Comparison of Techniques to Reduce Residential Lead Dust on Carpet and Upholstery: The New Jersey Assessment of Cleaning Techniques Trial

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High-efficiency particulate air (HEPA) filtered vacuum cleaners are recommended by the U.S. Department of Housing and Urban Development for cleaning lead-contaminated house dust. We performed a randomized field study to determine whether a conventional (non-HEPA) vacuum cleaner could achieve cleaning results comparable with those of a HEPA vacuum cleaner. We compared the lead loading reductions of these two vacuum cleaners in a total of 127 New Jersey homes of lead-exposed children. We used wet towelettes and a vacuum sampler to collect lead dust from carpets and upholstery before and after vacuum cleaning. The vacuum sampling data showed that the HEPA and non-HEPA vacuum cleaners resulted in 54.7% (p = 0.006) and 36.4% (p = 0.020) reductions in lead loading, respectively, when used on soiled carpets, although the overall difference in lead loading reduction between the two vacuum cleaners was not statistically significant (p = 0.293). The wipe sampling data did not show any significant lead loading reduction for either of the vacuum cleaners, suggesting that both vacuum cleaners fail to clean the surfaces of carpet effectively, considering that wipe sampling media simulate surface contact. On upholstery, the wipe sampling data showed a significant reduction in lead loading for the non-HEPA vacuum cleaner (22.2%, p = 0.047). Even with the significant reduction, the postcleaning lead loadings on upholstery were similar to those on carpets. The similar lead loading results for carpets and upholstery indicate that soiled upholstery may be as important a source of childhood lead exposure as carpets. *Key words:* carpet, cleaning, HEPA, HUD, lead, upholstery, U.S. Department of Housing and Urban Development, vacuum. *Environ Health Perspect* 110:1233–1237 (2002). [Online 16 October 2002]

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Household dust contaminated with lead is a major source of childhood lead exposure (Bornschein et al. 1986; Cambra and Alonso 1995; Charney et al. 1983; Clark et al. 1991; Davies et al. 1991; Lanphear et al. 1996; Rhoads et al. 1999; Thornton et al. 1990), with the hand-to-mouth pathway generally accepted as the most important exposure pattern for young children [U.S. Department of Housing and Urban Development (HUD) 1995]. Carpets, unlike bare floors or other smooth surfaces, serve as a reservoir of dust in home environments. A number of studies have shown that surface lead loading assessed by vacuuming carpets is far greater than that derived from vacuuming bare floors (Adgate et al. 1995; Lanphear et al. 1995; Sterling et al. 1999). Although little is known about how much lead dust is embedded in upholstered furniture, presumably old or dirty furniture can also contain substantial amounts of lead-contaminated dust.

Dust control can be effective in reducing children's exposure to lead [Centers for Disease Control (CDC) 1991; Charney et al. 1983; Hilts et al. 1995, 1998; Lioy et al. 1998; Rhoads et al. 1999; Roberts et al. 1999]. An effective dust control, however, needs more effort in cleaning carpets or rugs than in cleaning hard floor surfaces because carpets can store and trap amounts of dust. High-efficiency particulate air (HEPA) filtered vacuum cleaners are recommended by the HUD to clean lead-contaminated dwellings, both as an interim control measure and after lead abatement activities (HUD 1995). HEPA vacuum cleaners may be more effective in cleaning carpets than are regular household vacuum cleaners because the filter can prevent small particles from re-entrainment. Nevertheless, HEPA vacuum cleaners are expensive, and until recently, they were not widely available. Because dust lead levels in most households are generally not as high as dust lead levels after lead abatement work, use of a HEPA vacuum cleaner for home cleaning as an interim control measure might not be necessary. Little is known regarding the effectiveness of using a common type of household vacuum cleaner to clean lead dust in homes of children who have moderately elevated blood lead levels.

The New Jersey Assessment of Cleaning Techniques (NJACT) Trial compared the effectiveness of using a non-HEPA vacuum with using a HEPA vacuum cleaner, and the effectiveness of using a low-phosphate detergent with a high-phosphate detergent (or equivalently performing detergent) in reducing dust lead levels in homes of lead-exposed children. In this article we compare the efficacy of a HEPA and a non-HEPA vacuum cleaner in removing lead dust from carpets/rugs and upholstered furniture and also assess residential accumulation of lead dust in carpets and on upholstery after a 6-month period in selected NJACT trial participating homes.

