

SECTION A: CONCEPTUAL FOUNDATIONS

1 *Psychophysiology and psychophysiological inference*

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Nothing could be more obvious than that the earth is stable and unmoving, and that we are the center of the universe. Modern Western science takes its beginning from the denial of this commonsense axiom... Common sense, the foundation of everyday life, could no longer serve for the governance of the world. When "scientific" knowledge, the sophisticated product of complicated instruments and subtle calculations, provided unimpeachable truths, things were no longer as they seemed. (Boorstin, 1983, p. 294)

1.1 INTRODUCTION

Psychophysiology concerns the study of cognitive, emotional, and behavioral phenomena as related to and revealed through physiological principles and events. As a discipline, psychophysiology not only addresses fundamental questions regarding human processes (e.g., mind-body relationships, organismic-environmental transactions, psychosomatic disorders), but also provides a conceptual perspective and a methodological armamentarium that cuts across aspects of the biological, behavioral, and social sciences.

Two cardinal postulates underlying the discipline are that ¹physiological processes ~~subjective experience, and overt actions~~ all harbor information about human nature and ~~each of these domains also contains irrelevant data, artifacts, and misinformation.~~ Consequently, knowledge regarding physiological mechanisms, biometric and psychometric properties, and experimental design is important in extracting veridical information about human nature. Consistent with this perspective, verbal reports as the standard of validity are challenged, reductionism as being the idealized endpoint in studies of human nature is rejected, and overt behavior as the optimally sensitive or discriminable measure of underlying processes is questioned.

Consider, for instance, the human eye - a sensory receptor that is sensitive to only a narrow band of the electromagnetic spectrum. One could refer to this limited band of electromagnetic energy as the "psychological" domain since electromagnetic phenomena falling within this band have clear and obvious effects on human experience. However, the visible light band is but a small part of a broader, coherent spectrum of electromagnetic energy that can also influence human experience and behavior and can be revealed through the use of specialized equipment to extend the reaches of the human senses. Reference to the portion of the electromagnetic spectrum to which our eyes respond as "visible" rather than "psychological," therefore, more accurately denotes the existence of a broader electromagnetic spectrum and the interaction between this stimulus and a

particular information detection and processing mechanism. Note, too, that the existence and broader organization of the electromagnetic spectrum and its various effects on the behavior of humans and animals would not be comprehensible if observations were limited to the band of visible light.

Similarly, psychophysicists often utilize specialized equipment to study the spectrum of physiological events that allow functional descriptions and, in some instances, influence the operation of systems underlying human experience and behavior. To illustrate, consider the following sampler of psychophysiological research.

A neonate too young to comprehend or control purposeful behavior nevertheless exhibits heart rate responses when new or significant stimuli are presented; variations in this procedure reveal the attentional processes of neonates can be tracked using tracings produced by an electrocardiogram (Graham & Jackson, 1970). A young individual sleeping quietly with eyes closed periodically shows extended sequences of rapid eye movements, as assessed by electrooculography; awakening the individual during this period usually reveals the person was dreaming (Foulkes, 1962).

A student sits quietly as auditory tones are presented through headphones; averaging of the electroencephalographic recordings time-locked to these tones reveals a larger brain potential is evoked approximately 300 ms following unexpected tones, in contrast to those expected (Squires, Squires, & Donchin, 1976).

A college student, during a moment of self-disclosure, reflects briefly on an unpleasant experience; minute muscle action potentials, detectable using electromyography, mark this emotional event despite the person neither speaking about nor showing visible signs of the unpleasant thought or feeling (Cacioppo, Martzke, Petty, & Tassinari, 1988).

A suspect in a criminal case is questioned about evidence found at the scene of the crime; although the suspect denies knowing anything about the crime, physiological reactions are repeatedly more pronounced when information associated with the crime is presented than when equally provocative information not associated with the crime is presented (Lykken, 1981).

Married couples engage in a conflict conversational interaction while general autonomic activity is monitored; the higher the autonomic responses observed in this conflict interaction, the lower the marital satisfaction three years later (Levenson & Gottman, 1985).

An elderly individual who has bilateral occipitotemporal brain damage no longer seems to recognize her spouse or other familiar people; yet electrodermal activity is heightened when their pictures are presented (Tranel & Damasio, 1985).

An underlying theme in each of these studies is that the stimuli, thoughts, emotions, and experiences that are apparent to or can be articulated by the individual may represent but a narrow band of influences relevant to the governance of human experience and behavior. It should not be surprising, then, that psychophysiological research has provided insights into almost every facet of human nature, from the attention and behavior of the neonate to memory and emotions in the elderly. This book is about these insights and advances - what they are, the methods by which they came about, and the conceptualizations that are guiding progress toward future advances in the discipline.

Historically, the study of psychophysiological phenomena has been susceptible to "easy generalizations, philosophical pitfalls, and influences from extrascientific quarters" (Harrington, 1987, p. 5). Our objectives in this chapter, therefore, are to define the area of research and theory referred to as psychophysiology, review briefly major historical events in the evolution of psychophysiological inference, outline a taxonomy of logical relationships between psychological constructs and psychiological events, and specify a scheme for strong inference within each of the specified classes of psychophysiological relationships. Additional information about the history, foundations, principles, techniques, and theories of psychophysiology is provided in the subsequent chapters of this book.

