

# MULTILEVEL MODELING

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*I should venture to assert that the most pervasive fallacy of philosophic thinking goes back to neglect of context.*

John Dewey, 1931

## 1. THE NEED FOR MULTILEVEL MODELING

When one considers almost any phenomenon of interest to social and health scientists, it is hard to overestimate the importance of context. For example, we know that the likelihood of developing depression is influenced by social and environmental stressors. The psychoactive effects of drugs can vary based on the social frame of the user. Early childhood development is strongly influenced by a whole host of environmental conditions: diet, amount of stimulation in the environment, presence of environmental pollutants, quality of relationship with mother, and so on. The probability of teenagers engaging in risky behavior is related to being involved in structured activities with adult involvement. A child's educational achievement is strongly affected by classroom, school, and school system characteristics.

These examples can be extended to situations beyond where individuals are being influenced by their contexts. The likelihood of couples avoiding divorce is strongly related to certain types of religious and cultural backgrounds. Group decision-making processes can be influenced by organizational climate. Hospital profitability is strongly affected by reimbursement policies set by parent HMOs.

What all of these examples have in common is that characteristics or processes occurring at a higher level of analysis are influencing characteristics or processes at a lower level. Constructs are defined at different levels, and the hypothesized relations between these constructs operate across different levels. These types of "multilevel" theoretical constructs

require specialized analytic tools to properly evaluate. These multilevel tools are the subject of this book.

Despite the importance of context, throughout much of the history of the health and social sciences, investigators have tended to use analytic tools that could not handle these types of multilevel data and theories. In earlier years, this was due to the lack of such tools. However, even after the advent of more sophisticated multilevel modeling approaches, practitioners have continued to use more simplistic single-level techniques.

Why has this been the case? A number of epistemological traditions have shaped this behavior. First is the long reach of the positivist tradition. Even many years after philosophers of science have established the inadequacy of logical positivism as a framework for the biological, health, and social sciences, we still tend to emphasize research designs and analytic tools that trace their roots back to a positivist stance. For example, the emphasis on control over experimental and observational conditions, the reliance on control and comparison groups, and the use of modeling techniques that statistically “remove” or control for the effects of covariates all combine to provide a lot of precision over inferences. However, at the same time, they severely restrict the ability to measure or evaluate extra-individual, contextual effects.

Another aspect of positivism is that it is most effective at describing sciences that deal predominately with closed systems. The behavior of closed systems, such as the movement of planetary bodies, can be predicted based on knowledge of only a few variables, such as mass and velocity. The social and health sciences, on the other hand, deal with much more complex open systems (Bhaskar, 1989). With open systems, by definition, it is impossible to control, restrict, or remove the effects of outside contextual influences. Thus, it becomes important to be able to adequately measure and analyze those effects, using appropriate multilevel methods.

A second example is how the medical model has shaped much of our research. The medical model takes a reductionist view of health: Disease is seen simply as a defect in the person that is corrected by medical intervention. We can see how this plays out, for example, in how modern epidemiologists identify risk factors for disease. Epidemiology has constructed a number of powerful design approaches (e.g., case-control studies) and analytic tools (e.g., logistic regression that produces relative risk estimates) that are used to identify significant risk factors for development of, say, cardio-vascular disease. Important risk factors for CVD include genetic

predisposition; biology (high blood pressure); behavior (smoking, exercise); culture (ethnicity); and environment (access to health care). However, even though these factors clearly are operating at different levels, they are almost always measured at the individual-level (through surveys, for example), and little attention is paid to the mechanisms by which these factors operate. For example, is lack of exercise an individual issue of personal choice, or is it an ecological issue of lack of access to opportunities for physical activity in the immediate neighborhood?

Despite what the above critique suggests, there has been increasing interest and activity in promoting a more multilevel approach in the behavioral, health, and social sciences. One very prominent example is the 2000 report issued by the National Institutes of Health (NIH), entitled *Toward Higher Levels of Analysis: Progress and Promise in Research on Social and Cultural Dimensions of Health* (Office of Behavioral and Social Sciences Research, 2000). This report presented a new agenda for NIH research focusing on two goals: (a) expanding health-related social sciences research at NIH, and (b) integrating social science research into interdisciplinary, multilevel studies of health. For the purposes of this monograph, the most relevant recommendation of the report was to:

... support the development of state-of-the-art social science methods. Challenges include measurement at the group, network, neighborhood, and community levels; the further development of methods for longitudinal research; multi-level research designs that integrate diverse qualitative and quantitative approaches ...; and the development of improved methods for data collection and analysis. (p. 3)

Table 1.1 presents a conceptual framework based on the NIH report for understanding the interdependence among levels of analysis, here with an example from the area of tobacco control. Research programs on tobacco control exist at all levels of analysis, from the genetic up to the socio-cultural and political. Moreover, although research can occur strictly within any of these levels, much of the most important research will look at the links between the levels. For example, as we learn more about the genetic basis of nicotine dependence, we may be able to tailor specific preventive interventions to particular genotypes.