Methods

Cleaning and sampling methods. The methods for NJACT trial have been described previously (Rich et al. 2002). There were 127 New Jersey homes recruited with a child's blood lead level above 20 µg/dL at each home. These homes were referred to us either by the state health department or by local health departments in northern New Jersey. Upon recruitment, we scheduled a 1-day cleaning appointment with the study participant and then cleaned the house using a randomly selected cleaning protocol. We used a Nilfisk GS80 HEPA vacuum cleaner (Nilfisk of America, Inc., Malvern, PA) and a Eureka World canister vacuum cleaner (model 6865; Eureka Co., Bloomington, IL) to clean carpets and upholstery in homes assigned to the HEPA and non-HEPA cleaning, respectively. Because the study was also designed to test cleaning methods that were applied to hard surface cleaning, three cleaning combinations of the two vacuum cleaners and two types of detergents, trisodium phosphate (TSP) and household (Spic n' Span; Procter & Gamble, Cincinnati, OH) detergents, were used: *a*) TSP and HEPA, *b*) TSP and non-HEPA, and *c*) household detergent and non-HEPA. This randomized assignment to the three

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combinations of cleaning methods resulted in homes being assigned to the non-HEPA vacuum cleaner and the HEPA vacuum cleaner in an approximate 2:1 ratio. Because not all recruited homes had carpets or upholstered furniture, the total numbers of carpet and upholstery cleaning were less than the total homes that we recruited.

Vacuum cleaning followed the HUD guidelines (HUD 1995) which recommend that a beater bar or agitator attachment be equipped on the vacuum head while vacuuming carpets. Each carpet was vacuumed twice in perpendicular directions, and each pass was performed at a deliberate speed in order to maximize dust collection from the carpet. Upholstery vacuuming was performed with three to five passes over each surface with a smooth-edged nozzle. A new vacuum bag for the HEPA or non-HEPA vacuum was installed before vacuuming in each participating home.

Two dust-sampling methods were used side by side to collect lead dust on carpet and upholstery before and after cleaning in each household to evaluate cleaning effectiveness: a wet-towelette wipe method, as recommended by HUD (1995), and a vacuum method previously developed by the Environmental and Occupational Health Sciences Institute (EOHSI) (Wang et al. 1995). Before cleaning, study staff collected a wipe sample and an EOHSI vacuum sample from a selected carpet, and another pair of wipe and vacuum samples from upholstery in each household. Postcleaning samples were collected at least 1 hr after cleaning to allow any airborne dust that was generated by vacuuming to settle. Sampling sites adjacent to the respective precleaning sites were used. Wipe sampling was conducted within a 1-ft^2 template on the surfaces of carpet or upholstered furniture. The EOHSI vacuum sample method was performed using a canister vacuum to collect dust samples from carpets within a 2.78-ft^2 template and from upholstery within a 1-ft^2 template. We used a nozzle head with zigzag teeth when sampling carpets, and a smooth-edged nozzle head to avoid damaging fibers of the fabric when sampling upholstery. A cone-shaped sample bag made of polyethylene and polypropylene (5.2 oz. SMS; Home Care Industries, Inc., Clifton, NJ) was installed between the nozzle head and the vacuum hose to trap the collected dust.

In seven households after cleaning and dust sampling, we installed a new area rug to determine the extent to which lead contamination would recur within 6 months. We believe the rugs are lead-free because we did not find detectable lead levels using the EOHSI vacuum sampling. The new 6 × 9 ft area rug was laid on top of the old wall-to-wall carpet. Similarly, in selected houses we covered one piece of upholstered furniture with a rubber-backed couch cover, held in place with safety pins. After 6 months, study staff returned to the households and collected follow-up dust samples from the installed area rugs and/or couch covers. We compared the follow-up samples and precleaning baseline samples to evaluate dust buildup in the new carpet and on the upholstery cover over a 6-month period.

