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First comparison of symptom data with allergen content (Bet v 1 and Phl p 5 measurements) and pollen data from four European regions during 2009–2011

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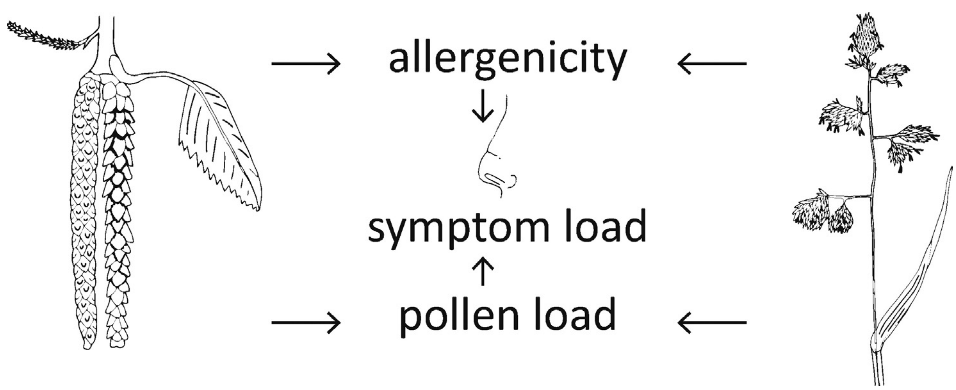
HIGHLIGHTS

- Allergen content is currently a main suspect for having a direct impact on symptoms.
- Measurements of main allergens (Bet v 1/Phl p 5) explain peaks in the symptom load.
- A direct pattern between the symptom level and the allergen content was not found.
- A focus on the development and onset of allergy symptoms is needed in monitoring.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: The level of symptoms in pollen allergy sufferers and users of the Patient's Hayfever Diary (PHD), does not directly reflect the total amount of pollen in the air. It is necessary to explain the symptom load and thus the development of allergic symptoms and to determine which environmental factors, besides the pollen load, influence variables. It seems reasonable to suspect allergen content because the amount of allergen varies throughout seasons and regions and is not always correlated with the total pollen amount.
Methods: Data on the allergen content of ambient air (Bet v 1 and Phl p 5) from 2009 until 2011 was used to compare the respective pollen and symptom loads for study regions in Austria, Germany, France and Finland.
Results: Our findings suggest that allergen amount (Bet v 1/Phl p 5) has a strong but regionally dependent impact on the symptom load of pollen allergy sufferers. Peak symptom loads can be traced with peak allergen loads. The influence of other important aeroallergens should also be assessed during the pollen season.

Abbreviations: HIALINE, EU-funded project called Health Impacts of Airborne Allergen Information Network; IgE, immunoglobulins E; PHD, Patient's Hayfever Diary; SLI, symptom load index.

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Patient's Hayfever Diary
Phl p 5
Symptom load index

Conclusion: Allergen concentrations have an impact on pollen allergy sufferers although not as clear as assumed previously. The pattern of pollen load and major allergen content distribution does not directly explain the symptom load pattern, although significant positive correlations were found. Thus, monitoring of symptoms via voluntary crowdsourcing should be considered for future pollen and symptom forecasts in order to support pollen allergy sufferers.

1. Introduction

In order to ease the burden of pollen allergy sufferers basic research is required as well as an in-depth understanding of vegetation, plant distribution, environmental pollution, aerobiology especially related to pollen information based on pollen counts. As an example, exact thresholds for a certain regional population to develop allergic symptoms (either in pollen grains per m^3 air or in allergen content in pg/m^3) were not determined (e.g. De Weger et al., 2013) and it is not known which factors are causing the diversity in the symptom levels throughout the pollen season in people affected. The history of pollen allergy has been studded with “why” questions from the very beginning. Bostock (1819) described the symptoms of pollen allergy, but was not aware of the causal agent and Blackley (1873) skin-pricked his own arm to recognize pollen as the cause of allergic symptoms. Since then innovations in various fields, including medicine, aerobiology, pollen information and molecular biology, have led to a growth of valuable knowledge for pollen allergy sufferers. Recent findings (Bastl et al., 2014; Buters et al., 2012) indicate the need for more extensive pollen information to support and optimize allergen avoidance, as it has been shown that daily pollen concentrations neither match perfectly with the symptom load of pollen allergy sufferers, nor with allergen content in the air. Up to now there is no answer to the question what the main determinant of the onset and development of allergic symptoms in pollen allergy sufferers really is. Allergen content is currently the main suspect as one of the factors causing the most impact (Brito et al., 2011). The nomenclature for allergen proteins follow the species' latin genus and species name (Phl p for *Phleum pratense*) as well as the sequence of their discover (e.g. Phl p 5 for the 5th discovered allergen of *P. pratense*). As far as we know allergen content is variable from pollen grain to pollen grain even within a taxon, e.g. birch pollen (Buters et al., 2012) and not proceeding synchronous with daily pollen concentrations (Buters et al., 2012, 2015). This is due to the fact that pollen allergens can also be present as small airborne respirable particles (Spieksma et al., 1995; Schäppi et al., 1997, 1999) and depend on pollen ripening (Buters et al., 2010). Furthermore, the pollen concentrations are not synchronous with the discomfort of pollen allergy sufferers (Bastl et al., 2014). Concluding it has to be tested whether allergen content (herein Bet v 1/Phl p 5) could be the main determinant of the symptom load. Hence, the aim of this study is to compare the measured allergen content (Bet v 1/Phl p 5) in four different regions of Europe within a retrospective study and to compare this data to the symptom load of pollen allergy sufferers during the respective pollination period in those regions to assess their relationship.

