The Relationship between Air Pollution, Weather, and Symptoms in an Urban Population

Clarification of Conflicting Findings[1-3]

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SUMMARY

Numerous studies have documented a relationship between air pollution, weather, and illness. Specific causes proposed to account for the effects have not stood up to critical examination, and the nature of the relationships has remained obscure. Indeed, contradictions and paradoxes are common within the general association between the environment and illness. The findings reported here support the belief that the environment—like some other modern health problems—must be examined differently than has been customary in the search for health effects, employing changed ideas of causality. The concept of the multiplex variable and some aspects of the philosophy of causality are discussed.

Introduction

Previous reports have documented a relationship between air pollution, weather, and the occurrence of acute respiratory symptoms in a panel of New York City residents (1–3). In general, the findings have suggested complex rather than simple associations and, not surprisingly, have failed to pinpoint single factors in the environment that might be held primarily responsible for illness. Indeed, the results have indicated considerable variation in the relationships from symptom to symptom, season to season, and year to year. Such contradictions and paradoxes within the general association between the environment and illness have also marked other investigations in which the subject has been examined in sufficient detail (4, 5). Notable in this regard is the literature on the relationship between air pollution and mortality (6–10).

The purpose of this paper is to re-examine some of these paradoxes within the framework provided by the concept of the environment as a multiplex variable, a variable seen as a cause that, although it may

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consist of conceptually discrete parts, acts as a whole in terms of its effects. When the findings were reviewed in that light, a more realistic picture of the interaction between the ambient environment and health emerged. Further, a clearer direction for future work emerged.

Materials and Methods

The Cornell Family Illness Study, which provided the data for the analyses recorded here, has been fully detailed previously (11, 12). A daily record of the prevalence of a number of common symptoms was maintained for 3 years for a panel of New York City residents living within a restricted geographic area. The 1,747 persons participating were followed by weekly interviews for an average of 48 weeks each. Air pollution data were obtained from a special monitoring station installed within the study area. Meteorologic information was obtained from that station and from the official U. S. Weather Bureau station located 4.5 miles away.

Using days as units, incidence and prevalence per 1,000 persons were calculated for the acute symptoms of headache, eye irritation, "common cold," sore throat, and cough.

Daily averages and changes from the preceding day were calculated for the following air pollutants: particulate matter, carbon monoxide (CO), sulfur dioxide (SO_2), and hydrocarbons, as measured in the study area. In addition, daily measurements of 11 air pollutants were obtained from the New York City monitoring station approximately 110 blocks from the study area. Daily averages and changes from the preceding day were calculated for 6 of the meteorologic variables. In addition, 7 functions of barometric pressure were derived. The list of variables is given in table 1.

The analyses used stepwise multiple regressions from programs available for the IBM 1130 computer. Stepwise multiple regressions, where daily incidence and prevalence of specific acute symptoms are the dependent variables, provide a descriptive model of the relationships between these symptoms and the environmental factors that co-existed in time. The stepwise procedure has the property of entering the pollutant and meteorologic variables one at a time in order of their ability to "explain" the variation in the dependent variable as measured by the multiple correlation coefficient. Assuming that observations from day to day are essentially independent and that the distributions of the relevant variables are at least continuous (except for missing information), the resulting models might also furnish a predictive tool to determine symptom response when environmental conditions are known. A more complete discussion of the use of this method for the data of this study was given by Thompson and associates (3).

Results

The results of the regression analysis are shown in table 2; all regressions shown were significant. In table 2 the level of each of the environmental factors (independent variables) required to "explain" the average rate of the symptoms is also shown. Only 13 of 27 independent variables proved useful as explanatory factors. These were in approximate order of importance: daily averages of temperature, particulate matter, wind velocity, radiation, CO, hydrocarbons, and SO_2; daily range and maximum of barometric pressure; daily average sky cover, and changes in averages from the preceding day of wind velocity and radiation. Most measures of change from the preceding day did not significantly contribute to the results. The multiple correlations between each symptom and the set of significant environmental factors ranged from 0.27 to 0.60.

Two features of the regressions were most notable. First, each symptom correlated with an environment whose features differed from the environments in which the other symptoms occurred. Second was the fact that no one environmental variable stood out in its ability to "explain" the presence of a symptom. Both important findings were underlined by the considerable differences in the regression drawn when the symptom "common cold" was examined separately by its prevalence, incidence, and incidence after three days.

