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Air Pollution, Weather, and Illness in a New York Population

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EVIDENCE has accumulated over the past several years to justify the statement that air pollution, as a generality, has an effect on health. While the effect has been most dramatically shown in the few recorded acute air pollution disasters[1,2] and in the exacerbation of pre-existing cardiopulmonary disease,[3-5] recent studies indicate that an adverse effect of urban air pollution at regularly occurring levels can be shown for normal children.[6,7] Attempts to understand the mechanism by which air pollution produces its effect on health have been frustrating, and it has not been possible, thus far, to isolate individual pollutants whose effects by themselves are capable of explaining the entire air pollution effect.

Previous reports from our group have indicated some effect of urban air pollution on a normal population,[8-11] but rather than clarifying the mechanisms, these have pointed to the multivariate nature of both the stimulus and the response.

This paper presents the results of analyses of some of the complex and interacting variables in the environment that appear to participate in the production of adverse health effects. These analyses represent steps in the larger process of delineating complex mechanisms.

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Methods

The study population, methods of data collection, and environmental monitoring have been described in previous reports.[12] A daily record of the prevalence of a number of common symptoms or illnesses was maintained for a period of three years, for a panel of New York City families living within a restricted geographic area. Persons (1,747) participating in the study were followed by weekly interviews for an average of 45 weeks each, providing 61,000 person weeks of information. In addition, air pollutants were measured in the study area and meteorologic measurements were available from both the study laboratory and from the city. Included in the first step in the analysis to be reported were the symptoms "common cold," cough, headache, and eye irritation. The four pollutants under consideration were particulate matter (COH), total hydrocarbons (THC), carbon monoxide (CO), sulfur dioxide (SO_2). The seven meteorologic factors considered initially were wind speed (wnd), precipitation (ppt), solar radiation (rad) in calories per unit area, temperature (tmp), relative humidity (rlh), sky cover (sky), and barometric pressure (bp). The daily average of each factor was used except for barometric pressure, for which the daily range—difference between maximum and minimum—was used.

Multiple correlation coefficients, to be report-

Table 1.—*Correlation Coefficients Between Pairs of Environmental Factors*

	Wnd	Ppt	Rad	Tmp	Rlh	Sky	Bp	Coh	Thc	So_2	Co
Wind	...	0.062	0.085	−0.372	−0.259	−0.089	0.439	−0.296	−0.260	−0.381	...
Ppt	...	...	−0.346	0.010	0.449	0.378	0.300	0.011	−0.087	−0.061	...
Rad	...	...	...	0.347	−0.641	−0.660	−0.252	−0.363	0.075	−0.230	−0.194
Tmp	...	...	...	...	0.122	−0.055	−0.366	−0.369	0.283	−0.138	−0.100
Rlh	...	...	...	...	...	0.707	0.107	0.124	−0.024	0.074	0.083
Sky	...	...	...	...	...	...	0.213	0.160	−0.018	0.055	0.031
Bp	...	...	...	...	...	...	...	0.131	−0.176	−0.040	0.016
Coh	...	...	...	...	...	...	...	...	−0.002	0.664	0.540
Thc	...	...	...	...	...	...	...	...	...	0.002	0.148
So_2	...	...	...	...	...	...	...	...	...	...	0.431

ed first, are appropriate for studying several variables simultaneously. This form of statistical analysis provides useful indicators of the relative importance of association of the environmental factors and each of the symptoms under inspection for the day of occurrence—the effect of time delay is not seen in this analysis.

Results of the Analysis

Table 1 shows the strength of association expressed as product moment correlation coefficients among pairs of environmental factors. Of the daily average of pollutants, the strongest associations were among pairs of the three pollutants COH, SO_2, and CO. Total hydrocarbon appeared least associated with the other pollutants. The relative strength of association among the pairs of the seven meterologic factors is also shown in Table 1. The strong positive correlation between sky cover and relative humidity is expected as well as the strong negative correlation of each of these with solar radiation.

Table 2 shows the relationship between certain pollutants measured at the study monitoring station (CFIS) and those measured at the New York City station, 110 blocks away.

The strength of association between four symptoms and certain environmental factors has been expressed as correlation coefficients displayed in a simple matrix in Table 3.

