

Original article

Association of asthma symptoms and severity with indoor bioaerosols

Background: In this study, repeated measurements were made of levels of mold spores, bacteria, and dust-mite allergens over a 7-month period in the homes of asthmatics, and relationships with measures of asthma severity were evaluated.

Methods: A sample of 57 asthmatic individuals, living in 44 homes in East Moline, Illinois, and nearby communities, participated in a panel study. The homes were visited up to nine times during the study to collect air and dust samples. Asthma severity indicators were derived from questionnaire data and from the daily health records from the panel study. Associations between indoor levels of mold spores, bacteria, and dust-mite allergens were tested with several asthma severity indicators.

Results: There was evidence of associations between all asthma severity measures and levels of total and Gram-negative bacteria, but mold-spore abundance was associated only with emergency room (ER) visits for asthma. No significant associations were found with house-dust-mite allergen and any of the asthma severity indicators, but the levels of dust-mite allergen were low, with median concentrations of 0.18 µg/g dust Der f 1 and 0.19 µg/g dust Der p 1.

Conclusions: Some evidence was found for associations of increased concentrations of Gram-negative bacteria and mold spores with asthma severity, particularly with ER visits. No association was found between house-dust-mite allergen and asthma severity indicators; however, the mite-allergen levels in the study homes were generally well below the proposed threshold level of 2 µg/g dust.

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A number of indoor environmental factors, including bioaerosol or allergen concentrations, have been implicated as causative or triggering factors for asthma. Some researchers have found that exposure to house-dust-mite allergens is a major risk factor for development or exacerbation of asthma symptoms (1–6). Mold spores have also been associated with increased respiratory symptoms; in two recent reviews, where mold levels were measured in either air or dust samples, there were significant associations with health outcomes in some of the studies, but there was not a consistent pattern of health responses to the measured mold concentrations in these studies (7, 8). A number of recent studies have also indicated that indoor levels of airborne bacteria or endotoxin, a component of Gram-negative bacterial cell walls, are associated with increased asthma severity (9–13).

This study was conducted in several adjacent communities located along the Mississippi River in

Illinois (the “Quad Cities” area). In addition to the fairly high prevalence of asthma and wheezing found in the area, these communities had experienced severe flooding in summer 1993, and it was expected that dampness and mold growth in the homes would be commonly reported. The concentrations of ambient air pollutants have been well below ambient air quality standards in this area. An effort was made to obtain a more representative assessment of indoor allergen exposures by obtaining a series of air and dust samples over a study period of up to 7 months, while information on other indoor environmental factors, such as the use of air conditioners or dehumidifiers, was obtained via questionnaire. The association between these indoor bioaerosol levels and several measures of asthma severity is reported here.

Material and methods

In this study, a group of 59 asthmatic residents, from 46 households, of East Moline, Illinois, and nearby communities, an area which had been severely flooded in summer 1993, was recruited to participate in a panel

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study from April through October 1994. An effort was made to recruit both severe and mild asthmatics, from both flooded and unflooded homes, based on responses to the questionnaires. Informed consent was obtained from all participants. Two families withdrew early in the study period; thus, the data for indoor mold and dust-mite levels are reported for 44 homes, with 57 asthmatic residents.

Asthma severity indicators

For each participating family, a questionnaire was administered at the beginning of the study to obtain information about household characteristics and health history of the participants. Participants were asked to visit the offices of an area physician, who conducted pulmonary function tests and allergy skin tests. Five indicators of asthma severity were derived from the responses to the health questionnaire (all are based on events occurring during the previous 12 months):

- 1) visit(s) to the ER for asthma
- 2) frequency of wheezing events
- 3) whether at least one work or school day had been missed due to asthma
- 4) whether asthma caused awakening during the night
- 5) whether asthma interfered with the ability to speak.

Indoor environmental measurements

Indoor bioaerosol and dust samples were collected from each of the participating residences throughout the study. Each home was visited repeatedly during the study period. With each visit, an initial survey was completed by the researcher (L.C.), including the date and time of data collection; information about weather factors such as indoor and outdoor temperature and humidity, cloud cover, and rainfall; and use of fans, open windows, or air conditioners. Air samples were collected with an Anderson sampler in three rooms in the home and also in the yard just outside the home. Dust samples were also obtained from the asthmatic subject's bedding and the carpets in the same rooms in the home.

