

Short communication

The association between synthetic bedding and adverse respiratory outcomes among skin-prick test positive and skin-prick test negative children

Background: Synthetic bedding has been associated with increased child wheeze and also higher allergen levels in several studies. We aimed to examine whether the association between synthetic bedding and adverse respiratory outcomes was more evident among skin-prick test (SPT) positive children.

Methods: A cross-sectional survey involving a population sample of 758 (81% of eligible) school children aged 8–10 years from randomly selected schools in the Australian Capital Territory in 1999. Parental questionnaires for ISAAC respiratory symptoms and child bedding were obtained. SPT results of 10 common allergens were available on 722 of the subjects (77% of those eligible). Synthetic pillow or quilt use was termed synthetic upper bedding.

Results: Synthetic quilt use was associated with asthma (Adjusted Odds Ratio 1.67 (1.05, 2.65)), recent wheeze (AOR 1.63 (1.03, 2.59)) and allergic rhinoconjunctivitis (AOR 2.11 (1.33, 3.34)) among SPT-positive children.

However, these associations were not apparent for SPT-negative children. Similarly, increasing synthetic upper bedding use was associated with more than 12 episodes of wheeze among SPT-positive children (AOR 1.69 (1.08, 2.64), $P=0.02$, per category) but not SPT-negative children (AOR 0.77 (0.26, 2.21), $P=0.6$, per category).

Conclusion: The apparent association between synthetic upper bedding and adverse respiratory outcomes was evident among SPT-positive but not SPT-negative children. Prospective intervention studies that aim to examine the effect of upper bedding composition on child asthma among SPT-positive children are required.

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An adverse role for synthetic bedding on asthma in childhood has been suggested by recent studies. Several cross-sectional studies have now reported nonfeather pillows or synthetic bedding to be associated with an increased wheeze in childhood (1–6). A London study found that the increasing use of nonfeather pillows from 1978 to 1991 was estimated to explain more than half the prevalence increase in current childhood wheeze (7). In addition, two cross-sectional studies have reported a positive association between nonfeather pillows or synthetic bedding and rhinitis (8,9).

The association between synthetic bedding and adverse respiratory symptoms may, to some extent, reflect that in recent decades patients with asthma and perennial rhinitis have previously been advised to replace feather bedding with ‘hypo-allergenic’ synthetic-filled bedding. However, reviews on this issue reveal that the evidence base for such advice is not strong (10–12). To reduce the likelihood of this selection

bias, several of the studies have also restricted the analysis only to those subjects who did not report changing their bedding owing to respiratory symptoms or adjusted for reported allergen avoidance (1–3,8,9). Despite this, the positive association between nonfeather or synthetic bedding and wheeze or rhinitis remained evident. Higher allergen levels within synthetic bedding may explain the association between synthetic upper bedding and adverse respiratory outcomes. Synthetic pillows have higher levels of house dust mite (HDM) (13–15), cat and dog allergens (16) than feather pillows. Higher HDM mattress levels have also been associated with synthetic pillows (17).

We postulated that if the adverse respiratory effect of synthetic bedding was owing to a higher allergen load, then the adverse effect of synthetic bedding would be more evident among children who were sensitized to aeroallergens rather than nonsensitized children. We investigated this issue by examining how the association

between synthetic bedding and respiratory outcomes varied by SPT status in a cross-sectional study of children in the Australian Capital Territory.