We can see the interdependent and hierarchical nature of these multilevel influences on health more clearly from another national initiative: the 2003

TABLE 1.1  
Levels of Analysis in Health Research  
With Examples From Tobacco Control

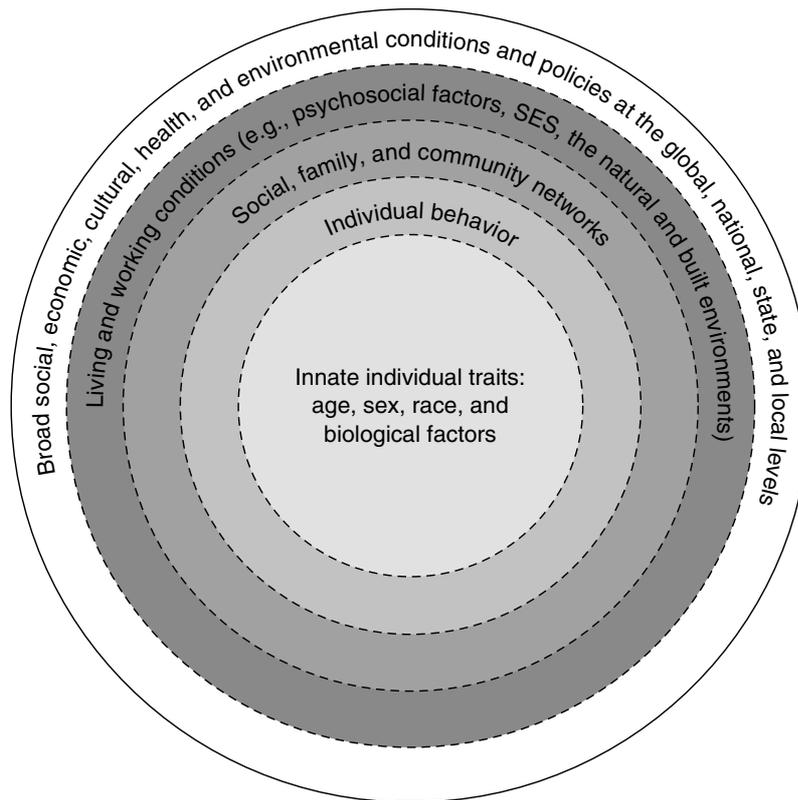
<i>Level of Analysis</i>	<i>Example From Research Programs in Tobacco Control</i>
Cultural/political	Measuring elasticity of the effect of cigarette taxation on population smoking rates
Social/environmental	Measuring the relative importance of family and peer environment on teen smoking incidence
Behavioral/psychological	Designing effective smoking prevention and cessation programs
Organ systems	Designing ways to block tumor formation in smokers
Cellular	Tracing metabolic pathways of nicotine uptake
Molecular/genetic	Examining the genetic basis of nicotine dependence

Institute of Medicine report on the future of public health. Figure 1.1, based on Figure S-1 from Gebbie, Rosenstock, and Hernandez (2003), shows an ecological model of the determinants of health. The IOM report emphasizes that public health professionals, including health researchers, must understand and utilize just such an ecological approach if they are to be successful at improving the nation's health in the future.

### **Theoretical Reasons for Multilevel Models**

The simplest argument, then, for multilevel modeling techniques is this: Because so much of what we study is multilevel in nature, we should use theories and analytic techniques that are also multilevel. If we do not do this, we can run into serious problems.

For example, it is very common to collect and analyze health and behavioral data at the aggregate level. Epidemiologic studies, for example, have shown that in countries where fat is a larger component of the diet, the death rate from breast cancer is also higher (Carroll, 1975). It might seem



**Figure 1.1** A Guide to Thinking About the Multilevel Determinants of Health

Source: Adapted from Gebbie, Rosenstock, and Hernandez (2003).

reasonable to then assume that women who eat a lot of fat would be more likely to get breast cancer. However, this interpretation is an example of the *ecological fallacy*, where relationships observed in groups are assumed to hold for individuals (Freedman, 1999). Recent health studies, in fact, have suggested that the link between fat intake and breast cancer is not very strong at the individual level (Holmes et al., 1999).

This type of problem can also work the other way. It is very common in the behavioral sciences to collect data from individuals and then aggregate the data to gain insight into the groups to which those individuals belong.

This can lead to the *atomistic fallacy*, where inferences about groups are incorrectly drawn from individual-level information (Hox, 2002). It is possible to be successful assessing ecological characteristics from individual-level data; for example, see Moos's work on social climates (Moos, 1996). However, as Shinn and Rapkin (2000) have convincingly argued, this approach is fraught with danger, and a much more valid approach is to assess group and ecological characteristics using group-level measures and analytic tools.