A total of 265 bioaerosol sampling visits were conducted at approximately 3-week intervals in each of the homes for 4–7 months. Bacterial and mold spores were collected on Andersen (Atlanta, Georgia) one-stage bioaerosol samplers (N-6) containing 400 air-jet holes with a cut diameter of 0.8 μm , at a height of about 1 m off the ground. Dust was collected with a Sears Kenmore 2.0 vacuum cleaner using a clean cotton filter inside a plastic dust trap attached to the vacuum tube. Each dust sample was a pooled sample of 1 min of vacuuming of a 1-m² area on the bedding and 1 min of

vacuuming of a 1-m² area of the floor next to the bed. Further details on sampling and analytic methodology are provided in separate publications (14, 15).

During each sampling visit, bacteria and fungal spores were sampled in the basement of the house (in the eight houses without basements, the sample was collected in the living room), and about 2 m outside the house. Fungal spores were sampled in the basement (or in the living room if there was no basement), in the kitchen, and in the bedroom of one of the asthmatics in the house (if the asthmatic was living in the basement, the sample was collected in the bedroom of another family member or in the living room). For 23 of the fungal samples, four replicate samples were made over a short period in the same part of the house to determine the reproducibility and accuracy of the bioaerosol sampling.

Statistical analysis

Univariate chi-square tests were used to assess the significance of relationships between dichotomized indicators of asthma severity and indoor bioaerosols (16). Overall concentrations of indoor bacteria, mold, and dust-mite allergens were calculated for each home, with all measurements from the home (excluding outdoor samples). The overall means were then dichotomized on the basis of either the mean or median levels for all homes combined (again excluding outdoor samples). Weighted means were calculated with the number of samples collected in each home as the weighting factor. Because dust mites are more prevalent during the warmer months, analyses were also conducted with mean concentrations of dust-mite allergens from the warmer months of the study (July through October).

For chi-square test analyses, data for asthma severity measures were dichotomized into any/no variables; for wheezing frequency, the data were dichotomized as frequent wheezing (more than 12 times/year) and less frequent wheezing. Additional analyses were conducted with regression models in which the indoor allergen levels were used as continuous data; the concentration data were not normally distributed, so they were log-normalized for use in these models. In logistic regression models, dichotomized health variables were used, and log-linear regression models were also run, with log-normalized data on frequency of wheezing or visits to the emergency room (ER). These additional models were used for further exploration of associations found in the initial analyses, and the results of chi-square tests are primarily presented here.

Results

Characteristics of homes and study participants

The characteristics of the households of study participants are summarized in Table 1. Because participants

Table 1. Household characteristics

Total no. of homes	44
Reported no flooding ever	19 (43%)
Reported flooding in past 10 years	25 (57%)
Reported flooding in summer 1993	17 (39%)
Reported mold growth in home	20 (45%)
Reported dampness in home	15 (34%)
Own furred pets	22 (50%)
Own feathered pets	7 (16%)
Have plant(s) in home	35 (80%)
Have air-conditioning	36 (83%)
Use dehumidifier	15 (34%)
Use humidifier	21 (48%)

were selected to overrepresent residents in flooded or damp homes, the proportions reporting dampness or mold growth are somewhat larger than those found in the larger survey in East Moline, in which 28.3% reported current dampness in the home and only 8.8% of the survey reported mold growth during the previous 12 months.

The characteristics of the panel study participants are summarized in Table 2. Most (93%) had asthma diagnosed by a doctor, and the remaining four participants had signs or symptoms of asthma. Participants ranged in age from 5 to 49 years. Of the 46 for whom allergy skin test results were available, dust-mite allergy was most commonly reported; allergy to pollen and mold spores was also fairly common.

Data on the concentrations of viable mold spores, dust-mite allergens, and bacteria are presented in Table 3. It can be observed that the concentrations of dust-mite allergen found in this study were generally very low.