Material and methods

The source population for the population-based survey (18) was children born in 1989–90 and who attended school in the Australian Capital Territory (ACT) in 1999. The eligible school sample (18) consisted of children who attended the first 11 randomly selected primary schools from a list of ACT government and nongovernment schools. A questionnaire was sent home to parents from school. This included questions on respiratory symptoms and eczema from the International Study of Asthma and Allergy in Childhood (ISAAC) (19). The validity of these questions has previously been examined. A positive history of wheeze or whistling in the chest over the past 12 months had a sensitivity of 0.85 and specificity of 0.81 for respiratory physician diagnosis of asthma (20). Data were collected on home heating, parental smoking, child exposure to active smoking in the same room, child bedroom ventilation and other factors. Parents were also asked to report on the child's type of bed, mattress, composition and type of bedding items under the child, as well as the composition and type of bedding items over the child during winter. SPT was used to assess the cutaneous reaction to exposure to the house dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*, cat, dog, *Alternaria tenuis*, ryegrass, birch, plantain, paspalum and wattle (Hollister-Stier, Bayer, Australia) and positive (histamine 6 mg/ml) and negative (glycerine) controls. For aeroallergens, wheal allergen reactions of 3 mm or greater at 15 min were classified as positive. Medications with antihistaminic action were not used for children for the week prior to testing. In addition, baseline lung function measures were obtained for children examined between June and November 1999, partially for related winter indoor air quality study (18). Participants were instructed not to use beta agonist medication within 6 hours of the test. Children performed forced expiratory manoeuvres standing without a nose clip following a standard protocol (21) using an Alpha compact spirometer (Vitalograph, Buckingham, UK) which was calibrated at the beginning of every session and checked hourly thereafter (18).

Definitions

Following the ISAAC terminology, 'recent' refers to 'within the past year' (19). Wheeze refers to wheezing or whistling in the chest. Persistent wheeze refers to more than 12 episodes of wheeze in the past year compared to none. Allergic rhinoconjunctivitis was defined in a similar way to the ISAAC phase 1 prevalence study (19). That is, a positive report of sneezing or a runny or blocked nose when the child did not have a cold in the past year that was accompanied by itchy-watery eyes. SPT positivity is defined as a positive skin test (≥ 3 mm) to one or more of the aeroallergens on SPT. The use of the terms SPT-positive or SPT-negative throughout this paper complies with the recently revised nomenclature for allergy by the EAACI nomenclature task force (22). HDM allergy refers to a positive skin test to *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* or both. Synthetic bedding refers to the use of a synthetic-filled pillow and/or synthetic quilt.

Statistical methods

Odds ratios were calculated using the method of Mantel and Haenszel for univariate analysis. Multiple logistic regression was used to control simultaneously for multiple confounders, providing adjusted odds ratios (23). To assess whether an association between

synthetic bedding and a respiratory outcome differed by SPT status after controlling for confounders, a model was first built with terms for synthetic bedding and each confounder and the dependent variable was one of several respiratory outcomes examined. A second model was then built in the same way as the first but also with a term for SPT status and an interaction term between synthetic bedding and SPT status. The resulting reduction in deviance obtained by using the second model compared to the first was then assessed using the *P* value associated with the log likelihood ratio test (23). Tests for interaction often use a higher significance than $P = 0.05$ (24). Here, interactions with *P* values of 0.1 or less are reported. Maternal and paternal history of asthma were not routinely adjusted for because these factors could partially reflect shared bedding practices within the household. That is, parental asthma could have occurred as a consequence of shared exposure to synthetic bedding. In this case, parental asthma would be a correlate of synthetic bedding use and thus control for parental asthma would not be appropriate (25). At the time of the study, children with asthma in Australia were advised to avoid sheepskins, use impermeable mattress covers and sleep in uncarpeted rooms (26). We thus examined whether the patterns we found between synthetic bedding and respiratory symptoms by SPT status were also present for these other possible markers of allergen avoidance. Multiple linear regression models were used to examine the associations between exposures and continuous outcomes such as the lung function measures of forced expiratory volume in one second (FEV₁), forced vital capacity (FVC) and the ratio of FEV₁ to FVC with adjustment for relevant covariates (23). Bedding items are not used alone but in combination. To examine if increasing amounts of synthetic bedding were associated with increased risk of each outcome, we constructed four categories of upper bedding by the approximate volume of synthetic material with 0 = no synthetic pillow nor quilt; 1 = synthetic pillow; 2 = synthetic quilt; 3 = synthetic pillow and quilt. We assessed the linear trend for increasing risk across categories using the chi-square test for linear trend in the univariate analysis and the *P* value associated with a one-category increase in synthetic bedding in the multiple logistic regression models. Statistical analyses were performed using STATA 7 (27).

