The interactive effects of poor air quality and extreme heat on health

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Summary

- Extreme heat and poor air quality have independently been associated with increased morbidity and mortality
- These events are increasing in intensity and frequency due to climate change
- The synergistic effects of heat and air quality have been studied on a time series scale, with inconclusive results
- There remains a gap in research in spatial studies, as well as a gap in knowledge to recommend policy changes and procedures

Predictions of the future effects of climate change on human health are difficult and imperfect. However, we can begin to understand this complicated topic by investigating the synergistic effect of two major contributors to climate change on human health known today: air quality and temperature. There is increasing concern regarding the health impacts of a changing globe, with policy changes and international calls to attention creating a demand for accessible, conclusive research and knowledge generation. This level of concern requires both environmental health and public health fields to be well informed, coordinated, and proactive.

The effects of extreme heat events on health have been studied extensively(1) in response to heat waves in Europe (in 2003) and Chicago (in 1995) causing thousands of deaths. Health Canada and the World Health Organization have identified older adults, infants, those with chronic health conditions, the homeless, and low-income earners as vulnerable populations, and recommend that Heat Alert Response Systems be implemented (2). Apart from the vulnerable populations, many other variables can affect the health risks of extreme heat events, including geographical region, seasonal effect, and other environmental variables such as wind and humidity. Extreme heat has been shown to increase all-cause hospital admissions (3) as well as ambulance service usage (4). Heat events have been studied as continuous variables as well as categorical variables, using synoptic classification of air masses (5) or weather typing (6,7), using such terms as ‘dry’, ‘temperate’, and ‘tropical’.

Independent of heat, the effect of non-natural particle pollution on mortality, morbidity, and hospital admissions has been reported repeatedly (8). Statistically significant relationships between mortality and short-term exposure to air pollution were found for all non-accidental, respiratory, and cardiovascular-related mortality (7). Many air pollutants have been identified as risk factors for health, with ozone (O_3), nitrogen dioxide (NO_2), and particulate matter with aerodynamic diameter of <10 or <2.5 um ($PM_{2.5}$, PM_{10}) being the most commonly measured (9). O_3 has been associated with higher levels of hospital admissions, respiratory symptoms, impaired lung development, and mortality, and a study of 88 US cities found that previous day PM_{10} concentrations were positively associated with total mortality counts (10). Additional to these acute circumstances, health effects due to exposure to air pollution are cumulative and have been found to non-linearly affect health for many days after exposure (7).

Projections of a warming climate will add to the current health burden caused by pollutants. Ozone levels are increased on a hot day**,** and higher PM effects occur in warmer and drier climates (11)**.** Meteorological variables such as temperature and humidity play important roles in determining patterns of air quality over multiple scales in time and space. Many populations that are independently at greater risk during poor air quality and extreme heat events overlap (2)**,** indicating that groups such as older adults, young children, and those with chronic diseases may be extremely vulnerable to climate change.

The purpose of this review is to explore the current literature surrounding the interactive effects of poor air quality and extreme heat on human health. It will identify research, policy, and knowledge gaps, which are important to identify as this issue becomes more prevalent with our changing climate.

Methods

A literature search was conducted using Ovid (Medline) with the keyword strings (temperature or heat or climate) and (air pollution or air quality) and (health or emergency or morbidity or mortality). The results were restricted to English, peer-reviewed journal articles, and human studies, published from 2005 to 2015. Beyond this, a manual search of reference lists was done, and older articles that were heavily cited and extremely relevant were included. A total of seven papers were included in the formal evidence review. More details on the selected studies are included in Table 1 of the Appendix.

Evidence Review

There have been several studied published by Li et al. examining the interactive effects of temperature and PM_{10} (12-14). In a time series study of Guangzhou City from 2005 to 2009 (12), results showed that high temperature amplified the effect of PM_{10} on all health outcomes compared to normal temperature and low temperature. The studies in Tianjin City (13), Beijing, and Brisbane (14) offered similar conclusions, with statistically significant interactions between PM_{10} and temperature for cardiovascular, cardiopulmonary, and ischaemic heart disease mortalities. The authors concluded that as a public health concern, it is important to control and reduce emission of air particles, particularly on extreme-high-temperature days.

