EcoHealth 9, 440–447, 2012
DOI: 10.1007/s10393-012-0787-1

ECOHEALTH

Original Contribution

Hay Fever in a Changing Climate: Linking an Internet-Based Diary with Environmental Data

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Abstract: Investigating the impact of climate change on human health requires the development of efficient tools that link patient symptoms with changing environmental variables. We developed an internet-based hay fever diary linked to simultaneously recorded pollen load and weather variables in Canberra, Australia over spring 2010. We recruited 42 hay fever sufferers to complete a simple online pollen diary daily over a period of 60 days. In conjunction, daily airborne pollen load was counted and meteorological data collected simultaneously. We focused on the relationships between temperature, rainfall, pollen count and rhinoconjunctivitis symptoms. Pollen load increased after a peak rainfall event until the end of the study. Compliance was high, averaging 79% of days per person. Nasal rhinoconjunctivitis symptoms increased in concert with increasing pollen load, and then remained high. Mucosal itching increased more gradually and strongly coincided with increased daily maximum temperature. Our study successfully demonstrated the feasibility of linking pollen load and climate variables to symptoms of rhinoconjunctivitis in the Australian community. However, a larger study would better explore the nature of associations between these variables. Similar online methods could be used to monitor a range of health responses to our changing environment.

Keywords: allergic rhinitis, Internet, pollen, hay fever, allergy, aerobiology

INTRODUCTION

Allergic disease is one of the leading causes of chronic illness in Australia and in many other developed countries. Allergic rhinitis is the most common of these, affecting 17% of Australians (ABS 2010, Access Economics, ASCIA 2007). Seasonal allergic rhinitis, or 'hay fever' is associated with pollen release in spring and early summer (Canonica et al. 2007; Hu et al. 2008). Symptoms include nasal obstruction, rhinorrhoea, sneezing, itchy nose, eyes and throat, headache and lethargy. Symptoms have significant effects on quality of life (Canonica et al. 2007). Based on current trends, there is a predicted 70% increase in the prevalence of allergic disease in Australia by 2050, with the majority of

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Published online: October 27, 2012

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this being due to increases in prevalence of allergic rhinitis (Access Economics, ASCIA 2007). The drivers of such increases are poorly known and the influence of global climate change has yet to be assessed in this context.

One of the clearest examples of the effects of climate change on human health lies in the relationship between changes in pollen phenology and distribution, and the prevalence of associated allergic symptoms (Jäger 2000; Clot 2003; Beggs 2004; Shea et al. 2008). Airborne pollen composition is likely to change with changes in plant distribution and abundance (Beggs 2004; Shea et al. 2008). The timing of pollen release is changing as critical temperatures for bud break, flowering and anthesis occur earlier in the spring (Rasmussen 2002). Higher atmospheric CO_2 concentrations may also increase the quantity of pollen, and higher temperatures may increase pollen allergenic protein content (Beggs 2004). This may translate into earlier and more severe seasonal allergic symptoms (Shea et al. 2008).

Both asthma and rhinoconjunctivitis are positively associated with spring pollen load, in particular grass pollen load (Suphioglu 1998; Schäppi et al. 1998; Huynh et al. 2010). Studies on pollen and climate correlations with allergic conditions have focused on asthma, as represented by healthcare presentations (Hill et al. 1979; Kljakovic and Salmond 1998; Newson et al. 1998; Tobías et al. 2003; Kim et al. 2008; Huynh et al. 2010). In contrast, there are few studies on environmental correlations with hay fever (Pedersen 1984; Schäppi et al. 1998; Cakmak et al. 2002; Fuhrman et al. 2007; Johnston et al. 2009).