From the evaluation of replicate samples from the

Table 2. Characteristics of panel study subjects

Total no. of subjects	57
Doctor-diagnosed asthma	53 (93%)
ER visit(s) in past 12 months	9 (16%)
Hospital admission in past 12 months	4 (7%)
Wheezing events per year	
None	3 (5%)
1–3	7 (12%)
4–12	17 (30%)
> 12	27 (47%)
Unknown	3 (5%)
Female sex	32 (56%)
Current smoker	8 (14%)
Ever smoked	17 (30%)
Skin test conducted	46 (81%)
Positive for dust mite, 31 (67%)	
Positive for trees, 21 (46%)	
Positive for grass, 19 (41%)	
Positive for ragweed, 19 (41%)	
Positive for cat, 18 (39%)	
Positive for dog, 17 (37%)	
Positive for molds, 16 (35%)	
Positive for cockroach, 8 (17%)	

Table 3. Descriptive statistics for indoor concentrations of viable mold spores (in CFU/m³), dust-mite allergen (in µg/g dust), and bacteria (in CFU/m³)

	Mean	SD	Minimum	10%	Median	90%	Maximum
Total fungi (n=849)	2190	3344	0	270	1560	4120	48760
<i>Alternaria</i> (n=849)	61	119	0	0	0	173	1122
<i>Aspergillus</i> (n=849)	618	793	0	10	387	1492	8703
<i>Botrytis</i> (n=849)	25	85	0	0	0	73	989
<i>Cladosporium</i> (n=849)	289	463	0	0	160	723	5271
<i>Curvularia</i> (n=849)	8	37	0	0	0	40	564
<i>Epicoecum</i> (n=849)	4	33	0	0	0	0	747
<i>Helminthosporium</i> (n=849)	40	114	0	0	0	127	1273
<i>Penicillium</i> (n=849)	576	1500	0	11	217	1221	32251
Der p 1 ^a (n=312)	0.72	1.56	−0.10	−0.01	0.19	1.88	12.14
Der f 1 ^a (n=312)	1.15	4.22	−0.32	−0.02	0.18	2.18	62.30
Total bacteria (n=257)	1258	786	220	599	1056	1800	4006
Gram-positive (n=257)	589	566	105	221	411	756	2904
Gram-negative (n=257)	826	575	80	362	686	1186	2793

^a Some below-zero values in concentrations of dust-mite allergen were found due to variations in detection limit, and these have been set to zero for analysis.

homes, the coefficient of variation followed a normal distribution and had a mean of 12%. An evaluation was also carried out to determine whether the specific room in each home chosen to represent exposure gave significantly different concentrations than the rest of the house. Twenty-six of the dwellings exhibited no difference between rooms; of the other 18 homes, only eight rooms were found which had significantly higher concentrations than the “within house” average ($P < 0.05$), indicating low between-room measurement variability (17).

Relationship between asthma severity and bioaerosol levels

Bacterial concentrations. Bacterial concentrations showed more consistent evidence for association with asthma symptoms than concentrations of either fungal spores or dust-mite allergen. In analyses using dichotomized variables, all associations between total, Gram-positive, and Gram-negative bacteria concentrations and asthma severity indicators were positive, statistical significance being reached for the associations between ER visits and total bacteria, and near significance being found between ER visits and Gram-negative bacteria (Table 4). However, chi-square tests for associations between dichotomized bacterial levels and other asthma severity measures did not show statistically significant associations (Table 4). While the data are not shown here, similar associations were found in analyses using alternative regression methods; in these models, significant associations were also found between wheezing frequency and total, Gram-positive, and Gram-negative bacteria (all $P < 0.05$) (data not shown).

Indoor mold concentrations. Little evidence was found for a relationship between asthma severity indicators and indoor mold levels, although there are indications

Table 4. Associations between indicators of asthma severity and levels of indoor mold and dust-mite allergen

