

Infant Sleep Machines and Hazardous Sound Pressure Levels

AUTHORS: Sarah C. Hugh, MD,^a Nikolaus E. Wolter, MD,^a Evan J. Propst, MD, MSc,^{a,b} Karen A. Gordon, PhD,^{a,b} Sharon L. Cushing, MD, MSc,^{a,b} and Blake C. Papsin, MD, MSc^{a,b}

^aDepartment of Otolaryngology, Head and Neck Surgery, University of Toronto, Toronto, Canada; and ^bHospital for Sick Children, Toronto, Canada

KEY WORDS

hearing loss, noise induced, infant development, infant equipment, noise, sleep

ABBREVIATIONS

CCOHS—Canadian Centre for Occupational Health and Safety
dBA—A-weighted dB

ISM—infant sleep machine

NIOSH—National Institute for Occupational Safety and Health

Dr Hugh designed the study, acquired and analyzed data, and drafted the initial manuscript; Dr Wolter designed the study, acquired data, and reviewed and revised the manuscript; Drs Propst, Gordon, Cushing, and Papsin conceptualized and designed the study and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

www.pediatrics.org/cgi/doi/10.1542/peds.2013-3617

doi:10.1542/peds.2013-3617

Accepted for publication Jan 21, 2014

Address correspondence to Blake C. Papsin, MD, MSc, Department of Otolaryngology, Head and Neck Surgery, 555 University Ave, Toronto, ON, Canada M5G 1X8. E-mail: blake.papsin@sickkids.ca

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

Copyright © 2014 by the American Academy of Pediatrics

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.



WHAT'S KNOWN ON THIS SUBJECT: Many parenting Web sites encourage use of infant “sleep machines” to play ambient noise while infants sleep. Noise recommendations for hospital nurseries suggest a limit of 50 A-weighted dB, whereas occupational standards limit exposure times for noise >85 A-weighted dB.



WHAT THIS STUDY ADDS: We measured the maximum sound level outputs of infant sleep machines and found that several devices are capable of producing levels that may be damaging to infant hearing and may be detrimental to auditory development.

abstract

FREE

BACKGROUND AND OBJECTIVE: Infant “sleep machines” (ISMs) produce ambient noise or noise to mask other sounds in an infant’s room with the goal of increasing uninterrupted sleep. We suggest that the consistent use of these devices raises concerns for increasing an infant’s risk of noise-induced hearing loss. We therefore sought to determine the maximum output levels of these sleep machines.

METHODS: Sound levels of 14 ISMs played at maximum volume were measured at 30, 100, and 200 cm from the machine using correction factors to account for a 6-month-old’s ear canal.

RESULTS: Maximum sound levels at 30 cm were >50 A-weighted dB for all devices, which is the current recommended noise limit for infants in hospital nurseries. Three machines produced output levels >85 A-weighted dB, which, if played at these levels for >8 hours, exceeds current occupational limits for accumulated noise exposure in adults and risks noise-induced hearing loss.

CONCLUSIONS: ISMs are capable of producing output sound pressure levels that may be damaging to infant hearing and auditory development. We outline recommendations for safer operation of these machines. *Pediatrics* 2014;133:1–5

Noise leads to sleep disturbance and arousal in infants,^{1,2} and acoustic disturbance can have direct physiologic effects on infants and can negatively influence both the quality and quantity of their sleep. Today, in the noisy environment in which many professionals work, live, and raise their families, the acoustic environment can often disturb an infant's (and possibly secondarily, parents') sleep. Infant "sleep machines" (ISMs) have been used as an increasingly widespread solution to these acoustic interruptions. ISMs have been designed to produce noise for 2 purposes: to provide ambient noise to soothe an infant during sleep or to mask disturbing environmental sounds by producing louder sounds and therefore prevent arousal from sleep.