1.2 THE CONCEPTUALIZATION OF PSYCHOPHYSIOLOGY

The body is the medium of experience and the instrument of action. Through its actions we shape and organize our experiences and distinguish our perceptions of the outside world from sensations that arise within the body itself. (Miller, 1978, p. 14)

Anatomy, physiology, and psychophysiology are all branches of science organized around bodily systems whose collective aim is to elucidate the structure and function of the parts of and interrelated systems in the human body in transactions with the environment. Anatomy is the science of body structure and the relationships among structures. Fields of study within this discipline include surface anatomy (the study of the form and markings of the surface of the body), gross anatomy (the study of structures that can be examined without a microscope), systemic anatomy (the study of specific systems of the body such as the nervous or cardiovascular systems), and developmental anatomy (the study of structural development from the fertilized egg to the adult form) (Solomon & Phillips, 1987).

Physiology concerns the study of bodily function or how the parts of the body work. What constitutes a body part in physiology varies with the level of bodily organization going from the chemical (e.g., actin, myosin) to cellular (e.g., muscle fiber) to tissue (e.g., striated muscle) to organ (e.g., biceps) to body system (e.g., muscular system) to the human organism (Figure 1.1). Thus, the anatomy and physiology of the body are intricately interrelated.

Fundamental to the conceptualization of psychophysiology are the assumptions that (1) human perception, thought, emotion, and action are embodied phenomena and (2) the responses of this corporeal body can help reveal the mechanisms underlying human nature. Psychophysiology, therefore, is also intimately related to anatomy and physiology but is concerned with what might be termed supraphysiological or psychological phenomena - the experience and behavior of organisms in the physical and social environment - rather than with the structure or function of body parts per se (see Figure 1.1). Among the complexities added when moving from physiology to psychophysiology are the capacity by symbolic systems of representation (e.g., language, mathematics) to communicate and to reflect upon history and experience and the social and cultural influences on physiological response and behavior. Both of these contribute to plasticity, adaptability, and variability in behavior (Cacioppo, 1982; Gale & Edwards, 1983). And although psychology and psychophysiology share the goal of explaining human experience and behavior, physiological constructs and processes are an integral component of theoretical thinking in psychophysiology.

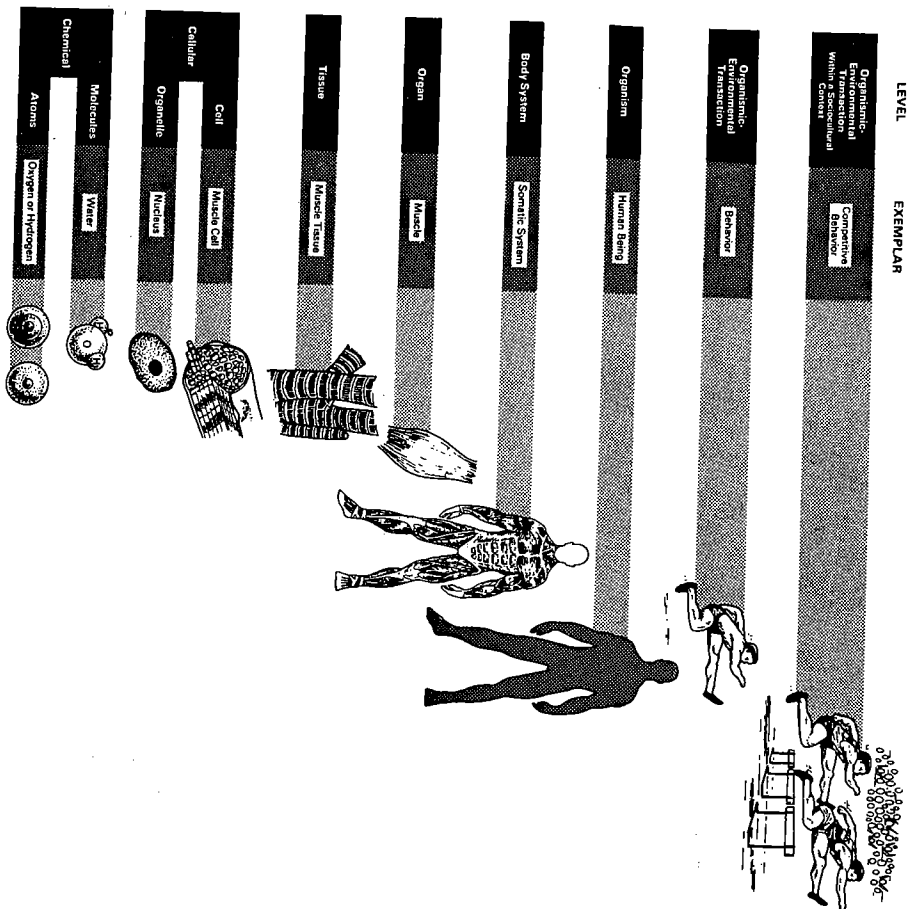


Figure 1.1. Levels of structural organization underlying human behavior.

