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CHAPTER 2

Aging, Health, and the Environment: An Ecological Model

INTRODUCTION

Research in the epidemiology of aging addresses a variety of topics that are related to health, functioning, and longevity. Leading areas of research include the study of the effects of age and aging on survival and mortality; physical functioning and activities of everyday life; cognitive functioning; depression and other psychosocial disorders; falls and injuries; and, of course, disease and comorbidities. In each case, the central question is to what extent and for what reasons are some people and, indeed, some populations, able to do well as they age, while others are not. Moreover, there is a strong interest in learning how these age-associated patterns of health, functioning, and longevity are affected by differences in geography or place, gender, race, ethnicity, and socioeconomic status.

Epidemiological research in aging has drawn from a wide range of scientific disciplines, including the biologic, behavioral, social, and environmental health sciences. In this chapter, an *ecological model* is proposed as a comprehensive framework to summarize the diversity of that research and to provide a sense of the "big picture." Aging represents a complex blending of physiological, behavioral, social, and environmental changes that occur at both the level of the individual and at the level of the wider community. An ecological model, we believe, is ideally suited to describe and explain that complex blend.

The ecological model has a long history in the biologic, behavioral, social, and health sciences (Bronfenbrenner, 1979; McLeroy, Bibeau, Steckler, & Glanz, 1988; Sallis & Owen, 1997; Green & Kreuter, 2004). Depending on the time and discipline, the model has taken different forms. Some forms of the model highlight the connections among biologic, behavioral, and social factors, while other forms emphasize the significance of the social and physical environments—the "context." Elements of the model are reminiscent of the components of "agent," "host," and "environment" that make up the traditional epidemiological perspective. It is important to note that the word "ecological" also has been used in epidemiology to characterize a largely descriptive approach to population health that is based on associations between, on the one hand, a summary measure of the population such as per capital consumption of high-fat foods, and, on the other hand, the incidence or mortality rate of some health outcome, such as colorectal cancer (Morgenstern, 1998). This approach often has been used for international comparisons and, more importantly, as a way of generating hypotheses that are then tested directly in case-control or prospective studies of individual consumption patterns and disease outcomes among people in that population. In some cases, such "aggregate" or group-level associations found in the population have been used incorrectly as evidence that specific individuals in those populations who consume high-fat diets are themselves at elevated risk for colorectal cancer. This, of course, is an example of the "ecologic fallacy"—falsely generalizing from associations found at the level of the population to associations found at the level of the individual. It is fair to say that the prospect of committing this fallacy has discouraged and even intimidated some researchers from conducting systematic investigations of population health—a point to which we will return in later chapters.

THE ECOLOGICAL MODEL—AN OVERVIEW

Today, there is a renewed interest in the utility of an ecological approach in public health and epidemiology. Recent position statements by leading scientific bodies, including the National Institutes of Health, the National Academy of Sciences, and the Institute of Medicine, are based on the ecological model as a framework to characterize and to encourage multidisciplinary work in the health sciences. The Ottawa Charter on Health Promotion also uses the ecological model as a foundation for its recommendations (www.euro.who.int/AboutWHO/Policy/20010827_2). Although there are different versions of the ecological model, the version included in *Healthy People 2010*, a government document that outlines the U.S. public health agenda for the first part of the this century, includes the key elements of the ecological model, as shown in Figure 2–1 (U.S. Department of Health and Human Services, 2000a).

An ecological model is based on the assumption that patterns of health and well-being are affected by a dynamic interplay among biologic, behavioral, and environmental factors, an interplay that unfolds throughout the life course of individuals, families, and communities (Smedley & Syme, 2000). This model also assumes that age, gender, race, ethnicity, and socioeconomic differences shape the context in which individuals function, and therefore directly and indirectly influence health risks and resources. In addition, the ecological model serves to identify multiple points of possible intervention in public health, from the microbiologic to the environmental levels, to postpone the risks of disease, disability, and death; and enhance the chances for health, mobility, and longevity. The metaphor of the "Chinese box" (boxes within boxes) has been used by some researchers to capture the multilevel, integrated quality of the ecological model (Susser & Susser, 1996, p. 676): "The outer box may be thought of as representing the overall physical environment which, in turn, contains societies and populations (the epidemiological terrain), single individuals, and individual physiological systems, tissues, and cells, and finally (in biology) molecules." Whether referred to as "eco-epidemiology," "social

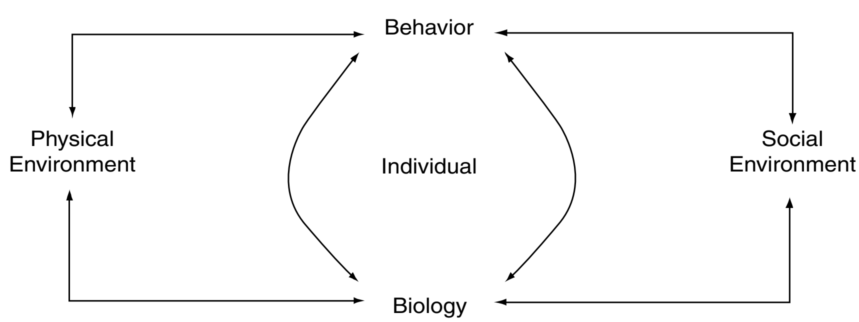


FIGURE 2–1 Ecological Model. Determinants of Health (Detail). (From U.S. Department of Health and Human Services.

ecological," or "ecosocial," in each case, the value of viewing epidemiology and public health in a broader historical, social, economic, political, and environmental context is underscored (Susser & Susser, 1996; Stokols, 1992; Krieger, 2001).

An ecological model has been used to describe and explain the effects of multilevel factors on both the causes (or etiology) of health conditions as well as on the consequences (or course) of those conditions. Later, we will examine the age-associated causes of major health conditions, such as cardiovascular disease, cancer, diabetes, Alzheimer's disease, and osteoarthritis. We will also examine the extent to which the course of those conditions contributes to patterns of health, functioning, and longevity. The likelihood of disability among people and populations has received special attention and has been explained as a multilevel process—"the disablement process." The process, as described originally by Verbrugge and Jette (1994), is initiated by a pathology with an associated level of physiological or cognitive impairment that may lead, in turn, to functional limitations and, ultimately, to a disability (Figure 2–2). The transition from pathology to disability, especially from functional limitations to disability, depends on the intersections of the individual's capacity and behaviors, as well as the relative resources and demands of the social and physical environments. Functional limitations are defined as restrictions or difficulty in the performance of generic tasks that typically involve upper- and lower-body strength, balance, fine dexterity, and walking speed. Disability, on the

Pathology	**Impairment**	**Functional Limitation**	**Disability**
Disease, injury, congenital developmental condition	Dysfunction and structural abnormalities in specific body systems musculoskeletal, cardiovascular, etc.)	Restrictions in basic physical and mental actions (ambulate, reach, grasp, climb stairs, speak, see standard print)	Difficulty doing activities of daily life (personal care, household management, job, hobbies)
Example			
Denervated muscle in arm due to trauma	Atrophy muscle	Cannot pull with arm	Change of job; can no longer swim recreationally

Note. From "The Disablement Process," by L. Verbugge and A. M. Jette, 1994, Social Science & Medicien, 38(1), pp. 1–14. Adapted with permission.

FIGURE 2–2 The Disablement Model

other hand, refers to the inability to perform specific social roles in everyday life because of health or physical problems.

The Verbrugge–Jette Disablement Model (1994) has served as an important frame of reference for research in the epidemiology of aging and disability. In fact, a recent Cooper Conference in Dallas, Texas, used the model as the basis and foundation for a symposium on the significance of physical activity as a strategy to prevent physical disablement in older adults (Rejeski, Brawley, & Haskell, 2003). While the model continues to play a critical role in facilitating research in this area, suggestions for revision have been made. For example, Anita Stewart (2003) has recommended that the model be expanded to include physiologic aging and disuse, in addition to the current focus on disease pathology, as primary engines of disablement. This is based on the observation, to be discussed in more detail in Chapter 4, that functional limitations and disabilities are not only found among older people with frank disease pathology. She also recommends that assessments of functioning be expanded and not defined negatively, as is the case with "impairments" and "limitations." Recommendations of this kind are leading to a more comprehensive assessment of aging, health, and functioning.

In addition to the study of the causes and consequences of disease, the ecological model has been used to study the process of aging itself. By far the clearest connection between epidemiology and gerontology is found in the work of M. Powell Lawton and his colleagues in what has come to be defined as the "general ecological model of aging" (Lawton, 1986; Nahemow, 2000). However, unlike the model in epidemiology, which is focused on a variety of health and functional outcomes, the work of Lawton and colleagues focuses exclusively on behavior and well-being. The primary thesis is that human behavior and function result from the competencies of the individual, the demands or "press" of the environment, and the interaction or adaptation of the person to the environment. Moreover, the relationship between individual competency and the environment is viewed as a dynamic process; both the press of environments and levels of individual competencies change as part of the process of aging. This interaction is summarized in terms of the "Press-Competence Model" (see Figure 2–3)

Competence lies on a continuum from low to high along the vertical axis, while environmental press goes from weak to strong, along the horizontal axis. The line moving from low to high on both axes represents

