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Community Response to the Impact of Thunderstorm Asthma Using Smart Technology

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Abstract

Background: The most severe thunderstorm asthma (TA) event occurred in Melbourne on the 21st November 2016 and during this period, daily pollen information was available and accessible on smart devices via an App. An integrated survey within the App allows users to self-report symptoms.
Objective: To explore patterns of symptom survey results during the period when the TA event occurred.
Methods: Symptom data from the Melbourne Pollen Count and Forecast App related to asthma history, hay fever symptoms, and medication use was explored. A one-week control period before and after the event was considered. Chi-square tests and logistic regression were used to assess associations between sex, age, symptoms, and medication use.
Results: Of the 28,655 responses, during the 2016 pollen season, younger (18 to 40 years) males, with no hay fever and no asthma were the most single and regular responders. During the TA event for new users, sex was only significantly associated with hay fever ($p = 0.008$) of which 60.2% of females' responses reported having hay fever, while 43% of males' responses did not. Those with mild symptoms peaked during the TA event.
Conclusions: Many individuals completed the survey on the app for the first time during the TA event indicating the potential of digital technologies to be used as indicators of health risk among populations at risk of TA events.

Keywords

hay fever, symptoms, digital health, thunderstorm asthma

Introduction

Thunderstorm Asthma (TA) is defined as an asthma attack triggered by abrupt changes in environmental conditions such as sudden changes in temperature and wind speed, which is usually accompanied by thunderstorm activity. All TA events in Australia have occurred during peak grass pollen seasons.[1] The grass pollen season in Melbourne is usually between October and December and the onset of its peak occurs when the air contains a sufficient amount of pollen (50 grains per m^3 of air) to trigger symptoms of hay fever and allergic asthma in most susceptible individuals.[2] TA events in Melbourne have been reported in the 1980s, 2010 and as recently as 2016.[3,4] In Melbourne all TA events have occurred in November, when airborne

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grass pollen are at a peak. The largest epidemic TA episode on record occurred in Melbourne on the 21st November 2016, resulting in around 9,900 patients presenting at hospital emergency departments.[5] On that day, around one call every four seconds flooded the emergency line and 60 supplementary ambulances were deployed. The event, resulted in nine deaths, and has been defined as the most catastrophic TA epidemic to date.[6] The risk of more epidemic TA events is likely to grow with changing climatic conditions and longer more intense pollen seasons.[7] In response to the Melbourne TA event that occurred in 2016, the Victorian government established a pilot forecasting system for epidemic thunderstorm asthma in south-eastern Australia.[8] TA events are not limited to the pacific region, with similar unprecedented TA events also observed in England, Canada, Italy, and Iran,[3,9,10] for which health services had not been adequately prepared.[4] The development of early warning systems to predict TA events and messaging systems or technologies to inform the public are clearly desirable.

Public health warnings and information have traditionally been disseminated using print, television or radio.[11] Recently, smartphone-synced devices have become a cost-effective central component in reaching wider and diverse audiences.[12] Around 2.5 billion people around the world own a smartphone and it's estimated that this will increase dramatically in the coming years.[13,14] On average a smartphone owner will use around 25 applications (apps) per month.[15] Such wide diffusion of technology should motivate health-care providers to implement and enhance patients' interaction with this technology which can empower users to take an active role for their own health.[16] There is a plethora of literature and websites focusing on such apps, but the uptake of these tools is for the most part unknown.[17] In our systematic review,[18] we found a dearth of evidence-based apps, as opposed to the large number of smartphone apps available for the general asthmatic population to monitor self-management and medication use. In addition, the readiness of such technology to record symptoms as they occur remains insufficiently studied.[19]

The Melbourne Pollen Count and Forecast is a free service provided by the University of Melbourne. Pollen forecasts are disseminated to the public via its website (https://www.melbournepollen.com.au/) and a smartphone application which can be downloaded for free from the Apple App Store (https://itunes.apple.com/au/app/melbourne-pollen-count/id707461899) or from Google Play for Android (https://play.google.com/store/apps/details?id=com.plenum.pollen). The Melbourne Pollen Count and Forecast App incorporates a symptom survey which allows users to record their symptoms as they occur and to share this information along with basic demographic data with researchers. The service is utilised by thousands of people of all ages during the Melbourne pollen season,[20,21] and was in operation during the TA event of 21st and 22nd November 2016. We have used the survey results from the App during the pollen period of 2016 to describe changes in user symptom score profiles during the weeks before, during and after the 2016 TA event.