	Emergency room visits ^a (n=59)	No. of wheezing events ^a (n=59)	Missing sleep due to asthma ^a (n=59)	Asthma interference with speech ^a (n=59)	Missing work/school ^a (n=59)
Total spores	2.8 (0.7–11.1)	1.4 (0.5–4.4)	1.7 (0.5–5.1)	2.2 (0.7–6.7)	0.8 (0.3–2.5)
<i>Cladosporium</i>	3.1 (0.8–12.5)	0.8 (0.2–2.2)	2.8 (0.9–8.5)	1.2 (0.4–3.5)	0.9 (0.6–5.0)
<i>Aspergillus</i>	1.7 (0.4–6.8)	0.5 (0.2–1.5)	0.9 (0.3–2.6)	0.7 (0.2–2.0)	0.7 (0.2–2.0)
<i>Penicillium</i>	1.9 (0.5–7.4)	1.4 (0.5–4.1)	1.5 (0.5–4.4)	2.2 (0.8–6.5)	1.2 (0.4–3.5)
<i>Alternaria</i>	2.2 (0.5–8.7)	0.3 (0.1–1.0)	4.8 (1.6–14.6)	1.8 (0.6–5.0)	1.8 (0.6–5.0)
Der f 1	0.43 (0.05–3.8)	0.32 (0.08–1.34)	0.44 (0.12–1.72)	0.44 (0.11–1.88)	0.74 (0.19–2.85)
Der p 1	0.86 (0.16–4.7)	0.57 (0.16–2.02)	0.72 (0.21–2.48)	0.53 (0.14–1.97)	0.53 (0.14–1.97)
Total bacteria	5.8 (1.3–25.8)	2.2 (0.8–6.7)	2.5 (0.8–7.5)	2.6 (0.9–7.7)	1.4 (0.5–4.1)
Gram-positive	2.8 (0.7–11.1)	2.0 (0.6–6.2)	2.3 (0.7–7.4)	1.1 (0.4–3.5)	1.6 (0.5–4.8)
Gram-negative	4.4 (1.0–19.1)	1.4 (0.5–4.0)	1.5 (0.5–4.2)	2.3 (0.8–6.6)	1.3 (0.4–3.6)

^a Results of chi-square tests of dichotomized health measures and dichotomized levels of mold spores, bacteria, and dust-mite allergen presented as odds ratio (95% CI). Boldface text denotes statistically significant associations ($P < 0.05$).

that ER visits for asthma were associated with indoor mold levels (Table 4). In chi-square tests using dichotomized ER visit data and mold-spore counts, associations with indoor mold-spore concentrations were all greater than 1.0 although none of the associations were statistically significant. Results for the other four asthma severity measures were highly variable, with one significant positive and one nearly significant negative association; due to the multiple tests conducted, these findings may well be due to chance (Table 4). When analyzed by log-linear regression (using log-transformed mold-spore concentrations as continuous data), the results yielded similar findings, but several of the associations found for ER visits reached statistical significance in these analyses (data not shown).

It has been noted that mold spores in outdoor ambient air may penetrate into the home and may significantly influence indoor mold-spore concentrations; in fact, outdoor concentrations generally exceeded the indoor concentrations in this study. In an effort to determine the potential influence of outdoor mold-spore concentrations in this study, associations between the respiratory health measures and concentrations of outdoor mold spores (measured with an Andersen sampler) were tested. In addition, multivariate models, containing both the indoor mean mold-spore concentrations and the outdoor mold-spore concentrations, were used to assess the influence of the addition of outdoor mold levels to the model containing indoor mold-spore concentrations.

As found with indoor measurements, the only significant associations found were for ER visits with outdoor total spores (OR 10.500, 95% CI 1.915–57.585) and with *Alternaria* (OR 4.857, 95% CI 1.063–2.191). While there was significant correlation between the indoor and outdoor concentrations for each of the mold genera, with Spearman correlation coefficients ranging from 0.22 (*Curvularia*) to 0.59 (*Cladosporium*), the two indoor and outdoor concentrations generally had little effect on one another when included in the same

models. In all cases, the inclusion of both indoor and outdoor concentrations resulted in only small changes in the effect estimate for each when compared with the effect estimates obtained in single-variable models (data not shown).

Concentrations of dust-mite allergen. No significant associations were found between any of the indicators of asthma severity and concentrations of dust-mite allergen. As described previously, the levels of dust-mite allergen in the study homes were very low, with individual measurements exceeding 2 µg/g dust found in only seven homes. When the data were dichotomized on the basis of the 2 µg/g dust allergen level, there was still no evidence for associations with asthma severity.