1.2.1 Psychophysiology as a scientific field of study

Psychophysiology is still quite young as a scientific discipline although the concept of such a discipline dates back at least 150 years (Adams, 1839). Studies conducted around the turn of the century can be found involving the manipulation of a psychological factor and the measurement of one or more physiological responses (e.g., Berger, 1929; Darrow, 1929; Eng, 1925; Jacobson, 1930; Mosso, 1896; Peterson & Jung, 1907; Sechenov, 1878; Tarchanoff, 1890; see also, Troland, 1929–1932; Woodworth, 1938/1947), and such studies would now be considered as falling squarely under the rubric of psychophysiology. Chester Darrow (1964), in the inaugural Presidential Address of the Society for Psychophysiological Research, identified Darwin (1872/1873), Vigoroux (1879), James (1884), and Féré (1888/1976) as among the field's earliest pioneers. Yet the first scientific periodical devoted exclusively to psychophysiological research, *Psychophysiology Newsletter*, was not begun until 1955 as an outgrowth of *Polygraph Newsletter* (Ax, 1964a). The Society for

Psychophysiological Research was formed 5 years later, and the first issue of the scientific journal *Psychophysiology* was published but a quarter century ago. When precisely psychophysiology emerged as a discipline, therefore, is difficult to specify, but it is usually identified with the formation of the Society for Psychophysiological Research in 1960 or with the publication of the first issue of *Psychophysiology* in 1964 (Powles, 1975; Greenfield & Sternbach, 1972; Sternbach, 1966). Scientific organizations for psychophysiological research have since been established around the world, including Great Britain, Japan, Australia, and West Germany.

The formation of this international society and journal brought together scientists from diverse fields including physiology, neurology, electrical engineering, experimental psychology, clinical psychology, neuropsychology, psychiatry, and social and developmental psychology (e.g., Cacioppo & Petty, 1981; Kaplan & Bloom, 1960; Porges & Coles, 1976). The diverse goals and interests of these individuals, the technical obstacles confronting the early investigators, and the importance of understanding the physiological systems underlying their observations fostered a partitioning of the discipline into physiological measurement areas.

The organization of psychophysiology in terms of underlying physiological systems, or what can be called *systemic psychophysiology*, remains important today both for theoretical and pedagogical reasons. Physiological systems provide the foundation for information processing and behavior and are often the target of systematic observation. Hence, an understanding of the physiological system(s) under study and the biological principles underlying the responses being measured is important not only for the discrimination of signal from artifact, the safety of the individuals involved, and the acquisition and analysis of digital arrays and descriptive parameters that are reliable and valid representations of the physiological events of interest, but also for the stimulation of plausible hypotheses, the development of appropriate operationalizations, the guidance of inferences based on physiological data, and consequently, the advancement of theory regarding human nature.

Like anatomy, physiology, and psychology, however, psychophysiology is a broad science organized in terms of a *thematic* as well as a *systemic* focus. For instance, *cognitive psychophysiology* concerns the relationship between elements of human information processing and physiological events. *Social psychophysiology* concerns the study of the cognitive, emotional, and behavioral effects of human association as related to and revealed through physiological measures, including the reciprocal relationship between physiological and social systems. *Developmental psychophysiology* deals with developmental changes in psychophysiological relationships as well as the study of psychological development and aging through noninvasive physiological measurements. *Clinical psychophysiology* concerns the study of disorders in the organismic-environmental transactions and ranges from the assessment of disorders to interventions and treatments of the disorders. And *applied psychophysiology* deals with the implementation of psychophysiological principles in practice, such as operant training ("biofeedback"), desensitization, relaxation, and lie-detection procedures.

In each of these areas, the focus of study draws on but goes beyond the description of the structure or function of cells or organs to investigate the organism in transactions with the physical or sociocultural environment. Some of these areas, such as developmental psychophysiology, have counterparts in anatomy and physiology but refer to complementary empirical domains (see Figure 1.1). Others,

such as social psychophysiology, have no direct counterpart in anatomy or physiology because the focus begins beyond that of an organism in isolation; yet the influence of social and cultural factors on physiological structures and functions, and their influence as moderators of the effects of physical stimuli on physiological structures and functions, leaves little doubt as to the relevance of these factors to anatomy and physiology as well as to psychophysiology (e.g., see Barclay, 1976; Cacioppo & Petty, 1983; Cacioppo, Petty, & Andersen, 1988; Waid, 1984). In sum, whether organized in terms of a systemic or a thematic focus, psychophysiology can be conceptualized as a natural extension of anatomy and physiology in the scientific pursuit of understanding human nature.