Methods

Study Design, Subject Recruitment, Demographic Data and Symptom Score Collection

Here, the study design is cross-sectional where we assess a period before, during and after the 2016 TA event (14th–29th November 2016). The Melbourne Pollen Count and Forecast App operates during the peak grass pollen season in Melbourne Australia. The digital service provides daily grass pollen forecasts and allows users to self-enrol themselves for participation in the citizen science program by interacting with the survey widget and submitting survey scores related to their hay fever symptoms and optionally provide demographic data. Details about the questions asked to participants and the outcome variables obtained have been previously described.[20,22] In this study we defined 'regular responders' as those for whom the number of submissions were found to be more than four over the course of the current pollen season (1st October – 30th December 2016). Whereas 'single responders' were defined as those who submitted a survey only once. To ensure that only relevant survey submissions were assessed in this study, survey scores from users who did not provide a GPS location, or which were located more than 50 kms from the Parkville spore trap were removed from the analysis as previously described.[20] The survey data was primarily approved for use by the South Western Sydney Local Health District Human Research Ethics Committee (HREC) LNR/15/LPOOL/478; Australian Hay fever Survey and the Human Research Ethics Committees of the University of Melbourne and Melbourne Health (1647764.1 and QA2015148).

Statistical Analysis

We used survey results from App users during the 2016 pollen season. We used a one-week control period before and after the TA period. Chi-square tests were used to explore the associations between sex, age, symptoms, and medication variables. Age was dichotomized as 18 to 40 years and 41 to 61 years. All the other variables i.e., asthma, hay fever, taking medication were categorical as yes or no. Symptom scores were ordinal with increasing in intensity from 1 to 5. Logistic regression was used to

adjust the analysis of those variables to each other and between time periods. Two-sided p values less than 0.05 were considered as statistically significant. All analyses were performed using Stata statistical software (StataCorp. Stata Statistical Software: Release 16.1. College Station, TX).

Results

Of the 28,655 filtered responses (16,032 responses from males and 12,623 from females), 58.5% and 59.2% were 18 to 40 years of age respectively (Table 1). Overall, 4,130 male responders (25. 7%) and 4,094 female responders (32.4%) were asthmatic. Compared to females, most males were not previously diagnosed with asthma (74.3%) nor hay fever (62%); tended to have less than moderate symptoms or no symptoms at all (77.6%). However, 58.8% of females and 55.5% of males reported taking their medications during the 2016 grass pollen season ($p < 0.001$). A significant association between asthma diagnosis, hay fever diagnosis, taking medication, and symptoms scores were observed with sex ($p < 0.001$).

Characteristics of app users one week prior to the event are displayed in Table 2. More females reported severe symptoms (8.4%). Among all responses, 64.7% of males and 59.2% of females did not have a formal diagnosis of having hay fever ($p = 0.004$). During the TA event (Table 3) differences were observed between males and females taking medication during the TA event ($p = 0.008$). About 17.7% of male responders and 18.8% of female responders self-assessed their symptoms as being severe (i.e., obvious, and intolerable) although this was not statistically significant. Table 4 shows the characteristics of regular responders and new users for the week after the TA event. Of females, 33.4% were asthmatic and 50.40% had hay fever ($p < 0.001$). Asthma, hay fever, and symptoms scores were significantly associated with sex in this period.

Age group was not statistically associated ($p=0.60$) and asthma status was no longer significantly associated ($p=0.76$) with responder's sex during the period and one week after the TA event when we fitted a logistic regression. However, differences in hay fever status and symptoms scores (other than mild) between males and females were still significant even after being adjusted to each other and over time periods (Table 5).

Figure 1 shows the number of participants' responses reporting no symptoms, mild symptoms, and sever symptoms, by asthmatic status and sex. The number of responses from both non-asthmatic males and females increased in the number of responses and this was greater for those reporting mild symptoms leading up to and including the day of the TA event. Similar increases were observed for asthmatic responders, but the magnitudes were considerably less than non-asthmatics. Figure 2 shows the number of users with no symptoms, mild symptoms, and severe symptoms by hay fever and sex. Similar trends were observed among male and female responders, having no symptoms during the TA event. Similar increases were observed between females with and without hay fever but male responders without hay fever were slightly higher compared to males with hay fever. Those with mild symptoms peaked during the TA event. Online supplementary Figure 3 and Figure 4 shows the number of single response use having no symptoms (A), symptoms (B) and severe symptoms (C) for the period 14 to 29 November 2016 by asthma and gender, and by hay fever and gender respectively.

