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ORIGINAL PAPER

Development of personal pollen information—the next generation of pollen information and a step forward for hay fever sufferers

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Abstract Pollen allergies affect a large part of the European population and are considered likely to increase. User feedback indicates that there are difficulties in providing proper information and valid forecasts using traditional methods of aerobiology due to a variety of factors. Allergen content, pollen loads, and pollen allergy symptoms vary per region and year. The first steps in challenging such issues have already been undertaken. A personalized pollen-related symptom forecast is thought to be a possible answer. However, attempts made thus far have not led to an improvement in daily forecasting procedures. This study describes a model that was launched in 2013 in Austria to provide the first available personal pollen information. This system includes innovative forecast models using bi-hourly pollen data, traditional pollen forecasts based on historical data, meteorological data, and recent symptom data from the patient's hayfever diary. Furthermore, it calculates the personal symptom load in real time, in particular, the entries of the previous 5 days, to classify users. The personal pollen information was made available in Austria on the Austrian pollen information website and via a mobile pollen application, described herein for the first time. It is supposed that the inclusion of personal symptoms will lead to major improvements in pollen information concerning hay fever sufferers.

Keywords Personal pollen information · Real-time personal symptom loads · Pollen allergy · Pollen count information · Patient's hayfever diary · Mobile pollen application

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Introduction

IgE-mediated allergies are a growing problem with an increase in prevalence and severity (Bousquet et al. 2011) and have already a considerable socioeconomic impact. A percentage of 5 to 30 % of the population in industrialized countries suffers from allergic rhinitis or allergic asthma (Asher et al. 2006). The occurrence of pollen allergies is thought to be still on the rise (D'Amato et al. 2007). In Austria, approximately two million people suffer from allergies according to the first Austrian allergy report (Maucher 2006). According to this report, the most prevalent type is pollen allergy with about 200,000 sufferers; this affects about 10 % of the allergic population in Austria. Two principal closely related allergic diseases are associated with pollen allergy: allergic rhinitis (hay fever) and asthma (Demoly and Bousquet 2006; Tan and Corren 2011). Allergy therapy is based on (1) prevention of exposure, (2) suppression of symptoms through measures including medication, and (3) specific immunotherapy (Schmid-Grendelmeier 2012). The most effective way to suppress allergic symptoms is to avoid contact with the allergen (Lau-Schadendorf and Wahn 1994; Reiss 1997). The Austrian Pollen Information Service has supported the Austrian population suffering from pollen allergy since 1976 with pollen forecasts and pollen information and therefore notably contributes to allergen prevention.

Monitoring atmospheric concentrations of pollen is the basis for classic pollen information. Pollen forecasts are valuable to pollen allergy sufferers in many countries (Gonzalo-Garijo et al. 2009; Karatzas 2009; Karatzas et al. 2013). These pollen forecasts rely on pollen data and on forecasting pollen loads in the current season (Levetin and Van de Water 2003). However, user feedback indicates that this kind of pollen information is no longer sufficient for pollen allergy sufferers (Berger 2007).

In a study currently submitted for publication, Bastl et al. (submitted) have developed a symptom load index to compare the symptom loads of birch, grasses, and ragweed in Austria and Germany. The results of the study demonstrate a notable variation in symptom load levels concerning the respective aeroallergens, the relationship between pollen amount and symptom level as well as levels between years. A pollen allergy study undertaken in Turkey (Celik et al. 2005) tested pollen allergy sufferers sensitized to poplar and grasses and showed that grass pollens lead to a much higher symptom load level than poplar pollen. Another factor that has to be taken into account is the individual reaction of allergy sufferers during the pollen season. The severity of symptoms of allergy sufferers may vary and change within a single pollen season (Berger et al. 2013a). Studies on aeroallergens have demonstrated that the amount and intensity of allergen contents can diverge across different pollen types, countries, and even days (Buters et al. 2012; Galan et al. 2013). Hence, allergen content is not always correlated with pollen counts, showing a more than 10-fold difference in most cases (Buters et al. 2012). Therefore, a variety of factors affect the accuracy of forecasts based solely on pollen load: (1) different pollen types induce different symptom load levels, (2) every individual reacts differently during the pollen season, and (3) allergen content is not always correlated with the total amount of pollen in the air.