Discussion

Viewed as an attempt to determine what in the ambient environment of air pollution and weather was causally related to symptoms in a normal urban population, the results were disappointing and conflicting.

TABLE 1
MEANS AND STANDARD DEVIATIONS OF ENVIRONMENTAL VARIABLES AND ACUTE SYMPTOMS, CORNELL FAMILY ILLNESS STUDY, NEW YORK CITY, 1962–1965

Description	Mean	SD
Days with no inversion, %	0.49	0.50
Days with inversion, %	0.46	0.50
Days with isotherm, %	0.05	0.22
Headache prevalence, %	2.83	1.54
Headache incidence, %	1.02	0.63
Eye irritation prevalence, %	1.79	0.98
Eye irritation incidence, %	0.30	0.34
Cold prevalence, %	7.61	3.61
Cold incidence, %	0.88	0.72
Sore throat prevalence, %	1.91	1.23
Sore throat incidence, %	0.43	0.45
Cough prevalence, %	5.00	2.39
Cough incidence, %	0.60	0.54
Particulate matter (COH) average	1.73	0.87
Particulate matter (COH) change*	0.00	0.75
CO average, ppm	3.72	2.49
CO change, ppm	−0.04	2.31
Hydrocarbons average, ppm	4.54	1.94
Hydrocarbons change, ppm	0.00	1.25
SO_2 average, ppm	0.16	0.10
SO_2 change, ppm	0.00	0.09
SO_2, ppm†	0.20	0.16
Ammonia, ppm†	0.03	0.02
Aldehyde, ppm†	0.05	0.03
Oxidant (A. M.), ppm†	10.83	13.90
Oxidant (P. M.), ppm†	10.13	14.15
CO (A. M.), ppm†	2.95	1.72
Nitrogen dioxide, ppm	10.74	7.99
Sodium chloride, ppm†	5.52	5.79
Dust count†	2.71	1.58
Particle matter (COH)†	248.74	158.86
Organic acid†	6.04	5.80
Nitrogen monoxide, ppm†	6.27	6.34
Wind velocity average, mph	9.34	3.69
Wind velocity change, mph	−0.03	4.05
Precipitation average, (inches)	0.03	0.10
Precipitation change, (inches)	0.00	0.14
Radiation average	0.30	0.15
Radiation change	0.00	0.15
Temperature average, °F	51.29	16.76
Temperature change, °F	−0.02	6.11
Relative humidity average, (%)	60.08	15.53
Relative humidity change, (%)	−0.02	15.88
Sky cover average	4.50	3.18
Sky cover change	0.00	3.69
Barometric pressure (maximum R), mm Hg	0.03	0.02
Barometric pressure (maximum F), mm Hg	0.03	0.02
Barometric pressure (maximum), mm Hg	30.14	0.21
Barometric pressure (minimum), mm Hg	29.91	0.25
Barometric pressure (range), mm Hg	0.22	0.15
Barometric pressure change, mm Hg	0.00	0.21
Barometric pressure average, mm Hg	30.03	0.23

*"Change" is change of average from preceding day; average is daily average.
†Measured at the New York City Station. The other measurements were within the Cornell Family Illness Study Area (lower east side of Manhattan).

TABLE 2

STEPWISE MULTIPLE REGRESSIONS* OF SYMPTOM RATES WITH AIR POLLUTION, AND WEATHER VARIABLES WITH LOGS; MULTIPLE CORRELATION COEFFICIENTS AND THE RELATIVE CONTRIBUTIONS† OF THE ENVIRONMENTAL VARIABLES

Symptom Rates (per 100) (Depend. Variable)	Multiple Correlation Coefficient	Relative Contributions of the Independent Environmental Variables											
		Particulate Matter Average	CO Average	SO_2 Average	Hydrocarbon Average	Wind Velocity Average	Wind Velocity Change	Radiation Average Change	Temperature Average	Relative Humidity Average	Sky Cover Average	Barometric Maximum	Pressure Range
"Common cold"													
Prevalence	0.60	10.8	7.1			28.5	−0.04	−14.1	27.8				
Incidence	0.35	1.3	0.9			0.3		−1.8	−3.0				
Incidence with 3-day lag	0.32								−6.4	3.1		11.6	
Cough prevalence	0.52	5.6	5.6		3.5	19.4		−5.4	−13.4				
Sore throat prevalence	0.41	3.3				0.02			−11.7				
Headache prevalence	0.39	−2.6		−1.0	−3.1	−6.2		−6.7	3.6		−4.5		
Eye irritation prevalence	0.27				−1.6				6.2				−1.4

*All statistically significant regression coefficient (F and t tests, $P < 0.005$).