Despite the high prevalence of allergic rhinitis in the Australian community, the clinical management of allergic rhinitis only accounts for six per 1,000 encounters with general practitioners, and nearly two thirds of allergic rhinitis sufferers have never consulted their GP for their condition (BEACH data, Fahridin and Britt 2008; AIHW 2011). However, few studies that correlate environmental data with allergic disease have investigated allergic symptoms in the community, rather than the healthcare setting (Negrini et al. 1992; Schäppi et al. 1998; Florido 1999; Johnston et al. 2009). Our objective was to investigate the feasibility of using an internet-based symptom diary linked to daily collection of pollen and meteorological data. To this end, we firstly evaluate the success of an internet-based pollen diary, and secondly, we evaluate the link to environmental variables, by describing the relationships between pollen load, climate, and self-reported symptom severity of rhinoconjunctivitis in the context of similar aerobiological studies.

Methods

Setting

Canberra City, in the Australian Capital Territory has ~300,000 residents. It has a temperate, continental climate, with rainfall spread throughout the year, peaking in spring and late summer. Canberra is surrounded by pasture grassland, and has native *Eucalyptus* dominant forests and pine plantations to the south. The prevailing wind is from the northwest. The study ran for 60 days from 28th September to 26th November 2010.

Participants

The study was advertised on internet noticeboards, via posters placed around the Australian National University campus and via social media. We recruited 42 participants for the study. Participants were sent an initial information sheet, a consent form and a questionnaire, asking their email address, gender, age, and whether they had seen a doctor about their symptoms. Participants were considered eligible if they lived in Canberra, self-reported experiencing allergic rhinitis, and were planning to be in Canberra for most of the study period.

Data Entry

A web-based data entry interface for users was developed using the Django web framework (http://www.djangoproject.com/), with data stored in a relational database. The homepage explained the project and had a link to the privacy statement. On receipt of their consent forms, participants were given a login and password, which they were encouraged to change. Start and end date was flexible. Participants could fill in and change their symptoms daily, or up to 1 week in retrospect.

Each day, participants were asked to respond to the following questions: Did you have a runny/blocked nose or sneezing? (Response: none/mild/moderate/severe) Did you have itchy eyes/nose/mouth/throat? (Response: none/mild/moderate/severe) Were you in Canberra? (Response: yes/no) Symptoms were then converted to scores, where: no symptoms = 0, mild = 1, moderate = 2 and severe = 3.

Compliance was defined as days in which nasal symptoms were logged, expressed as a proportion of days from recruitment until study end. If participants missed more than 5 days in a row, they were sent an email. Bulk emails were found to be less effective than personal emails. Although there was no explicit question asking if participants had a cold/flu, participants were encouraged to email the study when this occurred.

Pollen Count

This was collected continuously using a Burkard volumetric trap (Burkard Manufacturing, Rickmansworth, Hertfordshire, UK) according to the manufacturer's instructions. The sampler was positioned on the roof of Health Protection Services, a two-storey building located southwest, and upwind, of Canberra's city centre. The position of the trap conforms to Australian Standard AS 2922-1987, Ambient air- guide for the siting of sampling units (Standards Association of Australia, Sydney, NSW) for environmental monitoring. Sampled air was pumped over a coated microscope slide at a rate of 10 L min^{-1}. The microscope slide had previously been coated with silicon-based adhesive (Lanzoni s.r.l., Bologna, Italy), and was advanced across the air inlet over the day via a clockwork motor. Slides were changed daily at 4 pm, giving a 24-h record of pollen on each. Once removed from the pollen trap, slides were mounted in warmed Calberla's stain. Slides were observed using an Olympus BH compound microscope with 20× objective (Olympus Optical Co., Tokyo, Japan). Pollen was counted by one lengthwise traverse along the middle of the microscope slide.

Weather Monitoring

This was continuously recorded with an automatic weather station directly adjacent to the spore trap. Weather parameters such as wind speed and direction, temperature, precipitation, and humidity were collected each day.

Statistics

Data were analysed using Genstat 7th Edition (2007, Lawes Agricultural Trust, UK). Associations between average symptom scores and environmental parameters were analysed via simple linear regression and split-line linear regression. Relationships between pollen and symptoms were analysed the data for autocorrelation, however, data limitations restricted including autoregressive terms in our models.