Other variables

In a separate report (14), we found that levels of dust-mite allergen were significantly associated with the presence of pets in the home. In addition, previous studies have indicated that asthma severity may be associated with atopic status, smoking in the home, sex, or family history of asthma. While there were not sufficient data to conduct subgroup analyses, indicator variables were created for 1) allergy to dust mites, 2) allergy to molds, 3) presence of smokers in the home, 4) presence of furry pets in the home, 5) sex, 6) a close family relative having been diagnosed with asthma, and 7) reconstruction of the home after flooding. When tested individually with the indicators of asthma severity, the only significant association found was between allergy to molds and missing work or school due to asthma (OR 3.857, 95% CI 1.044–14.244), and this may well be due to chance with the large number of analyses conducted. When included in logistic regression models with the bioaerosol levels, none of these potential risk factors for asthma were found to influence substantially the results of the analyses when compared with univariate models with the

allergens. In addition, atopy to molds or house-dust mites was not significantly associated with the measured allergen levels (molds or house-dust-mite allergen) in the homes.

Discussion

In this study, the relationship between asthma severity and indoor environmental factors was evaluated. In an effort to assess aeroallergen exposure levels in the home more accurately, repeated air and dust samples were collected in each home over the study period. The results suggest that increasing levels of airborne bacteria are associated with increased asthma severity, and that increasing levels of airborne mold spores are associated with increased risk of ER visits for asthma. No evidence was found for associations between measures of asthma severity other than ER visits and mold-spore concentration, or for associations between any asthma severity indicators and concentration of dust-mite allergen or household environmental factors such as dampness or flooding in the home.

The mold spore and bacterial concentrations found in this study are comparable to those measured in previous studies. In Taipei (Taiwan), the geometric mean concentration of viable mold spores was 599 CFU/m³ (18), while airborne fungal concentrations ranged from 8 to 6030 CFU/m³ in Iowa (USA) homes (19). In classrooms in Sweden, viable bacteria concentrations reached a maximum level of 1100 CFU/m³ (12), and viable bacteria levels ranged from 100 to 8800 CFU/m³ in residences in another Swedish study (11). In contrast, the concentrations of dust-mite allergen found in this study were generally lower than have been found previously. Custovic et al. (4) found mean Der p 1 concentrations of 3.6, 1.2, and 4.4 µg/g dust in mattresses, bedroom carpets, and bedding, respectively, in UK homes. In New Mexico (USA), the geometric mean concentrations of Der p 1 and Der f 1 were 0.18 and 0.13 µg/g, respectively (5), while Der p 1 concentrations in bedroom floor dust in a Dutch study ranged from 0.104 to 60.527 µg/g (20).

Associations with airborne bacterial concentrations

All associations between asthma severity indicators and airborne bacterial levels were positive, although few were statistically significant. The strongest evidence for a relationship was found with ER visits; significant associations were found with both total bacteria and Gram-negative bacteria levels. In alternative regression analyses using bacterial levels as continuous data, it was noted that several of the associations found with other asthma severity measures also reached significance (data not shown).

In Sweden, current asthma was found to be significantly associated with viable bacteria levels in

the classrooms (12). However, in a similar study, asthma symptoms were significantly increased in residences with higher total bacteria concentrations ($P < 0.05$), but not with viable bacteria (11). The results of this study are consistent with an association between bacterial levels and asthma, and it is notable that concentrations of viable Gram-negative bacteria appear to be associated with increased asthma severity, but no significant associations were found with viable Gram-positive bacteria (Table 4). This is consistent with the findings of previous studies; in two studies, endotoxin levels in house dust were associated with increases in wheezing and medication use, but no associations were found with measures of dust-mite allergen in the homes (9, 13). In a third study, exposure to dust-mite allergen was associated with increased risk of developing asthma, and endotoxin levels in house dust were associated with increased severity of disease (11). Although endotoxin levels were not directly measured in this study, the associations found between concentrations of Gram-negative bacteria and asthma severity indicators are consistent with a finding that endotoxin exposure is a risk factor for exacerbation of asthma.

Associations with airborne mold spores

Participants reporting visits to the ER were more likely to live in homes with high levels of molds, as indicated by the positive odds ratios found for each of the molds (Table 4), but the associations did not reach statistical significance. Little evidence was found for associations between concentrations of indoor viable mold spores and the remaining indicators of asthma severity. When analyses were conducted with only participants allergic to molds, little evidence for associations was found; however, only 16 of the participants had positive allergy skin tests to mold spores.