ISMs are intended to be placed near an infant's crib or mounted directly on its side rail. These products have been popularized by parents and "baby sleep experts," as evidenced by the large number of Web sites that proclaim their "benefits." These Web sites encourage parents to operate the machine continuously while an infant sleeps³ and to play the sounds loudly, at a volume equal to or louder than an infant's cry.^{4,5} Many Web sites put ISMs on the must-have list for any nursery.^{6,7} A number of different models are widely available both in Canada and the United States. Because noise can have deleterious effects on the physiologic state and hearing of infants, we assessed the outputs of these devices. It is clear that noise exposure in infants can have deleterious effects on physiologic state. Tachycardia was measured in both term and preterm infants after pulsed or continuous noise stimulation.^{2,8,9} Tachycardia, hypotension, and episodic bradycardia have been observed in infants undergoing MRI,¹⁰ a loud procedure.¹¹ Apnea in response to sound stimulation has been observed in infants and other mammals,

with these episodes occurring with greater frequency and duration with younger age.¹² Most relevant to this study was that background noise leads to sleep disturbance and arousal in infants.^{1,2} These studies indicate that noise can have direct physiologic effects on infants and can negatively influence both the quality and quantity of their sleep.

Noise can also induce hearing loss at high output levels. The Canadian Centre for Occupational Health and Safety (CCOHS) and the US National Institute for Occupational Safety and Health (NIOSH) have recommended a workplace noise limit of 85 A-weighted dB (dBA) for an 8-hour exposure, with a 3-dBA exchange rate,^{13,14} indicating that for every 3-dBA increase above 85 dBA, the allowed exposure time is halved. Exposures in excess of this recommended noise dose are considered harmful and risk development of noise-induced hearing loss.¹⁴ These limits exist for adults in the workplace and may not be sufficiently conservative to be applied to infants who are undergoing auditory, speech, and language development. Additionally, the resonance properties of the smaller infant ear canal, when compared with the larger canal of an adult, result in higher-frequency sounds being amplified by the canal.¹⁵ Furthermore, animal experiments suggest that early exposure to noise leads to increased vulnerability to age-related hearing loss.¹⁶ With these factors in mind, a 50-dBA-equivalent noise level averaged over 1 hour has been recommended as a maximum safe exposure for infants in hospital nurseries and NICUs.^{17,18}

Given the potential for deleterious physiologic effects and noise-induced hearing loss, it behooves us to study ISMs in greater detail to better understand these risks and to develop recommendations for caregivers who wish to use these devices. This caveat is

especially true in the context of an environment in which Web sites encourage playing ISMs loudly. We hypothesized that maximum output levels of some ISMs would be within ranges considered detrimental to the inner ear of infants.

METHODS

Sound Level Measurements

Fourteen ISMs widely available in the United States and Canada were procured for testing. ISMs were identified at and procured from major online and brick-and-mortar infant-accessory stores. ISMs were excluded from study only on the basis of an inability to procure a model. Each machine produced between 1 and 10 masking noise sounds, for a total of 65 sounds across 14 devices. Noise sounds included white noise, nature sounds (including rain, thunder, wind, ocean, river, campfire, insect, and bird sounds), mechanical sounds (including traffic, train, airplane, and machinery sounds), and heartbeat sounds. Measurements were made by using a sound level meter (model 831; Larson Davis, Depew, NY) in a sound booth (ambient noise <25 dBA). The sound level meter microphone was fit with a 2-mL coupler to simulate the ear canal so that sound measurements were taken where the tympanic membrane would be in a human. The machine and sound level meter were placed on tables of equal height, and measurements were made at 3 distances: 30 cm (to simulate machine placement on a crib rail or within a crib near the rail), 100 cm (to simulate machine placement near a crib, such as on a nearby table), and 200 cm (to simulate machine placement across the room from a crib). With the machine set to maximum volume, 3 trials of 30-second sound level measurements were performed for each sound to obtain the equivalent 30-second sound level octave band analysis

(ie, component sound level in each octave band from 8 Hz to 16 kHz, measured in dB). The sound level in each octave band was averaged across the 3 trials.

Determination of Maximum “Effective Output Level”

To correct for the difference in resonant properties between the 2-mL coupler and an infant’s external auditory canal, standard infant ear correction factors for a 6-month-old¹⁹ were applied to the averaged sound levels in each octave band (Table 1). Because the human ear is less sensitive to low-frequency sounds than to high-frequency sounds, sound level meter intensity readings (measured in dB) were then weighted by using standard A-weights for each frequency^{20,21} and converted to dBA (Table 1). For all measured sounds, an “effective output level” was calculated by using the following equation:

$$Leq_{eff} = 10 \log \left[10^{(L_1/10)} + 10^{(L_2/10)} + \dots + 10^{(L_{12}/10)} \right]$$

where Leq_{eff} is the effective output level in dBA and L_1 to L_{12} are the A-weighted sound level values in dBA at each octave band frequency from 8 Hz to 16 kHz.