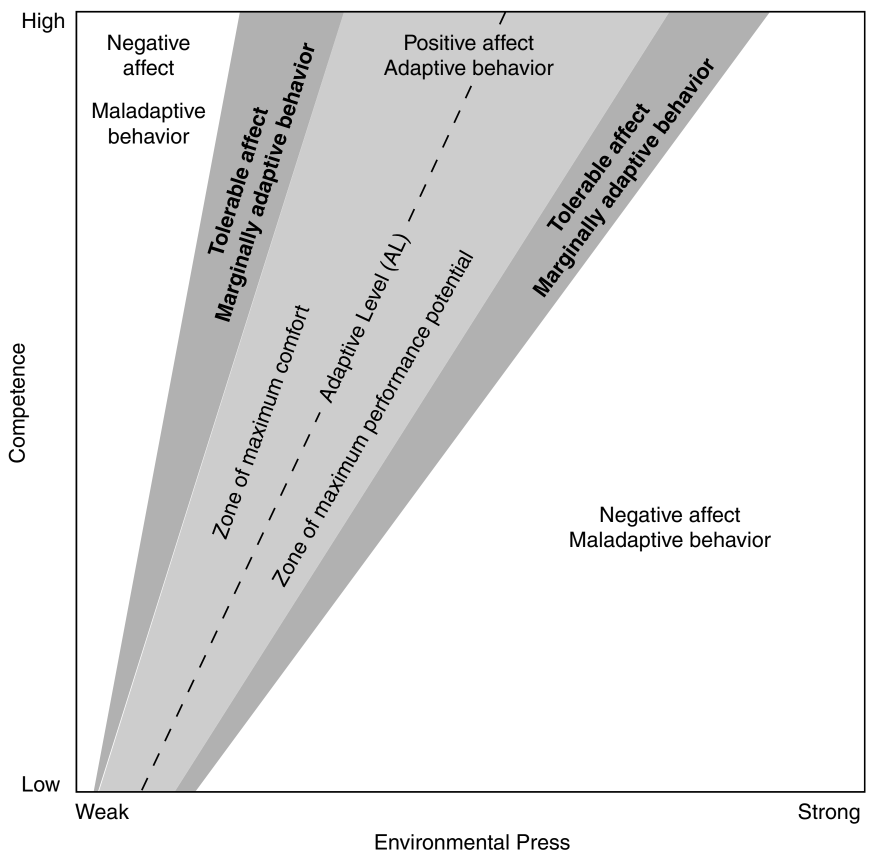


FIGURE 2–3 Lawton and Nahemow's Press-Competence Model

adaptation, the theoretical point at which the level of environmental press matches the level of individual competence. With aging, there is a general, although highly variable, reduction in individual competence. If environmental press remains constant, individual behavior and function is adversely affected. To the right of the line is the "zone of maximum performance," which is characterized by high press, challenges and stimulation. This zone encourages active behavior by eliciting motivating responses. To the right of this zone is a marginal zone, where individuals continue to function, but with some difficultly. Falls, stress, and other indicators of maladaptive behavior start to occur here. To the right of the marginal zone is the zone of negative affect and maladaptive behavior, where the individual can no longer maintain an acceptable degree of functioning. This is the point at which the demands of the environment exceed the individual's ability to meet those demands. According to Verbrugge and Jette (1994), this is the point of disablement. On the other hand, to the left of adaptation line is the zone of maximal comfort, an area characterized by weak environmental press and a general relaxation from environmental demands. To the left of that zone is another marginal zone, in which the absence of environmental stimulation begins to lead to boredom. Finally, the final zone is the zone of negative affect and maladaptive behavior. In this case, the environment is so unchallenging that it contributes to functional passivity, disuse, and limitation. This, in turn, perhaps may lead to a sense of "helplessness" (Seligman, 1975).

Lawton also distinguished between environmental docility and environmental proactivity (Lawton 1989, 1990). Environmental docility refers to those situations in which personal competence declines and behavior is increasingly affected by characteristics of the environment. In contrast, environmental proactivity describes situations in which an increase in personal competence enhances a person's ability to make use of environmental resources and achieve a more positive outcome.

Proposals have been made to enhance the utility of Lawton's person-environment fit model for research in epidemiology and public health (Glass & Balfour, 2003). While acknowledging the strengths of this model, Glass and Balfour report that the person-environment fit model rarely has been used to assess physical health. They note that "environmental press" has proven to be difficult to operationalize in epidemiologic research, especially regarding the identification of hypothesized pathways between neighborhood characteristics and health outcomes. Second, they indicate that little attention has been given to how person-environment fit is affected over time. Third, and perhaps most significantly, Glass and Balfour argue that the model underestimates the inverse of environmental press, that is, features that are conductive to functioning and that may lead to the "buoying" of behavioral competence. This is an important observation. It underscores the point that successful adaptation is not simply due to the absence of barriers, as is stated in the preamble to the constitution of the World Health Organization, that health is not merely the absence of disease or infirmity, but rather "complete physical, mental and social well-being." In this case, environmental buoying is associated with environmental flexibility, as well as prostheses, resource availability, enrichment, and social support. Environmental buoying and press are placed in a broader context that affects person-environment fit and, in turn, affects the likelihood of personal competence, level of adaptive or maladaptive responses, and ultimately health and functional outcomes.

One of the dilemmas of the person-environment model, as noted by Benyamin Schwartz (2003, p. 14) in a recent review of Powell's work, is the nature of the interrelationship between the individual and the environment:

> The interactional approach to the relationships between older persons' behavior and the environment introduced the subject–object problem into the philosophical foundation of environment aging studies. This dualistic concept of the individual allowed two simultaneous but mutually exclusive interpretations under which the theories of environmental gerontology would be developed. At the same time it created a fundamental problem: On the one hand, the older individual is perceived as one of the "elderly," whose actions and behavior are determined by the external forces of the environment; on the other hand, the individual is seen as a freely thinking, freely acting subject whose actions and behavior are determined by his or her own personal inner drives and desires. The problems that emerge from this duality revolve around two issues: Is the individual's behavior determined by conditions in his or her environment, or in his or her own internal wiring? And how can the environment and the person interactively shape each other?

The relationship between the individual and the larger social and physical environments, which is one of the central questions in sociology and social philosophy, is a key component of the ecological model. Increasingly, commentators see the distinction between the individual and the larger environment as a false dichotomy. Anthony Giddens, a leading British sociologist (1984, p. 139), for one, opposes this conceptual distinction between the individual and social–physical environment, or what he refers to as "micro- or sociological" and "macro-sociological" study, noting that "The two are not infrequently set off against one another, with the implication that we have to choose between them, regarding one is in some way more fundamental than the other." Rather than a dualism, in Gidden's view, the individual and the broader social and physical structure are, by definition, interrelated. It is not possible to understand one without a consideration of the other. Put differently, the interaction is both constraining and enhancing. For example, interaction among individuals takes place in a particular setting or place at a particular point in time. The interaction, of course, is prescribed or constrained by societal and cultural patterns of behavior—the context. While the interaction itself may serve to reinforce those societal and cultural prescriptions, it may be modified to adapt to new societal and environmental challenges. Of course, the opportunities to enhance or modify those patterns are affected as well by social and economic resources, such as summarized by positions of class, status, and power. In general, those with greater resources, such as those of higher socioeconomic status, have a greater range of choices and are in the best position to adapt to changing circumstances to affect change. In contrast, those of lower socioeconomic status have a more restricted range of choices and less opportunity to adapt or alter the course of events. It is important to emphasize, however, that even among the people with fewer options, choices are still available and choices are still made. Carol Ryff and colleagues (1999, p. 17) have addressed this issue with specific reference to aging and the significance of life events:

> The experiential substance of people's lives becomes a profitable context for joint focus on how life opportunities and life difficulties are distributed across the social order, and what their consequences are for individual functioning.

THE ECOLOGICAL MODEL—KEY COMPONENTS

In this section, we will address the central components of the ecological model that will serve as the framework for a consideration of the topics to follow. If the biologic, behavioral, social, and environmental nodes of this model enable us to see the scope of work in the epidemiology of aging, the connections among those nodes suggest the causal pathways that either have or should be examined. In this way, the model serves as both a typology of what has been done and as an agenda for what should be done in this field. This will be challenging. As Ana Diez-Roux (1998, p. 220) has written, "Perhaps the most challenging aspect of multilevel analysis is it requires a theory of causation that integrates micro- and macro-level variables and explains these relationships and interactions across levels." Accordingly, we will be begin by considering some key themes that set the stage for a theory of causation across these multilevel levels of biologic, behavioral, social, and environmental factors.

Theories of Aging as Explanations of "Weathering"

There are a number of major theories of aging (Carey, 2003). Each theory can be arrayed hierarchically from the molecular level, to the cellular, to the systematic, and, finally, to the evolutionary level. In general, a theory can be defined as a set of logically connected propositions designed to both describe and explain some phenomena. A theory serves to identify a set of important variables, to specify the relationship between those variables, and, most importantly, to provide an explanation or reason for the relationship among those variables.

Although the molecular, cellular, and systematic theories of aging address the aging process at different levels of biologic organization, a common theme is the proposition that the likelihood of an error or malfunction in processes increases with time. The site and etiology of the error differ depending on the scope or level of the theory. These errors or malfunctions, in turn, render the organism more susceptible to the onset of disease, disability, and death. The timing and extent of those age-related errors or malfunctions, followed later by an elevation in the risk of ill health and overall "weathering," seem to be due to the interplay of genetic and environmental factors throughout the life course.

Molecular theories of aging focus on the extent to which cellular function and integrity changes over time. Along these lines, the gene regulation theory is based on the proposition that genetic expression is diminished and structurally altered following reproductive maturity, resulting in a loss of genetic integrity. Other theories posit that accumulation of random molecular damage inhibits regular genetic expression. Important from our perspective, in some cases, these theories include the proposition that the accumulation of environmental damage is associated with age-associated errors and malfunctions.

