Analysis of Hymenoptera Stings Reported to the Illinois Poison Center

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ABSTRACT Although there is some detailed research on anaphylactic reactions to Hymenoptera venom, there continues to be little epidemiological data about the distribution, trend, and factors associated with the occurrence of Hymenoptera envenomations in humans. We describe characteristics of persons suffering Hymenoptera stings from bees, wasps, and hornets as reported to the Illinois Poison Center, and assess seasonal, climatologic, and time trends of calls for envenomations between 2002 and 2007. Mean daily temperature and mean daily atmospheric pressure were positively associated with envenomations, whereas wind speed was negatively associated with envenomations. We also observed a significant increase in calls for envenomations on summer holidays ($P < 0.001$). In addition, our findings showed that the number of calls for envenomations declined by nearly half after 2005 ($P < 0.001$) compared with previous years. Our findings indicate that the decline in bees, wasps, and hornets may be widespread, affecting both wild and commercial populations, and that the decline appears to have been rapid and sustained in recent years. Poison center data are a valuable resource for the surveillance of poisoning in humans, but our findings show that the data can be used to monitor changes in nonhuman species.

KEY WORDS Hymenoptera stings, bees, colony collapse disorder, surveillance, poison center

The insect order Hymenoptera includes wasps, hornets, bees, sawflies, and ants. Human interactions with these insects can often result in injury from their venom. Reported lifetime prevalence of exposure to Hymenoptera stings ranges from 56 to 95% in the general human population (Incorvaia et al. 1997, Charpin et al. 1992, Kalyoncu et al. 1997, Fernandez et al. 1999). In addition, there are >150,000 emergency room visits for Hymenoptera sting injuries occurring each year in the United States (O'Neil et al. 2007), and ≈50 reported deaths annually (Langley 2005).

Hymenoptera venom is a major cause of allergic and anaphylactic reactions. The annual incidence of allergic reactions to Hymenoptera venom in the United States population is estimated between 0.3 and 4.0% of exposed persons (Chafee 1970, Settipane and Boyd 1970, Golden et al. 1989, Charpin et al. 1990, Fernandez et al. 1999, Navarro et al. 2004, Langley 2008), although it appears to vary by geographic region (Fernandez et al. 1999, Antonicelli et al. 2002). Research indicates that the estimated incidence of fatalities ranges between 0.09 and 0.45 per 1,000,000 persons suffering anaphylactic reaction (Charpin et al. 1994, Langley 2005). The proteins phospholipase A, hyaluronidase, and mastoparan are the primary immunogens found in Hymenoptera venom (Frankland and Lessof 1980, Ewan 1985, Hoffman 2008). Mild allergic reactions include dizziness, pruritus, urticaria, edema, nausea, vomiting, and diarrhea. Severe reactions include cardiac arrhythmias, bronchospasm, organ failure, and cardiac or respiratory arrest.

Although there is some detailed research on the anaphylactic reactions to the venom from various Hymenoptera species, there continues to be little epidemiological data about the distribution, trend, and factors associated with occurrence of stings in humans. Because data on human exposures to Hymenoptera envenomations are usually presented as an aggregate of various Hymenoptera species (e.g., bee, wasp, and hornet envenomations combined), recent reports of large declines in commercial and wild bee populations in the United States (Goulson et al. 2008) may also be reflected in corresponding human exposure data. For this study, we used call data from the Illinois Poison Center to: 1) describe characteristics of persons suffering stings specific to bees, wasps, and hornets as reported to the Illinois Poison Center; 2) assess seasonal and annual trends of calls for exposures to these species between 2002 and 2007; and 3) define factors that are associated with an increased risk of stings from bees, wasps, and hornets.

Materials and Methods

Data Sources. The Illinois Poison Center (IPC) provided a complete dataset of all calls made to IPC between 2002 and 2007. Trained nurses, pharmacists, and physicians receive the phone calls and provide the

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caller with poison prevention and management information. The IPC staff is trained in data entry protocols and collects a wide range of information about the exposed person, including demographic information, reported insect species, place of envenomation, and treatment follow-up. The IPC staff identifies exposure sources using a variety of information, including patient self reports (i.e., nonmedical caller), history provided by the patient to medical personnel, physical exam findings reported by health care providers, and emergency medical personnel description of the scene, such as signs, symptoms, and physical evidence (e.g., stingers).