Results

General features

Asthma questionnaire data were available on 758 out of 935 (81%) children who were enrolled at the school at the time of testing. 722 of these children (95% of questionnaire participants, 77% of the total eligible) participated in skin prick testing. Spirometric lung function data were available on 515 out of the 657 (78%) children initially selected. Table 1 shows that the prevalence of asthma ever and recent wheeze were 34.3% and 25.2%, respectively, among the school sample. The prevalence of allergic rhinoconjunctivitis was 24.1%. Of the individual aeroallergens tested, the highest sensitization prevalence was for ryegrass (29%) but sensitization to house dust mite allergens was also common (*Dermatophagoides pteronyssinus*, 26%; *Dermatophagoides farinae*, 19%). Synthetic pillows were used more commonly than synthetic quilts (Table 1). For children not using a synthetic pillow ($n = 82$), most (67%) used a feather pillow. For children not using a synthetic quilt ($n = 459$), most (76%) used a feather quilt. Thus, most children not using synthetic bedding slept with a feather pillow or quilt. As

Table 1. Characteristics of the population sample

Categorical variables	Total n	%
Male	758	52.6%
Synthetic pillow	758	89.1%
Synthetic quilt	757	39.3%
Asthma ever	758	34.3%
Episodes of wheeze in past 12 months:		
0	567	74.8%
1–3	124	16.4%
4–12	42	5.5%
More than 12 episodes	25	3.3%
Hospital attendance due to asthma	752	10.0%
Allergic rhino-conjunctivitis	754	24.1%
Aeroallergen sensitization	722	45.6%

Continuous variables	n	Mean	Standard Deviation
Age	758	9.3	1.9
Maximum Forced Expiratory Volume (FEV ₁) (in litres)	515	1.94	0.35
Maximum Forced Vital Capacity (FVC) (in litres)	515	2.22	0.39
FEV ₁ /FVC ratio (%)	515	0.87	0.06

previously reported, the association between atopy and wheeze increased with increasing frequency of wheeze episodes per year, OR = 1.00 (reference); 1–3 episodes per year, OR = 3.27 (2.15, 4.97); 4–12 episodes per year, OR = 3.44 (1.75, 6.75); more than 12 episodes; OR 8.70 (3.07, 24.55) (26).

Synthetic bedding, wheeze and child lung function

We used the spirometric measure of the ratio of FEV₁ to FVC adjusted for child height and gender, as a measure of airway obstruction. Children who had recent wheeze were significantly more likely to have a reduction in this measure (Adjusted difference –1.5% (–2.7, –0.3); $P = 0.02$). Children who used any synthetic pillow tended to be more likely to have a reduction in FEV₁ to FVC ratio, in the order of –1.5% (–2.7, 0.3). Synthetic quilt use was not associated with reduced lung function (Adjusted difference –0.8% (–1.8, 0.2)). The small sample size did not allow a full examination of synthetic upper bedding on the FEV₁/FVC ratio for SPT-positive and SPT-negative children separately.

Univariate analysis for respiratory symptoms

Synthetic pillow use was associated with a nonsignificant increase in the odds of allergic rhinoconjunctivitis, asthma, wheeze and SPT positivity. Synthetic quilt use was significantly associated with an increased prevalence of asthma (OR 1.46 (1.08, 1.98)), persistent wheeze (OR 2.54 (1.14, 5.65)) and allergic rhinoconjunctivitis (OR 1.55 (1.12, 2.14)). Synthetic quilt use was not associated with atopy (OR 1.11 (0.82, 1.50)). We examined whether possible markers of allergen avoidance were associated with synthetic bedding. Use of an

uncarpeted bedroom, no sheepskin or plastic or allergen mattress cover were not significantly associated with synthetic pillow or quilt use except children using a plastic or allergen mattress cover were more likely to sleep under a synthetic quilt (OR 1.82 (1.07, 3.10)). Importantly, children who reported to have changed bedding as a result of asthma ($n=68$) were not significantly more likely to use a synthetic pillow (OR 0.75 (0.36, 1.55)) or synthetic quilt (OR 1.43 (0.87, 2.34)).