One of the most well known cellular theories of aging is the free-radical theory or free-radical accumulation theory, which is based on a mechanistic link between aging and metabolism. Free or unstable oxygen molecules are a byproduct of metabolism. These unstable molecules, in turn, are a source of cellular damage in a number of different cell components, such as lipids, protein, carbohydrates, and nucleic acids. Of particular significance, especially for our purposes, is that the free-radical theory of aging is proposed as a generalized mechanism for aging, or as Carey (2003, p. 91) writes, "a 'public' mechanisms of aging—common mechanisms among diverse organisms that are conserved over the course of evolution." A related cellular theory is based on the proposition of finite cell life. It is hypothesized that there is a finite period of population doublings, known generically as The Hayflick Limit, after Leon Hayflick, the scientist who first proposed "replicative senescence." Current research is focusing on telomeres. Telomeres are located on the ends of chromosomes and are necessary for proper chromosomal function and replication. Following from this theory of aging, research indicates that there is a progressive loss in the length of the telomeres and, as a result, a progressive loss in the ability to transmit the full genetic complement across generations (Aviv, Levy, & Mangel, 2003). In addition, recent research indicates a connection between this cellular process and difficulties of everyday life (Epel et al., 2004). As summarized by Carey (2002, p. 92): "The simplest theory for accounting for the Hayflick Limit is one in which permanent cell-cycle arrest is due to a checkpoint mechanism that interprets a critically short telomere length as damaged DNA and causes cells to exit the cell cycle." Later, Carey writes (2003, p. 92): "Although telomere length has historically been used as a means to predict the future life of cells, a new model frames the connection between telomere shortening and cellular senescence by introducing the concept of a stochastic and increasing probability of switching to the uncapped/noncycling state."

System theories of aging are based on aging and the regulation and coordination of organ systems. One well-known theory is the immunological theory of aging, which is based on the competencies of mechanisms that operate before and after infection (innate and adaptive immunity), and is supported by evidence that indicates that immunological function declines with age.

Unlike these theories, the *evolutionary* theories of aging address the issue of the aging of the human species. Rather than focusing primarily on the weathering and ultimate destruction of the system, this theory examines to what extent aging confers an evolutionary advantage to the human species. Moreover, unlike other theories, evolutionary theories of aging provide a comprehensive underpinning for an ecological model of aging. For that reason, we will discuss the evolutionary theory of aging in more detail.

Evolutionary Theories of Aging

Why do humans age, or to put it differently, what is the evolutionary advantage of an aging population for the human species? Moreover, why do humans live so long after their reproductive capacity is gone—what some have referred to as the "menopause paradox"? Some have argued that there is an "aging gene," which manifests itself in one of two ways. First, it is claimed that aging is a genetically programmed means to limit population size and avoid overcrowding. Second, aging is an adaptive process to facilitate the turnover of generations, thus aiding in the adaptation of the species to a changing environment. In contrast, others, such as Thomas Kirkwood (1999), argue that these explanations run counter to one of the basic principles of evolution: Species are programmed to survive, not to die.

Kirkwood (1999) and others have proposed a Disposable Soma Theory. This theory assumes that aging is probably caused by the gradual and progressive accumulation of damage in the cells and tissues that comes from the need to react and adjust to a changing and demanding environment. Over time, the capacity to react to this changing environment becomes more difficult. With age, physiological systems need more resources and time to adjust to environmental demands. As Kirkwood writes (1999, p. 145):

> Natural selection did not design us to age, but it did design us to cope with all kinds of vicissitudes, such as illness, cold, and hunger. Many of the challenges that occur as a result of aging doubtless mimic other challenges that occur in younger individuals as a result of the sheer unpredictability of life. In time, the cumulative effects of aging test even the cleverest of homeostatic mechanism to the limit. That is why, as we age, we find that our adaptive response to physiologic stress declines.

With aging, the maintenance of the human body (soma) becomes more difficult. More metabolic resources are diverted from reproduction to somatic maintenance. As humans evolved and became more sophisticated, they were better able to control and manage environmental risks, especially within the context of social groups. As Kirkwood (1999, p. 68) writes, "Our ancestral species found that living in social groups made good sense because there was safety in numbers, especially if those around you were your kin, who would have a genetic interest in your survival."

The aging of the population helps to maintain the human species in other ways. While aging requires that increased resources be directed away from reproduction to somatic maintenance, that is not to say that older people fail to help maintain the species. Quite the contrary, for as a social species humans require extended time for nurturance and socialization. In terms of maintenance of the species, it is more appropriate for aging humans to spend time assisting in the nurturance of their children and grandchildren than it is for them, such as would be the case with aging women, to actually give birth to more children. In fact, some have argued that menopause makes evolutionary sense in that it protects aging women from the rigors of childbirth and makes them available to assist in the nurturance of developing children and grandchildren. Ronald Lee (2003) recently expanded on this idea by arguing that the need for "intergenerational transfers" not only explains the aging of people beyond their reproductive years but also explains relative survival across the life course and the reasons why juvenile mortality declines with age. More important, this evolutionary theory of aging explains why humans age and adjust to a changing environment within a social context. For our purposes, it suggests an *evolutionary explanation* for why age-associated patterns of health, functioning, and longevity in human populations result from multilevel connections across biologic, behavioral, social, and environmental factors over the life course.

Homeostasis, Allostasis, and Allostatic Load

Human aging can be described in terms of the maintenance of physiological balance (homeostasis) through an ongoing process of adaptation (allostasis) to changing, stressful environmental demands (Brunner, 2000). Allostasis was first introduced by Sterling and Eyer (1988, pp. 631–651) to explain why human survival requires that "an organism must vary parameters of its internal milieu and match them appropriately to environmental demands." The autonomic nervous system, the hypothalamic-pituitary-adrenal (HPA) axis, and the cardiovascular, metabolic, and immune systems protect the body by responding to internal and external stress. This is sometimes explained in terms of the "fight or flight" mechanism. When acute or chronic environmental threat persists, allostatic mechanisms become impaired, and a weathering process is initiated that is described as "allostatic load (AL)." This, of course, is particularly important to consider in the context of aging. Not only do older people experience an accumulation of environmental challenges and, in some cases, insults, they also experience declines in the capacity to meet those challenges. Allostatic load represents the cumulative biologic burden exacted on the body through attempts to adapt to life's demands (McEwen & Seeman, 1999; Seeman, Singer, Rowe, Horwitz, & McEwen, 1997; Seeman, McEwen, Rowe, &

Singer, 2001). Dysregulation in one or more of the biologic systems involved in allostatis is reflected in characterizations of the multiple pathways to pathophysiology and a diversity of chronic conditions. As Taylor and colleagues (1997) have noted, this process helps to explain how "an unhealthy environment gets under the skin."

Different analytical strategies have been used to calculate allostatic load scores for individuals. An initial operationalization of the notion of AL used assessments of 10 biologic parameters reflecting functioning of the hypothalmamic-pituitary-adrenal (HPA) axis, sympathetic nervous system, cardiovascular system, and metabolic processes. Dysregulation was defined in terms of scores in the upper quartiles. Overall severity of AL was based on the number of systems in which resting scores were recorded in the extreme quartiles. Higher scores on a summary numerical measure of allostatic load were shown to predict four major health outcomes: incident cardiovascular disease (CVD), decline in physical functioning, decline in cognitive functioning, and mortality. Although the summary measure of allostatic load was a significant predictor of outcomes, none of the individual components exhibited strong predictive capacity. This finding suggests that risk for the above outcomes is related to the overall impact of dysregulation across multiple regulatory systems. Later formulations, based on canonical weights, were based on the full range of scores and did not assume that the indicators of dysregulation were uniform across the different physiologic systems. The purpose of this analysis was to determine which linear combination of biomarkers was maximally correlated with which linear combination of functional change scores. The weights in the best linear combinations for predicting decline in physical and cognitive functioning were called canonical weights, which, in turn, served as the basis for a more comprehensive scoring scheme for allostatic load. It was determined that four primary mediators—epinephrine, norepinephrine, cortisol, and DHEA-S represented the most parsimonious set of prognostic indicators of allostatic load. Finally, the most sophisticated strategy to date for the measurement of allostatic load is based on a technique referred to as recursive partitioning (Zhang, Yu, & Singer, 2003). Based on a set of candidate independent variables and study outcomes, this technique systematically identifies the most parsimonious set of physiologic items as well as the best cut points for determination of severity. This strategy affords an opportunity to identify specific combinations and cut points of physiologic systems.

Despite the promise of research in this area, it is important to realize that this is a relatively new area of study and that criticisms have been raised. First, there are concerns that the measurements are based on resting levels and may not accurately reflect the actual allostastic process, a process that may be better reflected in a setting based on an environmental challenge. Second, there is concern that only a small number of indicators of dysregulation have been available for examination. Finally, the indicators used have been those that have been available in existing population studies, such as the MacArthur Study on Successful Aging (Seeman et al., 1997, 2001). As a result, it has not been possible to examine a full complement of possible biologic systems. It is recommended that future studies include immune measures that reflect general levels of proinflammatory activity in an individual.

One of the interesting questions is why some aging people have better allostatic capacity than others. There is evidence that genetic, familial factors may play a role. For example, there is a growing body of research stating genetic factors may be associated with extreme longevity (Perls, Kunkel, & Puca, 2002). It is reported that the life spans of human monozygotic twin pairs are statistically more similar to each other than life spans of dizygotic twins; the magnitude of this difference indicating that approximately one quarter to one third of what determines life span is genetic (Finch & Tanzi, 1997). Behavioral and social factors are important as well. Those who engage in healthful behaviors and those who maintain social bonds with others are less likely to exhibit dysregulation.

There is evidence that experiences in the early years affect allostatic competence in adulthood. For example, life history profiles were constructed using data from the Wisconsin Longitudinal Study (Singer & Ryff, 1999). Individual lives were represented by information from five domains:

1. Family background and early life experiences
2. Occupational experiences from first job through employment status at ages 59–60
3. Adult family life
4. Mental health, psychological outlooks, and beliefs in adulthood
5. Physical health in adulthood

Persons who had predominantly negative experiences in three of the first four domains were defined to have essentially negative profiles.