Laboratory analysis. Wipe samples were soaked and then digested in a laboratory microwave (MDS-2000; CEM Corporation, Matthews, NC). Lead concentrations (micrograms per gram) of wipe samples were determined by using a flame atomic absorption spectrometer (FAA; 3100; Perkin-Elmer, Norwalk, CT). For those samples with concentrations under the FAA detection limit (0.5 µg/mL in solution), a graphite furnace atomic absorption spectrophotometer (GFAA; Perkin-Elmer Zeeman 5100; Perkin-Elmer) with a detection limit of 2.5 µg/L (in solution) was used. Details of wipe sample analysis have been described previously (Rich et al. 2002).

Vacuum sample bags were weighed in a temperature- and humidity-controlled room using a microbalance (Sartorius A120S; Sartorius Corporation, Edgewood, NY). After postsampling weighing, if available, approximately 0.2 g of dust was measured and placed into a test tube (30-mL Oak Ridge Centrifuge Tube; Nalgene, Rochester, NY). Nitric acid [10 mL of 19% (vol/vol)] was added to the samples, and then the samples were microwave digested for 23 min at 81% power using the U.S. Environmental Protection Agency (EPA) soil sample protocol (U.S. EPA 1991). After cooling, deionized water was added to dilute each sample to 20 mL for FAA analysis. Samples that were below the detection limit were analyzed on GFAA.

Statistical analysis. All dust wipe data were adjusted using a linear regression equation to correct for laboratory difference (Rich et al. 2002). All data derived from the wipe and vacuum samples were log-transformed (base 10) before statistical analysis because they appeared log-normally distributed. We used one-half of the GFAA detection limit for wipe or vacuum data under the detection limit. Paired-sample t-tests were performed separately for the wipe and vacuum data to compare pre- and postcleaning lead loadings and to compare precleaning lead loadings of carpets and upholstery in the same houses. Pearson correlation coefficients were calculated to examine relationships between the two sampling methods and between precleaning lead loadings and lead loading reductions. A nested-factorial design analysis of variance (ANOVA) using the generalized linear model was conducted to compare the two cleaning methods using HEPA and non-HEPA vacuum cleaners in lead loading reduction. We used SPSS for Windows 9.0 (SPSS, Chicago, IL) to run all statistical analyses.

Results

Carpet cleaning. We collected 89 and 90 pairs of pre- and postcleaning carpet samples using the wipe and EOHSI vacuum sampling methods, respectively. There was one EOHSI vacuum sample missing in a pre- and postcleaning pair that was collected in a non-HEPA home. More than 96% of the carpet samples from either the wipe or EOHSI vacuum sampling method had lead levels greater than the detection limit, and most of the samples with values below the detection limit were the postcleaning samples. Data from the EOHSI vacuum sampling method showed a significant reduction (50.6%, p = 0.014) in mean lead loading for cleaning using the HEPA vacuum cleaner but did not result in a significant difference (14.0% reduction) for cleaning using the non-HEPA vacuum cleaner (Table 1). The wipe sampling results indicated that neither of the cleaning methods yielded a significant reduction in lead loading. To examine whether cleaning performance was affected by precleaning dust lead levels, we conducted correlation analyses between precleaning lead loadings and lead loading reductions with the wipe data and the EOHSI vacuum data. Both the databases indicated that lead loading reductions were moderately associated with the precleaning levels (r = 0.41 for wipe and 0.32 for vacuum). Because dust lead reductions were affected by precleaning levels and dust lead levels in the participants' homes varied substantially [EOHSI vacuum geometric standard deviation (GSD) = 8.7 and 9.5 for

Table 1. Pre- and postcleaning lead loadings (µg/ft^2) of carpets and upholstery by vacuum cleaner type.