Monitoring personal pollen load is possible (e.g., Mitakakis et al. 2000; Sehlinger et al. 2013), but it is time consuming and costly and thus not a solution for the allergic population. The personalized pollen-related symptom forecast was the first step in the right direction (Berger et al. 2013b). This attempt used pollen data from the European Aeroallergen Network (EAN) and symptom data from the patient's hayfever diary (PHD) and presented calculations based on historic data. It was shown that personal pollen information (PPI) can be obtained, but this is only possible as a service using real-time symptom data. These services are in development and another attempt has recently been made in the Netherlands in which personal risks are calculated through multiple regression analysis and supplied to grass pollen allergy sufferers only (De Weger et al. 2013).

PPI was a service introduced in Austria in the spring of 2013. Arrangements to distribute this service in Germany and France also were made within the same year. Implementation of the PPI was completed in mid-2013 in Germany and should be realized by the start of the pollen season in 2014 in France. The new model for the PPI was successfully implemented and made available to the Austrian population in 2013 in several ways: it was integrated in the Austrian pollen information service (www.pollenwarndienst.at) with a login option and integrated in the pollen application on mobile devices (http://www.pollenwarndienst.at/gratis-pollen-app.html). To date, the mobile pollen application including the PPI system has been downloaded more than 90,000 times on Android and iOS and approximately 25,000 active users are recorded (Android only). In this paper, we describe the operation of this new PPI service, which is based on real-time symptom data and represents the next generation of forecasting individual pollen-induced symptoms.

Materials and methods

The PPI system contains various elements of classic pollen information and combines traditional and innovative forecast methods using meteorological data, aerobiological expertise, and real-time symptom data to classify the user (Fig. 1). In addition to forecasting models, based on historical pollen data, regional meteorological data, and aerobiological expertise, an innovative model developed by the Finnish Meteorological Institute (FMI) is used to allow the provision of more precise pollen information within the PPI system. This SILAM dispersion model (Prank et al. 2013; Siljamo et al. 2012; Sofiev et al. 2012) combines a range of meteorological data, such as wind, temperature, and precipitation, with data from the EAN database (https://ean.polleninfo.eu/Ean/), receiving daily or bi-hourly pollen data from around 35 countries and 300 sites all over Europe. All classic pollen data are connected in a data exchange (DEX) interface (Fig. 1). The key feature of the PPI shown is the implementation of real-time symptom data and the classification of the user in "high," "average," "low," and "non-responding" categories within the DEX interface (Fig. 1). Symptom data were requested from the PHD developed in cooperation with the Austrian Pollen Information Service, the Stiftung Deutscher Polleninformationsdienst, Réseau National de Surveillance Aérobiologique France, the ORL Department at Vienna Medical University, and the Allergy-Centre-Charité Berlin. This is a free web-based tool that allows objective assessment of allergy-related symptoms (www.pollendiary.com). PHD users provide daily reports on their location and symptoms per organ (eyes, nose, and bronchi) as well as relevant medication use. The PHD user process is described in detail in Bastl et al. (submitted).

Background of the PPI

Here the statistical background of PPI is described. The median symptom level and the interquantile range of symptoms are estimated for each day for all users who submit data on the corresponding day. A screen window of 5 days is used so that calculations are renewed every day and changes in symptom levels during the pollen season can be tracked accurately. Therefore, constant entries in the PHD are required to receive and take full advantage of PPI. Zero symptom values are omitted from the calculations. Following the