Persons who had very positive childhood experiences but who had negative experiences on at least two of the other domains were defined to have poor adult profiles subsequent to positive childhood profiles. The results indicate that there is a long-term protective effect from a positive childhood, even in the face of considerable adversity in adulthood. These results underscore the importance of the life course, another key component of the ecological model.

Research to date has been based on the availability of data in existing study populations. Recently, there has been a call for researchers to step back and consider the types of physiological data that should be used to provide a more definitive test of the allostatic load hypothesis.

Life Course

It follows logically that the interplay of biologic, behavioral, social, and environmental factors must occur over time. The important task is to determine how development at the individual level is affected by broad demographic factors, such as age, period, and cohort effects. Although this may seem at first glance to be a rather abstract notion, it is really the basis of most historical novels, novels in which the lives of individuals are played out against a historical background of social, political, and economic forces.

There are two bodies of research that underscore the importance of the life course in epidemiological studies (Kuh & Ben-Shlomo, 1999). The first body of research, based on the work of David Barker and his colleagues (Barker, Eriksson, Forsen, & Osmond, 2002), assumes that events surrounding critical periods of early development, most notably during gestation, affect the subsequent risk of chronic diseases. The second body of research assumes that the accumulation of exposures and "insults" over the life course affect later risk for disease. Although these two approaches are often presented as distinct, there is no apparent reason why the risk of disease in adulthood and the senior years cannot be due to both accumulated risk and exposures occurring at critical points of development. In fact, Neal Halfon and Miles Hochstein (2002, p. 433) argue that one of the key components of a life course perspective is recognition that "different health trajectories are the product of cumulative risk and protective factors and other influences that are programmed into biobehavioral regulatory systems during critical and sensitive periods."

Age differences in health outcomes may be the result of a variety of factors. A cross-sectional examination reflects in many ways, a simple snapshot of differences in health outcomes among people in different age groups. Because older people are survivors, the magnitude of the age difference may be less than would be found for an examination of a cohort of people across the life course. Accordingly, a longitudinal examination that compares a cohort of people as they age would provide a more precise estimate of age-related differences. It is important to emphasize that such age-related differences could not necessarily be attributed to factors associated with aging. The differences may reflect characteristics of specific cohorts of people, that is, generations of people "moving through time." T. Kue Young (1998, p. 180) provides a succinct description of derivation and significance of "cohort" in epidemiologic research:

> It comes from the Latin cohors, meaning "warriors." A Roman legion consisted of 10 cohorts, each with 300–600 soldiers. In epidemiology, cohort is initially used to refer to a birth cohort, a group of individuals born at the same time (usually the same year) whose health experience can be followed as the group ages.

Young (1998, p. 10) goes on to write that, "Cohort effect, also called generation effect, refers to the unique set of environmental conditions to which a particular generation or birth may have been exposed during some time its life span." This means that some of the age differences may be due to specific characteristics and events that affected a particular generation of older people at some point in their lives. Age differences also may be due to period effects, that is, extrinsic factors, such as environmental factors that were present in a particular calendar year, which affected people across the life course. Together, these factors are summarized as age, period, and cohort effects.

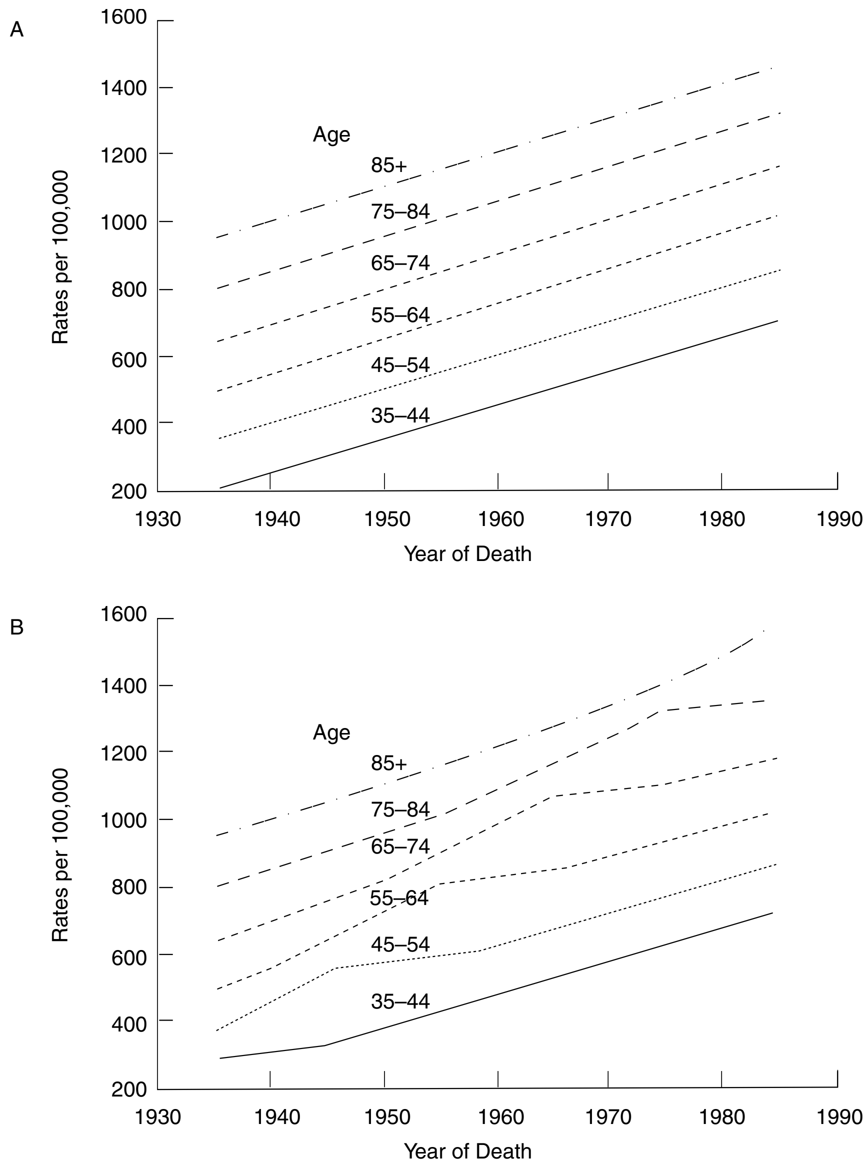
The circumstances of exposures and behaviors over the life course point to the importance of broad demographic factors occurring at the population level that affect the subsequent patterns of disease within populations. As noted previously, age, period, and cohort effects are three well-known demographic variables. Age, in this case, refers to the age distribution or composition of a population. A period effect, often represented by one or more calendar years, refers to an event, such as the Dutch famine—a time during the Nazi occupation of Holland in 1944 in which access to food was severely limited, in which the health of the population regardless of age was affected (Roseboom et al., 2001). A cohort effect refers to events that affect a generation of people as they age. Although these factors are presented as three independent variables, there is considerable discussion about whether the effects are truly independent. This, in turn, has important implications for describing and explaining the association between aging and health. Despite these concerns, which will be addressed in more detail in later chapters, it is important to note that there are demographic factors that operate at the level of the population that affect health at both the level of the population and at the level of the individual.

Age-period-cohort analysis is a technique, then, that is used to describe the relative effects of each of the three factors. The traditional method is to present health data, for example, age-specific mortality rates for different cohorts of people, in other words, people with different birth years, who died in different years. Table 2–1 is an example of an age-period-cohort analysis of age-specific mortality rates for people who died from a particular condition.

While the descriptive tabular analysis of age, period, and cohort effects is useful, it is not designed to provide precise estimates of the independent effects of each factor. Analytic strategies have been developed to examine the independent and joint effects of each of the three factors through multivariate statistical analysis. There remains considerable controversy, however, about the appropriateness of this strategy, as it is argued that the three factors are not independent and, in fact, are confounded by definition. With information on two of the factors, the value of the third factor can be derived. This issue, referred to in the literature as "the identifiability problem," will be discussed in more detail in Chapter 10 (Xu et al., 1995). Although there are significant concerns about the best analytic strategy to use to examine age, period, and cohort effects, it is important to emphasize again how useful these three factors are for obtaining a more complete qualitative description of aging, health, and function than would be the case if we relied on chronological age alone.

Elaine M. Brody provides another example of the utility of this approach in her book, *Mental and Physical Health Practices of Older People* (Brody, 1985). Instead of presenting data for an entire cohort of people, she presents data for a single individual—a 75-year-old woman. She highlights key biographical events in the woman's life, compared to events that

Table 2–1 Age-specific curves for hypothetical data showing mortality rates per 100,000 population by year of death (A) without a cohort effect present and (B) with a cohort effect present. Adapted from Selvin (1996: 106–107).



were occurring at the same time in society. It provides a very effective way to compare the biographies of individuals against the backdrop of history, noting in particular, the key political and social events of the period.

In addition to age, period, and cohort effects presented at either the level of the population or, as is the case with Brody's example, a life-course approach must include an appreciation of how older people interpret change and how it affects their self-concept, as well as their expectations for the future. Work in this area is part of a broader research agenda in the "Developmental Sciences" (Settersten, 1999; Halfon & Hochstein, 2002).

The issue of the life course and time figure prominently in the standard research designs used in epidemiology—the case-control design and the longitudinal or prospective design. Each design addresses time in a different way. With regard to the case-control study, cases are people with the health outcome of interest, for example, breast cancer, heart disease, or diabetes. The controls are people who are similar to the cases with the exception of their disease status. The task is to obtain information about the cases and controls, typically retrospective information, such as past behaviors and exposures, that preceded the onset of the disease, which may provide an opportunity to establish how the cases are different from the controls. This information, in turn, ideally provides insight into the etiology or causes of the disease. In the case of the longitudinal or prospective design, the objective is to identify a group of people without the health outcome of interest and then follow them over time and record which of these people develops the disease. Recent research suggests that the time interval that is typically used in most studies in epidemiology—including studies in the epidemiology of aging—must be extended.