2. Material and methods

2.1. Allergen content

This retrospective study uses Bet v 1 and Phl p 5 measurements of four countries (Austria, Germany, France and Finland), which took part in the HIALINE study during the period of 2009 to 2011 (Buters et al., 2015, 2012). The values obtained were used for comparison with symptom data in the study presented here. The procedure of allergen measurement of Bet v 1 and Phl p 5 is described in detail in Buters et al. (2010, 2012, 2015). The Bet v 1 and Phl p 5 air content values derive from the pollen grains trapped in the Chemvol® sampler and were measured as pg/m^3 (Buters et al., 2012). The HIALINE study (Buters et al., 2012, 2015) only indirectly tested whether free allergen (D'Amato et al., 2008), apart from that encapsulated in the pollen grains, was present in the air and only focused on one major allergen protein per pollen type. The term “allergen content” is thus used in this work as in former works (Buters et al., 2010, 2012, 2015) and refers to Bet v 1 and Phl p 5. Hence, it does not mean the whole content of possible allergens (major and minor allergens, free and encapsulated) in the air.

2.2. Symptom data

The Patient's Hayfever Diary (PHD) provided symptom data for this study. This free online web-based tool has also been available as the “pollen app” since 2013 in some countries (Austria, Germany; Kmenta et al., 2014) and is a highly practicable tool for both scientists and pollen allergy sufferers (e.g. Bastl et al., 2014; Karatzas et al., 2013; Kmenta et al., 2014; Voukantsis et al., 2013). Its wide distribution in several European countries, as well as the growing number of users every year, provide a large and valuable dataset concerning pollen allergy symptoms (e.g. Bastl et al., 2014). We used the methodology described in Bastl et al. (2014) to calculate the symptom load index (SLI) based on the PHD symptom data for each study region during 2009–2011. This includes normalizing the data to come to an alternated symptom score ranging from a minimum of 0 to a maximum of 10. In the following, the average symptom score is calculated for the respective season in the respective region. The whole PHD data for each country was not used, only the data from the region where the allergen measurements were performed following the regional definitions in EAN and the PHD (Austria: Pannonian lowlands; Germany: Allgäu, Oberbayern, Bayrischer Wald; France: Rhône-Alpes; Finland: southern Finland). This procedure avoids a levelling of the results. The birch or grass pollen season was also calculated based on local pollen data, namely the centre of allergen measurement (Vienna, Lyon, Turku, Munich). We assume that the allergen content is representative for the region, as the pollen concentrations are, and we thus confirm that the period of the respective pollen seasons is used as the basic reference due to their pre- and post-season availability to summarize the allergen measurement values during the season and the SLI calculation during the very same defined pollen season within the region. Datasets (daily symptom reports) and PHD user numbers vary per year and are still on the rise (Table 1). Over all regions, seasons and years, we used the data from 4115 users and their 65,250 datasets for analysis. The detailed breakdown per pollen season and year is listed respective of the region, together with the time period chosen in Table 1. Results are listed in Table 2 together with the sum of allergen content during the pollen seasons 2009–2011. PHD symptom datasets have already proven to give relevant and stable insight into the allergenic burden of a population on a national, regional and local level (Bastl et al., 2015b). This is also true when applied during a short pollen season with only a minor fraction of the population affected (Bastl et al., 2015a).