1.2.2 *Physiological and psychological perspective*

We have suggested that psychophysiology is intimately related to anatomy and physiology, and further that knowledge of the physiological systems and responses under study contributes to both theoretical and methodological aspects of psychophysiological research (see also, Coles, Donchin, & Porges, 1986; Parts II and III of this volume). Physiological or technical expertise alone, however, is no substitute for a well-conceived experimental design. As Coles, Gratton, and Gehring (1987) noted, knowledge of the physiological systems, although contributory, is logically neither necessary nor sufficient to ascribe psychological meaning to physiological responses. The ascription of psychological meaning to physiological responses ultimately resides in the quality of the experimental design and the psychometric properties of the measures (see Strube, chapter 2). For instance, although numerous aspects of the physiological basis of event-related brain potentials remain uncertain, functional relationships within specific paradigms have been established between elementary cognitive operations and components of these potentials by systematically varying one or more of the former and monitoring changes in the latter (see Coles, Gratton, & Fabiani, chapter 13).

The point is not that either the physiological or the psychological perspective is preeminent, but rather that both are fundamental to psychophysiological inquiries; more specifically, that physiological and psychological perspectives are complementary. Inattention to the logic underlying psychophysiological inferences simply because one is dealing with observable physiological events is likely to lead either to simple and restricted descriptions of empirical relationships or to erroneous interpretations of these relationships (e.g., see review by Cacioppo, Petty, & Tassinari, 1989). Similarly:

an aphysiological attitude, such as is evident in some psychophysiological research, is likely to lead to misinterpretation of the empirical relationships that are found between psychophysiological measures and psychological processes or states. (Coles et al., 1986, p. ix-x)

Thus, the joint consideration of physiological and functional perspectives reduces errors of operationalization, measurement, and inference, and hence, enriches theory and research on human processes and behavior.

1.2.3 *Definitions of psychophysiology*

Thus far, we have discussed the major assumptions, levels of analysis, and goals of psychophysiology, and we have traced briefly the history of the field as a scientific

discipline. Specifying a formal definition of psychophysiology is more difficult. Some of the initial definitions of psychophysiology were in operational terms such as research in which the polygraph was used, research published by workers in the field, and research on physiological responses to behavioral manipulations (cf. Furedy, 1983). Other early definitions were designed explicitly to differentiate psychophysiology from the older and more established field of physiological psychology by designating what was unique at that time about psychophysiological inquiries, such as the use of humans in contrast to animals as subjects, the manipulation of psychological or behavioral constructs rather than anatomical structures or physiological processes, and the measurement of physiological rather than behavioral responses (Stern, 1964). Illustrative definitions offered over the past several decades follow:

Psychophysiology... is our name for the science which starts with the facts learned by introspection, and seeks their determinants in the physical structures and processes of biological organisms. Its problem is solely that of determining the formal laws, or mathematical functions which hold between curious respective aspects of consciousness and of living matter. (Troland, 1929, p. 144)

Psychophysiology is the science which concerns the physiological activities which underlie or relate to psychic events. (Darrow, 1964, p. 4)

Psychophysiology is best defined by its goals and methods as they are described in the reports published by its research workers.... The general goal of psychophysiology is to describe the mechanisms which *translate* between psychological and physiological systems of the organism.... The progressive theme of psychophysiological method has been to extend measurement to more covert behavior with decreasing interference with the organism. (Ax, 1964b, p. 8)

Any research in which the dependent variable (the subject's response) is a physiological measure and the independent variable (the factor manipulated by the experimenter) a behavioral one. (Stern, 1964, p. 90)

Psychophysiology is the study of the interrelationships between the physiological and psychological aspects of behavior. It typically employs human subjects, whose physiological responses are usually recorded on a polygraph while stimuli are presented which are designed to influence mental, emotional, or motor behavior; and the investigator need not be a psychologist. (Sternbach, 1966, p. 3)

The field of psychophysiology is concerned with the measurement of physiological responses as they relate to behavior. (Andreassi, 1980, p. 3)

Psychophysiology is the study of psychological processes in the intact organism as a whole by means of unobtrusively measured physiological processes. (Furedy, 1983, p. 13)

Psychophysiology is the study of mental or emotional processes as revealed through involuntary physiological reactions that can be monitored in an intact subject. (Lykken, 1984, p. 175)

Psychophysiology as a scientific discipline is concerned with the theoretical and empirical relationships among bodily processes and psychological factors. (Ackles, Jennings, & Coles, 1985, p. ix)

In general terms, psychophysiology is the scientific study of the relationship between mental and behavioral activities and bodily events. (Surwillo, 1986, p. 3)

Psychophysiology... is characterized by an emphasis on human behavior as a complex system in which physiological responses, subjective experiences and overt behavior interact in

complex ways such that to separate out any one of these aspects from the others is to severely limit the theoretical or practical value of any explanatory models that are developed. (Christie & Gale, 1987, p. 8)