RESULTS

Sixty-five sounds across 14 ISMs were tested at distances of 30, 100, and 200

cm. For all sounds, effective output level decreased with increasing distance.

In Fig 1 A–C, the distribution of the maximum effective output level of the 14 ISMs is plotted. The mean maximum effective output levels at 30, 100, and 200 cm were 79.1 dBA (range: 68.8–92.9 dBA), 70.5 dBA (range: 61.3–82.5 dBA), and 63.3 dBA (range: 49.2–76.2 dBA), respectively.

Three ISMs were capable of producing noise >85 dBA at a distance of 30 cm.

All 14 ISMs were capable of producing noise >50 dBA at distances of 30 and 100 cm. Interestingly, 13 of 14 ISMs were capable of producing noise >50 dBA at a distance of 200 cm.

DISCUSSION

We sought to measure maximum effective output levels of a variety of commercially available ISMs to determine if output levels were in an intensity

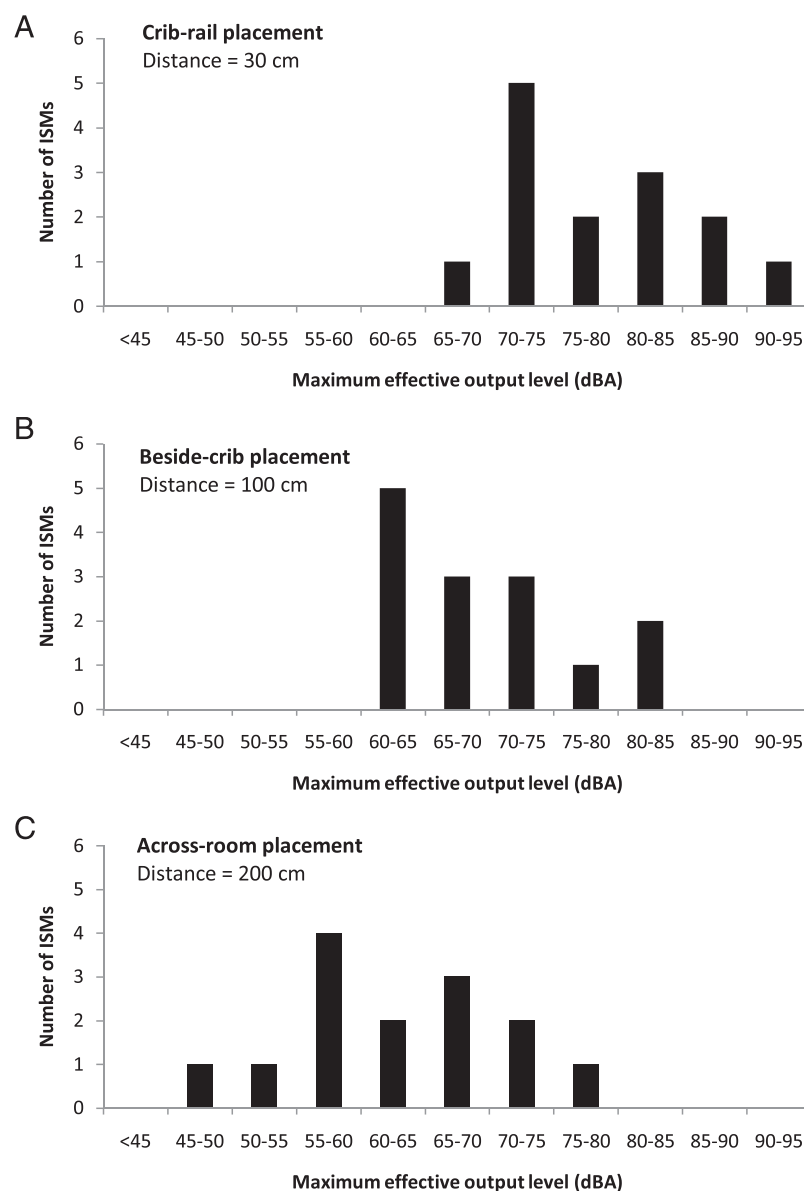


FIGURE 1 Distribution of the 14 tested ISMs by their maximum effective output level measured at 3 separate distances of 30 (A), 100 (B), and 200 (C) cm.