Although the order Hymenoptera includes a variety of insects, including ants, in this analysis we only include cases of reported envenomations (stings) from bees, wasps, and hornets. The exposure coding system used by the poison center does not distinguish among species of bees, wasps, and hornets. Calls for information about Hymenoptera stings without a reported exposure were excluded. Approximately 16% of the calls that IPC receives each year are for information about poisonings and do not involve an exposure.

Population Data. We used the American Community Survey to calculate population density (number of persons divided by number of square miles in a given area) and rates (United States Census Bureau 2005–2007). We used the American Community Survey rather than the 2000 Census because it was conducted between 2005 and 2007. Population estimates from the American Community Survey overlap with years used in this study. We used the Illinois population estimates stratified by age and gender to calculate rates.

Climatological Data. Weather data were obtained from the National Climatic Data Center (United States Department of Commerce 2009). We used reported average daily temperature (Fahrenheit), average wind speed, average daily standard atmospheric pressure, total daily precipitation, and presence of fog/haze and thunderstorms. In Illinois, 65% of the population lives in the northeast corner of the state (Cook County and collar counties; greater Chicago metropolitan area). For this reason, we used daily weather data reported by the station at Chicago O'Hare Airport. Because very few calls for Hymenoptera envenomations occur during cold months (November through March), we evaluated the relationship between Hymenoptera envenomations and weather using the complete time series (all months) and a truncated time series that included only warm months (April through October) to determine whether any associations persisted.

Statistical Approach. For the descriptive analysis, age- and gender-specific rates were calculated. We also present data for place of exposure, treatment in a health care facility, severity of exposure, and route of exposure. The Pearson correlation was used to calculate the level of correlation between two continuous variables.

We hypothesized that there might be differences in levels of exposures between rural and urban areas as measured by population density. To evaluate the relationship between the number of calls for stings and population density, we used zip codes of the place of exposure and merged that information with population estimates from the American Community Survey. We stratified the cumulative number of Hymenoptera envenomation calls by three categories of population density based on United States Census Bureau definitions: 1) urban areas, $\geq$1,000 persons per square mile; 2) medium density areas, 500–999 persons per square mile; and 3) rural areas, $<$500 persons per square mile (United States Census Bureau 2000).

Autoregression Model. An autoregression model was used to evaluate the relationship between the time series of daily counts of Hymenoptera envenomations with weather conditions and activity on summer holidays. Ordinary linear regression models are based on several statistical assumptions, in particular that the errors are independent. However, in time series data, this assumption is often incorrect. Data are often correlated over time or autocorrelated. In other words, we often find in time series data that what happens today is often influenced by what happened yesterday. When ordinary linear regression models are used for time series data and fundamental assumptions are violated: 1) the parameter estimates can be incorrect; 2) the model underestimates the standard errors; and 3) the model overestimates the t scores. Autoregression models (PROC AUTOREG) allow for modeling autocorrelation of the error term. We built the final multivariable autoregression model using the forward selection method. Potential predictors were added to the model only if they significantly improved the model. The trend in calls was not linear, so we used a polynomial for time. The final multivariable model included time trend, average daily temperature, average standard atmospheric pressure, average daily wind speed, and summer holiday (dichotomous; yes/no). We used SAS (v9.1, SAS Institute, Cary, NC) software package for both the autoregression models and the Chow test.

Scan Statistic. The scan statistic is a statistical technique used to determine whether an observed increase or decrease in cases in a given period of time is statistically significant (Weinstock 1981). SatScan (v.7.0.3, Martin Kulldorff of Harvard Medical School and Information Management Services, Silver Spring, MD) was used for the temporal scan statistic. A Poisson distribution was used for the model (Kulldorff 1997). We used the scan statistic to identify days with most number of calls in any given year. Because our interest was to determine whether summer holiday weekends, 4 July and Labor Day, had the most calls for Hymeoptera envenomations, we also looked for the highest 3-d period in a given year (e.g., 3-d window). The scan statistic was also used to determine whether there was a significant decline in Hymenoptera envenomation calls between 2002 and 2007. A time series of monthly counts was used to identify whether a significant decline occurred.