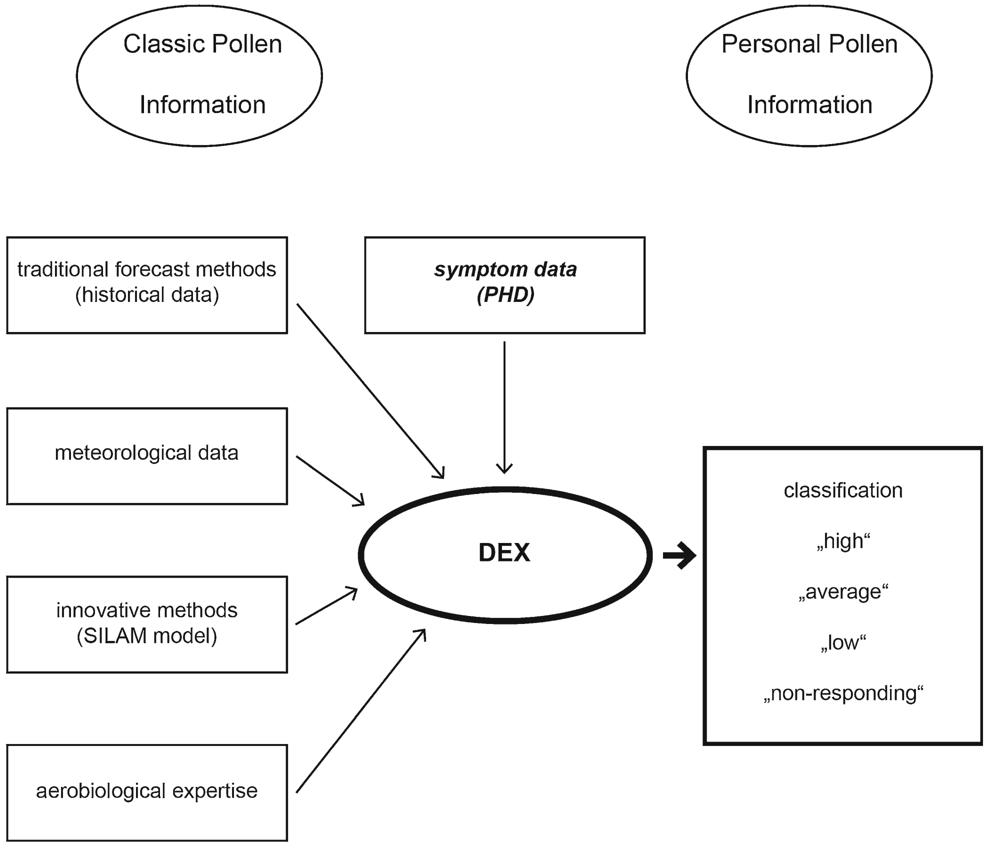

Fig. 1 Block diagram of PPI pillars: classic pollen information made up of traditional forecast methods (historical data), meteorological data, innovative forecast methods (SILAM model), and aerobiological expertise processed in the data exchange (DEX) interface (*bold*). Only the inclusion of the key feature, the symptom data (*bold italics*), is required to receive PPI. The classification in "high," "average," "low," and "non-responding" categories is also performed within the DEX interface

calculations, each user is classified. There are four classes: (1) "high," users within the highest 25 % symptom level bracket (all observations above median + IQR/2), (2) "average," users within the bounds of the mid 50 % bracket (all observations with a median ± IQR/2), (3) "low," users within the lowest 25 % symptom level bracket (all observations below median − IQR/2), and (4) "non-responding," users reporting no symptoms at all (observations of zero). Therefore, for n observed days, n memberships of classes are obtained for a user (one for each day). The frequency of these class memberships determines the classification of a specific user.

Results

A brief guide to the mobile pollen application

This section is devoted to a short description of the most important steps in the mobile pollen application. The application itself has not been described before and is presented here in its improved version including the PPI. The pollen application is provided as a free download on the Austrian pollen information website (www.pollenwarndienst.at; for Android and iOS).

The five main options in the menu are displayed at the bottom of the screen (Fig. 2a–f) and include "loads," "symptoms," "info," "doctors," and "settings." The option "symptoms" (Fig. 2a–d) is completely new and connects the application with the PHD. Users can also register directly in the application and enter their symptoms here. The option "loads" (Fig. 2e–f) includes the display of the general pollen load and the calculated personal pollen load for the next 3 days. The option "info" provides information on the most important aeroallergens and gives details of responsible persons and contacts. The option "doctors" is also new and is connected with Netdoctor to enable users to undertake a straightforward search for physicians and allergologists in their vicinity. The option "settings" allows users to select options concerning their favored selections within the application and choice of language and country.

The mobile pollen application is connected with the PHD and therefore a new option "symptoms" allows users to provide symptom data directly in the application. The first screen (Fig. 2a) asks the user to complete general information about their location, overall feeling, symptom severity, and symptoms related to specific organs as well as medication use. For each organ (eyes, nose, and lungs), users can select the symptoms they experience, for example, itchiness, foreign body sensation, and redness and watering in relation to eyes (Fig. 2b). After entering these data, users can display their personal pollen load or can compare their symptoms to specific aeroallergens. Users select a pollen type (for example,