Discussion

This study describes the trends and characteristics of survey results from a smartphone application used by individuals to self-monitor symptoms before, during, and after the world's most severe TA event in 2016. We showed that mild symptoms peaked up to and including the day of the TA event and this was higher among non-asthmatic males and females. Surprisingly, younger (18 to 40 years) males, with no hay fever or history of asthma were completing the surveys during this period. A significantly higher percentage of new female users during and after the event reported being diagnosed with hay fever. Our findings were similar to previous TA studies[23,24] where symptoms were common in males and younger age groups. This could be partly attributed to their professions and/or lifestyles possibly with increased exposure to the outdoors. In such circumstances it may be argued that these individuals could be more aware of forthcoming changes to climatic and outdoor conditions. An alternative explanation could be that younger participants and males, in general, used digital devices more frequently than middle-age or older age groups and were able to be pre-warned by monitoring conditions via online resources.[25]

Studies assessing the 2016 TA event reported individuals with undiagnosed asthma or stable asthma with little or no onset of symptoms until the occurrence of the TA event.[26,27] Indeed, during the 2016 event, most patients that attended emergency departments had not been diagnosed with asthma by a doctor. These observations support the view that undiagnosed asthma may be more prevalent in the community than once thought. Ongoing monitoring of large-scale crowd-sourced allergic rhinitis symptom data could potentially provide necessary data to be able to predict the penetrance of individuals with asthma related symptoms, and perhaps even rare epidemic TA events.

Hay fever is also an associated factor in susceptibility to TA.[28] As reported in a recent review,[29] almost all

Table 1. Characteristics of Survey Responses From Single and Regular Responders During the Grass Pollen Period (1st Sep 2016 to 31 December 2016).

	All Responders			Single Responders[A]			Regular Responders[B]		
	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**value	Male N (%)	Female N (%)	*p**Value
Total sample	16,032 (56)	12,623 (44)		755 (50.8)	732 (49.2)		13,433 (56.7)	10,345 (43.28)	
Age groups									
18–40	9,384 (58.5)	7,476 (59.2)	$p = 0.23$	471 (62.4)	494 (67.5)	$p = 0.03$	7,677 (57.1)	5,836 (57)	$p = 0.80$
41–61	6,648 (41.5)	5,147 (40.8)		284 (37.6)	238 (32.5)		5,756 (42.9)	4,405 (43)	
Asthma									
Yes	4,130 (25.7)	4,094 (32.4)	$p < 0.001$	167 (22.1)	241 (32.9)	$p < 0.001$	3,450 (25.7)	3,291 (32.1)	$p < 0.001$
No	11,914 (74.3)	8,529 (67.6)		588 (77.9)	491 (67.1)		9,994 (74.3)	6,950 (67.9)	
Hay fever									
Yes	6,100 (38)	6,084 (48.2)	$p < 0.001$	266 (35.2)	352 (48.1)	$p < 0.001$	5,058 (37.6)	4,937 (48.2)	$p < 0.001$
No	9,944 (62)	6,539 (51.8)		489 (64.8)	380 (51.9)		8,386 (62.4)	5,304 (51.8)	
Taking medication	16,044 (56)	12,623 (44)							
Yes	8,900 (55.5)	7,423 (58.8)	$p < 0.001$	444 (58.8)	407 (55.6)	$p = 0.21$	7,448 (55.4)	6,112 (59.7)	$p < 0.001$
No	7,144 (44.5)	5,200 (41.2)		311 (41.2)	325 (44.4)		5,996 (44.6)	4,129 (40.3)	
Symptoms score									
1 = no symptoms	4,441 (27.7)	2,754 (21.8)	$p < 0.001$	152 (20.1)	136 (18.6)	$p = 0.70$	3,849 (28.6)	2,288 (22.3)	$p < 0.001$
2 = mild symptoms[1]	4,416 (27.5)	3,227 (25.6)		145 (19.2)	126 (17.2)		3,863 (28.7)	2,720 (26.6)	
3 = slight[2]	3,593 (22.4)	3,135 (24.8)		187 (24.8)	187 (25.5)		2,971 (22.1)	2,562 (25)	
4 = Moderate[3]	2,370 (14.8)	2,322 (18.4)		148 (19.6)	152 (20.8)		1,904 (14.2)	1,844 (18)	
5 = Severe[4]	1,224 (7.6)	1,185 (9.39)		123 (16.3)	131 (17.9)		857 (6.4)	827 (8.1)	

*P value < 0.05, chi square, [1]slight and a nuisance. [2]obvious but tolerable. [3]obvious, inconvenient but still tolerable. [4]obvious and intolerable. [A]Number of submission = 1. [B]number of submission>4.