Table 1. Demographic characteristics for individuals reporting Hymenoptera envenomations Illinois Poison Center calls, 2002–2007

Demographic Data	*N*	%
Age		
0–4 yr	215	14.90
5–9 yr	151	10.50
10–14 yr	68	4.70
15–19 yr	61	4.20
20–24 yr	87	6.00
25–34 yr	216	15.00
35–44 yr	166	11.50
45–54 yr	204	14.10
55–64 yr	108	7.50
65–74 yr	89	6.20
75 and up	61	4.20
Unspecified	17	1.20
Gender		
Male	685	47.50
Female	757	52.50
Unspecified	1	0.10

Cumulative Sum Method (CUSUM). We also used the CUSUM method to identify whether a significant decline in calls occurred between 2002 and 2007 and to identify the point of the decline. CUSUM sums the difference between observed and expected counts during a given period (Page 1954). An anomaly or temporal shift occurs when cumulated observed counts exceed the upper bound of the expected values. The strength of CUSUM is that it is capable of detecting smaller shifts from the mean than other statistical methods, and it detects these shifts more quickly. In addition, the residuals can be calculated with an autoregression model, which takes into account autocorrelation. Based on the output from the autoregression model, the recursive residuals are plotted to determine the point of a break when the exact date is not known. Recursive residuals are a linear transformation of ordinary residuals (Galpin and Hawkins 1984). A break is indicated when the plotted residuals wander outside of the confidence intervals on the CUSUMSQ plots. SAS (v9.1, SAS Institute, Cary, NC) was used for the Poisson CUSUM analysis (Lucas 1985, Rogerson and Yamada 2004).

Results

Between 2002 and 2007, there were in total 1,443 calls regarding envenomations from bees, wasps, and hornets. The average annual crude incidence rate was ≈11 calls per 100,000 persons. The highest average annual age-specific incidence rates based on poison center calls were among children under the age of 5 yr (4.0 calls for Hymenoptera stings per 100,000 persons), followed by children ages 5–9 yr (2.9 per 100,000). The proportion of calls and crude rates for Hymenoptera stings was approximately equal among males and females (Table 1).

Nearly all the reported stings occurred at home (95.5%). Only 20 (1.4%) exposures occurred in the workplace, three at school (0.2%), and the remainder occurred in a public area or an unspecified area.

Table 2. Autoregression time series model of predictors of reported Hymenoptera envenomations Illinois Poison Center calls, 2002–2007

	Parameter estimate	SE	*t* value	*P* value	R^2
All daily data					0.385
Holiday	1.11	0.19	5.77	<0.001	
Average daily temperature	0.03	0.00	16.12	<0.001	
Average standard atmospheric pressure	0.62	0.15	4.08	<0.001	
Average daily wind speed	−0.01	0.01	−1.98	0.047	
AR1	−0.39	0.02	−19.47	<0.001	
Truncated daily data (April–Oct.)					0.288
Holiday	1.01	0.26	3.93	<0.001	
Average daily temperature	0.04	0.00	8.84	<0.001	
Average standard atmospheric pressure	0.80	0.31	2.61	0.009	
Average daily wind speed	−0.03	0.01	−2.14	0.033	
AR1	−0.35	0.03	−13.28	<0.001	

Models included an autoregressive term (AR1) and a linear trend and quadratic trend parameters.

Whereas 1,294 (89.7%) did not require medical treatment or observation, 58 cases did receive some form of treatment/observation at a health care facility. However, another 91 cases refused referral for treatment by the medical professionals at the call center. The most common route of exposure was dermal (97.6%), but 34 (2.4%) cases were stung after ingestion, and one person was stung in the eye. Among those who were exposed through ingestion, 17 (50%) were children between the ages of 0 and 9 yr. We observed no relationship between population density and calls for Hymenoptera stings.

Weather. The daily time series of calls for Hymenoptera stings was positively correlated with average daily temperature (Pearson's correlation = 0.476; $P < 0.001$) and negatively associated with average wind speed (Pearson's correlation = −0.244; $P < 0.001$). Table 2 shows the parameter estimates of weather variables significantly associated with Hymenoptera envenomation calls based on the autoregression models. Using the complete daily time series, mean daily temperature and mean daily atmospheric pressure were positively associated with envenomations, whereas wind speed was negatively associated with Hymenoptera stings. Almost 40% of the variation in daily calls for Hymenoptera envenomations was explained by the parameters in the model. Calls for Hymenoptera stings were not associated with daily precipitation, fog/haze, or thunderstorms.