In summary, the topics of theories of aging, most notably the evolutionary theory of aging; homeostatsis, allostasis, and allostatic load; and the life course represent three underlying themes that serve as a foundation for a specific consideration of the ecological model. Together, these themes underscore three points: First, a consideration of the epidemiology of aging, health, functioning, and longevity should be based on a multilevel perspective that includes biologic, behavioral, social, and environmental levels. Second, those levels are interrelated. For example, health outcomes depend on physiological factors, such as allostatic capacity, to respond to environmental challenges. That capacity depends on a variety of factors that includes genetics, behavioral patterns, and level of social contacts and support. Third, these multilevel factors unfold over the life course of individuals and populations.

EPIDEMIOLOGY OF AGING—AN ECOLOGICAL MODEL

The ecological model presented in this section builds on the previous themes and other models used in the fields of epidemiology, gerontology, sociology, environmental psychology, developmental science, environmental design, and urban planning (Catalano, 1979, 1989; Macintyre & Ellaway, 2000; Stokols, 1992; McElroy et al., 1988; Smedley & Syme, 2000). Our purpose here is to use the ecological model both as a typology for what is being done and as an agenda for what should be done in the field of the epidemiology of aging. Rather than thinking of the major topics in this field, such as survival, physical functioning, and disease and comorbidities, as distinct areas of research, this model serves to underscore that the areas are, in fact, interrelated. Indeed, it is only by thinking of the field in this way that we can appreciate recent work to identify the causal pathways in aging, health, functioning, and longevity. The model, then, serves as a blueprint of what is to follow in the book. Subsequent chapters will address each of the key topic areas in this field as outcomes. These include survival and mortality; physical functioning and activities of everyday life; cognitive functioning; depression; falls and injuries; and disease and comorbidities. For example, research on physical functioning and activities of everyday life will be addressed in chapter 4. This will include examinations of both the independent and joint effects of biologic, behavioral, social, and environmental factors on patterns of physical functioning in aging populations. In Chapter 3, research on aging and survival will be addressed. Research on physical functioning also will be included, but only as it relates to patterns of survival, and so on. It is hoped that this approach will underscore the connections among the key topic areas. Moreover, it will point to areas of needed research, a topic that will be described in more detail in Chapter 12.

In the subsequent sections of the present chapter, we will describe the components of the ecological model by starting, as researchers in public health often do, by addressing the demographic and socioeconomic patterns of aging, health, and functioning in the population. This often establishes the framework for subsequent examinations. In other words, after describing the demographic and socioeconomic patterns of health and functioning, the next task is to attempt to explain the reasons for these patterns. This will include a consideration of characteristics of the physical environment, in terms of both toxic environmental exposures and characteristics of the built environment; the social environment, including living arrangements and social networks; and health behaviors, such as tobacco consumption, diet and nutrition, and alcohol consumption; and levels of physical activity. Although we will not devote separate chapters to these topics, each will figure in the discussion of survival; physical and cognitive functioning; depression; falls, injuries, and automobile crashes; disease and comorbidities; and general health, frailty, and successful aging.

This ecological model is only intended to illustrate the range of variables and underscore the point that the variables are interrelated. The model is divided into three sections (circles). The top circle includes demographic (age, gender, race, and ethnicity), socioeconomic, environmental (physical and built), social (social capital, living arrangements, social networks, and social support), psychosocial (self-efficacy, social control, and sense of coherence), and physiological factors. The second circle includes standard health and functional outcomes. It is important to note that with the exception of the demographic factors, the variables are interrelated (in other words, each variable affects and, in turn, is affected by each other variable). Indeed, the outcomes that are displayed in the second circle also may affect over time the variables listed in the first circle. The third circle represents vital status (alive or dead). It is important to realize that the model is not intended to present specific, hypothesized causal relationships (or causal links across independent, intermediary, and dependent variables.) Rather, the model represents a simple heuristic device to guide our consideration of research in the epidemiology of aging.

The following sections present a more detailed description of the variables included in the two, interrelated circles of the ecological model.

Age

Age, as noted previously, is one of the key variables in epidemiology. Chronological age is associated with the incidence and prevalence of most

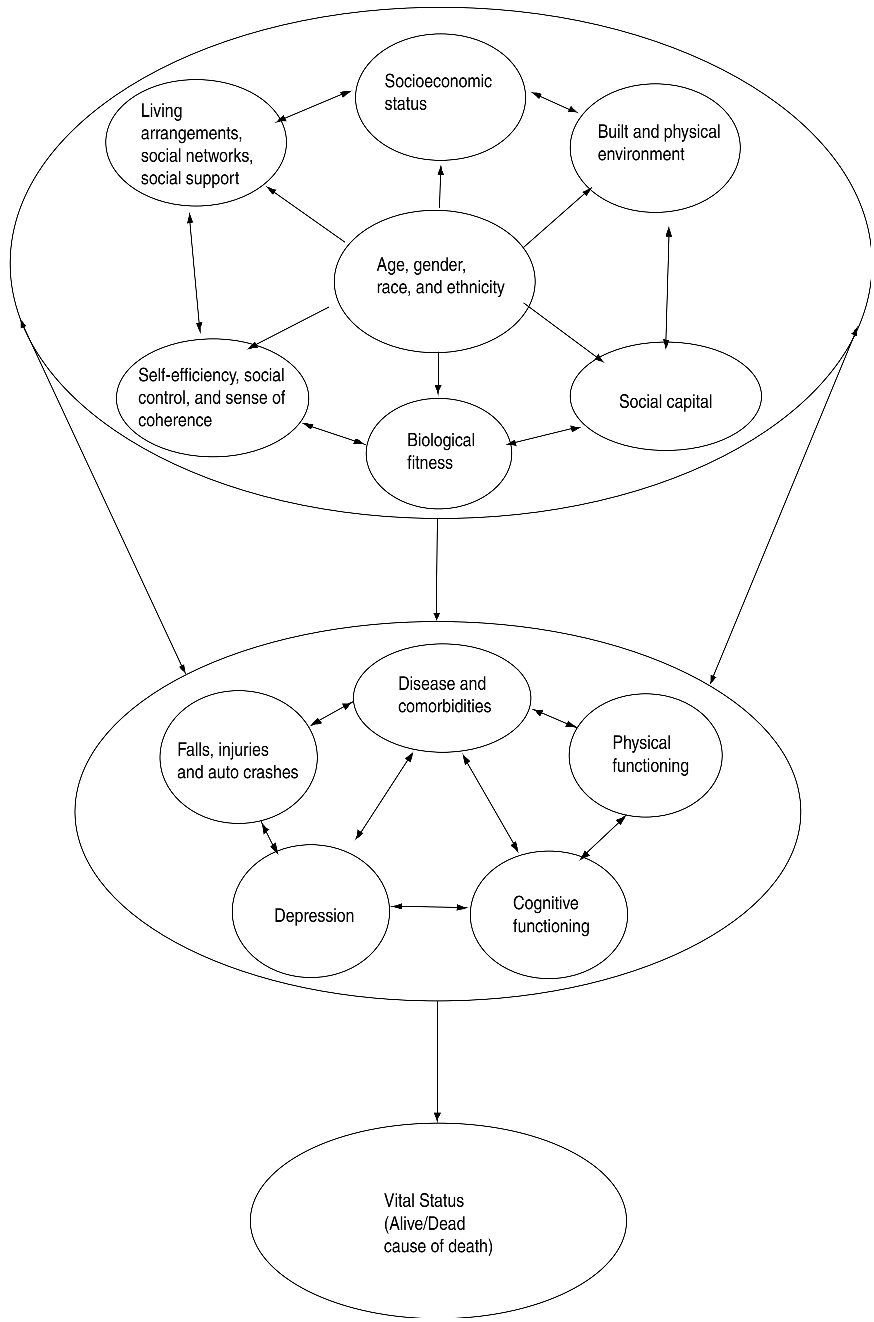


FIGURE 2–4 Ecological Model

conditions, as well as the risk of death. Because age is considered to be a marker for a variety of biologic, behavioral, social, and environmental factors, much of epidemiological research is designed to understand what it is about age that affects patterns of health and well-being. These age-associated patterns, in turn, may be due to the aging process itself, coupled with exposures resulting from the shared experiences of a specific cohort or generation of people over time as well as exposures associated with living in a particular historical period. Although birth date and age are often readily available for purposes of research, the manner in which age is summarized may affect the nature of a study. For example, if age is summarized as a continuous variable, the estimate of risk may be based on a unit change of age, often summarized as one year. So, for example, if the risk for colon cancer associated with age is 1.15, it can be interpreted to mean that the risk of that cancer increases by 1.15 (approximately 15%) for every one-year increase in age. Although this is a useful summary, it does not take into account the extent to which the absolute magnitude of risk may change over specific periods of age. This may be captured by categorizing age into "meaningful categories," for example, ages 45–54, 55–64, 65–74, 75–84, and 85 years of age and older. If the age group of 45–54 years, is used as a referent, each risk estimate would specify the level of risk for each subsequent age group. This strategy assists in determining whether the magnitude of risk varies as a function of age.