Table 2. Characteristics of Survey Responses From All, Single and Regular Responders During the Control Period One Week Before TA Event (14–20 November 2016).

	All Responders			Single Responders[A]			Regular Responders[B]		
	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value
Total sample	1,533 (58)	1,108 (42)		41 (50)	41 (50)		1,382 (59.4)	945 (40.6)	
Age groups									
18–40	942 (61.4)	700 (63.2)	p = 0.36	20 (49)	23 (56)	p = 0.50	844 (61.1)	585 (61.9)	p = 0.68
41–61	591 (38.6)	408 (36.8)		21 (51)	18 (44)		538 (38.9)	360 (38.1)	
Asthma									
Yes	362 (23.6)	283 (25.5)	p = 0.25	2 (4.9)	12 (29.3)	p = 0.003	342 (24.8)	233 (24.7)	p = 0.96
No	1,171 (76.4)	825 (74.5)		39 (95.1)	29 (70.7)		1,040 (75.2)	712 (75.3)	
Hay fever									
Yes	541 (35.3)	452 (40.8)	p = 0.004	6 (14.6)	16 (39)	p = 0.01	502 (36.3)	393 (41.3)	p = 0.01
No	992 (64.7)	656 (59.2)		35 (85.4)	25 (61)		880 (63.7)	565 (58.7)	
Taking medication									
Yes	906 (59.1)	666 (60.1)	p = 0.60	28 (68.3)	24 (58.5)	p = 0.35	814 (58.9)	582 (61.6)	p = 0.19
No	627 (40.9)	442 (39.9)		13 (31.7)	17 (41.5)		568 (41.1)	363 (38.4)	
Symptoms score									
1 = no symptoms	332 (21.7)	245 (22.1)	p < 0.001	6 (14.6)	4 (9.8)	p = 0.12	302 (21.8)	213 (22.5)	p = 0.001
2 = mild[1]	488 (31.8)	287 (25.9)		6 (14.6)	6 (14.6)		459 (33.2)	257 (27.2)	
3 = slight[2]	398 (26)	262 (23.7)		17 (41.5)	10 (24.4)		346 (25)	224 (23.7)	
4 = moderate[3]	227 (14.8)	221 (19.9)		5 (12.2)	15 (36.6)		208 (15.1)	182 (19.3)	
5 = severe[4]	88 (5.7)	93 (8.4)		7 (17.1)	6 (14.6)		67 (4.9)	69 (7.3)	

*P value < 0.05, chi square, [1]slight and a nuisance. [2]obvious but tolerable. [3]obvious, inconvenient but still tolerable. [4]obvious and intolerable. [A]Number of submission = 1. [B]number of submission>4.

Table 3. Characteristics of Survey Responses During the Melbourne Thunderstorm Asthma Event (21 and 22 November 2016).