	HEPA				Non-HEPA			
	n	Pre GM (GSD)	Post GM (GSD)	p-Value	n	Pre GM (GSD)	Post GM (GSD)	p-Value
Carpets								
EOHSI vacuum	31	52.4 (8.7)	25.9 (11)	0.014	58[a]	54.4 (9.5)	46.8 (8.6)	0.431
Wipe	31	7.02 (3.9)	5.44 (5.3)	0.154	59	8.76 (4.9)	8.70 (4.1)	0.971
Upholstery								
EOHSI vacuum[b]	25	3.55 (31)	2.24 (38)	0.547	55	11.2 (26)	1.41 (36)	0.001
Wipe	25	3.87 (3.5)	3.25 (4.6)	0.349	52[a]	7.26 (4.4)	5.65 (3.8)	0.047

GM, geometric mean.
[a]Missing samples in pre- and postcleaning pairs. [b]More than 35% of overall pre- and postcleaning data for upholstery replaced with one-half the detection limit.

precleaning levels of the HEPA and non-HEPA groups, respectively], we stratified our analyses by examining results from carpets with high lead loading to evaluate performance of the HEPA and non-HEPA vacuum cleaners.

We used 10 µg/ft^2 (antilog of 1) as the cutoff point for precleaning data derived from the EOHSI vacuum method because there is no vacuum-dust lead clearance standard established for carpets and we wanted to retain the bulk of the data. Approximately 80% of the baseline data were above this cutoff for both vacuum cleaners. The new database, termed "soiled," increased the percentage of lead loading reduction for the HEPA data by 4.1% (from 50.6% to 54.7%) and especially for the non-HEPA data by 22.4% (from 14.0% to 36.4%) as measured by the EOHSI vacuum samples but did not significantly change the results observed based on the wipe data (Table 2). The smaller vacuum lead loading reduction for the non-HEPA data than for the HEPA data suggests a better cleaning performance by the HEPA vacuum cleaner on carpets. To confirm this, we performed a nested-factorial design ANOVA for the soiled data. The results indicate that both vacuum cleaners reduced dust lead levels in soiled carpets effectively ($p < 0.001$) and that the difference between the lead loading reductions resulting from the two vacuum cleaners was not statistically significant ($p = 0.293$). Thus, on soiled carpets, both HEPA and non-HEPA vacuum cleaners were effective in reducing dust lead loading, as determined by vacuum sampling, but were not demonstrably different in cleaning performance.

Upholstery cleaning. There were 80 and 77 pairs of pre- and postcleaning upholstery samples collected by the EOHSI vacuum method and the wipe method, respectively. Three wipe sample pairs were incomplete because of missing samples. Unlike the carpet data, a large portion of the EOHSI vacuum samples (37.5%) failed to yield detectable levels of lead. This was mostly related to inadequate dust recovery. In contrast, 98% of the wipe samples yielded measurable levels, indicating that the wipe method is more appropriate than vacuum sampling for use in assessing the effectiveness of upholstery cleaning.

The upholstery data showed a significant lead loading reduction for the non-HEPA vacuum cleaner by both the EOHSI vacuum and wipe sampling techniques, whereas no significant reduction was found for the HEPA vacuum group (Table 1). The cleaning performance by the HEPA vacuum cleaner, however, may have been affected by the low precleaning dust lead levels, as shown by both the EOHSI vacuum method and the wipe sampling method. Lead loading reductions were associated with precleaning lead loadings for upholstery as indicated by the wipe method ($r = 0.30$) and especially the EOHSI vacuum method ($r = 0.65$). We removed a small portion of low-end upholstery data using 3.15 µg/ft^2 (antilog of 0.5, half of cutoff point for carpet data) for the precleaning wipe data as a cutoff point. The "soiled" upholstery database showed significant differences for the non-HEPA vacuum method but still no significant difference for the HEPA vacuum method (Table 2).

Dust lead levels in carpets and upholstery. We combined precleaning data of the HEPA and non-HEPA homes where there were carpets and upholstery to compare the baseline dust lead levels (Table 3). Lead loading on upholstery was lower than on carpets, as shown by both the EOHSI vacuum and wipe sampling methods. The mean dust lead loading was 9.4 times higher in carpets than on upholstery by the EOHSI vacuum method, but it was only 1.5 times higher by the wipe method. This result indicates that upholstered furniture is not as significant a reservoir for lead dust as are carpets; however, it may be similar to carpets in importance as a source of childhood lead exposure via surface contact, as indicated by the similar mean lead loadings derived from the wipe method.

