dx.doi.org/10.1016/j.ijporl.2015.09.018
0165-5876/Published by Elsevier Ireland Ltd.

available toys. A preliminary screening was performed using a portable sound level meter (Radioshack Sound Level Meter, Forth Worth, TX) at multiple locations of two large national retail stores. All sound producing toys were tested. From the initial group of 114 toys, those that exceeded 80 dB at speaker level were selected for further evaluation. This initial screening led to twenty-six popular toys designed for a variety of age groups that were subsequently analyzed as below.

The toys were then further tested in a standard audiometric booth (double-walled anechoic chamber) in our laboratory. For each toy, measurements were taken at 0 and 30 cm from the speaker using a digital sound meter (Sound Level Meter 2238 Mediator; Bruel & Kjaer, Narum, Denmark). The sound meter was set to record the greatest amplitude of sound, *LCpeak*, expressed in dB, across all frequencies. Then, the sound intensities at various corresponding frequencies for each toy, at both distances, were also measured. Subsequently, the above process was repeated with the speakers occluded using 3M 2307 adhesive masking tape (1/2 in. × 60 yd, tensile strength: 23 lb) which is also used as a packaging tape (Fig. 1). We detected the location of the toys' speaker and then we cut the tape based on the length of the speaker. If the width of the speaker was more than the width of the tape, we used more tape to cover it completely. However, we avoided to overlap the tapes on each other at the speaker site in order to maintain the same thickness coverage for all speakers. In another words, we covered all the surface of the speaker by only one layer of the tape.

To obtain each measurement, the sound-producing button was pushed once and allowed to play for its natural course. If the toy had multiple buttons, the button with the loudest sound was utilized. These measurements were used to calculate a mean peak SPL for each toy at the two distances and conditions, i.e., unmasked vs. masked, as well as their corresponding frequencies (Table 1).

The range and means of all values were thereafter computed. Standard deviation (SD) was calculated using a baseline cutoff of 85 dB. Paired *t*-tests were performed to assess mean reduction in peak SPL and frequency by masking at 0 cm and 30 cm. All statistical procedures were performed using PASW (SPSS, Chicago, Illinois, USA) A p-value of <0.05 was considered to be statistically significant.

Fig. 1. Taping the toys' speaker using 3M 2307 adhesive making tape.

3. Results

Mean maximum noise amplitude before using tape on the speaker at 0 cm and 30 cm was 104 dB A (range, 97–125 dB A) and 76 dB A (range, 67–86 dB A), respectively. All the toys produced noise at 65 dB A SPL at speaker level, whereas 2 (14%) produced noise at more than 85 dB A SPL at a 30 cm distance.

Mean peak SPL after masking with tape at 0 cm and 30 cm distance was 88 dB A (range, 73–110 dB A) and 66 dB A (range, 55–82 dB A), respectively. This was a statistically significant decrease in noise amplitude after using tape to cover the speaker ($p < 0.001$).

Mean peak SPL for each frequency are summarized in Table 2. At the distance of 0 cm, masked toys showed a significant reduction in SPL from 0.5 to 8.0 kHz. At the distance of 30 cm, masked toys demonstrated a significant reduction in SPL from 1.0 to 4 kHz.

Table 1
List of tested toys, with corresponding peak sound pressure levels, in dB.