Gender

Gender is also an important variable in epidemiological studies. Patterns of health, functioning, and longevity have been shown to be associated with gender. Although women tend to have a greater life expectancy than men, women tend to report more functional limitations and disability than men. In addition to biologic factors, such as levels of estrogen or testosterone, there are behavioral, social, and environmental factors that account for gender differences in health outcomes. For example, research indicates that with the exception of sedentary behavior, women are more likely than men to engage in healthful behavior (Berrigan et al., 2003). Specifically, men are more likely than women to engage in risky behavior, such as exposure to tobacco, poor dietary practices, excessive alcohol consumption, and aggressive behaviors that elevate risk for violence and injury (Berrigan, Dodd, Troiano, Krebs-Smith, & Barbash, 2003). One recent national study indicated that men were 2.6 times more likely than women to report nonadherence to recommendations to five healthful behaviors. In contrast, women were 1.6 times likely than men to report adherence to every one of the five recommendations (Berrigan et al., 2003). Men also are more likely than women to be employed in hazardous occupations. Although it is only relatively recently that women have been included in clinical research trials, there is a growing body of research on women's health. Although historically included in studies as the "generic" human subject, there is relatively little research that has focused on the special health needs of men (International Longevity Center, 2004). This includes cultural prescriptions regarding the socialization of sex roles and how those prescriptions change over the life course as well as how they have changed in different historical periods. Of course, as we consider the issue of global patterns of aging, health, and functioning, the similarities and differences in cultural prescriptions for sex-role socialization in different parts of world must be taken into account.

Race and Ethnicity

As noted in Chapter 1, the aging population is not only becoming larger, it is becoming more diverse. In the United States, for example, the proportion of African-, Hispanic-, and Asian-Americans aged 65 and older is becoming larger, relative to non-Hispanic whites. In 2000, 83.5% of the U.S. population aged 65 and older was non-Hispanic white, compared to 8.1% African-American, 5.6% Hispanic white, 2.4% Asian or Pacific Islander, and 0.4% American Indian or Alaska native. In 2050, however, non-Hispanic whites will only represent 64.2% of those aged 65 and older. African-Americans will increase to 12.2%, Hispanic whites to 16.4%, Asian or Pacific Islander to 6.5%, and American Indian or Alaska native to 0.6% (U.S. Census, 2002).

As will be described in subsequent chapters, compared to non-Hispanic whites, African-American seniors are at elevated risk for a broad array of health conditions, functional limitations, and disabilities. Although Hispanic whites are typically in better health than African-American seniors, they too are at elevated risk for serious chronic health conditions, such as diabetes. Although Asian-American seniors represent a heterogeneous group, including Chinese-, Korean-, and Vietnamese-Americans, their health status is often comparable to that of non-Hispanic whites. Patterns of health, functioning, and longevity tends to vary by gender and, most notably, age. In general, racial and ethnic differences, especially between African-Americans and non-Hispanic whites, are most pronounced in the middle years. Less difference, especially among women, is found among seniors. Nevertheless, because health disparities are associated with differences in race and ethnicity, it is important to understand the implications of the increase in race and ethnic diversity of the growing senior populations for future incidence of health problems, limitations, and disabilities. As evidence of the importance of this topic, the National Academy of Sciences has recently published a comprehensive report titled Understanding Racial and Ethnic Differences in Late Life: A Research Agenda (Bulatao & Anderson, 2004).

The scientific consensus is that race is a social category of individuals who share certain phenotypic characteristics. Race is no longer thought of as a category characterized by homogeneous biologic inheritance. Ethnicity, on the other hand, refers to a social group that shares a distinctive social and cultural tradition. Interestingly, the U.S. Bureau of the Census and U.S. governmental health statistics restricts the use of ethnicity to people of Hispanic ancestry. In the 2000 U.S. census, if a person answered in the affirmative to the question, "Do you consider yourself Hispanic/Latino?" he or she then had the option of selecting one of eight categories of Hispanic from Puerto Rican to Other Hispanic/Latino.

Respondents also were asked to designate one or more racial classifications from a list of 16 categories. Unlike the ethnic/Hispanic classifications, race is classified in terms of white, African-American, Indian (American), and Asian/Pacific Islander. As will be discussed in more detail in later chapters, racial and ethnic classification remains a controversial issue. In 2003, an initiative was placed on the California state ballot calling for the termination of the collection of all race and ethnic data for state activities. Although the initiative was defeated, it prompted considerable debate and raised concern among public health researchers about the loss of this important demographic data. The important question is what is it about race and ethnicity that is associated with health outcomes? The answer to this question would include factors associated with genetic and familial patterns, socioeconomic status, environmental exposures, social and behavioral status, and, in many cases, experiences of racism and discrimination (Ren, Amick, & Williams, 1999; Williams, Neighbors, & Jackson, 2003). In addition, relative accessibility and quality of health care as well as use of native home remedies may play a role. How does age as well as the timing of experiences over the life course affect the association between race and ethnicity and health outcomes? To what extent does race and ethnicity affect life chances in terms of both the challenges that are faced and the resources that are available to meet those challenges?

There are a number of factors that complicate this investigation. For example, some racial and ethnic groups, such as Hispanic and Asian groups, have higher proportions of immigrants than other groups, such as African-Americans. This means that those who were able to migrate may be healthier than those who remained in the home country. Moreover, in some race and ethnic groups, those who become ill are likely to return to their home country to receive care, the so-called "Salmon Effect" (Bulatao & Anderson, 2004). These selection factors may result, therefore, in an inaccurate estimate of racial and ethnic differences in health outcomes.

Socioeconomic Status

Socioeconomic status, often assessed in terms of independent and aggregate levels of family income, education, and occupational status, as well as community-level indicators, is associated with health, functioning, and longevity over the life course (Seeman & Crimmins, 2001; Lynch & Kaplan, 2000). In general, those of lower socioeconomic status are at elevated risk and have a higher incidence of acute and chronic health conditions, functional limitations and disabilities, and premature death. There is evidence of a socioeconomic health gradient, that is, at each level of socioeconomic status, there is a higher level of overall health (Adler et al., 1994). There is evidence that racial and ethnic differences in health and well-being are due at least in part to differences in socioeconomic status.

Age and aging affect the consideration of socioeconomic status and health in several ways. First, while socioeconomic status may affect levels of health and functioning across the life course and across generations, the magnitude of that effect may vary with age (House et al., 1990). As with race and ethnicity, socioeconomic status, family income, education, and occupational status may have different implications in older populations. The strength of the association between family income and health may differ across different age groups. Among seniors, income may not reflect resources as well as measures of overall wealth. Because most seniors may no longer be employed in the jobs they had for most of their lives, occupational status may not be as indicative a measure of socioeconomic status as it is for younger groups. Although educational attainment is not affected with time, the meaning, significance, and past rewards associated with a specific number of years of formal education may be different across different generations. Second, the measurement of older people's current socioeconomic status may be less closely associated with current health status than is socioeconomic status at earlier points in the life course (Seeman & Crimmins, 2001; Beefe-Dimmer, Lynch, Turrell, Lustgarten, Rahunathan, & Kaplan, 2004). Finally, there is discussion about the significance of the "drift hypothesis," or the extent to which one's current health and level of functioning affects subsequent socioeconomic status (Harkey, Miles, & Rushing, 1976). In other words, serious health problems and functional limitations may have an adverse effect on a person's socioeconomic status and cause the person to drift downward in the social hierarchy. To the extent that older people are at greater risk for health problems and disabilities, they may be at greater risk for loss of economic resources. This all depends, of course, on the extent to which an older person can rely on an economic and social safety net.

Increasingly, socioeconomic status is being assessed at both individual and community levels (Robert, 1999; Macintyre, Mciver, & Sooman, 1993; Daly, Duncan, Kaplan, & Lynch, 1998). In addition to individual levels of income, years of education, and occupational position, summary measures of socioeconomic status at the community level are associated with individual and community health outcomes. The summary measures include median income, percentage of adults with 12 or more years of education, and inequality in income distribution (Robert, 1999). Haan, Kaplan, and Camacho (1987) have investigated the reasons for the association between socioeconomic status and poor health by studying mortality for nine years in a random sample of residents aged 35-years and more in Oakland, California. They found that residents of a federally designated poverty area experienced higher age-, race-, and sex-adjusted mortality, compared to residents of nonpoverty areas. Most important, the relationship between quality of health and places of residence persisted, even after adjusting for characteristics of the individual residents. These factors included baseline health status, race, income, employment status, access to medical care, health insurance, coverage, tobacco use, and alcohol consumption. These findings suggest that characteristics of the physical environment should be investigated.

There is evidence of a health gradient associated with levels of socioeconomic status (Adler et al., 1994). In other words, it is not simply that those in poverty are in poorer health than those with higher levels of socioeconomic status. Instead, at each level of socioeconomic status, there is a corresponding increase in health. Of course, the magnitude of this difference may vary by the specific health outcome. There is little information about the extent to which the association between socioeconomic status and health outcomes varies by chronological age.

There is also research that indicates that the absolute level of inequality, that is, the extent of the socioeconomic difference in the population, has an effect that is independent of the association between socioeconomic status and health. Those communities with less extensive income differential have an overall lower mortality rate than communities with more extensive income differential (Lobmayer & Wilkinson, 2002). There is some controversy about the mechanisms by which income differentials affect specific health outcomes. Some researchers contend that the material disadvantages associated with lower socioeconomic status, such as less access to nutritious food, is the primary explanation for the association (Lynch, Smith, Kaplan, & House, 2000; Lynch, Smith, Hillemeir, Shaw, Rahunathan, & Kaplan, 2001). Others contend that adverse psychosocial factors, such as greater anxiety and less social cohesion, associated with poorer socioeconomic status, are the primary explanations for ill health (Kawachi & Kennedy, 1997; Subramanian, Lochner, & Kawachi, 2003; Lobmayer & Wilkinson, 2002). Some commentators question the nature of this argument, noting instead that these explanations are not mutually exclusive. In other words, it is possible that both material and psychosocial pathways may account for the association between socioeconomic status and the magnitude of income inequity and health outcomes. To our knowledge, it is unknown to what extent the independent and joint effects of those factors on health vary by chronological age. It is also unknown whether the independent and joint effects of those factors vary over the life course and whether the relative strength and sequencing of those factors affect patterns of health later in life.