Results

In all, 42 participants were recruited to the study, 52% were male, 50% were between 20 and 29 years old, 33% were 30–39-years-old and 17% were over 40 years. Thirty one percent of respondents reported having seen a specialist for allergic conditions. Sixty-six percent of participants spent their weekdays in the same central Canberra location.

Pollen

The overall pollen count for was 5,007 grains m^{-3} and 10,187 grains m^{-3} for October and November, respectively. Over the study period, pollen load increased, however, there was large day-to-day variation (Figure 1). There was a contrast in pollen composition between the first 21 days of the study and the following 39 days. Initially, tree pollen dominated, including *Pinus*, and European angiosperms (Quercus, Alnus, Ulmus, and Fraxinus). Following a large rainfall event on day 18, pollen from the family Cupressaceae (*Callitris* and *Cupressus*) and Poaceae (grass) pollen dominated, increasing to the end of the study (Figure 1; Table 1). Other allergenic species identified after day 21 included plantain (*Plantago* spp.), Paterson's curse (*Echium plantagineum*), and dock/sorrel (*Rumex* spp.).

Weather

Temperature increased over the 60 days, with peaks coinciding with peaks in pollen load. 247 mm of rain was recorded over the study period. There were three major rainfall events, during which pollen load decreased. After the first rainfall event, peaking at day 18, there was an increase in pollen load and change in pollen composition (Figure 1).

Participant Response

Of the 42 participants, on average three quarters (30, max: 39, min: 23) logged their symptoms on any 1 day. The mean number (SD) of active days participants were in the study was 41.6 days (SD 13.0). The compliance was 79%. This increased to 89% of person days on which a reminder was issued (129 of 145 person days). Participants spent on average 0.9 days away from Canberra over the reporting period (SD 3.1).

Reported Symptoms

On average, respondents reported nasal symptoms on 4.7 days per week (SD 1.7), and reported mucosal itching symptoms on 3.6 days per week (SD 1.9). There was an increase in the proportion of respondents who had nasal symptoms on day 22 of the study, after which prevalence of symptoms appeared to plateau (Figure 1). This contrasts with a more gradual linear increase in the proportion of respondents with mucosal itch symptoms over the study. However, the average symptom score tracked both weather and pollen load, increasing after day 22, decreasing with pollen load during a rainfall event on days 33–36, and was high, following the high pollen load on most days from then until the end of the study (Figure 1).

Results of split-line and simple linear regression between average symptom scores, pollen load and maximum daily temperature are shown in Table 2. Average symptom scores for both rhinitis and mucosal itch symptoms increased with increasing total daily pollen load (minus Cupressaceae pollen), grass pollen load and Cupressaceae pollen load (Table 2). Because of the extreme Cupressaceae pollen load on several days, it was separated from total pollen load in the analyses, however, symptom scores also increased with increasing total pollen load (including Cupressaceae pollen load, data not shown). Average symptom scores also increased with increasing daily maximum temperature (Table 2).

Relationships between average symptom severity and pollen load were driven by the high sensitivity of symptoms at pollen loads below a threshold, for example, 20 grains m^{-3} for grass pollen, while above this threshold, symptom scores were high but relationships with pollen load were weak (Table 2; Figure 2).

On analysis of the relationship between pollen and symptoms, residuals showed an autoregressive structure, with all relationships fitting an AR1 model. We were unable to include an AR1 term in our models due to data limitations.