TABLE 1 Standard Infant Ear Correction Values for a 6-Month-Old¹⁴ and A-Weighted Filter Values^{15,16}

| Frequency | Correction Value, dB | A-Weighted Filter Value, dB |
|----------------------|----------------------|-----------------------------|
| 8 Hz ^a | 0 | −70.4 |
| 16 Hz ^a | 0 | −56.7 |
| 31.5 Hz ^a | 0 | −39.4 |
| 63 Hz ^a | 0 | −26.2 |
| 125 Hz ^a | 0 | −16.1 |
| 250 Hz | 3 | −8.6 |
| 500 Hz | 7 | −3.2 |
| 1 kHz | 11 | 0 |
| 2 kHz | 13 | 1.2 |
| 4 kHz | 18 | 1.0 |
| 8 kHz ^a | 0 | −1.1 |
| 16 kHz ^a | 0 | −6.6 |

^a Frequencies for which correction value standard data were unavailable were assigned a correction value of zero.

range that would be considered detrimental to infant hearing.

We found that the loudest maximum effective output levels were measured at a distance of 30 cm, with a mean of 79.1 dBA (range: 68.8–92.9 dBA). Three of the ISMs produced outputs >85 dBA. Applying noise exposure recommendations endorsed by the CCOHS and NIOSH, our results suggest that if these ISMs were played continuously as recommended on numerous Web sites, infants would be exposed to sound pressure levels that exceed occupational noise limits for an 8-hour period. More worrisome is that the loudest ISM (producing a maximum effective output level of 92.9 dBA) would need to be played for only 2 hours before exceeding recommended occupational limits. It is crucial to consider, however, that CCOHS and NIOSH noise limits were designed to protect adults from occupational noise exposure and may not be conservative enough for infants. This discrepancy highlights the importance of carefully monitoring and limiting exposure of infants to such devices.

All 14 ISMs exceeded 50 dBA at distances of 30 and 100 cm. Thirteen of 14 ISMs exceeded 50 dBA at a distance of 200 cm. Infant-specific noise exposure guidelines for hospital nurseries and NICUs suggest that noise should be limited to an average level of 50 dBA measured over 1 hour.^{17,18} Results from the current study suggest that with crib-rail (30 cm) or beside-crib (100 cm) placement, the output of all ISMs exceed recommended limits. Even with across-room placement (200 cm), 13 of 14 ISMs exceeded recommended limits, with only 1 ISM producing a maximum effective output level below this limit (maximum effective output level of 49.2 dBA).

Even though maximum output levels were measured on ISMs tested in this study, most devices featured a volume

control, which suggests that safer ISM use is possible and that ISMs may be used in accordance with recommendations for hospital nursery noise. Furthermore, results from the current study reveal that increasing distance from the ISM results in a decrease in measured output level. This finding suggests that placing an ISM at a distance >200 cm from an infant may also lead to safer ISM use. However, we caution that a “safe” distance at which measured output was in accordance with hospital nursery noise recommendations (<50 dBA) was not determined in this study.

Even if ISM noise levels are kept within “safe” limits, mitigating concerns about noise-induced injury, we must consider that auditory pathways are immature at birth and require appropriate auditory input to develop normally. The type of auditory input can significantly shape auditory pathways over extended periods of time as has been shown in children who are deaf and who receive cochlear implants to hear.^{22,23} Exposing infants to continuous white noise is particularly concerning given that white noise, unlike speech which varies in frequency and intensity rapidly over time, has an almost constant intensity across a range of frequencies. Evidence in neonatal rats shows that the normal frequency map in the primary auditory brain is severely disrupted by continuous white noise exposure.²⁴ Moreover, prolonged white noise exposure during early development led to altered processing of sound intensity^{25,26} and alterations in behavioral development.²⁷ These findings reflect the importance of the type of auditory input to which the developing brain is exposed. Noise effectively masks normal auditory input such as speech, which varies in frequency and intensity, resulting in a loss of highly organized representation of frequency in the brain. Extrapolating

these findings to infants suggests that regular exposure to white noise through ISMs on a nightly basis could affect hearing, speech, and language development. Furthermore, it is unclear whether more complex sounds, such as music, may have deleterious effects on infants when used as masking noise, and this is a potential area for future research.