As noted previously, most measures of socioeconomic status, whether assessed at the individual or community levels, are based on objective indicators, such as family income, years of education, occupational status, as well as measures of wealth, including real estate and stock. There is also evidence that subjective indicators of social status are associated with measures of ill health (Singh-Manoux, Adler, & Marmot, 2003). One such measure includes a "ten-rung self-anchoring scale," displayed in the form of a ladder. Subjects are presented with a figure of the ladder and given the following instructions:

> Think of this ladder as representing where people stand in society. At the top of the ladder are the people who are best off—those who have the most money, most education, and the best jobs. At the bottom are the people who are worst off—who have the least money, least education, and the worst jobs or no job. The higher up you are on this ladder, the closer you are to people at the very top and the lower you are, the closer you are to the bottom. Where would you put yourself on the ladder? Please place a large "X" on the rung where you think you stand.

There is evidence that this measure provides an overall summary of various socioeconomic indicators. However, when such measures are held constant, the subjective measure is independently associated with health outcomes (Singh-Manoux et al., 2003). Importantly from our perspective, it is also argued that this subjective measure "reflects both changes in socioeconomic circumstances over the life course and cumulative social position better than current employment grade" (Singh-Manoux et al., 2003, p. 1332).

The Physical Environment

The physical environment refers to both the level of exposure to environmental pollutants and toxins as well as characteristics of the built environment, including housing, transportation, and land use. As noted previously, allostasis refers to a process by which physiological systems adjust and adapt to challenges resulting from stressors in the environment. It is well known that exposure to environmental pollutants and toxins are associated with a variety of acute and chronic health conditions. Much of the work in this area has focused on children, because of their physiological vulnerability, and on workers, because of the level of environmental exposures and workplace hazards (Committee on Chemical Toxicity and Aging, 1987). Although less attention has focused on the elderly, this is changing for a number of reasons. First, as noted previously, there is a growing recognition that current health status, for example, in the elderly, is due to events and exposures occurring over the life course. Because the elderly by definition have live a long time, there is a greater likelihood of elevated risk associated with accumulated exposures and environmental insults. Second, as with children, the elderly are physiologically vulnerable. This vulnerability is due to past and current health conditions as well as reductions in immunologic capacity associated with aging.

In 1985, the National Academy of Sciences prepared a report on the effects of environmental exposures on the aging processes, at the request of the Environmental Protection Agency and the National Institute of Environmental Health Sciences (Committee on Chemical Toxicity and Aging, National Research Council, 1987). The preparation of this report was based on the proposition that the principles of toxicology should be integrated with the principles of gerontology. As stated in the preface of that report (1987, p. vii): "The formation of the committee constituted one of the country's first organized efforts to bring together experts in the field of gerontology and toxicology to consider the interface between the two scientific disciplines." Although the report provides an excellent review of the principles of environmental health sciences, toxicology, and gerontology, it concludes that research in this area is scant (Committee on Chemical Toxicity and Aging, National Research Council, 1987, p. 163). Research recommendations in this area include the following: First, it is argued that the identification of biomarkers of aging was necessary to examine the effects of environmental agents on aging processes. A biomarker of aging is defined as "a biologic event or measurement of a biologic sample that is considered to be an estimate or prediction of one or more of the aging processes" (Committee on Chemical Toxicity and Aging, 1987, p. 39). Second, special effort should be made to take advantage of information that may be available on toxic exposures in particular populations. It is recommended that "persons exposed to specific chemical substances in an industrial setting or as a result of an 'experiment in nature' should be followed throughout life, so that the effects of such exposure that have long latent periods can be identified and investigated" (Committee on Chemical Toxicity and Aging, 1987, p. 167). Fourth, the development of animal models to investigate aging and environmental exposures is proposed. Finally, it is recommended that research be conducted on the effects of advancing age on pharmacokinetics (absorption, distribution, metabolism, and elimination), bioaccumulation, and other drug and chemical interactions and the influence of dietary factors, smoking, and other environmental factors.

In 2002, the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research

Council, in cooperation with the Environmental Protection Agency and the National Institute on Aging, convened a second conference to examine environmental exposures in older populations in Washington, DC. The purpose of the conference was to initiate a yearlong effort to develop a national agenda on the environment and aging. A number of themes were identified, including the following:

1. There are significant age differences in pharmacokinetics, absorption, metabolism, and excretion that are likely to influence the retention of toxic environmental chemicals as well as the potential for these chemicals to cause adverse effects.
2. Because lung and liver functions tend to decline with age, there may be increased susceptibility to chemical and physical and environmental agents.
3. Older adults may be more susceptible to some chemicals than to others, especially those chemicals that are more likely than others to accumulate in the bone, lipids, and tissues. For example, although exposure to lead is less common today than in the past, older people, because of past exposures, may have greater concentrations of lead in their bones, leading to adverse health and functional effects.

There is also a growing interest in characteristics of the built environment, including housing, transportation, and overall patterns of land use (Carp, 1987; Lindheim & Syme, 1983). In fact, the Institute of Medicine convened a conference in collaboration with the National Institute of Environmental Health Sciences to propose a "new vision of environmental health for the 21st century (2001). The final report, *Rebuilding the Unity of Health and the Environment* (Hanna & Coussens, 2001) included a chapter devoted to "Human Health and the Built Environment." Historically, most of the work in this area has focused on falls and injuries. There is evidence that certain elements of housing design, such as placement of stairs and lighting, are associated with the risk of falls, one of the leading causes of accidental death in older populations. Today, there is a growing appreciation that overall functioning is associated with both individual level of capacity as well as the level of environmental resources. Put differently, functional limitations and disabilities result when environmental demands exceed the capacities and resources of the individual or the population. A number of recent studies have indicated that one of the key mechanisms for fostering health and functioning is physical activity. More specifically, those who reside in neighborhoods that are characterized by greater housing density, with street and sidewalk grid pattern, and in proximity to goods and services are more likely to walk than people who reside in areas that are less dense, without grid patterns, and in less proximity to goods and services. More recently, research indicates that level of physical activity and functioning is associated with characteristics of the built environment (Moudon & Lee, 2003). As noted previously, Lawton (1986) argued that with age, physical capacity generally declines, and characteristics of the built environment and environmental design become more strongly associated with physical activity and functioning.

A number of different measures have been used to assess characteristics of the built environment (Macintyre, Ellaway, & Cummins, 2002). First, there are environmental audits. These audit measures provide an opportunity to systematically enumerate characteristics of the built environment at the street level. Items include width of street, presence and conditions of sidewalks, traffic flow, and presence of walking hazards and litter. Although professional researchers typically conduct the audits, residents also have used environmental audits of communities. Second, the built environment also can be surveyed by using available environmental sources of data. The geographic information system (GIS) consists of a "layering" of information on a geographic map. For example, it is possible to identify the number and type of housing, location of goods and services, street patterns, locations of parks and walking trails, and traffic flow. Third, self-reports also have been used. In addition to reporting on the characteristics of the environment, respondents also may provide evaluations of the environment. For example, respondents may be asked to evaluate the quality of the sidewalk or the extent to which they feel safe while walking in a particular area. The issue of safety prompts us to consider another important variable that we have included in the ecological model—"social capital."

Social Capital

Social capital is defined as "those features of social structures—such as levels of interpersonal trust and norms of reciprocity and mutual aid—which act as resources for individuals and facilitate collective action" (Kawachi & Berkman, 2000). It is important to emphasize at this point that social capital is a characteristic of neighborhoods and communities and not individuals, a point to which we will return (Subramanian et al., 2003). In fact, communities with higher levels of social capital may provide greater "opportunity structures," such as attractive and safe places to walk, to shop, and visit friends. Following from previous research in the social sciences (Coleman, 1988; Gouldner, 1960; Putman, 2000), social capital has typically been measured in a variety of ways, such as number of voters, number of voluntary associations, or reports of customs or "norms of reciprocity" in neighborhoods. It is presently unknown, however, to what extent social capital affects health through the development and maintenance of self-efficacy and to what extent social capital operates directly on healthful behaviors, such as physical activity and proper diet and nutrition.

Living Arrangements, Social Networks, and Social Support

The social environment refers to living arrangements, marital status, and social networks. A number of studies have indicated that those with stronger social ties experience greater health, functioning, and longevity than those who are socially isolated (Seeman, 1996). This is important for a consideration of health and functioning in older populations. First, the association between social networks and health has been reported across the life course, including among older populations. Second, older people are at risk for losing important social contacts as they age. There is less contact with children and friends, and relatives may be lost to death or institutionalization. The loss of a spouse has been associated with subsequent health problems and an elevated risk of death in the surviving spouse, especially among widowers. Third, providing care for an ill or disabled spouse can cause health problems for the caregiver, especially if the ill spouse suffers from dementia.

There is evidence that social networks are associated with positive health for a number of reasons. First, contact with friends and relatives may provide opportunities of tangible, informational, or emotional support. Second, contact with friends and relatives may be associated with healthful behaviors, such as proper nutrition and physical activity. There is evidence that those older males living with a spouse eat more regularly and eat more nutritious foods than older males who live alone. In addition, married women and males with five or more friends and relatives are more likely to engage in regular physical activity than women who are not married and males with less than five friends and relatives.