Recent reviews of the literature have found consistent associations between reported dampness or mold growth in the home and respiratory illness; however, the evidence from studies that directly measured mold spore concentrations is less conclusive (7, 8). The results of this study suggest some possible associations between indoor mold levels and admissions to the ER for asthma, but do not provide statistically significant evidence to support associations between indoor mold spore concentrations and adverse respiratory effects.

In the East Moline area, the outdoor mold-spore concentrations were considerably larger than indoor concentrations of *Aspergillus*, *Cladosporium*, and *Penicillium*, a finding which is in contrast to findings from some previous studies (21). In this study, when both indoor and outdoor mold-spore levels were included in multivariate analyses, the findings were negligibly different from the results of individual

analyses. These findings suggest that, where adverse respiratory effects are found with exposure to mold spores, both indoor and outdoor sources of molds may contribute to the effects. Su et al. (22) used factor analysis to group fungal genera, finding one group of fungi, including *Cladosporium* and *Alternaria*, considered to be outdoor fungi, while *Penicillium* and *Aspergillus* were included in the group considered to be indoor fungi. Children living in homes with higher levels of the outdoor fungi were significantly more likely to report hay fever ($P=0.003$) and wheezing/asthma ($P=0.008$), but no associations were found between wheezing or asthma with the other groups of fungi.

Associations with allergens of house-dust mite

There were no positive associations between levels of dust-mite allergen in the homes and any of the asthma severity indicators. Earlier studies have indicated that a threshold of 2 $\mu\text{g/g}$ dust may exist for sensitivity to dust-mite allergen (1). Some have indicated that allergen levels must exceed 10 $\mu\text{g/g}$ dust before significant effects are seen on respiratory health (23). With the low levels of dust-mite allergen found in this study, it is not surprising that no associations with asthma severity were found.

One strength in this study is the extensive measurements made to determine exposure levels to allergens. Verhoeff & Burge (7) recommend that fungal samples be repeated over time within one season and in different seasons. In this study, an effort was made to define exposure levels more accurately via repeated sampling throughout the study period, and it was considered unlikely that within-house variability was a major source of exposure misclassification (17). However, the sampling interval for airborne allergens was only 33–133 s, and it is possible that the sampling design was still insufficient to describe accurately overall exposure to bioaerosols. It can be seen that the mold-spore concentrations are quite variable, so that the median level is zero for several genera. This high level of variation in measurements both over time and between homes may require alternative, longer-term measurements to be made to characterize more accurately levels of indoor mold spores. In contrast, bacteria concentrations were less variable, a finding which may be one reason why stronger evidence was found for asthma severity associations with bacteria than with mold spores.

One weakness of this study is its small sample size. As a panel study, it was not feasible to recruit a large number of participants and conduct repeated mea-

surements and analyses of bioaerosols in each home; this weakness is common among such studies. As a result, the confidence intervals for the associations tend to be large; it is perhaps notable that significant associations were found in this small study.

In addition, recall bias may also have influenced the results of in this study. ER visits are generally infrequent; thus, accurate recall is likely. However, it is possible that some participants may have difficulty in recalling the number of days missed from work or school, as well as in ranking their wheezing frequency for the previous 12 months. The investigator (M.A.R.) who administered the initial questionnaire noted that the participants had particular difficulty in recalling frequency of wheezing during the past 12 months. For the more subjective measures, we suspect that recall bias would, in fact, result in fewer reported health effects. It is notable and perhaps not surprising that the strongest evidence of associations with bioaerosol levels was with ER visits, which would be expected to have the least recall bias.

The study participants were selected on the basis of a diagnosis of asthma or having current asthma symptoms. While selection bias should not be an issue regarding the selection of participants to overrepresent residents of flooded or damp homes, it is possible that the selection of asthmatics for participation in the panel study resulted in a study group that was too homogeneous to allow detection of differences in asthma severity. Selection of an overly homogeneous group of asthmatics would be expected to result in bias toward a null result.

In summary, the results from this study suggest that in the East Moline, Illinois, area asthma severity increases, particularly the risk of ER visits for asthma, with airborne bacteria concentrations, and there are indications that ER visits for asthma are associated with increased mold-spore abundance. The levels of dust-mite allergen in the homes were low, and no significant associations were found between asthma severity and concentration of dust-mite allergen.

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