Correlation of sampling methods. We conducted correlation analyses between the EOHSI vacuum and wipe sampling methods applied on carpets before and after cleaning. Data below the level of detection were not included. Both pre- and postcleaning data showed that the vacuum and HUD wipe methods were moderately correlated ($r \approx 0.70$, $p < 0.001$). This correlation result is quite substantial considering the difference between the two methods. We did not conduct a correlation analysis for the upholstery data because of a relatively large portion of nondetects of EOHSI vacuum samples on upholstery. Details of the comparison of the two sampling methods have been described previously (Bai et al. in press).

Six-month follow-ups. Six-month follow-up sampling was completed for seven carpet and five upholstery sample sets. The follow-up lead loadings, by either the wipe or the EOHSI vacuum method, showed various trends from the precleaning lead loadings (Table 4). This result indicates that dust lead accumulation on carpets is likely to be sufficient to return dust lead to the precleaning (baseline) levels during a period of 6 months. The follow-up lead loadings on upholstery, shown as the wipe data, were all less than the baseline levels after 6 months. Nevertheless, there were two lead loading increases, shown by the EOHSI vacuum samples. The wipe and vacuum data on upholstery suggest that there are certain levels of dust lead accumulation on upholstery that may not be as high as the baseline levels.

Discussion

Both the HEPA and non-HEPA vacuum cleaners significantly reduced carpet lead loadings measured by the EOHSI vacuum sampling technique, when the carpets showed relatively high dust-lead loadings (Table 2). The HEPA vacuum cleaner used in this study appeared to be better than the non-HEPA vacuum cleaner in removing lead dust from the carpets, as indicated by the relatively large reductions in lead loading for the HEPA group (Tables 1 and 2), although the difference in dust lead reductions between the two vacuum cleaners was not statistically significant. The difference between lead loading reductions resulting from the HEPA and non-HEPA vacuum cleaners may be due to their different characteristics: the HEPA vacuum cleaner was equipped with a HEPA filter bag and performed with a strong suction flow rate (87 ft^3/min, reported by the manufacturer, Nilfisk of America), whereas the non-HEPA vacuum cleaner used a regular household vacuum bag and operated with a flow rate of 66.3 ft^3/min (tested by Inter Basic Resources, Inc. Grass Lake, MI). The

Table 2. Pre- and postcleaning lead loadings (µg/ft^2) of carpets and upholstery (soiled).

	HEPA				Non-HEPA			
	n	Pre GM (GSD)	Post GM (GSD)	*p*-Value	*n*	Pre GM (GSD)	Post GM (GSD)	*p*-Value
Carpets[a]								
EOHSI vacuum	25	118 (3.8)	53.3 (7.7)	0.006	47	113 (5.3)	71.6 (6.3)	0.020
Wipe	25	11.4 (2.8)	8.97 (3.9)	0.254	47	11.5 (4.8)	10.3 (3.8)	0.615
Upholstery[b]								
EOHSI vacuum	13	6.41 (21)	3.43 (25)	0.483	37	8.46 (30)	1.02 (33)	0.007
Wipe	13	11.0 (1.7)	9.42 (2.9)	0.528	37	14.4 (3.0)	9.34 (3.4)	0.005

GM, geometric mean.
[a]Carpet selection: precleaning levels of EOHSI vacuum data ≥ 10 µg/ft^2 (antilog of 1.0). [b]Upholstery selection: precleaning levels of wipe data ≥ 3.15 µg/ft^2 (antilog of 0.5).

Table 3. Mean precleaning lead loadings on carpets and upholstery in the same houses.

	n	GM	GSD	95% CI
EOHSI vacuum (µg/ft^2)				
Carpet	58	47.9	12	(25.0–91.7)
Upholstery	58	5.11	29	(2.12–12.3)
Wipe (µg/ft^2)				
Carpet	57	6.53	4.1	(4.48–9.51)
Upholstery	57	4.37	3.9	(3.04–6.30)

Abbreviations: CI, confidence interval; GM, geometric mean.