	All Responses			New Users			Responses From 6:00 am to 6:00 pm in 21 November			Responses From 6:01 pm in 21 November to 6:00 am 22 November			Responses From 6:01 am to 6:00 pm in 22 November.		
	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	*Male* N (%)	*Female* N (%)	*P*Value*
Total sample	912 (57.5)	674 (42.5)		215 (54.7)	178 (45.3)		250 (60.1)	166 (39.9)		149 (60.6)	97 (39.4)		357 (58.8)	250 (41.2)	
Age groups															
18–40	612 (67.1)	439 (65.1)	p = 0.41	150 (69.8)	120 (67.4)	p = 0.61	171 (68.4)	107 (64.5)	p = 0.40	96 (64.4)	68 (70.1)	p = 0.35	246 (68.9)	161 (64.4)	p = 0.24
41–61	300 (32.9)	235 (34.9)		65 (30.2)	58 (32.6)		79 (31.6)	59 (35.5)		53 (35.6)	29 (29.9)		111 (31.1)	89 (35.6)	
Asthma															
Yes	232 (25.4)	217 (32.2)	p = 0.003	72 (33.5)	75 (42.1)	p = 0.07	56 (22.4)	46 (27.7)	p = 0.21	42 (28.2)	33 (34)	p = 0.33	85 (23.8)	85 (34)	p = 0.006
No	680 (74.6)	457 (67.8)		143 (66.5)	103 (57.9)		194 (77.6)	120 (72.3)		107 (71.8)	64 (66)		272 (76.2)	165 (66)	
Hay fever															
Yes	360 (39.5)	304 (45.1)	p = 0.02	101 (47)	101 (56.7)	p = 0.05	87 (34.8)	70 (42.2)	p = 0.12	66 (44.3)	47 (48.5)	p = 0.52	140 (39.2)	115 (46)	p = 0.09
No	552 (60.5)	370 (54.9)		114 (53)	77 (43.3)		163 (65.2)	96 (57.8)		83 (55.7)	50 (51.5)		217 (60.8)	135 (54)	
Taking medication															
Yes	625 (68.5)	419 (62.2)	p = 0.008	133 (61.9)	99 (55.6)	p = 0.21	200 (80)	127 (76.5)	p = 0.39	118 (79.2)	76 (78.3)	p = 0.87	211 (59.1)	135 (54)	p = 0.21
No	287 (31.5)	255 (37.8)		82 (38.1)	79 (44.4)		50 (20)	39 (23.5)		31 (20.8)	21 (21.7)		146 (40.9)	115 (46)	
Symptoms score															
1 = No Symptoms	196 (21.5)	128 (19)	p = 0.09	48 (22.3)	35 (19.7)	p = 0.45	18 (7.2)	4 (2.4)	p = 0.10	11 (7.4)	7 (7.2)	p = 0.68	115 (32.2)	62 (24.8)	p = 0.01
2 = Mild s[1]	221 (24.2)	139 (20.6)		49 (22.8)	37 (20.8)		40 (16)	23 (13.9)		18 (12.1)	7 (7.2)		111 (31.1)	62 (24.8)	
3 = Slight[2]	170 (18.6)	157 (23.3)		41 (19.1)	43 (24.1)		48 (19.2)	42 (25.3)		26 (17.5)	21 (21.5)		69 (19.3)	61 (24.4)	
4 = Moderate[3]	164 (18)	123 (18.2)		36 (16.7)	22 (12.3)		76 (30.4)	44 (26.5)		33 (22.1)	19 (19.6)		38 (10.6)	44 (17.6)	
5 = Severe[4]	161 (17.7)	127 (18.8)		42 (19.1)	41 (23)		68 (27.2)	53 (31.9)		61 (40.9)	43 (44.3)		24 (6.7)	21 (8.4)	

*P value < 0.05, chi square, [1]slight and a nuisance. [2]obvious but tolerable. [3]obvious, inconvenient but still tolerable. [4]obvious and intolerable.

Table 4. Characteristics of Survey Responses From New, Single and Regular Responders During the Period One Week After TA Event (23–29 November 2016).

	All Responses			New Users			Single Response Use[A]			Regular Responses[B]		
	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value	Male N (%)	Female N (%)	*p**Value
Total sample	1,403 (55.7)	1,115 (44.3)		128 (54.2)	108 (45.8)		60 (47.2)	67 (52.6)		1,155 (56.6)	884 (43.4)	
Age groups												
18–40	862 (61.5)	694 (62.2)	p = 0.69	79 (61.7)	86 (79.6)	p = 0.003	40 (66.7)	46 (68.7)	p = 0.811	703 (60.9)	525 (59.4)	p = 0.50
41–61	540 (38.5)	421 (37.8)		49 (38.3)	22 (20.4)		20 (33.3)	21 (31.3)		452 (39.1)	359 (40.6)	
Asthma												
Yes	365 (26.0)	372 (33.4)	p < 0.001	46 (35.9)	47 (43.5)	p = 0.23	13 (21.7)	25 (37.3)	p = 0.05	292 (25.3)	287 (32.5)	p < 0.001
No	1,038 (73.8)	743 (66.6)		82 (64.1)	61 (56.5)		47 (78.3)	42 (62.7)		863 (74.7)	597 (67.5)	
Hay fever												
Yes	540 (38.5)	562 (50.4)	p < 0.001	55 (43)	65 (60.2)	p = 0.008	26 (43.3)	34 (50.7)	p = 0.40	423 (36.6)	449 (50.8)	p < 0.001
No	863 (61.5)	553 (49.6)		73 (57)	43 (39.8)		34 (56.7)	33 (49.3)		732 (63.4)	435 (49.2)	
Taking medication												
Yes	630 (44.9)	544 (48.8)	p = 0.05	46 (35.9)	51 (47.2)	p = 0.07	32 (53.3)	26 (38.8)	p = 0.10	529 (45.8)	446 (50.4)	p = 0.03
No	773 (55.1)	571 (51.2)		82 (64.1)	57 (52.8)		28 (46.7)	41 (61.2)		626 (54.2)	438 (49.6)	
Symptoms score												
1 = no symptoms	643 (45.8)	405 (36.3)	p < 0.001	69 (53.9)	35 (32.4)	p = 0.004	27 (45)	19 (28.3)	p = 0.40	524 (45.4)	330 (37.3)	p < 0.001
2 = mild[1]	457 (32.6)	352 (31.6)		40 (31.2)	38 (35.2)		11 (18.3)	18 (26.9)		399 (34.5)	285 (32.2)	
3 = slight[2]	206 (14.7)	213 (19.1)		13 (10.2)	18 (16.7)		12 (20)	16 (23.9)		167 (14.5)	163 (18.4)	
4 = moderate[3]	64 (4.6)	106 (9.5)		4 (3.1)	11 (10.2)		6 (10)	9 (13.4)		48 (4.2)	80 (9.1)	
5 = severe[4]	33 (2.3)	39 (3.5)		2 (1.6)	6 (5.6)		4 (6.7)	5 (7.5)		17 (1.5)	26 (2.9)	