As is apparent, there is disagreement regarding the definition of psychophysiology. A major problem in reaching a consensus has been the need to give the field direction and identity by distinguishing it from other scientific disciplines while not limiting its potential for growth. Operational definitions are unsatisfactory for they do not provide long-term direction for the field. Definitions of psychophysiology as studies in which psychological factors serve as independent variables and physiological responses serve as dependent variables distinguish it from fields such as physiological psychology but have been criticized for being too restrictive (Furedy, 1983; cf. Coles, 1988). For instance, such definitions exclude noninvasive studies of higher order mental processes in which physiological events serve as the independent/blocking variable and human experience or behavior serves as the dependent variable (e.g., the sensorimotor behavior associated with operantly conditioned or endogenous changes in cardiovascular or electroencephalographic activity), and studies comparing changes in physiological responses across known groups (e.g., the cardiovascular reactivity of offspring of hypertensive vs. normotensive parents). Moreover, psychophysiology and physiological psychology/psychobiology share goals, assumptions, experimental paradigms, and in some instances, databases but differ primarily in terms of the level of analysis (e.g., organismic-environmental vs. organ-cellular level) and, consequently, the experimental strategy typically employed (e.g., noninvasive-reversible vs. invasive-irreversible experimental procedures). These fields clearly have a great deal to contribute to one another, and ideally this complementarity should not be masked in their definition by the need to distinguish these fields (e.g., see Johnson & Anderson, chapter 8).

The emergence of areas of research in psychoneuroendocrinology (e.g., Baum, Grunberg, & Singer, 1982; Frankenhauser, 1983; Mason, 1972), behavioral neurology (e.g., Lindsley, 1951; Tranel & Damasio, 1985; Tranel, Fowles, & Damasio, 1985; see Matsumoto, Walker, Walker, & Hughes, chapter 3), and psychoneuroimmunology (e.g., Ader, 1981; Henry & Stephens, 1977; Jemmott & Locke, 1984; Kiecolt-Glaser et al., 1984; see Kennedy, Glaser, & Kiecolt-Glaser, chapter 6) raises additional questions about how to define the discipline of psychophysiology. Importantly, anatomy and physiology encompass the fields of neurology, endocrinology, and immunology due both to their common goals and assumptions and to the embodiment, in a literal sense, of the nervous, endocrine, and immunological systems within the organism. Given the parallels among anatomy, physiology, and psychophysiology outlined in the preceding, however, psychophysiology should be defined in terms that accommodate its early focus on the actions of the nervous system as well as more recent psychological and behavioral studies involving neural, endocrinological, and immunological systems and the interactions among these systems.

To summarize, psychophysiology is based on the assumptions that human perception, thought, emotion, and action are embodied phenomena and that the physical responses of the corporeal body, in an appropriate experimental design, can shed light on human nature. The level of analysis in psychophysiology is not on isolated components of the body, but rather on organismic-environmental transactions, with reference to both physical and sociocultural environments.

Psychophysiology can therefore be defined as the scientific study of social, psychological, and behavioral phenomena as related to and revealed through physiological principles and events. In this way, a hierarchy is formed in which anatomy is concerned with bodily structure, physiology with bodily functions, and psychophysiology with organismic-environmental transactions (see Figure 1.1).

In the following section, we review some of the major historical developments that have contributed to contemporary thought in psychophysiology. As might be expected from the discussion thus far, many of these early developments have stemmed from studies of human anatomy and physiology.

1.3 HISTORICAL DEVELOPMENT

We often think, naively, that missing data are the primary impediments to intellectual progress - just find the right facts and all problems will dissipate. But barriers are often deeper and more abstract in thought. We must have access to the right metaphor, not only the requisite information. Revolutionary thinkers are not, primarily, gatherers of facts, but weavers of new intellectual structures. (Gould, 1985, Essay 9)

Although psychophysiology as a formal discipline is only about 30 years old, awareness of and interest in interrelationships between psychological and physiological events can be traced as far back as the early Egyptians and Greek philosopher-scientists. The Greek philosopher Heracitus (c. 600 B.C.) referred to the mind as an overwhelming space whose boundaries could never be fully comprehended (Bloom, Lazerson, & Hofstadter, 1985). Plato suggested that rational faculties were located in the head; passions were located in the spinal marrow and, indirectly, the heart; and instincts were located below the diaphragm where they influenced the liver. Plato also believed the psyche and body to be fundamentally different; hence, observations of physiological responses provided no grounds for inference about the operation of psyche (Stern, Ray, & Davis, 1980). Thus, despite the fact that the peripheral and central nervous system, brain, and viscera were known to exist as anatomical entities by the early Greek scientist-philosophers, human nature was dealt with as a noncorporate entity unamenable to empirical study. The classification of observations instead tended to be along qualitative lines without measurement, empirical assessment, or validation.

In the second century A.D., Galen (c. 130-200) formulated a theory of psychophysiological function that would dominate thought well into the eighteenth century (Brazier, 1959, 1961; Wu, 1984). Hydraulics and mechanics were the technology of the times, and aqueducts and sewer systems were the most notable technological achievements during this period. Bloom et al. (1985, p. 13) suggest: "It is hardly by accident then, that Galen believed the important parts of the brain to lie not in the brain's substance, but in its fluid-filled cavities." Based on his animal dissections and his observations of the variety of fluids that permeated the body, Galen postulated that humors (fluids) were responsible for all sensation, movement, thoughts, and emotion; and that pathologies - physiological or behavioral - were based on humoral disturbances. The role of bodily organs was to produce or process these humors, and the nerves, although recognized as instrumental in thought and action, were assumed to be part of a hydraulic system through which the humors traveled. Galen's views became so deeply entrenched in Western thought that they went practically unchallenged for almost 1500 years.