2.3. Data presentation

Note that allergen measurements were not performed in Austria in 2009, and therefore no symptom and pollen data was retrieved for this year. The sample size of the symptom data was too small in 2009 for some regions, since the PHD was introduced in that year and was

Table 1
Raw data of the study: The number of PHD users is listed, as well as the number of available datasets for the SLI calculations. The period chosen to define the respective birch or grass pollen season is included and follows the EAN definition. It is based on pollen data from the centre of allergen content measurement. Blank spaces are left where datasets were too small to include them into the analysis.

	Austria	Germany	France	Finland
PHD users	Pannonian lowlands	Allgäu, Bayern	Rhône-Alpes	Southern Finland
Birch pollen season				
2009	Not evaluated		3	
2010	576	19	107	404
2011	717	107	110	227
	1293	**126**	**220**	**631**
Grass pollen season				
2009	Not evaluated	17		
2010	391	26	95	289
2011	615	143	106	163
	1006	**186**	**201**	**452**
Total	**2299**	**312**	**421**	**1083**
Datasets	Vienna	Munich	Lyon	Turku
Birch pollen season				
2009	Not evaluated		41	
2010	5735	283	301	3413
2011	7770	1617	796	1967
	13,505	**1900**	**1138**	**5380**
Grass pollen season				
2009	Not evaluated	369		
2010	9099	791	1099	6082
2011	16,935	4242	1685	3035
	26,034	**5402**	**2784**	**9117**
Total	**39,539**	**7302**	**3922**	**14,497**
Season definition on pollen data from (in DD-MM)	Vienna	Munich	Lyon	Turku
Birch pollen season				
2009	Not evaluated	06–04 to 23–04	12–03 to 08–05	25–04 to 24–05
2010	29–03 to 30–04	07–04 to 30–04	07–04 to 29–04	27–04 to 16–05
2011	02–04 to 23–04	29–03 to 23–04	29–03 to 22–04	24–04 to 14–05
Grass pollen season				
2009	Not evaluated	10–05 to 07–08	17–05 to 20–07	12–06 to 19–08
2010	22–05 to 31–07	21–05 to 10–08	23–05 to 31–07	03–06 to 13–08
2011	14–05 to 20–08	08–05 to 06–08	06–05 to 07–08	01–06 to 11–08
Total pollen during the season	Vienna	Munich	Lyon	Turku
Birch pollen season				
2009	Not evaluated	5510	1524	4973
2010	10,550	5628	1250	24,515
2011	3038	3350	1322	7507
Grass pollen season				
2009	Not evaluated	960	4426	1327
2010	2632	362	3398	1153
2011	2184	735	2256	1276

not as established at that time as it is now. We defined the PHD sample size per year, and region as too small, if the following criteria were met based on a pre-analysis: fewer than 15 users and fewer than 40 datasets (Table 1; those were the years 2009 for Austria and Finland, 2009 for the birch pollen season for Germany and 2009 for the grass pollen season for France). We omitted that data, since it would result in unrealistic values that would skew the results. Data summarized for each season is presented in Table 2 and compares average SLI, total allergen content and total pollen data. The detailed season analysis is presented in Figs. 1–2 for the year 2011 and for the other years in the Supplements (Figs. 3–12) and shows the daily values of SLI and allergen content data (pollen data was omitted to avoid scaling problems). We chose the data from 2011 as exemplary, because most symptom data was available for this year and it is important to present daily data next to the general analysis to show prospects and limitations of this study.

Table 2
Results from the SLI calculations in comparison to the sum of allergens measured and the total amount of birch and grass pollen during the respective birch or grass pollen season.

	Austria	Germany	France	Finland
SLI values normalized	Pannonian lowlands	Allgäu, Bayern	Rhône-Alpes	Southern Finland
Birch pollen season	–	–	4.74	–
2009	5.19	3.10	5.97	5.77
2010	5.49	5.53	5.73	6.03
2011				
Grass pollen season	–	3.90	–	–
2009	3.59	3.99	5.16	4.61
2010	3.32	3.17	4.09	4.70
2011				
Allergen content in pg/m^3 (HIALINE)	Vienna	Munich	Lyon	Turku
Birch pollen season	Bet v 1	Bet v 1	Bet v 1	Bet v 1
2009	no data	12,279.23	2348.63	7066.97
2010	20,279.59	13,822.78	6309.36	14,802.01
2011	9170.50	15,577.96	2083.11	6690.97
Grass pollen season	Phl p 5	Phl p 5	Phl p 5	Phl p 5
2009	no data	6544.52	30,994.12	1471.56
2010	7208.49	6557.19	30,346.36	1283.46
2011	3825.79	5266.53	22,554.21	1375.30