*P value < 0.05, chi square, [1]slight and a nuisance. [2]obvious but tolerable. [3]obvious, inconvenient but still tolerable. [4]obvious and intolerable. [A]Number of submission = 1. [B]number of submission>4.

Table 5. Adjusted Analysis of the Associations Between Responses' Sex, Age, Asthma, Hay Fever, Taking Medication, Symptoms Score, and Time Periods.

	Odds Ratio	95% Confidence Interval	p-Value
Age group (years)			
18–40 (Ref)	1		
41–61	1.03	0.93–1.14	0.60
Asthma			
Yes	0.98	0.85–1.13	0.76
No (ref)	1		
Hay fever			
Yes	0.73	0.64–0.83	<0.001
No (ref)	1		
Taking medication			
Yes	1.10	0.99–1.22	0.08
No (ref)	1		
Symptoms score			
1 = no symptoms	1		
2 = mild[1]	0.96	0.84–1.09	0.54
3 = slight[2]	0.76	0.66–0.88	<0.001
4 = moderate[3]	0.61	0.52–0.73	<0.001
5 = severe[4]	0.65	0.53–0.79	<0.001
Time periods			
14–20 November 2016 (Ref)	1		
21–22 November 2016	1.03	0.90–1.17	0.67
23–29 November 2016	0.86	0.76–0.96	0.008

Notes: Adjusted to each other.
[1]slight and a nuisance.
[2]obvious but tolerable.
[3]obvious, inconvenient but still tolerable.
[4]obvious and intolerable