Discussion

This study demonstrated the effective use of simple web-based tools linking people's symptoms with local environmental

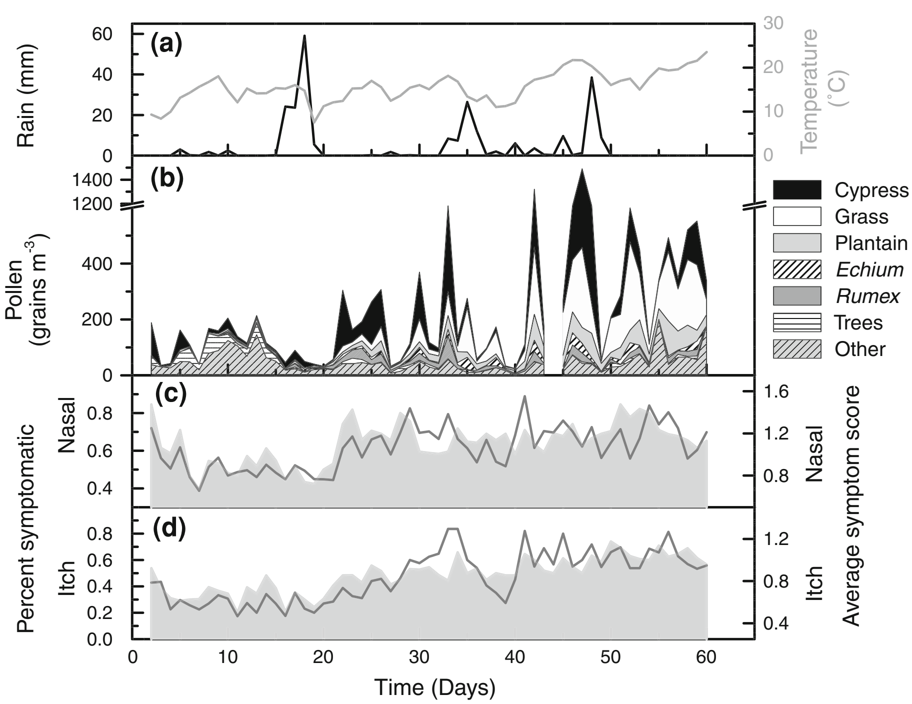

Figure 1. Climate, pollen and symptoms over the study. **a** Daily rainfall (*black line*, left hand axis, and 24 h average temperature (*grey line*, right hand axis). **b** Pollen load, with overall height of peaks representing total pollen load, and the relative contribution of each plant group demonstrated in colour. From *top to bottom*, cypress (*black*), grasses (*white*), plantain (*light grey*), Paterson's curse (*Echium*, *white, diagonal stripes*), dock/sorrel (*Rumex*, *dark grey*), European trees (*white, horizontal stripes*) and other species (*grey, diagonal stripes*). **c** Nasal symptoms over time, with percent of respondents reporting symptoms (*grey shading*, left hand axis), and average symptom score (*black line*, right hand axis, where 0 = no symptoms, 1 = low, 2 = moderate, 3 = severe). **d** Mucosal itch symptoms over time, with percent of respondents reporting symptoms (*grey shading*, left hand axis), and average symptom score (*black line*, right hand axis, where 0 = no symptoms, 1 = low, 2 = moderate, 3 = severe). No pollen was collected on day 44, due to technical failure.

Table 1. Dominant Taxa, and Their Pollen Load Over the Study, Divided into Two Time Periods, Day 1–18, and Day 19–60

Taxa	Pollen load (grains m^{-3}), median (25th–75th percentiles)	
	Day 1–18	Day 19–60
Cupressaceae	11.6 (6.1, 28.2)	41.3 (7.1, 129.2)
Plantago	0.9 (0.0, 4.6)	26.9 (13.8, 46.2)
Rumex	0.9 (0.0, 7.4)	13.5 (4.4, 22.3)
Eucalyptus	0.9 (0, 2.8)	4.6 (1.8, 11.2)
Echium	0.0 (0.0, 1.9)	7.1 (1.8, 16.4)
Pinus	13.9 (2.4, 22.2)	0.8 (0, 1.38)
European trees[a]	22.8 (6.0, 37.7)	2.7 (1.4, 7.2)
All grass	3.54 (1.36, 5.1)	41.8 (13.1, 152.1)