Table 2.—*Correlation Coefficients Between Environmental Factors Measured at New York City Laboratory and Cornell Family Illness Monitoring Station (CFIS)*

		New York City Lab		
		Particulate Matter	SO_2	CO
CFIS	COH	0.563	0.602	0.391
	SO_2	0.452	0.559	0.349
	CO	0.378	0.352	0.413

As shown in Table 3, low tmp (as well as low humidity and a wide range in bp) is highly associated with the daily prevalence of "common cold" and cough symptoms. High tmp and the daily prevalence of eye irritation are positively associated. Also found in association with "common cold" and cough are the environmental factors of wnd and COH. Carbon monoxide appears to be associated with respiratory symptoms while THC show a negative association with those symptoms. The relationships of SO_2 appears to be less strong than COH.

This multiple regression analysis sought to clarify the relationships between the levels of some pertinent environmental factors and the prevalence of certain symptoms in a panel of a normal urban population. Of the four symptoms studied, the prevalence of respiratory symptoms (common cold and cough) was found more strongly associated with atmospheric factors than was prevalence of headache or eye symptoms.

Previous reports from our group using other methods of analysis have also pointed to an association between certain symptoms in the study population and pollutants.[8-11] In this analysis an apparent association is demonstrated not only between certain of the symptoms and pollutants but the symptoms and weather factors. But here, as in the previous analyses, it has not been possible to single out one factor whose contribution appeared so strong as to negate the importance of the other environmental variables or which could solely account for the variation in prevalence of the symptoms. Similarly, while the results of this analysis

Table 3.—*Correlation Coefficients Between Certain Prevalent Symptoms and Environmental Factors*

	Symptoms				
	Headache	Eye Symptoms	Colds	Cough	Sore Throat
Wnd	−0.054	−0.114	0.245	0.217	0.176
Ppt	0.033	−0.031	−0.004	0.004	0.030
Tmp	0.152	0.258	−0.609	−0.494	−0.456
Rlh	0.118	0.077	−0.119	−0.119	−0.029
Bp range	−0.101	−0.161	0.299	0.269	−0.199
COH	−0.043	−0.088	0.264	0.194	0.240
CO	0.147	0.091	0.207	0.219	0.188
Total HC	−0.111	−0.108	−0.139	−0.152	−0.234
SO_2	−0.009	−0.033	0.102	0.112	0.058

point to the association between symptoms and pollutants, the results do not further clarify the complex relationships between the environmental variables and the symptoms.

As another step in understanding the nature of the health effects of air pollution a "Principal Components" analysis was undertaken. Although the subject of considerable continuing controversy, the Principal Components analysis is a mathematical method that has been used to derive "factors" in which a number of different variables are represented. These "factors" represent the degree of overlap or similarity among the variables as measured by correlation coefficients. The "factors" may be thought of as corresponding to patterns of interaction in time, in which case the variables which occur together most often have the highest loadings (weights) in that pattern. Another interpretation is that the "factors" are geometric axes on which the variables, like vectors, are projected, in which case the degree to which a variable projects on each axis is its loading (weight).

If the "factors" which are derived by the method contain both illness and environmental variables with high weights, they can be considered simply as "factors" in which there is no differentiation between independent and dependent variables.[13]

On the other hand, the "factor" may be considered as "standing for" (as an index of) a specific set of variables[14,15] such as an environmental index if it is environmental variables that have the highest weight and essentially determine the "factor." In the latter case, the "factor" is the index, and the "factor" scores are the values of the index, so the index can then be taken as a new variable.

Table 4.—*Variables Used in Principal Components Analysis*

No.	Name	Mean	SD
1	No inversion	0.49	0.50
2	Inversion	0.46	0.50
3	Isotherm	0.05	0.22
4	Headache prevalence rate	2.83	1.54
5	Headache incidence rate	1.02	0.53
6	Eye prevalence rate	1.79	0.98
7	Eye incidence rate	0.30	0.34
8	Cold prevalence rate	7.51	3.61
9	Cold incidence rate	0.88	0.72
10	Sore throat prevalence rate	1.91	1.23
11	Sore throat incidence rate	0.43	0.45
12	Cough prevalence rate	5.00	2.39
13	Cough incidence rate	0.60	0.54
14	COH (CFIS) average	1.73	.087
15	COH (CFIS) change	0.00	0.75
16	CO (CFIS) average	3.72	2.49
17	CO (CFIS) change	−0.04	2.31
18	Hydrocarbons (CFIS) average	4.54	1.94
19	Hydrocarbons (CFIS) change	0.00	1.25
20	SO_2 (CFIS) average	0.16	0.10
21	SO_2 (CFIS) change	0.00	0.09
22	SO_2 (NYC)	0.20	0.16
23	NH_3 (NYC)	0.03	0.02
24	Aldehyde (NYC)	0.05	0.03
25	Oxidant (AM) (NYC)	10.83	13.90
26	Oxidant (PM) (NYC)	10.13	14.15