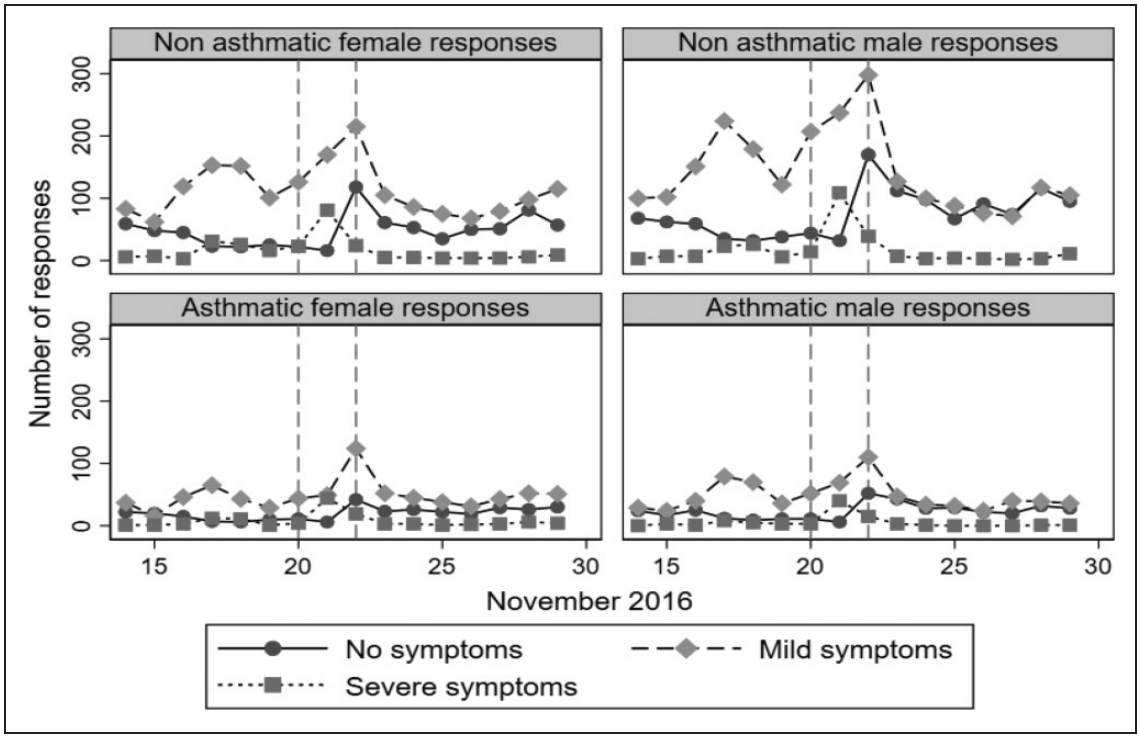

Figure 1. Number of all responders having no symptoms, symptoms, severe symptoms for the period 14–29 November 2016 by reported asthma status and sex.

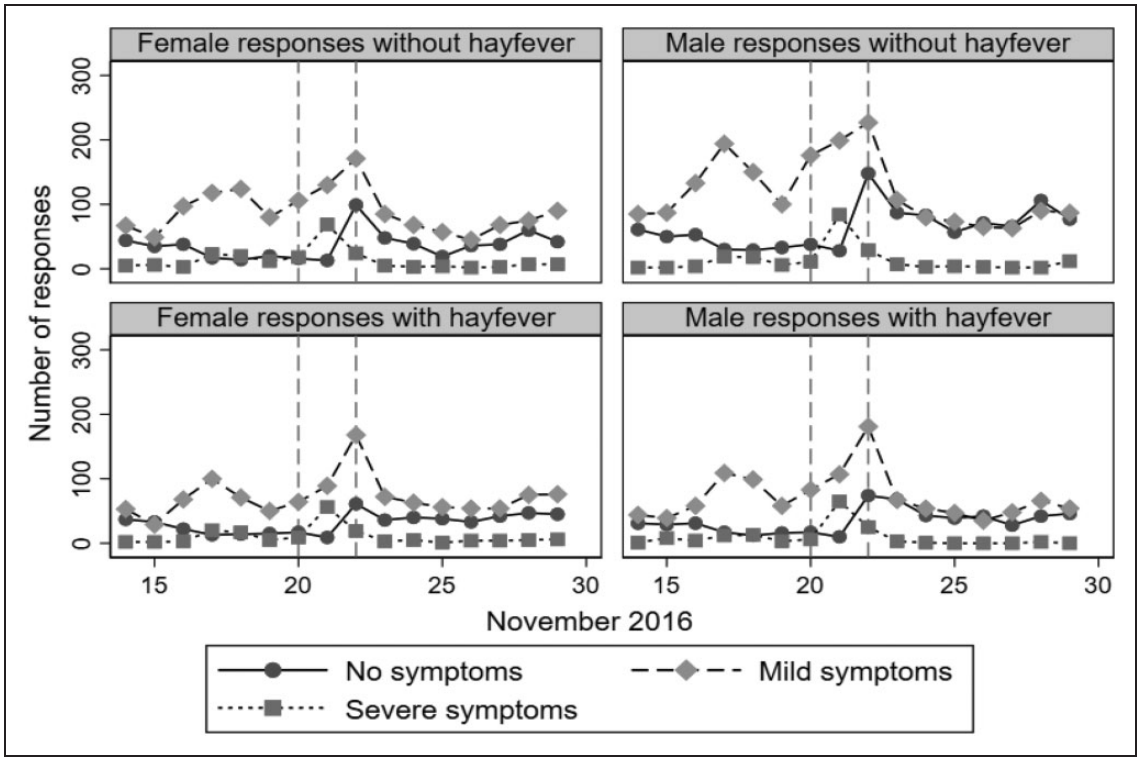

Figure 2. Number of all responders having no symptoms, symptoms, severe symptoms for the period 14–29 November 2016 by reported hay fever status and gender.

individuals affected in TA events had hay fever, often undiagnosed. Notably, hay fever is a condition that is under appreciated for which patients self-manage their condition with support from a pharmacist but usually not medical doctors during the hay fever season.[30] In this study, a significant number of new female users before and after the TA event reported having hay fever. Furthermore, a sharp increase in app survey responses during the TA event among both males and females with hay fever and severe symptoms suggests an underlying environmental mechanism during the event. Abrupt changes in weather such as a consecutive hot days and then a drop in temperature coupled with high humidity,[29] high concentrations of air pollution,[31] aero-allergens[32] or a combination of all these factors may have contributed to the phenomena.