HEPA vacuum filtration is believed to prevent dust re-entrainment, which may recontaminate carpet surfaces after using a non-HEPA vacuum cleaner. This study did not measure differences of the emission of lead particulates from the two vacuum cleaners' exhaust stream; however, after a postcleaning settling period of at least 1 hr, dust lead loadings on floors were not found significantly elevated in houses that had been cleaned with the non-HEPA vacuum cleaner compared with the HEPA vacuum cleaner (Rich et al. 2002). This finding suggests that re-entrainment should not be a major source of postcleaning contamination.

In recent research conducted by the California Department of Health Services (CDHS) using several types of non-HEPA household vacuum cleaners (canisters, shop, and uprights), no detectable airborne lead levels (< 0.5 µg/m^3) were observed after vacuuming vinyl floors in housing units with lead loadings up to 800 µg/ft^2 (Wall S. Personal communication). Also, CDHS laboratory particle counts conducted before, during, and after non-HEPA vacuuming of real-world lead test dust from vinyl floors in a HEPA-filtered environmental clean room were consistent with submicrometer aerosol generation by the non-HEPA motor, rather than re-entrainment of vacuumed lead dust. (Wall S. Personal communication). Thus, the differences in carpet cleaning efficacy between vacuum cleaners tested in this study may have been due to factors other than the presence or absence of HEPA filtration capacity (e.g., suction power). Despite the lesser cleaning efficacy, the non-HEPA vacuum cleaner did achieve a moderate reduction in carpet lead loading in the most soiled carpets, and other non-HEPA household vacuum cleaners would be expected to perform similarly to the model tested in the study. This is important because lower priced vacuum cleaners, many of which do not have HEPA filters, are more affordable to low-income families who experience the most severe lead hazards. Although some HEPA filters are now available for less expensive vacuum cleaners, the cost of their replacement can be substantial.

Table 4. Lead loading comparisons between samples from precleaning carpet and upholstery and follow-up samples from new area rugs and upholstery covers installed and left in place for 6 months.

Home	Wipe (µg/ft^2) Pre[a]	Wipe (µg/ft^2) Follow-up[b]	EOHSI vacuum (µg/ft^2) Pre[a]	EOHSI vacuum (µg/ft^2) Follow-up[b]
Carpets				
1	3.80	6.51	29.5	120
2	0.66	0.55	1.48	2.04
3	21.9	4.61	39.8	129
4	13.2	83.7	302	831
5	6.87	8.01	426	38.0
6	17.2	30.6	257	302
7	41.5	20.4	104	165
GM	8.63	9.49	66.9	90.6
GSD	4.0	5.0	7.1	6.8
Upholstery				
1	NA	NA	14.8	45.7
2	0.74	0.59	25.7	3.89
3	3.80	3.39	147	69.2
4	7.05	5.57	22.4	50.1
5	4.61	2.63	123	0.05[c]
GM	3.09	2.33	43.5	7.90
GSD	2.7	2.6	2.9	21.2

Abbreviations: GM, geometric mean; NA, sample unavailable.
[a]Precleaning values on original carpets or upholstery. [b]Follow-up values from new area rugs or upholstery covers that had been in place for 6 months. [c]Use of one-half detection limit in place of nondetected datum.

Although data from the EOHSI vacuum method showed significant lead loading reductions for carpets, the wipe data did not show any significant lead loading reduction for either the HEPA or non-HEPA vacuum cleaner (Tables 1 and 2). The EOHSI vacuum sampler can collect dust embedded in carpets (Wang et al. 1995), whereas the wet towelette wipes are considered a surface sampling method. Apparently, the two vacuum cleaners reduced dust lead levels within the carpet pile significantly, but failed to show the same cleaning efficacy on carpet surfaces after just one vacuuming. The vacuuming augmented with a beater bar was probably more effective in removing larger dust particles from carpets versus fine particulates, which have been considered to adhere closely to carpet fibers, probably because of the charge generated by contact (e.g., vacuuming) (Rodes et al. 2001). The wipe media might then have collected a fraction of strongly adherent dust from fibers at the carpet surfaces because the wet towelettes could loosen and remove these particles. A vacuum cleaner with a dirt detector was reported helpful in removing nearly all dust from carpets (Roberts et al. 1999). With the help of the dirt detector, this vacuum cleaner may be able to remove more dust from carpets than other vacuum cleaners, resulting in a significant surface lead reduction. In addition, frequent vacuuming for longer time periods with occasional steam cleaning may be more effective in removing dust from carpets. Alternatively, removal of old carpets and area rugs may ultimately be a more cost-effective option (Ewers et al. 1994).