To obtain the greatest value from the method, an increased number of variables derived from the illness and environmental data were employed in the analysis. Both incidence and prevalence rates per 1,000 per day were calculated for the acute symptoms headache, eye irritation, "common cold," sore throat, and cough. Daily averages and changes from the preceding day were calculated for the air pollutants; COH, CO, SO_2, THC, as measured in the study area. In addition, daily measurements of 11 air pol-

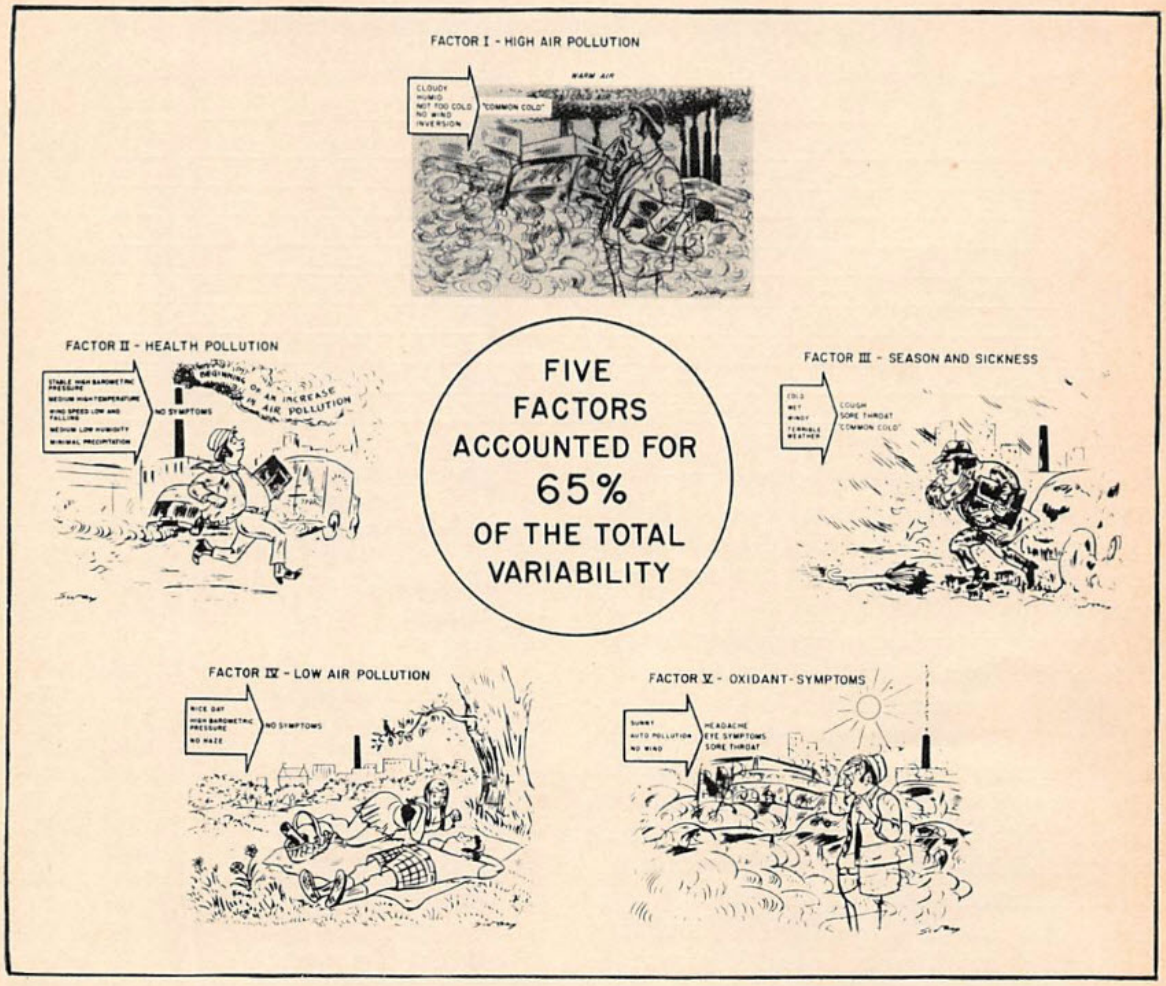


Fig 1.—Principal components analysis.

lutants were obtained from the New York City monitoring station (121st St and Lexington Ave) about 110 blocks (5.5 miles) from the study area. Daily averages and changes from the preceding day were calculated for six of the metropolitan meteorological variables, and seven functions of bp were derived. Information on the presence or absence of a meteorologic inversion was also used. The list of variables is contained in Table 4.