For statistical analysis we decided to analyse the correlation between SLI and allergen content and between SLI and pollen data for each study region, year and pollen season separately as regional and seasonal variance is known, which is also reflected in the results (Table 3). The relationship of allergen and pollen data was already analysed before and thus not restudied here (Buters et al., 2012, 2015). We calculated the correlation coefficient between the daily data within the respective calculated pollen season (Table 1) by means of a Spearmen correlation. The statistical software R in version 3.2.2 was used (see R Core Team, 2015). A rank based correlation coefficient is used, because the data is clearly not normally distributed. Results of the significance test are presented as rho and p-values in Table 3. Note that we highlighted significant results for the respective datasets (* for reaching the 5% significance level and ** for results of higher significance that are judged as significant even with the Bonferroni correction). Bonferroni correction is used when multiple statistical tests are performed. The goal is to correct the significance level, so that the joint significance level is the originally selected one (Dunn, 1961).

3. Results

3.1. Austria

The total amount of Bet v 1 was considerably higher in 2010 than in 2011 in Austria as well as the total pollen, but the SLI was not (Table 2). The comparison of total Phl p 5 amount from 2010 and 2011 and the SLI and the total pollen during the grass pollen seasons shows a slight decrease and they are thus in accordance with each other (Table 2). The daily analysis shows great variation between the years and a bad tracing of peaks (birch pollen season 2011; Fig. 1) as well as good ones (birch pollen season 2010, grass pollen season 2010 and 2011; Fig. 2 and Supplements). Statistical results (Table 3) show significant values for the SLI in the birch pollen season 2010 (with allergen and pollen data), the grass pollen season 2010 (with allergen and pollen data) and the grass pollen season 2011 (with allergen data only).

3.2. Germany

While the average SLI is increasing from 2010 to 2011 during the birch pollen season, the respective allergen index rises together with the total birch pollen in the same period, although the rise from 2009