Numbers represent median, Q1 (25th percentile) and Q3 (75th percentile).
[a]Within European tree pollen, dominant tree taxa, in order of overall prevalence: *Quercus*, *Populus*, *Alnus*, *Ulmus*, *Fraxinus*.

data in Australia. This was achieved by using an internet-based symptom diary linked to daily collection of pollen and meteorological data. The high level of interest in the project was an important finding in our study, with participants recruiting their friends and colleagues. Despite the limited age range in the study, most participants were aged 25–44, the age at which allergic rhinitis shows highest prevalence (AIHW 2011). This population may also show the greatest interest in online symptom diaries. We have demonstrated that internet surveys can be effective with participants easily able to report daily symptoms, despite the length of the study. Furthermore, we were able to demonstrate the effective use of a web tool linking participants' reports of current health to the local climate. The web tools were inexpensive and simple to maintain. Django is a versatile web framework, and the diary could be adapted to suit any situation where daily reporting is required. The internet is a valuable tool for chronic disease management and monitoring (Daniel 2010). Online hay fever diaries have been successful in monitoring patient quality of life (Moriguchi et al. 2001). Indeed, the internet may have particular utility for conditions such as allergic rhinitis, where most patients do not consult clinicians. Allergic rhinitis sufferers whose management is guided by a health professional are found to have better treatment outcomes (AIHW 2011). As only 23% of study participants had consulted a specialist for advice on their hay fever, participants would benefit from hay fever risk and management advice communicated online.

Clinically, participants in this study could be classified as having persistent rhinitis based on the classifications of Canonica et al. (2007), where on average rhinitis symptoms arise on more than 4 days per week. Indeed, the Australian Capital Territory (Canberra) recorded the highest prevalence of allergic rhinitis of any state in Australia over 2007–2008 (AIHW 2011). Despite higher pollen loads in this study, symptom severity was comparable to that recorded by Schäppi et al. (1998). This may reflect the apparent pollen threshold at 20–40 grains m^{-3}, above which symptoms were consistently high, a pattern also reflected in the data of Schäppi et al. (1998). Indeed, several studies have defined maximum patient response at pollen loads of 50–80 grains m^{-3}, with linear responses below this (Davies and Smith 1973; Viander and Koivikko 1978; Negrini et al. 1992). However, previous studies were performed under lower pollen loads than this study, rarely extending past these thresholds.

We were able to show an increase in symptoms with increasing maximum temperature, as with increasing pollen load. Grass and Cupressaceae were the dominant plant taxa represented in this study, as in previous years in Canberra (Dass 2010; Sands 1967), Melbourne (Ong et al. 1995) and Sydney (Bass and Morgan 1997; Katelaris and Burke 2003). These and other dominant taxa are known to be aeroallergens (Galán et al. 2010; Bass et al. 1991; Bass and Morgan 1997).

While there was an apparent association between temperature and rhinoconjunctivitis symptoms, and between pollen load and hayfever symptoms, it must be remembered that all these variables increased over the season. Moreover, there was likely to be some autocorrelation in symptoms. If individuals had severe symptoms 1 day, it may take them more than a day to recover, and the additive effect of multiple days of a moderate pollen load may be more important to symptoms than a single high-pollen day. This study is a small one, and was intended as a pilot study. Better associations could be obtained in a study continuing over a longer time period, encompassing the entire pollen season. This would help to separate symptomatology by pollen taxa. Moreover, a larger sample size would increase the statistical power of the data, allowing more conclusions to be drawn from the analyses.