The Principal Components analysis used was of the type developed by Hotelling (preprogrammed).[16]

Results

Five major "factors" were produced by the Principal Components solution, which together accounted for 65% of the total variability within the data.

"Factor" characteristics, as noted earlier, are determined by contributions of the variables to the "factor," (and are similar to the amount of projection of a vector on an axis). The derived "factors" can be considered independently of each other. *It must be stressed that a "factor" is a synthetic entity produced by the analysis and that the names assigned to these "factors" are conceptual.*

Factor I.—The so-called "High Air Pollution" factor has high loadings of pollutants, temperature inversion, and meteorologic characteristics that are normally associated with pollution, at least in New York, and in which "common cold" has high loadings.

Factor II.—The "Health Pollution" factor occurs in certain changing environmental conditions.

Factor III.—The "Season and Sickness" factor relates high incidences and prevalences of cold, sore throat, and cough to inclement winter weather.

Table 5.—*The Relationships Between Symptoms and Environment as Portrayed by Principal Components Analysis**

Environmental Factors (Daily Av)	Factor V Eye Irritation, Headache, Sore Throat	Factor I Common Cold	Factor II Cough, Sore Throat, Cold
Pollutants—local project station			
CO		+0.6	
COH		+0.8	
SO_2		+0.7	
THC			
Pollutants—New York city station			
SO_2		+0.6	
CO		+0.5	
NO_2		+0.5	
Dust count		+0.5	
COH		+0.6	
Organic acid	+0.3	+0.3	
Nitrous oxide		+0.5	
Total oxidant	+0.3		
Meteorological parameters			
Wnd		−0.4	+0.3
Rad		−0.5	+0.4
Tmp	+0.3	+0.4	−0.6
Rlh		+0.4	−0.5
Sky		+0.4	−0.4
Bp	−0.3†	−0.4	+0.4
Ppt			−0.3
Inversion condition		+0.5	

*Numbers are relative weights in patterns.
†Range during day.

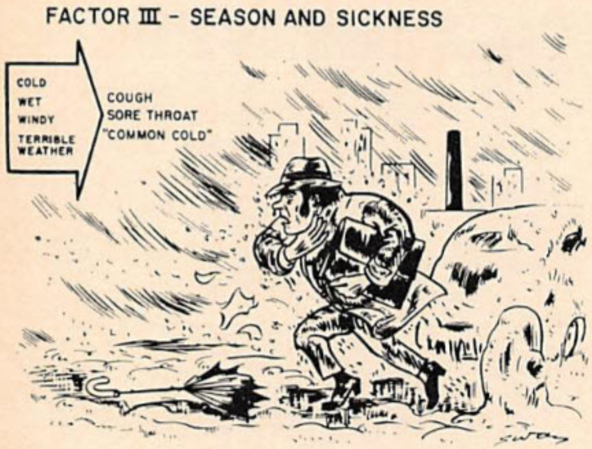
Factor IV.—The "Low Air Pollution" factor has negative weights of the pollutants and appropriate medium loadings of the meteorologic variables but high positive loading of barometric pressure maximums and averages for the day.

Factor V.—The "Oxidant-Symptom" factor, associated with pollutants such as oxidants and organic acids occurs in warmer weather and with stable barometric pressures. The factors are pictorially represented in Fig 1.

By going further into what each of these factors represents, one can delineate and explain some of the interactions that may occur between pollutants and meteorologic conditions and between symptoms and total environmental factors. For example, Factor I shows "common cold" and high air pollution associated with inversion conditions, low and decreasing wnd, low and decreasing rad, rapid increase in tmp and rlh, increasingly large amount of sky cover, and low bp with an increase in its maximum hourly change. Factor II represents the complex characterizing the beginning of an increase in air pollution: wnd already low but falling, minimal precipitation, medium high rad and tmp, medium low rlh and sky cover, and a stable but high bp associated with a lack of symptoms.