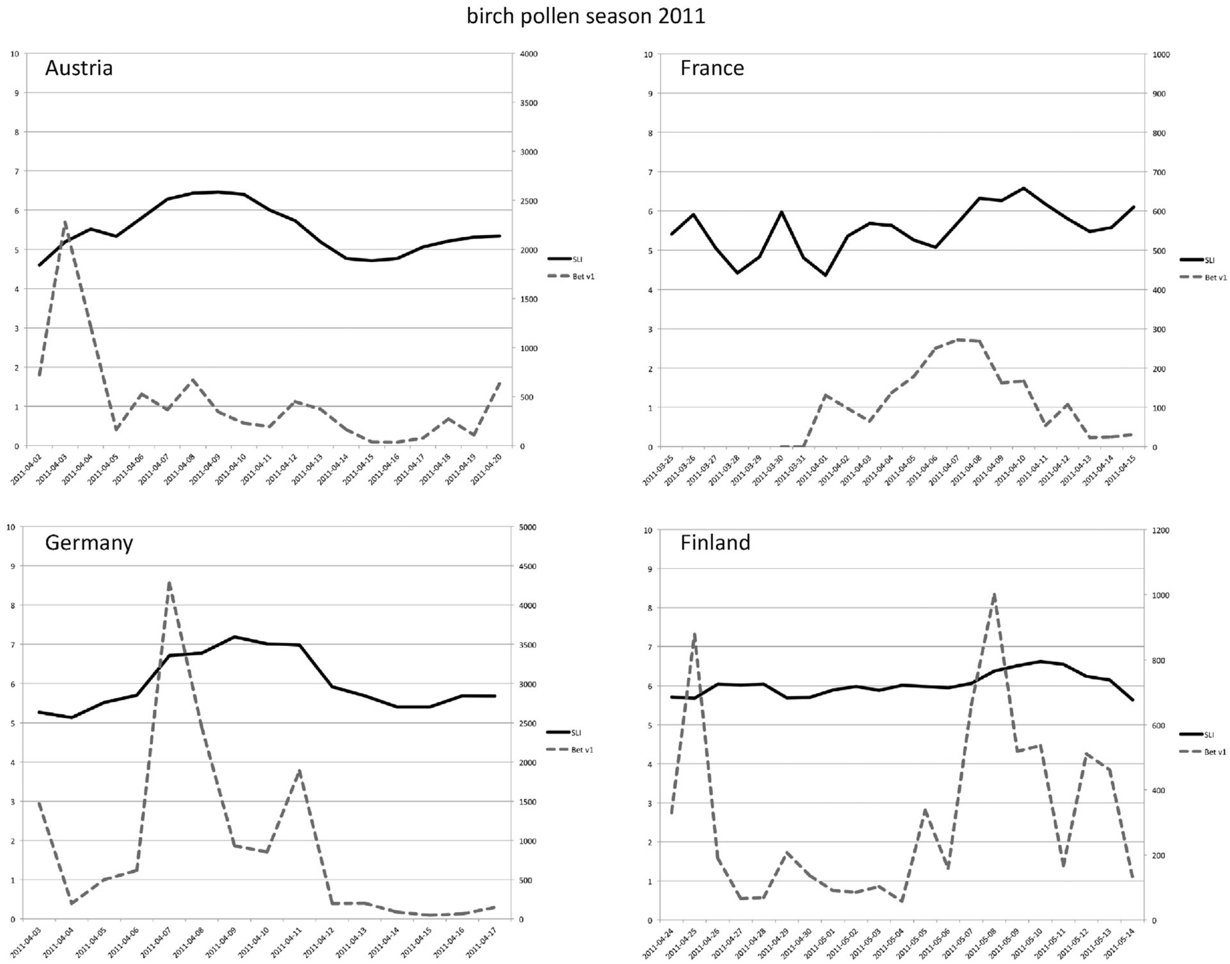

Fig. 1. Comparison of daily Bet v 1 values (pg/m^3; grey dashed line) with SLI values (normalized from 0 to 10; black line) for the four regions of Austria, Germany, France and Finland within the calculated birch pollen season in 2011. Note that the scale for the allergen content had to be adjusted depending on the region with France showing the lowest Bet v 1 values.

to 2010 in the allergen content is contrasted by a decrease of total birch pollen in those years (Table 2). A concurrent pattern can be observed for the grass pollen seasons for average SLI and allergen index, they both increase from 2009 to 2010 and decrease in 2011. On the contrary, the total grass pollen decreases from 2009 to 2010 and increases in 2011 (Table 2). The daily analysis for Germany shows nearly a simultaneous occurrence of the allergen measurement peak with a symptom peak for the grass pollen season (Fig. 2 and Supplements), but occurs earlier than the symptom peak during the birch pollen seasons (Fig. 1 and Supplements). Statistical results (Table 3) show significant values for the SLI in the birch pollen season 2010 (with allergen and pollen data), the birch pollen season 2011 (with allergen data only), the grass pollen season 2010 (with allergen and pollen data) and the grass pollen season 2011 (with allergen data only).

3.3. France

Bet v 1 content and SLI behave similar and increase from 2009 to 2010 and decrease from 2010 to 2011, whereas the total birch pollen decreases from 2009 to 2010 and rises from 2010 to 2011 (Table 2). A decrease is observed in all three parameters for the grass pollen seasons (Table 2). The comparison of daily allergen and symptom datasets (Figs. 1, 2 and Supplements) shows a fairly synchronous proceeding of both values, especially for the grass pollen season. The highest Phl p 5 values were measured in France in comparison to other regions under study here. Statistical results (Table 3) show significant values for the SLI in the birch pollen season 2010 (with pollen data only) and the grass pollen season 2010 (with pollen data only).

3.4. Finland

From 2010 to 2011 the Bet v 1 allergen index drops as well as the total birch pollen, but the SLI rose (Table 2). For the grass pollen season all three parameters rise from 2010 to 2011 (Table 2). The comparison of daily data shows that a Bet v 1 peak is followed with some time lag by a SLI peak (Fig. 1) and that some peaks can be traced with the allergen index, but not all of them (e.g. grass pollen season 2011; Fig. 2). Statistical results (Table 3) show significant values for the SLI in the birch pollen season 2010 (with pollen data only), the grass pollen season 2010 (with allergen and pollen data) and the grass pollen season 2011 (with allergen data only).