Summer Holidays. Calls for stings were positively correlated with summer holiday weekends (4 July and Labor Day; Pearson's correlation = 0.178; $P < 0.001$). In the autoregression model (Table 2), there was an increase of ≈1 call for Hymenoptera envenomations per day on summer holiday weekends. Using the scan statistic, the highest 3-d counts for stings in 2002 and 2003 occurred on Labor Day weekends (both $P <$

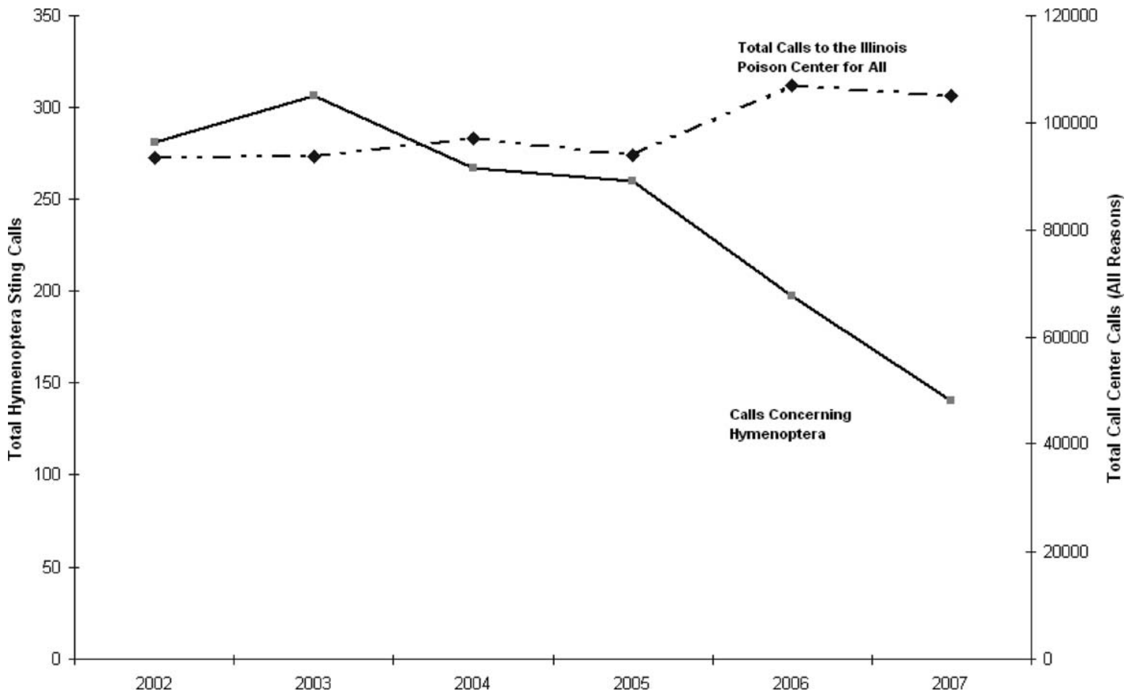

Fig. 1. Total calls to IPC for all reasons (—··◆—); calls concerning Hymenoptera (—■—).

0.001). In 2004, the highest single day count occurred on Labor Day weekend (scan statistic; $P < 0.001$). For the years 2005–2007, the highest count of calls did not occur on holiday weekends.

Trends. Approximately one-half of the calls regarding Hymenoptera stings were made between 3:00 in the afternoon and 8:00 at night (47.5%). We observed a strong seasonal pattern. Only 1.4% of the reported stings occurred between December and March compared with 77.5% during the months of July through September. Between 2005 and 2007, there was a 46.2% drop in calls for Hymenoptera stings despite an 11.8% increase in the total number of calls received for all exposure types by the Illinois Poison Center (Fig. 1). In the autoregression model, controlling for seasonal autocorrelation, the monthly trend for time was curvilinear. The time series of monthly calls for Hymenoptera stings was quadratic in shape, increasing initially and then declining over time (the quadratic variable for time [time squared]; $P = 0.028$). Based on the autoregression model using monthly counts, the CUSUM plot of the recursive residuals showed a significant structural break (decline in calls) occurring after August 2005. In addition, the scan statistic identified a significant decrease in the number of calls between January 2006 and December 2007 ($P < 0.001$).