Ren and Tong (15) examined the effect of PM_{10}, O_3, NO_2, and temperature on hospital admissions in Brisbane, Australia for the time period between 1995 and 2001. They found that PM_{10} exhibited more adverse health effects on warm than cold days. Airborne particles significantly modified the effects of temperature on respiratory hospital admissions and emergency visits, cardiovascular emergency visits and mortality, and non-external, all cause mortality. There was no evidence for effect on cardiovascular hospital admissions.

A time series study of 10 Canadian cities was conducted by Vanos et al (7) using synoptic weather types and measures of CO, NO_2, SO_2, and O_3. The study did not include particulate matter measurements. It was found that air pollution had a significant influence on acute human mortality, but varied based on the weather situation. Specifically, results showed that 'dry weather' type days exhibit an average increase of 7.8% in respiratory mortality due to any air pollutant exposure.

Alternatively, there are studies that found conflicting results. Pengelly et al. (5) collected meteorological and air quality data from the city of Toronto for a time period of 47 years, spanning 1953 to 2000. Synoptic classification of air masses was used along with O_3, NO_2, and CO measurements. Particulate matter data was not used. The burden of excess heat related mortality was quantified, and was not found to be attributable to air pollution. The authors concluded there was no significant relationship between heat-related mortality and high ozone levels.

Similarly, Samet et al. (16) studied the effect of total suspended particles and sulfur dioxide (SO_2) on mortality in Philadelphia between the years of 1973 and 1980, while adjusting for potential weather effect modifications. Synoptic weather classification was used, and little evidence of an interaction effect was found.

With inconclusive evidence, yet strong rationale for the relationship, it is clear that this field of research has not yet been saturated. There are important limitations to research in this area, including ecological fallacy, mortality misclassifications, and the ability to generalize the results.

A major limitation in this field of research is the effect of ecological fallacy. It is possible to use geographical positioning systems (GPS) to compare individual exposure measures of air quality to population measures (17), however, this is not common practice in wide-scale studies. Fixed-monitoring stations for daily weather and air pollution data are used, creating bias caused by exposure measurement error due to a lack of individual information. This error is likely to be random, which would usually result in an underestimation of the risk attributable to air pollution and temperature, biasing results toward zero (12). Jerrett et al., (18) modelled the association between $PM_{2.5}$ and mortality using small-area, intraurban exposure measures to circumvent this bias, and found effects nearly three times greater than in models relying on comparisons between communities. The effects of PM_{10} have also been suspected to be underestimated using a non-spatial approach (19). These studies, as well as a Canadian cohort study that uncovered large health effects with proximity to major roads at the intraurban scale (20), suggest that intraurban air pollution exposure gradients may be associated with even larger health effects than reported in interurban studies.

Mortality and morbidity misclassification is a limiting factor in studying heat and air pollution health effects, and amplifies the underestimation of risk. Air quality and heat have been shown to exacerbate previous conditions, with most of the elevated hospital admissions being a cause of cardiovascular, respiratory, or cancer cases. It has been shown that diabetes can be affected by poor air quality, and individuals with chronic diseases are at higher risk of heat-related illness. For this reason, it is difficult to study the direct effect of climate change on human health, and there is likely an under-representation of the effects in hospital administrative data and current literature. The fact that different health burden measurements are used in different studies indicates that many results cannot easily be compared and may have different meanings or interpretations.

Finally, the ability to generalize the results of these studies is limited. By studying specific geographical areas or time series, it is difficult to apply the results nationally or internationally. Social factors, demography, infrastructural factors, housing characteristics, and access to air conditioning are all variables that may have a role in the outcome, yet are not consistently controlled for. Herein exists a gap in research and knowledge, without fully understanding the roles of certain variables and confounders, though hypothesized to have an impact. Many variables which have been identified as confounders or modifiers have been inadequately studied or controlled for, including age, co-morbidities, geographical variation, lag effect, and future predictions.

Despite this, there are many strengths in the research. Numerous studies include reliable and accurate data, although not always using the same variables. Meteorological and air quality data are generally easy to access and there is limited missing data for many of these studies. With strong rationale and background research having been done on the individual impacts of heat and air quality on health, it is possible to extrapolate biological plausibility and hypotheses for this research. An untapped source of knowledge is spatial modelling of these synergistic effects. All journal articles found have been based on time series studies, yet larger-scale, geographical modelling of these relationships would allow for further understanding of social determinants and environmental controls.