This study is unique as it involves data collection during a catastrophic TA event, using a digital platform that can be accessed via a smartphone. Individuals were provided with grass pollen forecast information and a mechanism to report their symptoms during any time of the day. The data collection process is cost-effective as it reduces the costs that would otherwise be spent on survey design, printing and implementation but it is limited in collecting additional clinical information or past history, which is important in understanding factors that may confound, or mediate associations observed. Nevertheless, in the future it may be possible to link individuals health records with the survey responses received, if individuals provide consent as has been done by several other Asthma apps for the effective management.[33] Another limitation to note is that we were limited with the amounts and types of demographic information available: detailed/important patient background information that can impact the usage of such apps such as educational level, professionalism, working hours etc should be captured if possible, and adjusted in the analysis. Moreover, no objective parameters were available to interpret the subjectively severe symptoms among users with no previous diagnosis of asthma. For instance, it would have been ideal to have lung function testing results for all users, but at such scale this would be impractical. An alternative approach could be to integrate data recording from a smart spirometer or develop software which can identify and quantify wheeze via the smart devices integrated microphone.

Smart technology use is expanding and it may be possible to link the survey data provided by individuals to health care providers allowing the reporting of real time and local information on key environmental triggers of asthma to cater for the older population given that it is used widely by younger populations.[34] It is clear that user driven design approaches in App development would ensure that all potential users of the app and all

users submitting data to the citizen science project were catered for. Such approaches have been shown to improving the effectiveness, uptake and stickiness of Apps while simultaneously reducing user bias and improving the quality of generated data.[35] Moreover, user centred design of eHealth Apps which include input from all stakeholders during the design process, whether they are individuals who contribute data or are involved in data analysis, would without doubt improve the utility of acquired data sets. Nevertheless, due to the self-reported nature of the symptom data, and potential information bias, acquired data must be interpreted with caution. Yet despite the limitations present in this study, the symptom data presented here by age and sex are comparable to the findings of other studies in literature.[26,36]

In summary, symptoms surveys via digital mobile technology provides a new and exciting medium to support person centred health care and enhance personal capabilities to better manage symptoms and treatment control during environmental events such as TA that are likely to trigger allergic respiratory disease.

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Author Contributions

AA, ERL and BE conceived and designed the study. ERL built the mobile apps that provided the user symptom data. AA, MB, NS analysed the data with input and guidance from BE and ERL. AA, MB and BE developed the first draft of the manuscript. All co-authors contributed to subsequent drafts of the manuscript and approved the final draft for submission.

Statement of Human and Animal Rights

This article does not contain any studies with animal subjects.

Statement of Informed Consent

This study was conducted among participants who self-selected themselves and informed consent is not applicable.

Ethical Approval

Data collected was approved for analysis by the Human Research Ethics Committees of the University of Melbourne (1647764.1), Melbourne Health (QA2015148) and the South Western Sydney Local Health District (LNR/15/LPOOL/478).

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: JMD declares that QUT owns patents and patent applications (AU2008/316301; US PTO 14/311944; PCT/AU2015/050348; PCT/AU2014/000630/WO2014_201499) for which she is a named inventor. JMD leads the NHMRC AusPollen Partnership Project (GNT 1116107) with matching cash and in kind co-sponsorship from the Australasian Society of Clinical Immunology and Allergy, Asthma Australia, Bureau of Meteorology (BOM), Commonwealth Scientific and Industrial Research Organisation, Stallergenes Australia and Meteorology Switzerland. She is an investigator of the BOM's Victorian Thunderstorm Asthma Pollen Surveillance Project and has received grants from the NHMRC, Australian Research Council (DP170101630; DP190100376), National Foundation for Medical Research Innovation, the Allergy and Immunology Foundation of Australasia, Asthma Australia, Queensland University of Technology and contracted research grant from Stallergenes (France), in-kind provision of materials from Thermo Fisher (Sweden) and services from Sullivan Nicolaides Pathology (QLD, Australia). JMD's institute has received Honorarium payments and travel expenses for education sessions and conference presentations from Stallergenes Australia, GlaxoSmithKline, Wymedical, and Meda Pharmaceuticals. Other authors declare no conflicts of interest.

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Supplemental Material

Supplemental material for this article is available online.

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