Factor III represents periods of winter weather and low air pollution with increasing rain or snow, rlh and sky cover and decreasing rad, and an increasingly high bp. Factor III and Factor V are primarily symptom-connected, and Factor I also shows this connection. The relationships between the symptoms and the environmental variables in Factor I, Factor III, and Factor V are seen displayed in Table 5. In this table, the variables within the Factors are separated out so that the associations can be better seen. The symptoms that contributed heavily to these factors are displayed across the top of the table (eye irritation, headache, sore throat—"common cold" and cough, sore throat, "common cold"). Listed down the sides are the environmental variables which contributed heavily to the Factors.

The numbers in the body of the table indicate the relative weights of the environmental variables in the Factor to which the



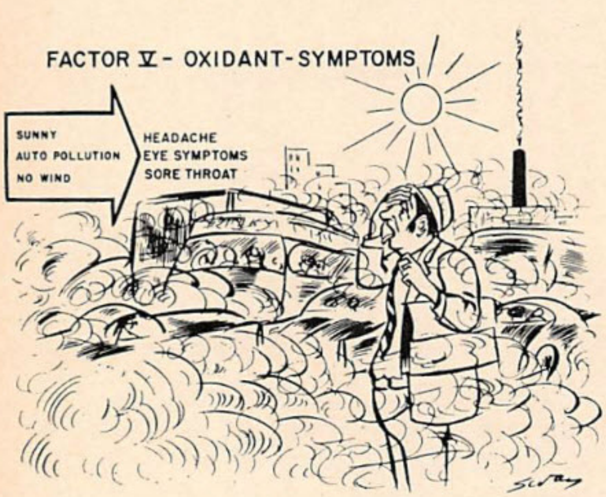


Fig 2.—Sore throat found in two different factors.

symptom variables on the top of the table contributed heavily. Thus, for example, Factor V, which had high loading of eye irritation-headache, also had high loadings of organic acid, total oxident, high tmp and bp.

From the table, it will be seen that sore throat and "common cold" appear in two different Factors. Where this occurred, the reported symptom was the same, but the environmental contributions were distinctly different. Thus, sore throat appears, together with eye irritation and headache, associated with elevated levels of organic acid, total oxident, as well as high tmp and stable bp (Factor V), a series of phenomena usually associated with summer inversion conditions. But sore throat also contributes heavily to Factor III in which is also found cough and the "common cold" as well as the environmental variables primarily present in the cold winter. The symptom "common cold" is also shared by two Factors: Factor III, the "Season and Sickness" Factor just mentioned, which relates high incidences and prevalences of cold, sore throat, and cough to bad winter weather, but also Factor I, the "High Air Pollution" Factor, where the symptom "common cold" is associated with inversion, stable bp, higher tmp, and virtually all the pollutants.

The findings that there are "two" "sore throats" and "two" "common colds" occurring in different environments and times is very important.

The results indicate that if symptoms were to be compared to pollutants or environmental conditions in a simple correlative manner, the relationship might be hidden, or by somewhat different use of pollutant or illness information, unexplained discrepancies might appear.

Comment

The search for an understanding of the effects of air pollution has been frustrating. The acute air pollution disasters yielded clear-cut evidence of an effect of air pollution on health, but the very rarity of these occurrences as well as the number of simultaneously occurring events has prevented the discovery of what substance or substances in the atmosphere produced the effect. The epidemiology of chronic obstructive pulmonary disease, as well as pulmonary function studies in adults[17] and children,[6] have clearly shown a relationship between the environment (including weather and air pollution) and some measure of the health of the study individuals. Here too, however, it has not been possible to single out one pollutant whose effect would account for the effects of the whole.

Laboratory investigations employing individual pollutants have consistently shown effects of the pollutants but have required levels far above those found in the urban atmosphere. In recent years, the studies of Amdur and her group[18,19] have suggested a synergistic effect between particle and gas in the production of increased airway resistance in animals. Epidemiologic evidence has also been mustered to show that for an effect of air pollution to be manifest, a combination of gaseous pollution, particulate matter, and certain weather conditions must be present.[20] These lines of evidence seem continually to suggest that the effects on health result from "air pollution" rather than air pollutants; that the "whole is greater than the sum of its parts" in the production of adverse health effects. The mechanisms, however, continue to remain obscure.

The analyses reported in this paper are part of a continuing effort to understand the nature of the effect. In an early section, a correlation matrix appeared to demonstrate the relationship between certain selected symptoms in a normal population and several meteorologic and pollution variables. Using this method of analysis, however, does not show any overwhelming association of the symptoms with any one pollutant; neither does it clarify the nature of the interdependencies or interrelationships. Previous papers from this group have demonstrated apparent relationships of symptoms in normal individuals to various pollutants and environmental factors, but they too have not clarified the interrelationships nor explained the inconsistencies present in our findings and the findings of others.