In the sixteenth century, Jean Fernel (1497–1558) published the first textbook on physiology, *De Naturali Parte Medicinae* (1542). According to Brazier (1959), this book was well received, and Fernel revised and expanded the book across numerous editions. The ninth edition of the book was retitled *Medicina*, and the first section was entitled "Physiologia." Although Fernel's categorization of empirical observations was strongly influenced by Galen's theory, the book "shows dawning recognition of some of the automatic movements which we now know to be reflexly initiated" (Brazier, 1959, p. 2). This represented a marked departure from traditional views that segregated the control of human action and the affairs of the corporeal world.

Studies of human anatomy during this period in history also began to uncover errors in Galen's descriptions (e.g., Vesalius, 1543/1947), opening the way for questions of his methods and of his theory of physiological functioning and symptomatology. Within a century, two additional events occurred that had a profound impact on the nature of inference in psychophysiology. In 1600, William Gilbert (1540 or 1544–1603) recognized a difference between electricity and magnetism and, more importantly, argued in his book, *Magnete*, that empirical observations and experiments should replace "the probable guesses and opinions of the ordinary professors of philosophy." Francis Bacon (1561–1626) took the scientific method a step further in *Novum Organum* (1620/1889), adding induction to observation and adding verification to inference. Brazier (1959) summarized the importance of this work as follows:

Scientists before him were content with performing an experiment in order to make an observation; from this observation a series of propositions would follow, each being derived from its predecessor, not by experiment but by logic. Bacon's contribution to scientific method was to urge, in addition, the rigorous application of a special kind of inductive reasoning proceeding from the accumulation of a number of particular facts to the demonstration of their interrelation and hence to a general conclusion. (p. 3)

Francis Bacon's formulation and subsequent work on the logic of scientific inference (cf. Platt, 1964; Popper, 1959/1968) led to the now familiar sequence underlying scientific inference: (1) devise alternative hypotheses; (2) devise a crucial experiment, with alternative possible outcomes, each of which will disfavor, if not exclude, one or more of the hypotheses; (3) execute the experiment to obtain a clean result; and (4) recycle to refine the possibilities that remain. Such a scheme was accepted quickly in the physical sciences, but traditional philosophical and religious views segregating human existence from worldly events slowed its acceptance in the study of human physiology, experience, and behavior (Brazier, 1977; Harrington, 1987; Mecacci, 1979).

William Harvey's (1578–1657) *De Motu Cordis* (1628/1941), not only represented the first major work to use these principles to guide inferences about physiological functioning, but it also disconfirmed Galen's principle that the motion of the blood in the arterial and venous systems ebbed and flowed independent of one another except for some leakage in the heart. Pumps were an important technological development during the seventeenth century, and Harvey perhaps drew on his observations of pumps in positing that blood circulated continuously through a circular system, pushed along by the pumping actions of the heart, and directed through and out of the heart by the one-way valves in each chamber of the heart. Galen, in contrast, had posited that blood could flow in either

direction in the veins. To test these competing hypotheses, Harvey tied a tourniquet above the elbow of his arm just tight enough to prevent blood from returning to the heart through the veins but not so tight as to prevent blood from entering the arm through the arteries. The veins swelled below but not above the tourniquet, implying that the blood could be entering only through the arteries and exiting only through the veins (Miller, 1978). A variation on Harvey's procedure is used in contemporary psychophysiology to gauge blood flow to vascular beds (see Johnson & Anderson, chapter 8; Papilio & Shapiro, chapter 14).

During this period, which coincided with a burgeoning world of machines, the human eye was conceived as functioning like an optical instrument whose image was projected onto the sensory nerves of the retina; movement was thought to reflect the mechanical actions of passive balloonlike structures (muscles) inflated or deflated by the nervous fluids or gaseous spirits that traveled through canals in the nerves; and higher mental functions were still considered by many to fall outside the rubric of the physical or biological sciences (Bloom et al., 1985; Brazier, 1959; Harrington, 1987). The writings of René Descartes (1596–1650) reflect the presumed division between the mind and body. The actions of animals were viewed as reflexive and mechanistic in nature, as were most of the actions of humans. But humans alone, Descartes argued, also possess a consciousness of self and of events around them, a consciousness that, like the body, was a thing but, unlike the body, was not a thing governed by material principles or connections. This independent entity called mind, Descartes proposed, resides over volition from the soul's control tower in the pineal gland located at the center of the head:

The soul or mind squeezed the pineal gland this way and that, nudging the animal fluids in the human brain into the pores or valves, "and according as they enter or even only as they tend to enter more or less into this or that nerve, they have the power of changing the form of the muscle into which the nerve is inserted, and by this means making the limbs move." (Jaynes, 1973, p. 172, paraphrasing and quoting from Descartes)

Shortly following Descartes' publication of *Traite de l'Homme* (c. 1633), Steno (1638–1686) noted several discrepancies between Descartes' dualistic and largely mechanistic characterization of human nature and the extant evidence about animal and human physiology. For instance, Steno noted that the pineal gland (the purported bridge between the worlds of the human mind and body) existed in animals as well as humans, that the pineal gland did not have the rich nerve supply implied by Descartes' theory, and that the brain was unnecessary for many animal movements (cf. Jaynes, 1973). Giovanni Borrelli (1608–1679) disproved the notion that movement was motivated by the inflation of muscles by a gaseous substance in experiments in which he submerged a struggling animal in water, slit its muscles, and looked for the release of bubbles (Brazier, 1959). These observations were published posthumously in 1680, shortly after the suggestion by Francesco Redi that the shock of the electric ray fish was muscular in origin (Basmajian & Deluca, 1985; Wu, 1984).