Toys	0 cm (no tape)	0 cm (taped)	30 cm (no tape)	30 cm (taped)	Recommended age
Fischer-Price 1-2-3 Crawl-Along snail	103.0	82.0	70.0	56.0	<3 years old
Bright starts Chuck & Learn Barn (Pig)	99.0	88.0	86.0	65.0	<3 years old
Fischer Price Laugh & Learn Music Player	97.0	90.0	69.0	67.0	<3 years old
Sesame Street Let's Rock Grover Microphone	101.0	98.0	79.0	72.0	<3 years old
Sesame Street Elmo Guitar	101.0	82.0	73.0	62.0	<3 years old
Thomas & Friends Light-up Talking Percy	108.0	78.0	72.0	55.0	<3 years old
Fischer Price Laugh & Learn Guitar	97.0	86.0	69.0	63.0	<3 years old
Leap Frog Chat & Count	106.0	95.0	67.0	60.0	<3 years old
Leap Frog Lil' Phone Pal	106.0	85.0	69.0	63.0	<3 years old
B Your Turns	90.0	85.0	71.0	66.0	<3 years old
Tonka Toughest Minis UTV Police	101.0	94.0	84.0	82.0	3+ years old
Road Rippers Helicopter	97.0	88.0	73.0	64.0	3+ years old
Road Rippers Ambulance	101.0	87.0	81.0	64.0	3+ years old
Tonka Might Fleet Fire	104.0	83.0	79.0	68.0	3+ years old
Jakk's Pacific The Little Mermaid Musical Necklace	101.0	91.0	73.0	68.0	3+ years old
Disney's Doc McStuffins on Call Cell Phone	106.0	96.0	78.0	60.0	3+ years old
Sofia the First Time to Shine Sing-Along Boombox	111.0	92.0	85.0	72.0	3+ years old
Leap Frog Scribble & Write	105.0	84.0	78.0	65.0	3+ years old
Road Rippers K-9 units	99.0	85.0	78.0	64.0	3+ years old
Fischer-Price Skate & Spin Dora & Boots	119.0	89.0	86.0	69.0	3+ years old
Disney's Minnie Tinkle Bows Play Vacuum Cleaner	105.0	N/A	82.0	N/A	3+ years old
Bop it Tetris	103.0	73.0	76.0	62.0	8+ years old
Bop it Carabiner edition	98.0	78.0	69.0	64.0	8+ years old
Bop it! Smash	125.0	90.0	84.0	61.0	8+ years old
Twister Dance Rave	110.0	107.0	80.0	82.0	8+ years old
Legend Smoke N' Barrel	108.0	92.0	80.0	64.0	8+ years old

Table 2
Sound pressure level modulation at corresponding frequencies, at both distances.

		Mean SPL			
	Frequency (kHz)	SPL—no tape (dB)	SPL—taped (db)	SPL change (dB)	*p*-Value
0 cm	0.25	62.5	57.5	5.0	0.09
	0.5	78.7	70.7	8.0	0.01
	1	86.2	81.8	4.4	0.02
	2	84.0	77.8	6.2	0.002
	4	79.9	70.6	9.3	<0.001
	8	68.7	61.6	7.1	0.02
30 cm	0.25	36.3	38.8	−2.5	0.24
	0.5	52.0	48.4	3.6	0.19
	1	65.2	60.9	4.3	0.03
	2	62.4	58.0	4.4	0.04
	4	57.5	53.1	4.4	0.03
	8	41.7	44.6	−2.9	0.18

4. Discussion

Our results confirm that despite the pre-existing standards for maximum sound thresholds, excessively noisy toys are still on the market. Such highly intense sound pressure levels, even after a single exposure, can lead to significant hearing loss and tinnitus [18,19]. In children, these loud sounds may irreversibly damage hearing at a young age, which can be compounded by aging and further noise damage later in life.

To mitigate these risks, the most recent U.S. standards (Table 3) recommend that toys designed to emit non-explosive sounds should be no louder than 65 dB if continuous (A-weighted SPL, *LAe*), and 95 dB if impulsive (C-weighted SPL, *LCpeak*), when close to the ear (ASTM). For the purposes of this discussion, *LAe* and *LCpeak* can be used interchangeably, as they are considered to be equivalent across the measured frequencies of our toys [20]. When compared to national standards, our results indicate that the majority of the tested toys exceed both the close to ear and away from ear sound threshold recommendations. The mean peak SPL before using tape on toys at 0 cm was 103.9 dB A (range, 97–125 dB A), which is considerably higher than the recommendation of 95 dB A. None of the toys measured were compliant with this peak SPL recommendation (Table 1).

Sound masking with adhesive tape (Scotch shipping packaging tape) was effective in reducing the peak SPL from 103.9 dB A to 87.9 dB A. The peak SPL on all the toys, except three (Sesame Street Let's Rock Grover Microphone, Disney's Doc McStuffins on Call Cell Phone, and Twister Dance Rave), was decreased to at or below the recommended 95 dB *impulse* peak SPL with taping ($p < 0.001$), but still did not comply with the *continuous* sound level standards. However, the 95 dB maximum is equivalent to a jackhammer at 50′, which is extremely loud, and can still damage the auditory system of children when played continuously. We found that the most effective sound reduction was obtained at 30 cm, with taping. At this distance, the peak SPL decreased from 76.3 dB A to 66.0 dB A (range, 55–82 dB A), $p < 0.001$, when occluded, which is approximately the SPL of a normal conversation.