The principal components analysis which was next used, provided the derivation of "Factors" which served as multivariate indices of illness and environmental conditions. The five Factors derived appeared to perform the necessary task of providing the major dimensions of the problem of health effects and environment within the data. They show the relationships among the environmental variables and between these variables and symptomatology. More clearly than other methods thus far used by us or others, they show that the limited symptom response potential of the urban human is called upon by more than one and sometimes opposite sets of environmental factors. For example, sore throat occurs in both reducing and oxidizing atmospheres and at different times of the year. Should this be so, it is much clearer why inconsistencies have been found in the past and why it has been difficult, if not impossible, to show anything approaching a one-to-one relationship between environmental factors and health (Fig 2 and 3).

More and more it would appear that we will never obtain a simple one sentence un-

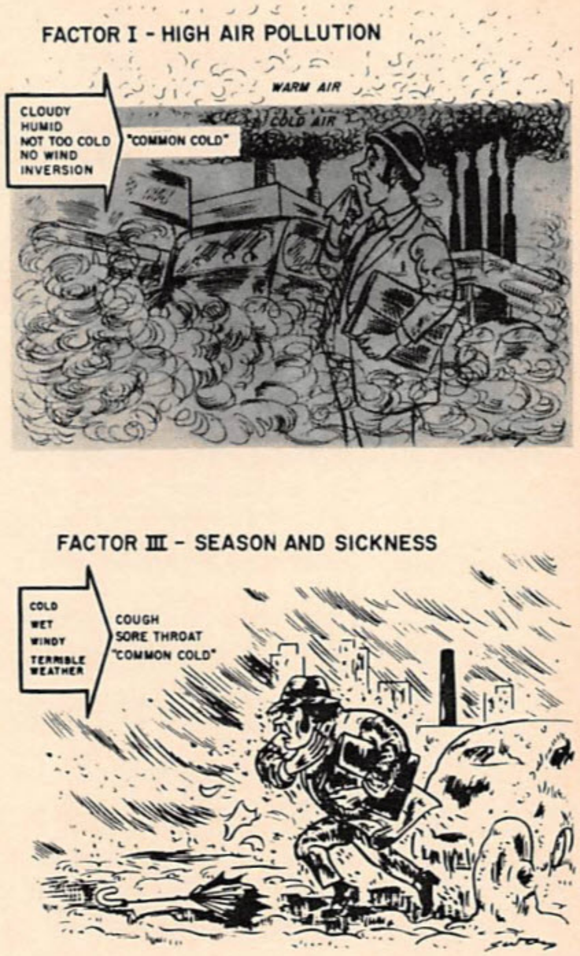


Fig 3.—Common cold found in two different factors.

derstanding of these complex relationships, and thus, more and more does it seem that apparent inconsistencies in results may not be inconsistent but a measure of our ignorance.

In the face of multifactor problems such as this, the difficulties of epidemiology become more pronounced. We use a method of data collection to produce the data. We then use a statistical method to attempt to show associations within the data, and finally, use our knowledge of the data-producing method, the statistical method, and our own experience with reality to evaluate the results. The inaccuracies and pitfalls in the steps are evident. It is clear that in problems such as these, we are in a primitive stage of knowledge.

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FAME, FORTUNE, OR HUMANISM

The physician's image is so traditionally involved with care and concern for a patient that the individual student will have been imbued with this ideal long before he enters medical school. However, the very nature of scholastic preparation may deprive young men and women entering into medicine of many opportunities for involvement with human relationships. Learning disciplines, particularly the basic sciences when taught in an atmosphere of intense competition, may isolate and dehumanize. Simultaneously, the student or trainee's awareness of the long road ahead with its great financial burdens and economic sacrifices may foster a restless striving toward mundane goals. Financial security, "success," and relief from deprivation and tension can insinuate themselves as objectives even before care and concern for patients. Ultimately, he may perceive the practicing physician from the viewpoint of his property and prestige rather than the service that he renders. These goals merge with the popular and traditional image of the physician to become a hazy montage of strivings for academic, monetary, and status gains superimposed upon and almost obscuring humanitarian expression.—Bressler, V.A.: Reflections on Medical Education in the Community Hospital, 1955-1965, *Ann Intern Med* **67**:443-449 (Aug) 1967.