Sense of Control, Coherence, and Self-Efficacy

Psychosocial factors have been identified as central explanatory variables in social epidemiology. For example, Leonard Syme (1989) argues that a sense of control or control of destiny serves to explain the association between a variety of social factors, such as socioeconomic status and social networks, and different health outcomes. This position is also associated with the work of Martin Seligman on a "sense of helplessness." Seligman writes (1975, p. 106):

> The life histories of those individuals who are particularly resistant to depression or resilient to depression may have been filled with mastery. These people may have had extensive experience controlling and manipulating the sources of reinforcement in their lives and may therefore perceive the future optimistically. These people who are particularly susceptible to depression may have had lives relatively devoid of mastery.

Seligman speculates that learned helplessness may be associated with a variety of health outcomes.

Aaron Antonovsky (1979) introduced a related term, "sense of coherence." Like Syme and Seligman, Antonovsky argued that the concept represented a parsimonious psychosocial variable that helped to explain the associations between a variety of demographic, socioeconomic, and social and behavioral factors on the one hand and a host of health outcomes on the other. In contrast, he defined a sense of coherence as a generalized sense of understanding events in everyday life as well as a sense of optimism that future events would unfold as well as one could expect. When he was once asked to distinguish between a sense of control and a sense of coherence, he explained that a person with a sense of coherence understands the rules of the game without necessary being able to control those rules (Antonovsky, personal communication, Spring, 1979).

Albert Bandura helped to introduce the concept of self-efficacy, and, as the subtitle of his book in this area indicates, viewed the concept as a vehicle for the exercise of control (Bandura, 1997). The concept of self-efficacy is one of the most commonly used concepts in public health and epidemiology. As we will see, there is a substantial body of research that indicates that people who demonstrate a sense of self-efficacy, defined here to mean a sense of confidence and competence, are more likely than others to reflect positive health outcomes. Bandura (1997, p. 3) defines self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments." Unlike a sense of control and a sense of coherence, self-efficacy does not refer to a generalized sense of competence. Instead, it is perceived as being specific to particular tasks, such as physical activity. This conceptual distinction is reflected in how the concepts are measured.

Measurement of a sense of control and a sense of coherence reflects generalized concepts. For example, Antonovsky designed a linking sentence to capture the key components and the possible relationships between those components. In contrast, measures of self-efficacy are specific to particular types of outcomes. For example, there are measures of self-efficacy regarding physical activity and other types of behavior. To my knowledge, neither measures of social control, competence, or self-efficacy have been designed for older populations.

Health Behaviors

It is well known that health behaviors, such as tobacco exposure, dietary practices, alcohol consumption, and physical activity, are associated with health, functioning, and longevity across the life course (McGinnis & Foege, 1993; Emmons, 2000). The likelihood for engaging in particular types of behavior, for example, the extent to which the older person is physically active, is associated with characteristics of the physical and social environments. This information, in turn, contributes to a better understanding of the racial, ethnic, and socioeconomic patterns of health, functioning, and longevity in aging populations.

Although research is often based on examinations of the health effects of single health behavior, recent research has examined specific patterns of behavior (Berrigan et al., 2003). Based on standard recommendations for such specific health behaviors as, tobacco exposure, alcohol consumption, physical activity, and diet and nutrition, Berrigan and colleagues examined patterns of behavior by age, gender, race, and ethnicity. Overall, adherence of tobacco and alcohol recommendations represented the most common combination of behaviors in the national sample. In contrast, the recommendations for physical activity and diet and nutrition were least likely to be followed. Overall, adherence in all five behaviors increased with age as well as higher levels of education and family income. As noted previously, women are more likely than men to adhere to positive health behaviors, with the exception of physical activity. African-Americans were least likely to observe proper health behaviors.

Tobacco Exposure

Exposure to tobacco is associated with a variety of health conditions (Giovino et al., 1995; 2002). Major exposures to tobacco smoke include direct exposure, in the form of cigarette smoking, and indirect exposure, in the form of passive exposure associated with environmental exposure. As we will see, exposure to tobacco is associated with a variety of health conditions, functional limitations, disabilities, and premature death. Although the frequency of exposure, especially direct exposure, declines with age, it is necessary to review the history of tobacco exposure over the life course. It also has been reported that tobacco exposure varies by cohort and period effects. For example, among the current cohort of older people in the United States and Western Europe, older males have had a greater exposure to tobacco than older women. Between the 1920s and the release of the U.S. Surgeon General's Report on tobacco in 1964, there was an increase in the prevalence of smoking among young adult women. Although smoking resulted in an increase of premature death, female smokers who survived to senior years are at greater risk for a variety of health conditions, functional limitations, and disabilities. Measurement of tobacco exposure is typically based on self-report, including reports of direct and indirect exposures over the life course. People are typically asked about the type, amount, and frequency of tobacco exposure during their lives. This is sometimes supplemented with tests to assess contemporary levels of nicotine in the blood. Measures of indirect exposure typically are based on questions following a household census. After asking about the number and relationships of others in the household, subjects are asked to indicate which of these people are regular smokers in the home. Measures of environmental smoke also include questions that ask the number of times in a regular day when the subject is in a situation in which he or she can smell or see cigarette smoke.

Diet and Nutrition

Past and current diet and nutritional patterns are associated with health, functioning, and longevity in older populations. Although obesity is an important public health problem in many countries, most notably in the developed countries, undernutrition and malnutrition is also a problem among older people as well. This may be due to a variety of factors, including health problems, depression, poor physical and cognitive functioning, impairment in the senses of smell and taste, as well as poor oral health. In addition, there is research that suggests that social and environmental factors also are associated with dietary and nutritional patterns in older persons (Davis, Murphy, Neuhaus, 1988; Davis, Murpy, Neuhaus, Gee, & Quiroga, 2000). Older people with limited physical access to markets that sell a variety of nutritious foods at reasonable prices are more likely to have poor nutritional status (Morland, Wing, Diez Roux, & Poole, 2002). Older people that live alone, especially older men, are less likely to consume nutritional meals on a regular basis (Davis et al., 1988). It is also reasonable to hypothesize that older migrants may be less likely to have an adequate diet, if their traditional foods are not readily available. With a reduction in energy needs, there is a concomitant decrease in nutritional intake. Wakimoto and Block (2001, p. 79) report that "Mean energy intake declines by 1000 to 1200 kcal in men and by 600 to 800 kcal in women between those aged in their 20s and those in their 80s." There appears to be significant declines in median protein, zinc, calcium, vitamin E, and other nutrients, especially in men. There also appears, however, to be an increase in the consumption of some other nutrients, especially among women. These include vitamin A, vitamin C, and potassium. This is consistent with consumption patterns that indicate that older women in particular consume higher levels of fruits and vegetables than younger women. It is important to realize that there is very little data available to judge the nutritional needs of older people as they age, especially for some nutrients such as proteins. In addition, although older adults are more likely than younger adults to take supplements, there is little information about nutritional needs in this area as well.

There are different methods for the assessment of diet and nutritional status. These include 24-recall and multiple-day diet diaries. There are also methods available, such as the Block questionnaire, that have been automated to provide nutritional assessment of specific foods.

Alcohol Consumption

Alcohol consumption refers to the type, frequency, and occasion of drinking alcohol. Unlike tobacco exposure and more akin to diet and nutrition, alcohol consumption is a type of health behavior that is not necessarily associated with problems of health, well-being, and longevity. Moderate consumption of alcohol, shown in some cases to be associated with some positive health outcomes, tends to decline with age. This decline, in turn, may be associated with problems of ill health. On the other hand, moderate consumption of alcohol, in some cases, may be associated with health conditions. For example, alcohol could lead to health problems and injuries, if it is taken in conjunction with one or more types of medications. If the older person is also operating an automobile, the combination of moderate amounts of alcohol and medications could lead to driving difficulties and elevate the risk of a crash (U.S. Department of Health and Human Services, 2000b).

The measurement of alcohol is often based on self-report. The Alameda County Survey (Berkman and Breslow, 1986) developed a series of questions on alcohol that represent a core set of items that have been adapted for use in other population surveys. For each type of alcohol (beer, wine, and spirits), respondents are asked whether they have consumed alcohol in the past year and, if so, how often they consumed alcohol and how much (number of glasses or drinks) was drunk at each sitting. In addition to providing an opportunity to examine consumption of each type of alcohol, it is possible to calculate an overall summary measure of alcohol.

Physical Activity

Level of physical activity is associated with a variety of health outcomes, functional limitations, disability, and longevity (U.S. Department of Health and Human Services, 1996). Physical activity is typically classified as either leisure-time physical activity (LTPA) or as utilitarian or everyday activities. Research indicates that men are more physically active than women, and that the overall prevalence of both LTPA and utilitarian walking declines with age. Reasons for the decline seem to vary by gender. Our own work in this area suggests a gender-age difference (Satariano, Haight, & Tager, 2000). In a study of older people in Sonoma, California, the absence of an exercise companion was identified as one of the major reasons for avoiding or limiting LTPA. Among men of the same age, the leading reason was disinterest. With increasing age, the reasons were more likely to be health-related and a fear of falling for both men and women.

The measurement of physical activity is based on both self-reports and direct assessments of activity. Direct measures of physical activity are based on the use of pedometers and accelerometers. Global position devices can now also be incorporated in the survey studies of physical activity.

Health, Functioning and Longevity

The remaining components of the ecological model include measures of health, functioning, and longevity. With the exception of longevity and vital status, each of the measures of health and functioning serve both as outcomes and predictors. In the subsequent chapters, specific health outcomes, beginning with mortality and cause of death will be examined.

CONCLUSION

The ecological model assumes that patterns of health and well-being in human populations are associated with a dynamic interplay of biologic, behavioral, social, and physical environmental factors, an interaction that unfolds over the life course of individuals, families, and communities. In the subsequent chapters, this model will serve as a blueprint for reviewing and evaluating the concepts, methods, and research in the epidemiology of aging.

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