†Relative contribution of a variable was derived by multiplying the regression coefficient for that variable (in that equation) by the mean value of that variable to indicate relative size of that variable in its contribution to "explaining" or "predicting" the over-all symptom rate.

Such disappointments are not new in the epidemiology of air pollution, where virtually no common pollutant in urban air has withstood close examination as a sole cause of human illness (13). Seen in another light, however, these same findings add further strength to the belief that the ambient environment must be examined in a manner different from what has been customary in the search for health effects in the past. Further, these otherwise conflicting findings make sense when seen within a changed framework of causality.

Expecting the ambient atmosphere to behave with respect to its health effects as a collection of independently acting components is an overly reductionist view of causality. Rather, the ambient atmosphere is a member of a class of variables that might be termed multiplex variables, which have the following characteristics. (*1*) The effect of the whole is greater than the effect of the sum of the known parts. (*2*) The relationships of the parts to each other are not fixed. (*3*) The manner in which the relationships of the parts vary is not fixed. (*4*) Time is one of the parts of a multiplex variable (14).

For these variables (poverty and aging are other examples), analysis of their effects by isolation of the effects of their components will not lead to understanding the influence of the whole variable, simply because it is not the part that produces the effect, but rather the whole.

It is interesting to re-examine the results of the regression analysis in the light of the concept of the multiplex variable. No attempt is made to choose from the regressions that independent variable or those variables that, because of the strength of the statistical association, seem to be acting in the production of the symptom; rather, the equations are viewed in reverse. During the analysis, the dependent variable is seen as drawing a picture of the environment in which it occurs. At first glance, the reasoning may appear to be circular, but it is not. The multiplex variable has been shown to be associated with the symptom, and the symptom, as dependent variable, describes in the analysis that configuration of the multiplex variable within which it occurs.

Looking again at the symptom "common cold" in the stepwise multiple regression, the three indices, "cold prevalence" described a setting in which air pollution and weather figured heavily: cold, cloudy, windy but stable, with considerable air pollution. "Cold incidence" described a similar environment in that both pollution and weather were present, which although less heavily weighted, seemed less changeable in character (absence of participation of change in radiation). "Cold incidence into which a three day lag has been introduced" described an environment in which weather appeared, but pollution seemed to play no part.

These situations were neither inconsistent nor paradoxic; they only seemed so if one wished to find an effect of, e.g., particulate matter or temperature or even their interaction. What was portrayed, then, was not the static interaction of factors to produce effects nor even a fixed but complex "set" in which effects occurred, but rather a dynamic unfolding through time in which new things could enter or leave (15, 16).

It is interesting, in this light, to review the analysis by Thompson and associates (3) of the same data. They divided the study period into its 9 seasons and then used stepwise multiple regression analysis in a manner similar to that used here. The environment was related to common cold incidence and prevalence in almost every season, but the strength of the relationship varied from season to season, as did the number of weights of the environmental variables that entered the regression. Again, the findings seem at first inconsistent, but the results, rather than being inconsistent, consistently showed an association of the symptoms with the new environment, and the association occurs in numerous environmental configurations. The results only seem inconsistent if the environmental parts are viewed as being relatively independent and fixed in effect.

As shown in table 3, Thompson and coworkers (3) portrayed pairwise correlations of air pollution and weather factors for 4 of the 9 seasons. The differences between the correlations among environmental factors from season to season and in the same season from year to year are clearly shown. Nevertheless, simplified conceptions of the environment and its components and how they act and interact seem to underlie most analytic techniques.