Upholstery, unlike deep pile carpets, did not store a significant amount of lead dust, as indicated by the EOHSI vacuum sampling method that collected only approximately one-seventh of the lead dust sampled from upholstery compared with carpets (Table 3) and failed to collect any lead-bearing dust from a significant fraction (~35%) of sampled furniture (large GSDs in Tables 1 and 2). However, the wipe data showed that the mean upholstery lead loading was not significantly different from the mean carpet lead loading (Table 3), indicating that upholstered furniture, before any cleaning, can be just as important a source of lead exposure via surface contact, even though the total lead stores are far less. The cleaning trial on upholstery showed a significant reduction in lead loading for the non-HEPA vacuum cleaner but not for the HEPA vacuum cleaner (Tables 1 and 2). This result in favor of the non-HEPA vacuum method is in contrast to the result suggesting the HEPA vacuum cleaner to be more effective in cleaning carpets. The reduced efficiency of the HEPA vacuum cleaner in cleaning upholstery may be, at least partially, due to the lower precleaning dust lead level and the smaller sample data set for the HEPA vacuum cleaner than for the non-HEPA vacuum cleaner. Even with a significant reduction in lead loading, the non-HEPA vacuum's cleaning ability remained limited on highly soiled upholstery because the mean postcleaning dust lead level, measured by the wipe media, was similar to that derived from carpets (Table 2). As suggested for carpets, more frequent and longer vacuuming with periodic steam cleaning may be more effective in reducing lead dust accumulation on upholstery.

The lead loadings measured by the wipe method on upholstery and carpets were considerably lower than those on bare floors, windowsills, and window troughs (Rich et al. 2002), which was also the case in a field study of various dust lead sampling methods (Lanphear et al. 1995). The nonsmooth surfaces of upholstery and carpets, which have textured fiber surfaces, can physically decrease the collection efficiency of wipes. This is consistent with the work of Reynolds et al. (1997), which demonstrated a low recovery rate (~26%) for sampling on carpets using the wet towelette wipe method in a laboratory chamber. Because the wipe method somewhat simulates hand contact, it may indicate that a child's hands are likely to pick up less lead per contact from a carpet than from a bare floor. Despite relatively low lead loading on the surface, carpets remain a major source of exposure when they are heavily loaded with lead dust. This is especially important considering the difficulty in effectively cleaning lead contaminated carpets. Upholstery, with the equivalent lead loading on the surface but a relatively low capacity for storing dust, may still be a significant source of childhood lead exposure, especially when heavily soiled.

The follow-up trial of area rugs and furniture covers indicates that, in the absence of effective lead source control, it takes 6 months or less for the dust lead levels in carpets and on upholstery to increase to the levels observed in this study before cleaning. This result suggests that replacing carpets and covering upholstery are of limited efficacy in reducing lead exposure in the absence of frequent cleaning or source control. Our previous work has shown that frequent cleaning can help avoid lead dust accumulation (Lioy et al. 1998; Rhoads et al. 1999); the present study shows that the household vacuum cleaner that was tested was similar in effectiveness to the tested HEPA vacuum cleaner in reducing lead dust in the homes of children with elevated blood lead levels. Thus, frequent cleaning for longer periods may be more important than using a specific vacuum cleaner to reduce dust lead levels in carpets and on upholstery.

Conclusions

In this study, a household vacuum cleaner without HEPA filtration performed nearly as well as a HEPA vacuum cleaner in cleaning soiled carpets. It can be used as a replacement cleaner for cleaning lead dust in carpets if a HEPA vacuum cleaner is not available. Frequent carpet and upholstery cleaning is encouraged because it appears that the effectiveness of one-time vacuuming is limited. Upholstered furniture may be as important a source of lead dust as carpets for surface contact, although it does not store as much dust as carpets.

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