A limitation of this study is that although we have shown that maximum output levels of ISMs used in close proximity are potentially dangerous, we do not know how they are being used in everyday life (ie, proximity of device to child, type of noise, volume, duration of exposure). Our concern, however, is that these devices are sold with limited or no instructions for safe use. Another limitation is that hearing evaluations have not yet been systematically performed in a large group of children previously exposed to ISM noise. Future studies investigating ISM use with serial physiologic, audiometric, and language evaluation in a large cohort of children are required. On the basis of results of the current study, we suggest the following recommendations to encourage safer use: (1) place ISMs as far away from infants as possible, (2) set the volume as low as possible, and (3) limit the duration of use (eg, timed shut-off or turn off device after the infant falls asleep).

CONCLUSIONS

ISMs can generate sound levels in excess of adult occupational noise limits and more conservative limits created for infants in hospital nurseries. Exposure to these devices may place infants at risk of developing noise-induced hearing loss or maldevelopment of the auditory system. The safe use of an ISM may be possible but requires policy recommendations for manufacturers and recommendations

for families that outline the parameters for their use. Examples of such recommendations could include the following:

Policy Recommendations for Safer ISM Use

1. Require manufacturers to limit the maximum output level of ISMs.

2. Require manufacturers to print warnings about noise-induced hearing loss on ISM packaging.
3. Require manufacturers to include a mandatory timer on devices marketed primarily for infants that would automatically shut the device off after a predetermined period of time.

Recommendations for Families to Encourage Safer ISM Use

1. Place the ISM as far away as possible from the infant and never in the crib or on a crib rail.
2. Play the ISM at a low volume.
3. Operate the ISM for a short duration of time.