3.5. General observations and statistics

In most observations the measured Bet v 1 and Phl p 5 matches graphically with the course of the SLI, especially during the grass pollen season and more than the birch/grass pollen load. This is not always the case (Fig. 1 and Table 2; birch pollen season), since the SLI does neither parallel the pattern of the Bet v 1 content nor the birch pollen load in Austria and Finland. The daily analysis for the region in Finland sheds light on some problems (Figs. 1, 2, Table 2 and Supplements): The highest Bet v 1 values were measured in Finland compared to other regions under study here and those values change markedly between the

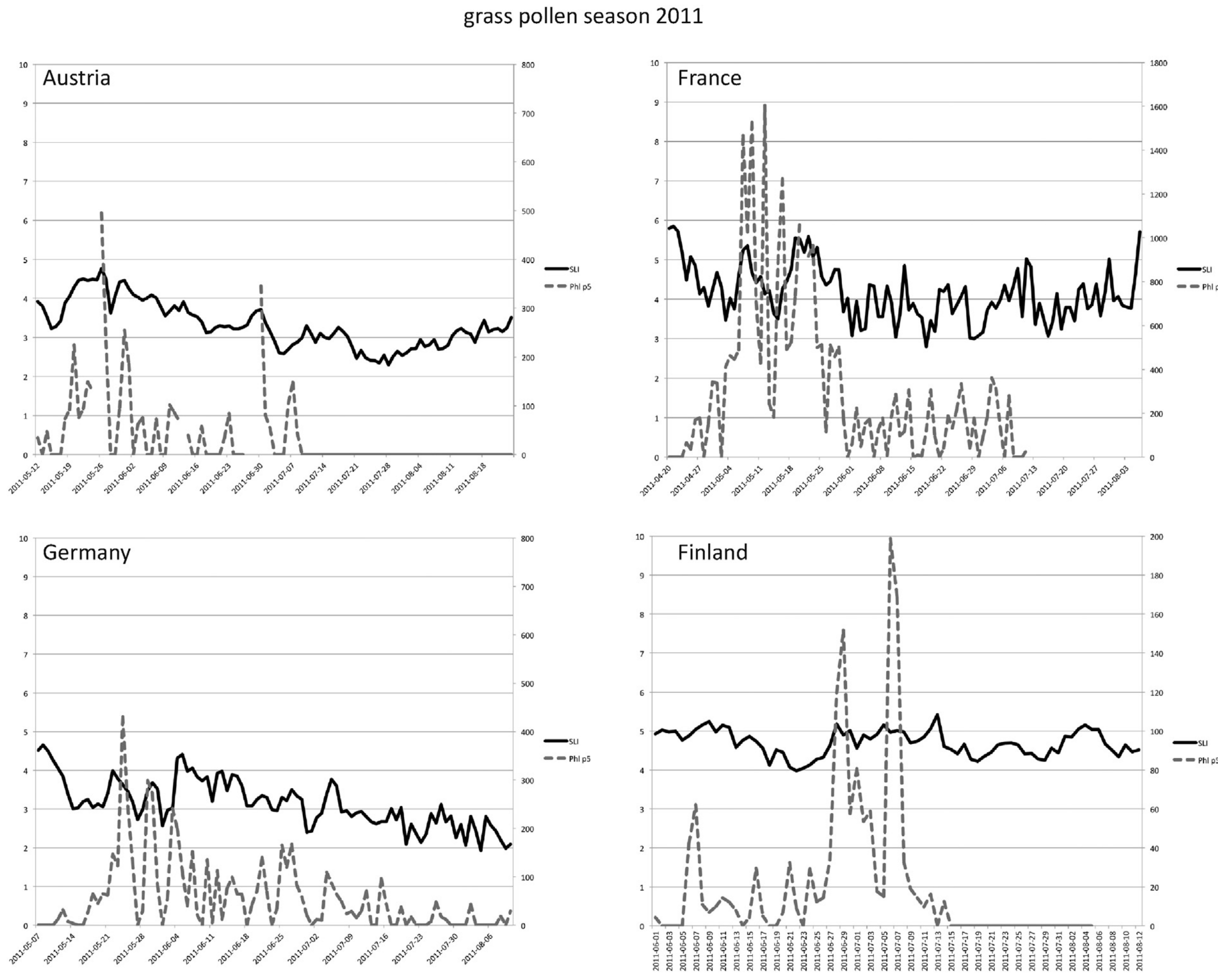

Fig. 2. Comparison of daily Phl p 5 values (pg/m^3; grey dashed line) with SLI values (normalized from 0 to 10; black line) for the four regions of Austria, Germany, France and Finland within the calculated grass pollen season in 2011. Note that the scale for the allergen content had to be adjusted depending on the region with Finland showing the lowest Phl p 5 values.

years. In 2011, there are Bet v 1 peaks that can be traced in the SLI, although it is throughout the season on a high level, which is explained by the general high allergen and pollen levels in that year (Fig. 1). The lowest grass pollen season occurs in Finland together with a relatively less variable SLI, although the SLI levels are comparable to those of other regions.