It is useful here to consider the sociological distinction between properties of *collectives* and *members* (Lazarsfeld and Menzel, 1969). Members belong to collectives, but various properties (variables) of both collectives and their members may be measured and analyzed at the same time. Lazarsfeld and Menzel identify analytical, structural, and global properties of collectives. *Analytical* properties are obtained by aggregating information from the individual members of the collective (e.g., proportion of Hispanics in a city). *Structural* properties are based on the relational characteristics of collective members (e.g., friendship density in a classroom). Finally, *global* properties are characteristics of the collective itself that are not based on the properties of the individual members (O'Brien, 2000). Presence of an anti-smoking policy in a school would be a global property of the school, for example.

Using this framework, it becomes clear that fallacies are a problem of *inference*, not of *measurement*. That is, it is perfectly admissible to characterize a higher-level collective using information obtained from lower-level members. The types of fallacies described above come about when relationships discovered at one particular level are inappropriately assumed to occur in the same fashion at some other (higher or lower) level.

### **Statistical Reasons for Multilevel Models**

When confronted with these very difficult conceptual problems, social scientists have tended to utilize traditional individual-level statistical tools for their data, even if their data and hypotheses are multilevel in nature. One approach has been to disaggregate group-level information to the individual level so that all predictors in a multiple regression model are tied to the individual unit of analysis. This leads to at least two problems. First, all of the un-modeled contextual information ends up pooled into the single

individual error term of the model (Duncan, Jones, & Moon, 1998). This is problematic because individuals belonging to the same context will presumably have correlated errors, which violates one of the basic assumptions of multiple regression. The second problem is that by ignoring context, the model assumes that the regression coefficients apply equally to all contexts, “thus propagating the notion that processes work out in the same way in different contexts” (Duncan et al., 1998, p. 98).

One partial solution to these statistical problems is to include an effect in the model that corresponds to the grouping of the individuals. This leads to an ANOVA or ANCOVA approach to modeling. Unfortunately, there are still a number of issues with this approach. First, in the case where there are many groups, these models will have many more parameters, resulting in greatly reduced power and parsimony. Second, these group parameters are often treated as fixed effects, which ignores the random variability associated with group-level characteristics. Finally, ANOVA methods are not very flexible in handling missing data or greatly unbalanced designs.

### **Scope of Book**

Based on the previous discussion, the purpose of this monograph is to provide a relatively non-technical introduction to multilevel modeling statistical techniques for social and health scientists. After this introduction, the book is split into two major sections. Chapter 2 introduces the two-level multilevel model and describes the steps in fitting a multilevel model, including data preparation, model estimation, model interpretation, hypothesis testing, testing of model assumptions, and centering. Chapter 3 covers useful extensions to the basic multilevel model including modeling non-continuous and non-normal dependent variables, using multilevel models with longitudinal data, and building three-level models. The presentation of these topics only assumes familiarity with multiple regression, and the text makes extensive use of example data and analyses. (All of the data, programs, and output are available from the author—see Appendix.) All of the statistical analyses were performed using HLM Version 5.04 (Raudenbush, Bryk, Cheong, & Congdon, 2000) and the *nlme* Version 3.1 mixed-effects library in R (Pinheiro, Bates, DebRoy, & Sarkar, 2003); all graphics were produced using R Version 1.7.1.

A useful definition to serve as a basis for the rest of the presentation is as follows: A multilevel model is a statistical model applied to data

TABLE 1.2  
Types of Multilevel Models and Structures  
Found in the Health and Social Sciences

<i>Type of Multilevel Model</i>	<i>Multilevel Structure</i>	<i>Examples</i>
Physical	Entities nested within the immediate physical environment, including the biological, ecological, and physically built environments	Diez-Roux et al. (2001) Perkins et al. (1993)
Social	Entities nested within social structures, including families, peer groups, and other types of social networks	Buka et al. (2003) Rice et al. (1998)
Organizational	Individuals and small groups nested within specific organizational contexts. Important organizational characteristics include size, management structure, communication aspects, organizational goals, and so on	Maes and Lievens (2003) Villemez and Bridges (1988)
Political/cultural	Individuals or groups of individuals nested within specific sociopolitical, cultural, or historical contexts	Lochner et al. (2001) Luke and Krauss (2004)
Temporal	Multiple observations of a single entity taken over time	Boyle and Willms (2001) Curran, Stice, and Chassin (1997)
Analytic	Multiple-effect measures nested within individual studies (i.e., meta-analysis)	Goldstein et al. (2000) Raudenbush and Bryk (1985)

collected at more than one level in order to elucidate relationships at more than one level. The statistical basis for multilevel modeling has been developed over the past several decades from a number of different disciplines, and has been called various things, including hierarchical linear models