REFERENCES

1. Gädeke R, Döring B, Keller F, Vogel A. The noise level in a children's hospital and the wake-up threshold in infants. *Acta Paediatr Scand*. 1969;58(2):164–170
2. Miller CL, Byrne JM. Psychophysiologic and behavioural response to auditory stimuli in the newborn. *Infant Behav Dev*. 1983;6(2-3):369–389
3. Rowell R. Should my baby sleep with white noise? My Baby Sleep Guide. Available at: www.mybabysleepguide.com/2012/12/should-my-baby-sleep-with-white-noise.html. Accessed May 3, 2013
4. Dubinsky D. Harvey's Karp's 'Happiest Baby' method for baby sleep and soothing. Baby Center Expert Advice. Available at: www.babycenter.com/0_harvey-karps-happiest-baby-method-for-baby-sleep-and-soothing_10373838.bc. Accessed May 3, 2013
5. Dubief A. Why babies love white noise. Troublesome tots. Available at: www.troublesometots.com/why-babies-love-white-noise/. Accessed May 3, 2013
6. Word of Mom. Baby essentials list—prepping your nursery. Available at: www.whattoexpect.com/blogs/baby-love-life-as-a-firsttime-mom/baby-essentials-list-prepping-your-nursery-. Accessed December 10, 2013
7. The Bump. Checklist: nursery. Available at: <http://pregnant.thebump.com/pregnancy/pregnancy-tools/articles/checklist-nursery.aspx?MsdVisit=1>. Accessed December 10, 2013
8. Vranekovic G, Hock E, Isaac P, Cordero L. Heart rate variability and cardiac response to an auditory stimulus. *Biol Neonate*. 1974;24(1):66–73
9. Field TM, Dempsey JR, Hatch J, Ting G, Clifton RK. Cardiac and behavioural responses to repeated tactile and auditory stimulation by preterm and term neonates. *Dev Psychol*. 1979;15(4):406–416
10. Philbin MK, Taber KH, Hayman LA. Preliminary report: changes in vital signs of term newborns during MR. *AJNR Am J Neuroradiol*. 1996;17(6):1033–1036
11. McJury M, Shellock FG. Auditory noise associated with MR procedures: a review. *J Magn Reson Imaging*. 2000;12(1):37–45
12. Anderssen SH, Nicolaisen RB, Gabrielsen GW. Autonomic response to auditory stimulation. *Acta Paediatr*. 1993;82(11):913–918
13. Canadian Centre for Occupational Health and Safety. Noise—occupational exposure limits in Canada. Updated July 4, 2011. Available at: www.ccohs.ca/oshanswers/phys_agents/exposure_can.html. Accessed May 2, 2013
14. National Institute for Occupational Safety and Health. *Criteria for a Recommended Standard—Occupational Noise Exposure*. Cincinnati, OH: National Institute for Occupational Safety and Health; 1998
15. Kruger B. An update on the external ear resonance in infants and young children. *Ear Hear*. 1987;8(6):333–336
16. Kujawa SG, Liberman MC. Acceleration of age-related hearing loss by early noise exposure: evidence of a missed youth. *J Neurosci*. 2006;26(7):2115–2123
17. Philbin MK, Robertson A, Hall JW III; Sound Study Group of the National Resource Center. Recommended permissible noise criteria for occupied, newly constructed or renovated hospital nurseries. *J Perinatol*. 1999;19(8 pt 1):559–563
18. Graven SN. Sound and the developing infant in the NICU: conclusions and recommendations for care. *J Perinatol*. 2000;20(8 pt 2):S88–S93
19. Provincial Health Services Authority. Training materials. Hearing equipment training and resource manual. Updated October 2, 2009. Available at: www.phsa.ca/Agencies-AndServices/Services/BCEarlyHearing/ForProfessionals/Resources/Training-Materials.htm. Accessed May 4, 2013
20. American National Standards Institute. *American National Standard Specification for Sound Level Meters (S1.4-1983)*. New York, NY: Acoustical Society of America; 1983
21. American National Standards Institute. *Design Response of Weighting Networks for Acoustical Measurements (S1.42-2001)*. Melville, NY: Acoustical Society of America; 2001
22. Papsin BC, Gordon KA. Cochlear implants for children with severe-to-profound hearing loss. *N Engl J Med*. 2007;357(23):2380–2387
23. Gordon KA, Wong DD, Papsin BC. Bilateral input protects the cortex from unilaterally-driven reorganization in children who are deaf. *Brain*. 2013;136(pt 5):1609–1625
24. Chang EF, Merzenich MM. Environmental noise retards auditory cortical development. *Science*. 2003;300(5618):498–502
25. Gao F, Zhang J, Sun X, Chen L. The effect of postnatal exposure to noise on sound level processing by auditory cortex neurons of rats in adulthood. *Physiol Behav*. 2009;97(3–4):369–373
26. Bures Z, Grécová J, Popelár J, Syka J. Noise exposure during early development impairs the processing of sound intensity in adult rats. *Eur J Neurosci*. 2010;32(1):155–164
27. Zhang J, Chen L, Gao F, Pu Q, Sun X. Noise exposure at young age impairs the auditory object exploration behavior of rats in adulthood. *Physiol Behav*. 2008;95(1-2):229–234

Infant Sleep Machines and Hazardous Sound Pressure Levels

Sarah C. Hugh, Nikolaus E. Wolter, Evan J. Propst, Karen A. Gordon, Sharon L. Cushing and Blake C. Papsin

Pediatrics originally published online March 3, 2014;

Updated Information & Services

including high resolution figures, can be found at:
<http://pediatrics.aappublications.org/content/early/2014/02/25/peds.2013-3617>

Permissions & Licensing

Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at:
<http://www.aappublications.org/site/misc/Permissions.xhtml>

Reprints

Information about ordering reprints can be found online:
<http://www.aappublications.org/site/misc/reprints.xhtml>

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™



PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Infant Sleep Machines and Hazardous Sound Pressure Levels

Sarah C. Hugh, Nikolaus E. Wolter, Evan J. Propst, Karen A. Gordon, Sharon L. Cushing and Blake C. Papsin

Pediatrics originally published online March 3, 2014;

The online version of this article, along with updated information and services, is located on the World Wide Web at:

<http://pediatrics.aappublications.org/content/early/2014/02/25/peds.2013-3617>

Pediatrics is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. Pediatrics is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 2014 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 1073-0397.

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™