An examination of the association between bedding and respiratory outcomes by SPT status

We then examined whether the significant associations that were observed between synthetic quilt use and various respiratory symptoms were evident among SPT-negative children to the same extent as SPT-positive children. Among SPT-negative children ($n=393$), synthetic quilt use was not significantly associated with asthma, wheeze or allergic rhinoconjunctivitis. Among SPT-positive children ($n=329$), synthetic quilt use was significantly associated with increased asthma (OR 1.75 (1.12, 2.74)), persistent wheeze (OR 3.50 (1.38, 8.83)) and allergic rhinoconjunctivitis (OR 2.14 (1.36, 3.36)). In contrast, use of a plastic or allergen occlusive mattress liner ($n=62$) was not associated with wheeze among either SPT-positive (OR 1.71 (0.84, 3.50)) or SPT-negative (OR 1.21 (0.46, 3.21)) children. Similarly, the association between noncarpeted bedroom floor or no sheepskin and wheeze did not vary by SPT status.

Multivariate analysis for respiratory symptoms

Table 2 reports the association between synthetic quilt use and respiratory outcomes separately for SPT-

Table 2. The association between synthetic quilt use and respiratory outcomes among nonatopic and atopic children

Respiratory outcomes	SPT-negative children		SPT-positive children	
	Adjusted Odds Ratio (95% CI) for synthetic quilt use	P-value	Adjusted Odds Ratio (95% CI) for synthetic quilt use	P-value
Asthma ever	1.15 (0.72, 1.83)	0.56	1.67 (1.05, 2.65)	0.03
Hospital attendance for asthma	0.51 (0.17, 1.47)	0.21	1.89 (1.03, 3.48)	0.04
Recent wheeze	1.27 (0.71, 2.27)	0.42	1.63 (1.03, 2.59)	0.04
Wheeze episodes in past 12 m:				
0 vs. none	1.00 (reference)	-	1.00 (reference)	-
1–3 vs. none	1.47 (0.75, 2.87)	0.27	1.55 (0.90, 2.67)	0.17
4–12 vs. none	1.08 (0.34, 3.41)	0.90	1.01 (0.43, 2.35)	0.99
More than 12 vs. none	0.45 (0.04, 4.72)	0.50	3.47 (1.33, 9.07)	0.01
Allergic rhinoconjunctivitis	1.04 (0.53, 2.00)	0.92	2.11 (1.33, 3.34)	0.002

NB. Odds ratios are adjusted for number of siblings, whether child was breastfed, maternal smoking in same room as child located, and home gas heater use.

negative and SPT-positive children. Among SPT-negative children, synthetic quilt use was not significantly associated with any of these outcomes. For SPT-positive children, synthetic quilt use was significantly associated with five of the seven respiratory outcomes, particularly persistent wheeze and allergic rhinoconjunctivitis (Table 2). Also, for SPT-negative children, there was no trend demonstrated for synthetic quilt use and increased wheeze episode frequency (test for linear trend, $P=0.6$). For SPT-positive children, however, synthetic quilt use was significantly associated with most outcomes with a significant trend (test for linear trend, $P=0.03$) across wheeze episode categories. Thus, synthetic quilt use was particularly associated with frequent wheeze among SPT-positive children. After adjustment for confounders, the following outcomes appeared more strongly associated with synthetic quilt use among SPT-positive children compared to SPT-negative children: past hospital attendance for asthma (Test for interaction, $P=0.04$), allergic rhinoconjunctivitis (Test for interaction, $P=0.007$) and frequent wheeze (more than 12 episodes compared to none) (Test for interaction, $P=0.1$). Similarly, for Table 3, there was a significant difference in the association between synthetic bedding and allergic rhinoconjunctivitis (Test for interaction, $P=0.02$) and frequent wheeze (more than 12 episodes compared to none) (Test for interaction, $P=0.07$). After adjustment for maternal or paternal asthma, a possible correlate of shared bedding practices, the association between synthetic quilt use and severe wheeze was of borderline significance only (AOR 2.70, $P=0.05$; AOR 2.47, $P=0.08$, respectively) among SPT-positive children. Adjustment for factors that related to socio-economic status including maternal education, paternal unemployment or marital status did not alter the results in Table 2. Among the entire sample, the relationship between synthetic quilt use and the respiratory outcomes in Table 2 did not differ significantly by whether the bedding had been changed owing to asthma. The data were too sparse to allow an examination of the effect of synthetic quilts for child subgroups defined by atopy and also reported bedding change.