Despite the prevalent belief during this period that the scientific study of animal and human behavior could apply only to those structures they shared in common (Bloom et al., 1985; Harrington, 1987), the foundations laid by the great seventeenth-century scientist-philosophers encouraged students of anatomy and physiology in the subsequent century to discount explanatory appeals to the human soul or mind (Brazier, 1959). Consequently, experimental analyses of physiological events and

psychological constructs (e.g., sensation, involuntary and voluntary action) expanded and inspired the application of technological advances to the study of psychophysiological questions. For instance, the microscope was employed (unsuccessfully) in the late seventeenth century to examine the prevalent belief that the nerves were small pipes through which nervous fluid flowed, and by 1849 Du Bois-Reymond provided evidence using the galvanometer of electrical charges from human muscles as a result of volitional muscle contraction.

According to Brazier (1959, 1977), that electricity might be the transmitter of nervous action was initially seen as unlikely because, drawing upon the metaphor of electricity running down a wire, there was believed to be insufficient insulation around the nerves to prevent a dissipation of the electrical signal. Luigi Galvani's (1737-1798) experiments on the effects of electricity on muscle contraction and the work that followed (see Cacioppo, Tassinary, & Fridlund, chapter 11) ultimately verified that neural signals and muscular actions were electrical in nature, that these electrical signals were the result of biochemical reactions within specialized cells, and that there was indeed some dissipation of these electrical signals through the body fluids that could be detected noninvasively at the surface of the skin. Specific advances during the nineteenth and twentieth centuries in psychophysiological theory and research are discussed in the remainder of this book. However, the stage had been set by these early investigators for the scientific study of psychophysiological relationships.¹

1.4 PSYCHOPHYSIOLOGICAL RELATIONSHIPS AND PSYCHOPHYSIOLOGICAL INFERENCE

We praise the 'lifetime of study,' but in dozens of cases, in every field, what was needed was not a lifetime but rather a few short months or weeks of analytical inductive inference.... We speak plausibly of taking measurements and making small studies that will 'add another brick to the temple of science.' Most such bricks just lie around the brickyard. (Platt, 1964, p. 351)

The importance of the development of more advanced recording procedures to scientific progress in psychophysiology is clear as previously unobservable phenomena are rendered observable. Less explicitly studied, but no less important, is the structure of scientific thought about psychophysiological phenomena. For instance, Galen's notions about psychophysiological processes persisted for 1500 years despite the availability for several centuries of procedures for disconfirming his theory in part because the structure of scientific inquiry had not been developed sufficiently (Brazier, 1959).

One important form of psychophysiological inference to emerge from the work of Francis Bacon (1620/1889) involves the identification of two or more hypotheses about some phenomenon, devising a set of conditions with alternative possible outcomes that will exclude one or more of the hypotheses, and establishing the conditions and collecting the observations while minimizing measurement error (cf. Platt, 1964; Popper, 1959/1968). If the data are consistent with only one of the theoretical hypotheses, then the alternative hypotheses with which the investigator began become less plausible. With conceptual replications to ensure the construct validity, replicability, and generalizability of such a result, a subset of the original hypotheses can be discarded, and the investigator recycles through this sequence. One weakness of this procedure is the myriad sources of variance in psychophysiological

investigations and the stochastic nature of physiological events and, consequently, the sometimes poor replicability or generalizability of the results (cf. O'Connor, 1985). A second is the intellectual invention and omniscience that is required to specify *all* relevant alternative hypotheses for the phenomenon of interest. Because neither of these can be overcome with certitude, progress in the short term can be slow and uncertain. Adherence to this sequence provides grounds for strong inference in the long term, however (Platt, 1964).