The statistical results complete the picture and show (1) regional differences (most significant correlations found for Munich vs. much

Table 3
Results from the statistical analysis. Allergen data (Bet v 1 and Phl p 5 respectively) and pollen data (birch and grass pollen data respectively) was correlated with the symptom data (SLI) for each study region, pollen season and year. Rho and p-values as well as the level of significance are presented (* for 5% level of significance; ** for significance even after the Bonferroni correction is applied). For easy view the values were rounded down to the second decimal place. Regional and seasonal variances are obvious.

Location	Pollen season	Year	Rho allergen	P allergen	Significance	Rho pollen	P pollen	Significance
Vienna (Pannonian Lowlands)	Birch	2010	0.80600868	2.99E-10	**	0.75583476	1.73E-16	**
		2011	0.28270424	0.1204508		0.40202109	0.40202109	
	Grass	2010	0.70407397	1.50E-11	**	0.79265342	1.09E-15	**
		2011	0.58883173	4.69E-11	**	0.68071464	0.68071464	
Turku (Southern Finland)	Birch	2010	0.13619263	0.5669611		0.60038009	0.00512731	*
		2011	0.328785	0.14560216		0.07184655	0.07184655	
	Grass	2010	0.39447103	0.00050562	**	0.26582432	0.02401497	*
		2011	0.28769673	0.01916222	*	0.40042344	0.40042344	
Lyon (Rhône-Alpes)	Birch	2009	0.12749105	0.52626988		0.21406191	0.27403972	
		2010	0.21760644	0.31855832		0.83503455	1.34E-06	**
		2011	0.1643164	0.52856633		0.2908783	0.2908783	
	Grass	2010	0.21465787	0.09955461		0.40560333	9.72E-05	**
		2011	0.19749198	0.07532637		0.21591171	0.21591171	
Munich (Allgäu, Bayern)	Birch	2010	0.50677974	0.01608423	*	0.74390644	0.0001107	**
		2011	0.58139628	0.02301082	*	0.69382302	0.69382302	
	Grass	2009	0.12965146	0.25169894		0.11371099	0.28867704	
		2010	0.70862303	9.50E-14	**	0.30974926	0.00313814	*
		2011	0.51659242	7.13E-08	**	0.36127292	0.36127292	

less in Lyon), (2) pollen seasonal differences (most significant results were found for the grass pollen seasons) and (3) annual differences (except for the Munich (region Allgäu, Bayern) no significant correlation neither with allergen nor pollen data was found for the birch pollen season 2011). Significant correlations were found more often for SLI with allergen data than for SLI with pollen data (except for Lyon, Southern France).

4. Discussion

We note that there are certain challenges and limits to the interpretation of the results. There is a marked regional and annual variation. Moreover, it is clear that every season has its own peculiarities and that allergen content varies within the years and between regions (e.g. extreme values found in France and in Finland; Table 2). As an example in 2010, the birch pollen season contained only a couple of days with higher birch pollen concentrations and Bet v 1 measurements in Finland. This thus skews the general picture of the season and is one of the explanations for the difficulty of the appliance of statistical tests to datasets of high complexity such as symptom datasets (Supplements). Another factor of uncertainty concerns the allergen measurements: Only the two major allergens (Bet v 1 and Phl p 5) were measured, and it remains unknown which other allergens (major or minor) were present and also had an impact on sensitized individuals. Pollen allergy sufferers also display different reactions to different allergenic proteins. Although Phl p 1 and 5 groups dominate the immune response to grass pollen extract, the group 12 allergens (profilins) are a cause of extensive cross-reactivity (Andersson and Lidholm, 2003). Panallergens also have an influence as important players in the manifestation of allergic sensitization, including profilins and polcalcins (Hauser et al., 2010). Allergenic proteins can occur without pollen in the air, or in conjunction with other particulate matter than pollen (e.g. pollen cytoplasmic granules; Chakra et al., 2012). Minor allergens were not measured during the HIALINE study, although it is known that they cause symptoms, as for example Bet v 5 for pollen-related oral allergy (Karamloo et al., 1999). All symptom data available was used in this study and the advantage of a large dataset was preferred over the possible bias. Sekerková and Polácková (2011) suggested that not only the home region of pollen allergy sufferers, but also their age determines the specificity of allergen-induced IgE antibodies. Children show an increase in Bet v 2 positivity and this frequency was higher in the paediatric group than in the adult group (Sekerková and Poláctková, 2011).