The effect of increasing amounts of synthetic upper bedding and the respiratory outcomes was then examined separately for SPT-negative and SPT-positive children. Among SPT-positive children, the proportion of children with asthma generally increased with increasing amounts of synthetic bedding ($P=0.03$) but this linear trend was not evident among SPT-negative children ($P=0.74$). Table 3 shows the average incremental increase in risk associated with an increase in synthetic bedding per category, after adjustment for confounders. Again, among SPT-negative children, increasing synthetic upper bedding was not significantly associated with an increase in risk of the respiratory outcomes. For SPT-positive children, however, increasing synthetic upper bedding was significantly and positively associated with asthma, past hospital attendance for asthma, persistent wheeze and allergic rhinoconjunctivitis (Table 3).

Subgroup analyses

We then restricted our analysis to children with either a synthetic or feather quilt ($n=659$). Again, for SPT-negative children, the use of a synthetic compared to feather quilt was not significantly associated with any of the outcomes listed on Table 3. However, among SPT-positive children, the use of a synthetic rather than feather quilt was associated with an increased likelihood of allergic rhinoconjunctivitis (AOR 2.14 (1.29, 3.56) or severe wheeze (AOR 3.32 (1.13, 9.76)). We then examined the effect of synthetic quilt use in HDM-sensitized children and children who were sensitized to the other aeroallergens tested but not HDM. Among HDM-sensitized children ($n=207$) synthetic quilt use was significantly associated with persistent wheeze (AOR 3.53 (1.11, 11.23)), and allergic rhinoconjunctivitis (AOR 2.98 (1.64, 5.42)). Among children who were SPT-positive but had a negative response to HDM ($n=122$) synthetic quilt use was not significantly associated with persistent wheeze (3.33 (0.64, 21.60)), and allergic rhinoconjunctivitis (AOR 1.32 (0.63, 2.74)).

Table 3 The association between increasing synthetic upper bedding (per category increase) and respiratory outcomes for nonatopic and atopic children

	SPT-negative children Adjusted Odds Ratio (95% CI) per category of synthetic bedding increase	P-value	SPT-positive children Adjusted Odds Ratio (95% CI) per category of synthetic bedding increase	P-value
Asthma ever	1.04 (0.84, 1.29)	0.73	1.25 (1.01, 1.54)	0.04
Past hospital attendance for asthma	0.68 (0.41, 1.12)	0.13	1.32 (1.00, 1.75)	0.05
Recent wheeze	1.05 (0.80, 1.38)	0.72	1.21 (0.98, 1.49)	0.08
Wheeze episodes in past 12 m: 0 vs. none	1.00 (reference)	-	1.00 (reference)	-
1–3 vs. none	1.12 (0.82, 1.53)	0.49	1.16 (0.90, 1.48)	0.25
4–12 vs. none	0.92 (0.54, 1.59)	0.78	1.04 (0.70, 1.54)	0.83
More than 12 vs. none	0.77 (0.26, 2.21)	0.62	1.69 (1.08, 2.64)	0.02
Allergic rhinoconjunctivitis	0.98 (0.73, 1.33)	0.92	1.44 (1.17, 1.78)	0.001

The odds ratio refers to an increase in one category across the four categories of no synthetic pillow nor quilt, synthetic pillow only, synthetic quilt only, both synthetic pillow and quilt. Results have been adjusted for number of siblings, whether child was breastfed, maternal smoking in same room as child located, and home gas heater use.

Discussion

This study provides no evidence to indicate that synthetic bedding is beneficial for childhood asthma. The findings add to the accumulating evidence that synthetic bedding may be associated with adverse respiratory outcomes (10,11). In this study, the adverse effect of synthetic upper bedding on respiratory outcomes was evident among SPT-positive children but not among SPT-negative children. The strengths of this cross-sectional survey were the availability of child bedding and SPT data on a population-based sample. The respiratory outcomes collected by questionnaire were based on standardized questions from the ISAAC respiratory protocol (19), and lung function data were collected in a standardized way. The finding of a significantly lower FEV₁/FVC ratio for children reported to have recent wheeze supports the use of questionnaire measures to identify respiratory symptoms.