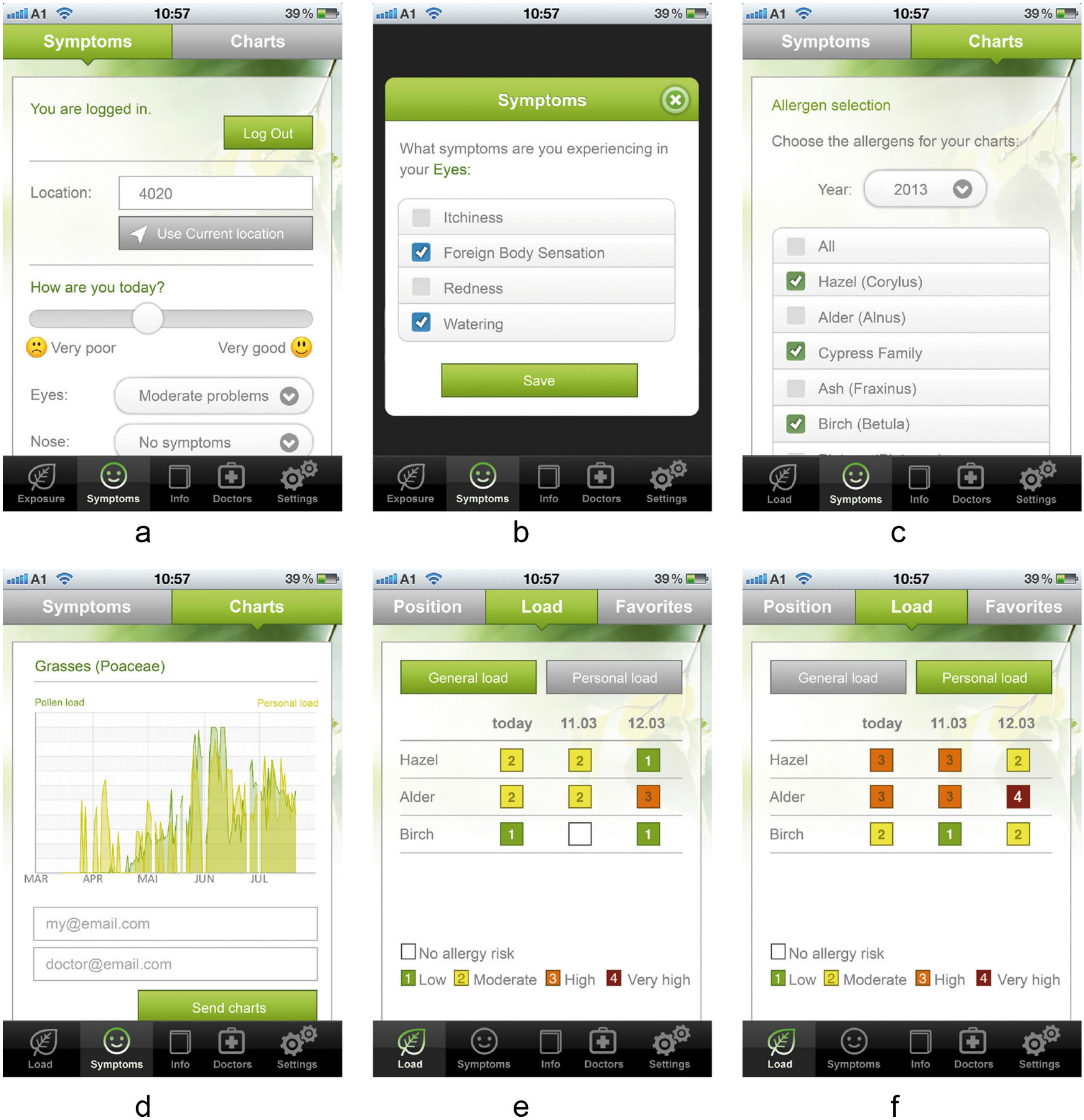

Fig. 2 Description of the most important steps in the mobile pollen application: **a** In the first step, users see the "symptoms" home screen within the mobile pollen application. Users enter their symptom data during this step, including the specifications concerning location, overall feeling, symptom severity, organ-specific symptoms, and medication use. **b** Screen in the "symptoms" option for completion of organ-specific symptoms, in this example, those related to eyes. **c** The next step for registered users is to view charts within the "symptoms" option and to pick aeroallergens of interest. **d** After the choice of the aeroallergen of interest (here, as an example, Poaceae), the chart is viewed. Personal symptoms (*yellow*) can be compared to the pollen load (*green*). **e** Within the "load" option users can find the general forecast based on pollen counts forecasting numerical pollen loads. **f** The personal forecast can be selected within the "load" option. This displays the personal risk of allergic symptoms for the next 3 days (based on actual pollen loads and personal entries). Users can note if their reactions are higher than the average by comparing to the general pollen load, as in this example screenshot

Poaceae (grasses), Fig. 2c) and a chart is created (Fig. 2d). This chart enables users to establish whether a certain aeroallergen might be inducing their symptoms and is helpful for both allergy sufferers and treating physicians. An automatic function enables the user to send the chart(s) direct to two email addresses.