Conclusions

Based on the evidence review conducted, it has been demonstrated that there is extensive research to be completed in this field. Most notably, it is suggested that studies should focus on being able to generalize results to alternate populations, as these are more relevant in providing policy suggestions and more complete, relevant understanding of topics. It is recommended that policy makers take into account the possibility of synergistic effects of heat and poor air quality, with some conclusive studies showing correlation in spite of the conservative results due to study limitations. This should be considered when recommending climate change policies and pollutant regulations, such as the Canada-US Air Quality Agreement and the World Health Organization’s Air Quality Guidelines (2).

Future considerations in research can be designed to create policy changes, warning systems, surveillance systems, and advise local health care to set targeted guidelines for an air-pollution-health relationship. It has been said that “hunger is hierarchical, smog is democratic” (21), arguing that environmental changes and their effects on human health are a serious and population-level public health concern. Health risks from atmospheric conditions and pollutants exist without boundaries or social distinctions (22), and environmental and health fields should unite in a coordinated effort in research and policy in the future of climate change.

Appendix

Table 1: Search results

Authors	**Setting**	**Methodology/Data**	**Findings**
Li et al., 2011 (12)	- Tianjin City - 11 urban & suburban districts - 1 January 2007 to 31 December 2009	- Mortality: non-accidental, cardiovascular, respiratory, cardiopulmonary, stroke, ischemic heart disease (influenza excluded) - 24 hour average values of PM_{10}, NO_2, SO_2, temperature - Adjusted for: seasonality, short-term fluctuation, relative humidity, public holidays	- Statistically significant relationships for total and cause-specific mortality except stroke - Interactive terms statistically significant for cardiovascular, cardiopulmonary, and IHD mortalities - High temperature could enhance PM_{10} effect on cause-specific population mortality
Li et al., 2012 (13)	- Beijing, China (2005-2009) - Brisbane, Australia (2004-2007)	- Non-accidental mortality (ICD-10) - PM_{10}, temperature - Adjusted for : seasonality, short-term fluctuations, relative humidity, and public holidays	- Statistically significant interactive effects of PM_{10} and mean temperature on mortality - High temperature can enhance the effect of PM_{10} on non-accidental mortality
Li et al., 2014 (14)	- Guangzhou City, China - 2005-2009	- Non-accidental, cardiovascular, respiratory, cardiopulmonary - PM_{10}, NO_2, SO_2 - Stratified parametric statistical model	- High temperature enhanced the effect of PM_{10} on all health outcomes compared with normal or low temperature - Significant interactive effects on respiratory mortality
Pengelly et al., 2007 (5)	- Toronto - 47 year span - 1953-2000	- Synoptic classification of air masses - O_3, SO_2, NO_2, CO, COH - Annual mean burden of illness (calculated from elevated mortality) - Daily heat-related mortality risk based on day-to-day variability in mortality	- No significant relationship between heat-related mortality and high ozone levels - Similar analysis failed to show a relationship between heat-related mortality and days with high NO_2 exposure - Quantified burden of excess heat-related mortality: not attributable to air pollution

Ren & Tong, 2006 (15)	- Brisbane, Australia - 1996-2001	- Three different time-series approaches (bivariate surface model, non-stratification parametric model, stratification parametric model) - PM_{10} - Respiratory hospital admissions, cardiovascular hospital admissions, respiratory emergency visits, cardiovascular emergency visits, non-external cause mortality, and cardiovascular mortality	- Airborne particles significantly modified the effects of air temperature on respiratory and cardiovascular hospital admissions - PM_{10} exhibited more adverse health effects on warm than cold days
Samet et al., 1998 (16)	- Philadelphia, PA - 1973-1980	- Total mortality - Four weather models - Temporal Synoptic Index, Spatial Synoptic Classification - TSP and SO_2 - Poisson regression model	- Little evidence that weather conditions modified the effect of pollution, regardless of the approach used to represent weather in the model
Vanos et al., 2014 (7)	- 10 Canadian cities - Subdivided analysis, combined results - 1981-1999, segregated by season	- Mortality measurements - CO, NO_2, O_3, SO_2 - Synoptic weather typing - Time series adjusted for temporal trends using natural spline and knots, lag times	- Dry weather types exhibit an average increase in 7.8% in respiratory mortality due to any air pollutant exposure - Combined effect of weather and air pollution is greatest when tropical-type weather is present in spring or summer

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