Our findings do not support the proposal that the apparent association between synthetic bedding and respiratory symptoms is due to the selection of synthetic bedding in response to respiratory symptoms because: (i) children who had bedding change owing to asthma were not more likely to use synthetic bedding; (ii) among SPT-negative children, children with severe respiratory symptoms (e.g., more than 12 episodes of wheeze) were not more likely to use synthetic bedding; (iii) another bedding item that could be preferentially used by children with asthma to reduce symptoms, an allergen-occlusive or plastic mattress liner showed a different pattern to synthetic bedding in that it was not significantly associated with wheeze among neither SPT-positive nor SPT-negative children and (iv) the association between synthetic bedding and respiratory outcomes did not differ by bedding change report. However, a limitation of this study was sufficient

sample size to conduct subgroup analyses by reported bedding change within the SPT-positive group. Furthermore, the cross-sectional design of this study did not allow us to evaluate the temporal association between synthetic bedding introduction and subsequent wheeze. Randomised controlled trials are required to fully exclude any contribution of bedding choice to the association between synthetic bedding and childhood wheeze.

Our observation that the association between synthetic bedding and adverse respiratory outcomes was evident particularly among SPT-positive children is consistent with previous suggestions that this bedding effect is mediated through allergen loading and/or a potentiation of bedding allergenicity. It is consistent with the hypothesis that the adverse effect of synthetic bedding is mediated by the previously documented higher house dust mite (13–15), cat and dog allergens (16) found in synthetic bedding. Secondly, these findings are also consistent with the possibility that synthetic bedding may enhance the allergenicity of allergens by producing the volatile organic compounds that interact with allergens to increase allergenicity (1) or by submicronic particle formation. Thirdly, it is possible that synthetic bedding may harbour lower levels of bacterial endotoxins than natural bedding, such as feather (28). High endotoxin exposure has been previously postulated to play a role in the down-regulation of child allergic disease (29). The observation that synthetic bedding was strongly associated with persistent wheeze rather than infrequent wheeze is consistent with the concept that infrequent wheeze may reflect infrequent exposures, for example viral infection, but bedding, a constant exposure, would be more likely to be associated with persistent wheeze. We have previously reported that the population attributable fraction for wheeze owing to atopy is higher for frequent wheeze than infrequent wheeze (30). If the

adverse effect of synthetic bedding was mediated through an effect related to allergen-induced airway change, one would expect synthetic bedding to be more strongly associated with frequent wheeze than infrequent wheeze, even among SPT-positive children. That is, the infrequent wheeze reported by SPT-positive children could reflect viral-induced and other wheeze of nonallergen-induced origin. Thus, the stronger associations observed for frequent wheeze in Table 2 and Table 3 are again consistent with a mechanism including allergen-induced wheeze.

It has been suggested that the possible adverse effect of synthetic bedding compared to feather bedding may be owing to a looser lining weave for synthetic materials (10,11). This suggestion is supported by the previous finding of higher cat and dog allergens as well as HDM allergens in synthetic compared to feather pillows (16). However, it may also be that the filling of the bedding, for example a filling that retains moisture, is important for promoting a house dust mite 'friendly' microenvironment among synthetic products and this should be examined in further work. The role of passive allergen transfer of ryegrass and other particles from the sleeping person's hair and clothing and the electrostatic properties of bedding with regard to allergen attraction and retention also require evaluation.

In conclusion, our findings that the associations between synthetic bedding and various respiratory outcomes were evident among SPT-positive, but not SPT-negative, children indicates that children who are

sensitized to aeroallergens may be most likely to be adversely influenced by the composition of bedding near their airways during sleep. However, the cross-sectional nature of this study and relatively small sample size limit a causal interpretation of these findings. This report does however, provide new information to assist the design of randomized controlled trials to assess the beneficial effects of feather or other nonsynthetic bedding on allergic asthma. Future intervention studies to assess the beneficial role of feather or other nonsynthetic bedding in childhood asthma should be conducted on children with asthma and aeroallergen allergy, particularly children with house dust mite allergy.

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