Pollen Load Prediction and Climate Change Adaptation

Measurement of daily pollen load has clinical utility, as it can inform patients of periods of pollinosis risk, enabling decisions about prophylactic treatment and travel (Subiza 2001). In many developed countries, pollen counts are provided to the public via mass media and the internet, for example the USA (pollen.com) and Europe (polleninfo.net). In Australia,

Table 2. Linear Regression of Symptoms (Nasal And Mucosal Itch) with Pollen Counts, and Maximum Temperature

	Nasal			Itch		
	Threshold (±SE)	R^2	P	Threshold (±SE)	R^2	P
Pollen						
Total[a]	95.0 (±2.09)	15.9		274 (±53.7)	26.2	
Grass	20.2 (±5.30)	45.1		19.4 (±1.85)	55.7	
Cupressaceae	44.8 (±3.13)	13.9		42.6 (±3.00)	14.4	
Max. temperature		25.0	<.001		36.0	<.001

For split-line regression, threshold values are displayed (with standard error of estimates). Above these values, regression lines are forced to a slope of 0, as little relationship is found between pollen counts and symptoms. Correlation coefficients are displayed (R^2), as are P values for simple linear regression on maximum daily temperatures.

[a]All pollen except Cupressaceae.

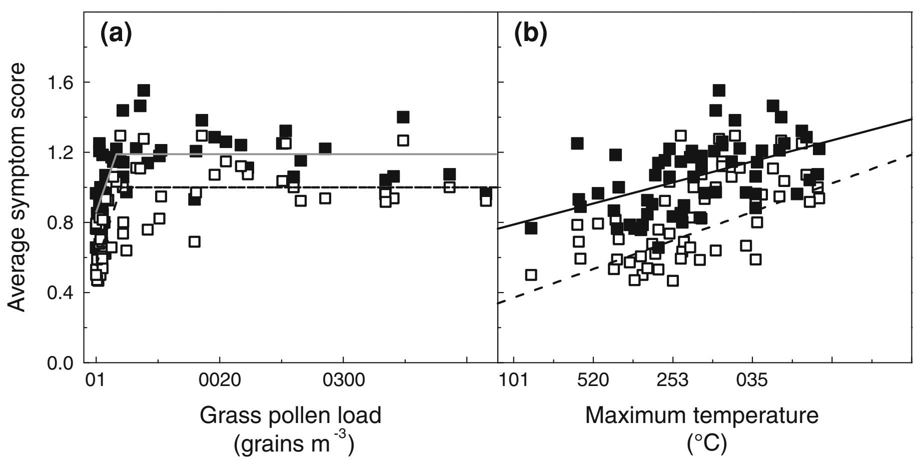

Figure 2. Daily average symptom score plotted against **a** grass pollen load and **b** maximum temperature for nasal symptoms (*filled symbols, solid line*) and mucosal itch symptoms (*hollow symbols, dashed line*).

for example in Wagga Wagga, Sydney and Melbourne, pollen is monitored during spring and summer. A commercial website also forecasts pollen load for capital cities but this is based on the crude relationship between humidity and wind speed (http://www.weatherzone.com.au/pollen-index/).

While available over the internet for some locations, pollen load forecasts are not widely utilised in Australia compared to North America and Europe. We believe that the participants in our study would benefit greatly from better predictions of pollen load and publicised pollen counts. Similar online tools have the potential to not only report environmental variables or symptom response, but to provide patient-specific information. Moreover, a similar online diary design could be used to monitor diverse illnesses in conjunction with environmental variables.

Conclusion

The study successfully demonstrated the link between pollen load and climatic variables to symptoms of rhinoconjunctivitis in the Australian community. Moreover, the study adds to the few studies relating allergic disease to environmental variables in Australia. Similar online methods could be used to monitor a range of health variables in our changing environment, allowing a greater understanding of the local effects of global climate change on health. The prevalence of allergic rhinitis in Australia is high and increasing, yet the majority of allergic rhinitis sufferers do not consult clinicians. An online tool for hay fever and pollen monitoring, coupled with clinical advice, could therefore play a vital role in allergic rhinitis management.

Acknowledgements

As this article went to press we were deeply saddened by the untimely passing of Marjan Kljakovic (1954–2012), who was highly regarded in New Zealand and Australia as an example of how GPs can produce quality, clinically relevant research. We benefited greatly from his knowledge, philosophy and friendship.

Authors wish to acknowledge the invaluable technical assistance of Health Protection Services and Ben Keaney.

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