Discussion

Our analysis indicated that weather conditions, season, and holidays were associated with increases in calls for Hymenoptera stings. Previous research has also shown that bee stings appear to occur primarily between August and October in the northern hemisphere (Fernandez et al. 1999). The relationship between temperature, atmospheric pressure, and wind speed with Hymenoptera activity has been documented as far back as 1925 (Lundie 1925, Burrill 1981, Heinrich 1984, Riessberger and Crailsheim 1997, Hilario et al. 2000, Kasper et al. 2008). Changes in air temperature and atmospheric pressure affect bee respiration and energy expenditure for flight and hovering (Withers 1981, Burrill 1981) and also affect a bee's pollination activity. Furthermore, there have been studies that show that defensive behavior (stinging) is associated with both air temperature and wind speed (Drum and Rothenbuhler 1984, Southwick and Moritz 1987, Kastberger 2009). Human behavior also changes with weather conditions and seasonal holidays. Outdoor activity increases when the weather is warmer and during holidays when people have the opportunity for outdoor activities. Our findings showed a significant increase in calls for Hymenoptera stings on summer holidays, primarily Labor Day weekend. Although our model indicates that there was an increase of only one call per day on holidays, IPC receives calls for only a fraction of all exposures (Langley 2008). The true magnitude of the increase in Hymenoptera exposures is likely much greater.

The most important finding was that the number of calls for envenomations declined by nearly half after 2005. Preliminary IPC data for the year 2008 show that the decline in reported envenomations has continued ($N = 116$ calls for Hymenoptera stings in 2008). The largest decline in honeybee populations in the United

States appears to have begun in the 1990s (Goulson et al. 2008). Beekeepers across the United States have reported rapid loss of honeybee populations in the order of 50–90% declines in a brood in some instances (Finley et al. 1996, Oldroyd 2007). This rapid loss of honeybee populations has been referred to as colony collapse disorder. The most recent widespread reports of colony collapse disorder began around 2006 (Frazier et al. 2007).

However, the decline in populations has not been restricted to honeybees, but includes other Hymenoptera species (Goulson et al. 2008). The general decline in Hymenoptera populations has been attributed to a loss of habitat, substantial reductions in wild flora, disease, pesticides, and a reduction in the genetic diversity through inbreeding and the introduction of nonnative species into regional habitats (Goulson et al. 2008). The poison center data used in this study include exposures in the general human population to both wild and commercial Hymenoptera species. Although it is unclear in which Hymenoptera populations the decline is occurring based on poison center data alone, the substantial decline we observed cannot be ignored and needs further investigation.

The vast majority of commercial honeybee colonies are located in rural areas of Illinois (USDA 2007). The reported Hymenoptera stings in this study occurred primarily in urban areas (75%) and involved only a small number of work-related exposures (1.4%), which indicates that Hymenoptera exposures in the poison center population likely involve wild Hymenoptera species or feral honeybees. Furthermore, between 2002 and 2007, the commercial population of honeybee colonies nearly doubled from 5,245 to 9,390 in Illinois (USDA 2007). If the exposures reported to the poison center involved a large proportion of commercial honeybee stings, we would have expected to see a rise in calls rather than a sharp decline. This information indicates that the decline observed in our study may relate primarily to a decline in wild Hymenoptera populations.

Limitations. Poison center data do not distinguish between bees, wasps, and hornets, because of the coding scheme used by poison centers. In addition, poison center data reflect calls, not incidence. Despite likely underreporting, the poison center data are still effective for evaluating changes in trends (Friedman 2009), and generally reflect the overall patterns of exposure, as is seen in this study. None of the findings based on poison center data for Hymenoptera stings in humans contradicted past epidemiological or entomological reports. However, because poison center data are not adequate in measuring the true magnitude of an exposure, there is a need for multiple data sources for any comprehensive surveillance program.

Conclusion

Poison center data are a valuable resource for the surveillance of poisoning in humans, but our findings show that the data can be used to monitor changes in nonhuman species. Although poison center data are not useful for evaluating the magnitude of an exposure (i.e., incidence and prevalence), the data accurately reflect the characteristics of those exposed and trends across time. Our findings regarding the relationship between weather and season with Hymenoptera stings correspond directly with entomological reports. Declines in honeybees have been reported in nearly every state in the United States during the past 10 yr by commercial beekeepers (VanEngelsdorp et al. 2008, MAAREC 2010). Our findings indicate that the decline in Hymenoptera species may be widespread, affecting both wild Hymenoptera species as well as honeybees. Databases collecting information on human health exposures should be considered for use in other fields when appropriate.

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