Users can find general pollen information in the option "loads" (Fig. 2e). This chart displays the forecasted pollen loads of the most important aeroallergens in Austria or those of the user's choice. This is based on pollen counts and presents the classic pollen information. The function personal load is enabled after the entry of symptom data for more than at least 5 days (Fig. 2f). This displays the calculated personal pollen load based on the individual symptoms and the actual pollen loads. Calculations are automatically undertaken every day, so that the system remains flexible and recognizes changes in the reaction of the pollen allergy sufferer and enables adaptation to the user's response. Therefore, users can be classified differently during the season. By comparing the personal pollen load with the general information, users can see if their reactions are higher or lower than those of the average of the population or the same.

Outcome of the mobile pollen application and the PPI

The first mobile pollen application for smartphones and tablets was distributed in 2012 by members of the Medical University Vienna, presenting only traditional pollen forecasts and information on several aeroallergens. The application presents the pollen load of the 12 most important aeroallergens within Austria for 3 days (today, tomorrow, and the day after tomorrow). In 2013, the pollen application was improved by connecting the PHD with the application. Users of the PHD or users registering their symptoms via this mobile application receive both the general pollen load and their personal pollen load. The general pollen load is based on classic pollen information forecasting numerical pollen loads. The personal pollen load is calculated for every user based on actual pollen loads, traditional and innovative pollen forecast models, meteorological data, and personal symptoms. As a result, pollen allergy sufferers are precisely aware of what they can expect over the next few days, depending on their personal status. Thus, prevention of exposure to the allergen and medication use can be optimized. This forecast is made possible due to a new model calculating real-time symptom data.

The new model allows the distribution of individualized information—the severity of personal pollen-induced symptoms—to pollen allergy sufferers. Symptom data allow the classification of users in high, medium/average, and low response categories. The inclusion of the zero class, the nonreacting pollen allergy sufferers, allows the smooth use of PPI throughout the year so that a birch pollen allergy sufferer who is not allergic to grass pollen, for example, will not receive a warning during the grass pollen season.

The mobile pollen application is available for the Android and iOS systems and has been widely adopted by the Austrian population (approximately 90,000 downloads in total). Furthermore, the application is an improvement compared to the previous version. Netdoctor was included for increased usability and to enable pollen allergy sufferers to obtain information rapidly, not only concerning general and personal pollen loads but also about where they can find physicians to treat them. "Favorites," the locations marked as favorite by users, are displayed automatically on launching the application or the PHD. The calendar function has been adapted so that it is now also possible to input personal symptoms within the mobile application not only on the specific day but also on any other day (as already implemented in the PHD).

Discussion

This study shows the successful application of PPI in a daily procedure. A similar aim was achieved in the Netherlands for grass pollen allergy sufferers (De Weger et al. 2013). However, this study shows a successful application related to more than one aeroallergen. The development of a symptom load forecast is expected to be an improvement for pollen allergy sufferers and physicians. It is likely to become an important tool for pollen allergy treatment and medication management as well as an important aid in avoiding exposure to allergenic pollen and planning medication and outdoor activities.

Therefore, the development of PPI and distribution of this service via websites and mobile phone applications is a major step forward in assisting the pollen allergic population to avoid their aeroallergens. The consequences for users and society could be of considerable value. Successful and optimized avoidance of the allergy-inducing pollen type leads to fewer days off work, greater ability to concentrate when studying and working, less money spent on medication, and less frequent and less severe symptoms.

Furthermore, including symptom data is also a solution to the challenges of personal lifestyle. It is known that pollen concentrations are different and lower in cars (Hugg et al. 2007) and buildings (Hugg and Rantio-Lehtimäki 2007) compared to the outside environment. The varying degree of indoor and outdoor activities in personal lifestyle has not previously been taken into account in forecast procedures. Although lifestyle is still not recorded, the provision of personal symptom data leads to a classification appropriate to the exposure and reaction of the allergy sufferer. It is expected that the use of the PPI will spread to other European countries, besides the ongoing implementation in Germany and France, as the system is easy to transfer and can be established in any country using classic pollen information and a symptom load diary.

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