One cause—one effect thinking in epidemiology is so enduring that such premises seem to underlie more sophisticated assumptions even when they are inappropriate. Because of this, when dealing with complex situations, there appears to be an almost un-

TABLE 3

PAIRWISE CORRELATIONS OF STANDARD SCORES OF ENVIRONMENTAL FACTORS FOR FOUR SEASONS

		Spring 1964	Spring 1963										
		Winter 1963–64	Summer 1964										
	CO		SO_2		Wind Velocity		Solar Radiation		Temperature		Relative Humidity	
Particulate matter	0.56	0.49	0.70	0.70	−0.42	−0.34	−0.33	−0.28	−0.24	0.11	0.20	0.03
	0.56	0.24	0.86	0.17	−0.59	−0.17	−0.27	0.04	0.27	0.36	0.28	0.07
CO			0.51	0.30	−0.11	−0.22	−0.32	0.03	−0.26	0.16	0.19	−0.04
			0.51	0.14	−0.32	−0.27	−0.18	−0.10	−0.18	0.21	0.14	0.13
SO_2					−0.31	−0.37	−0.25	−0.07	0.05	0.16	0.08	−0.05
					−0.64	−0.05	−0.11	−0.04	0.20	0.50	0.12	0.20
Wind velocity							0.27	0.15	−0.06	−0.39	−0.41	−0.33
							0.14	−0.02	−0.11	0.00	−0.16	0.06
Solar radiation									0.17	0.02	−0.74	−0.59
									−0.13	0.31	−0.73	−0.69
Temperature											−0.10	0.28
											0.17	−0.13
Relative humidity												
Barometric pressure	0.00	0.00	0.09	0.35	−0.31	−0.43	0.14	0.20	−0.41	−0.02	−0.07	−0.05
	−0.03	0.04	0.22	0.13	−0.46	−0.26	0.21	0.17	−0.25	−0.18	−0.39	−0.13

spoken belief that one is really dealing with a confusion of static one cause—one effect cases that can somehow be untangled like a knot.

The analyses and data herein represent inconsistencies in the effects of the environment on health if they are viewed in the traditional manner of trying to find those factors in the environment that are entirely or partly responsible for the particular effects observed. The inconsistencies fade when the dependent variable is seen as an exploratory probe pointing out the configuration of the multiplex variable with which it is associated. The findings suggest that the analytic solutions to the problems posed by multiplex variables are different from those posed by unifactorial or even multifactorial situations, and that the effect of the environment on health should be measured primarily in terms of its health effects, not its environmental constituents.

Nonetheless, the results do not explicate the nature of the relationships within the environment nor how the effects are produced. The problem is similar to an attempt to visualize a three-dimensional topography given only one cut through the model. What is required are multiple cuts, configurations of environment drawn by the health effects, to add the third dimension. A single analysis can be compared to a snapshot in a situation in which motion pictures are required. There is no reason why complex events that are related in both time and space cannot be analyzed (10).

The history of epidemiology is a history of success in circumstances in which one or a few factors operate in a comparatively simple manner. Today the task is to develop techniques appropriate to more complex situations. To do so will require not only refinements in measurement and analysis, but considerable change in conceptual framework.

RESUMEN

Relación entre la polución del aire, el clima y los sintomas en una populación urbana: clarificación de hallazgos en conflicto

Estudios numerosos han documentado una relación entre la polución del aire, el clima y la enfermedad. Las causas especificas propuestas como causantes de los efectos no han soportado el examen critico, y la naturaleza de las relaciones permanece obscura. En realidad, contradicciones y paradojas son comunes dentro de la asociación general entre el ambiente y la enfermedad. Los hallazgos reportados aquí soportan la creencia de que el ambiente, tal como otros problemas de salud modernos debe ser examinado diferentemente de lo que ha sido la costumbre en la busqueda de efecto de salud, usando ideas cambiadas de casualidad. Se discute el concepto del variable multiplex y algunos aspectos de la filosofia de a casualidad.

RESUME

Relation entre la pollution de l'air, le climat, et les symptômes constatés dans une population urbaine: clarification d'observations contradictoires

De nombreuses études ont fourni des éléments en ce qui concerns une relation éventuelle entre la pollution de l'air, le climat et la morbidité. Les causes spécifiques qui ont été proposées pour rendre compte des effets de la pollution de l'air et du climat n'ont pas résisté à un examen critique, et la nature de cette relation est demeurée obscure. A vrai dire, les contradictions et les paradoxes abondent en ce qui concerne une association générale entre le milieu et la morbidité. Les observations rapportées ici renforcent la croyance qui veut que le milieu, de même que d'autres problèmes modernes relatifs à la santé, doivent être examinés différemment qu'il n'a été coutume, lorsqu'il s'agit de rechercher les effets sur la santé, et ceci en ayant recours à des idées modifiées en ce qui concerne le causalité. Le concept de variable multiplex, et certains aspects de la philosophie de la causalité, sont discutés dans cet article.

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