Table 3
ASTM F 963-11, Section 4.5—Standards for sound producing toys.

Type of sound	Location	Criteria
Continuous	Close to the ear	A-weighted SPL, L_{Ae}, <65 dB
Continuous	Away from ear	A-weighted SPL, L_{Ae}, <85 dB
Impulsive	Close to ear	C-weighted SPL, L_{Cpeak}, <95 dB
Impulsive	Away from ear	No standard

The external auditory canal development continues until the age of 2 years, and thus its resonance frequency tends to be higher under that age [21]. As a result, young children are more susceptible to high frequency noise trauma [22]. Our study revealed that in addition to producing sounds greater than the recommended 95 dB at ear level, 100% of the toys do so at frequencies at or above 2000 Hz (Table 2), which may be lead to high frequency noise trauma. Similarly, a study by Harazin on 16 different toys showed that 81% of the toys emitted dominant sound levels in octave band at the frequency range from 2 kHz to 4 kHz [23]. Sleifer et al., also found that half of the toys they tested operated at a frequency above 2000 Hz and almost all of them produced sounds above 85 dB, regardless of the distance from the sound meter [24].

While both the volume and frequencies of noise emitted from these toys can be excessive, the use of occlusive tape significantly decreases the SPL across most frequencies, including the higher frequency ranges (Table 2). However, when played close to the ear, occlusive taping does not decrease the SPL below the recommended 95 dB at ear level at nearly all frequencies for several of the toys. At 30 cm, the SP levels were compliant with ASTM standards at all frequencies, with or without taping.

Although NIHL is well described in the adult population, little is known about the hazardous effects of loud noises on children. Toys are a significant source of hazardous sounds to children, which may contribute to hearing loss [25] A child's central auditory system does not fully mature until 10–12 years of age [26], so it is recommended that children remain in a relatively quiet environment for better processing and comprehension of all encountered information [4,27,28]. Some propose that chronic noise exposure during childhood affects basic language functions that may damage the process of reading acquisition [29,30]. Hearing impairment may disrupt a child's development in speech perception, listening comprehension educational, psychological, and social development [6,7]. These effects may be small in magnitude; however, they should not be neglected because there is a possibility of longstanding cumulative risk factors that may lead to hearing loss [31,32].

The benefits of occluding the toys' speakers with tape are clear, though there are certain limitations to using tape for masking in toys. While it leads to an immediate and simple solution, there is a certainly a low but real risk of removal and ingestion by children [33]. One must also be aware of the fact that taping may disturb the ventilation of the electronic components in some toys, which may cause malfunction. Additionally, some toys do not have a specific and single external location for their speaker and their design, makes them impossible to be occluded by tape (e.g., Disney's Minnie Tinkle Bows Play Vacuum Cleaner). However, using occlusive tape, while at safe distances, remains the most convenient option for intervention that can help mitigate the detrimental effects of loud toys.

One of the weaknesses of this study is that only selected retailers were surveyed. However, they are some of the most popular retailers in the United States, representing a significant volume of holiday toy sales. In addition, there is an inherent selection bias, as all toys were selected to be above the 80 dB level, while in a store environment. Thus, the true percentage of toys that do not comply with national and international standards remains unknown. It is clear that a sizeable volume of toys on the market is not compliant. Finally, sound levels were tested at static distances, which do not represent an accurate simulation of how children typically play with toys.

5. Conclusion

There are still a considerable number of toys on the market that produce unsafe sound pressure levels, which may contribute to irreversible hearing damage in a child's auditory system. The current

standards suggested by safety organizations are not strictly followed by toy manufacturers. Thus, proper use of loud toys with 30 cm between the speakers and the child's ear, with the speakers taped, should pose a minimal risk of NIHL from an otherwise loud noise exposure. However, since most children use toys at closer distances, use of tape is highly recommended to mitigate risk of NIHL, but the practice is still not enough to reduce the sound pressure levels at the speaker to below the recommended standards.

Source of funding

None.

Conflicts of interest statement

None.

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