This study shows that the SLI follows the allergen content (Bet v 1/ Phl p 5) in nearly all regions in all pollen seasons in a general sense (Table 2) and significant correlations could be found for many examples (Table 3). However, Lyon (Southern France) is an exception in this study, as significant correlations can be only found for this region for SLI with pollen data. It is not clear why, but we suspect that the allergen profile (measuring only one allergen protein), allergen potency which already proved to be not constant (Buters et al., 2015), protection effects due to high exposure and/or the population response (different pattern of sensitizations) could be a clue that could prove in further investigations as the right track. For the birch pollen season, the exceptions are Austria and Finland as well as the birch pollen season in 2011. It should be noted that the birch pollen season in 2011 were not as intense as usual and provided rather low annual birch pollen counts (Table 1) in Austria and Finland. When seasons are analysed in detail based on daily data, peak loads can be traced in most cases, but significant allergen content loads can also occur without major influence on the symptom load (July peak in the Austrian grass pollen season 2010; Supplements). However, there are different explanatory approaches that could clarify the situation concerning the SLI levels in Austria and Finland: alder (*Alnus*), hornbeam (*Carpinus*) and ash (*Fraxinus*) flower in spring and overlap with the birch pollen season. Hence, these aeroallergens could have an impact on pollen allergy sufferers as well. In Austria, the flowering period of alder did not overlap with that of birch, but both hornbeam and ash flowered more intensely during 2011 than in 2010 (personal observation). A large part of the population in Eastern Austria suffers from birch pollen allergy (41.7%), but a considerable fraction suffers from ash pollen allergy (17.7%; Hemmer et al., 2010). It is known that ash pollen allergy has a significant impact in Austria's neighbouring country Switzerland (Colombo, 2010; Gassner et al., 2014; Schmid-Grendelmeier et al., 1994) and a similar phenomenon could distort the results for Austria. We conclude that the SLI of Austrian PHD users cannot be explained by Bet v 1 content during the birch pollen season. We also found high beech pollen loads in the years of high birch pollen load in Germany (2011) and in Austria (2011; personal observation). Beech pollen is now increasingly acknowledged as being of allergenic importance, because its cross-reaction to birch and other tree pollen is well known (Eriksson, 1978; Eriksson et al., 1987; Maeda et al., 2008; Mari et al., 2003) and the beech allergen Fag s 1 was recently proposed to be included in the birch allergen group (Heath et al., 2015). In Finland, we observed that alder could be a factor influencing the SLI results. Alder flowered much less intensely during 2010 than during 2011 with a tenfold peak pollen load in the latter year (personal observation). The alder pollen load occurred earlier than the birch pollen load, but it is known that cross-reactivity of the main allergens Aln g 1 and Bet v 1 is high (Ebner et al., 1993). It could therefore be possible that pollen allergy sufferers reacted in a more intensive way when they were exposed to higher alder pollen loads. We thus suspect the influence of different allergen(s), since the Bet v 1 content measured matches the birch pollen count, although the former proved to be the more reliable predictor of the symptom load (France, Germany and grass pollen seasons in Austria and Finland). The analysis presented here further supports the variability between allergen content and pollen load (Buters et al., 2012, 2015).

5. Conclusions

This study supports the impact of the major allergen content of birch and grass pollen on the symptom level. Despite certain limits, which will pose a challenge in the future, we give the first insight into the relationship between symptoms, pollen, and allergen content (Bet v 1/ Phl p 5) and conclude that the latter is an important factor for allergy sufferers, and may play a more direct role than pollen concentrations. Allergen measurements have until now been too costly and time-consuming to allow the consequent monitoring of allergen content to enhance pollen information. Our results suggest the inclusion of symptom data should present a significant improvement for pollen allergy sufferers. This data is real-time and readily available, and should be processed and included in future in pollen information services.

Figures of the detailed analysis of all birch and grass pollen seasons during 2009–2010 that were analysed are provided for all regions available (Austria, Germany, France, Finland). Supplementary data associated with this article can be found in the online version, at doi:http://dx.doi.org/10.1016/j.scitotenv.2016.01.014.

Statement on conflict of interests

Katharina Bastl: reports no conflict of interests.
Maximilian Kmenta: reports no conflict of interests.
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Marje Prank: reports no conflict of interests.
Annika Saarto: reports no conflict of interests.
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