Importantly, physiological responses are often of interest only to the extent that they allow one to index a psychological process or state. This is an important endeavor, but the sequence underlying psychophysiological inferences often violates the logic of hypothetico-deductive research because inferences about events in the psychological domain are not based so much on the exclusion of alternative hypotheses as on reasoning by analogy. In a typical example, a physiological response is identified that is affected by variations in the psychological process of interest. This physiological response is subsequently monitored, perhaps in yet a different assessment context, in an effort to determine the likely presence or extent of the psychological process of interest (see review by Cacioppo & Petty, 1986). In an illustrative study, subjects were exposed to moderately or highly counterattitudinal assertions while electrodermal activity was monitored (Cooper, 1959). Results revealed greater changes in electrodermal activity following exposure to the highly counterattitudinal assertions. Based on prior research showing that emotionally arousing stimuli are associated with increased electrodermal activity, the higher electrodermal responding to highly rather than moderately counterattitudinal assertions was interpreted as meaning that more extreme attitudes were imbued with greater emotion. That is, electrodermal activity appeared *as if* an emotionally arousing stimulus had been presented. The problem with this form of psychophysiological inference is that knowledge that a statement is true (e.g., the manipulation of a psychological factor leads to a change in some target physiological response) does *not* imply that the converse is true. For instance, the prior research showing that factors other than emotional arousal can influence electrodermal activity (e.g., novelty stimulus significance; see Dawson, Schell, & Filion, chapter 10) was not considered. The logical flaw in this form of psychophysiological inference is termed the affirmation of the consequent (Runes, 1961; cf. Cacioppo, Petty, & Losch, 1986).

This need not be the case, however. In this section, we present a general framework for thinking about relationships between psychological concepts and physiological events, and we discuss the rules of evidence for and the limitations to inference in each (see also, Cacioppo & Tassinary, 1989).

1.4.1 A simple taxonomy of psychophysiological relationships

1.4.1.1 Elements in the psychological and elements in the physiological domains

A useful way to construe the potential relationships between psychological events and physiological events is to consider these two groups of events as representing independent sets (domains), where a set is defined as a collection of elements who together are considered a whole. Psychological events are conceived as constituting one set, which we shall call set Ψ , and physiological events are conceived as constituting another, which we shall call set Φ (Troland, 1929, p. 144-145).² Inspection of Figure 1.2 (upper left panel) reveals that all elements in the set of

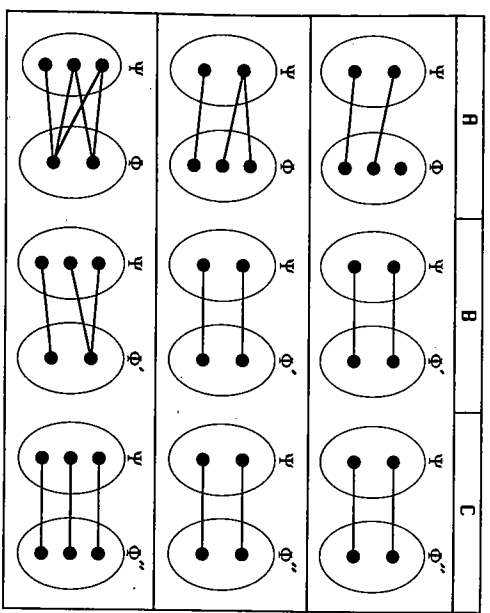


Figure 1.2. Depiction of logical relations between elements in the psychological (Ψ) and physiological (Φ) domains. *Panel A:* Links between psychological elements and individual physiological responses. *Panel B:* Links between psychological elements and physiological response patterns. *Panel C:* Links between psychological elements and profile of physiological responses across time.

psychological events are assumed to have some physiological referent, reflecting our adherence to the monistic identity thesis (i.e., the first assumption underlying psychophysiology).³

Focusing first on the top row of Figure 1.2, the existence of psychologically irrelevant physiological events (e.g., random physiological fluctuations; increased electrodermal activity due to minor variations in body temperature) is of importance in psychophysiology for purposes of artifact prevention or elimination. However, such elements within the physiological domain can be ignored if nonpsychologic factors have been held constant, their influence on the physiological responses of interest has been identified and removed, or it does not overlap with the physiological event of interest. These objectives are achieved through the application of proper psychophysiological recording techniques (which are discussed in detail in part III of this book). The important point here is that the achievement of these objectives simplifies the task of specifying psychophysiological relationships, in the ideal case, by eliminating physiological events that have no direct relevance to psychological events (e.g., see Figure 1.2, top row of panel B).

We can now state five general relations that might be said to relate the elements within the domain of psychological events, Ψ , and elements within the domain of physiological events, Φ (see Figure 1.3). These are as follows:

- 1 A one-to-one relation, such that an element in the psychological set is associated with one and only one element in the physiological set, and vice versa.
- 2 A one-to-many relation, meaning that an element in the psychological domain is associated with a subset of elements in the physiological domain.
- 3 A many-to-one relation, meaning that two or more psychological elements are associated with the same physiological element.

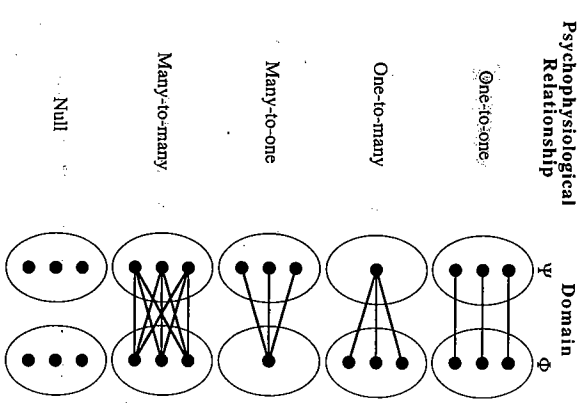


Figure 1.3. Possible relationships between elements in the psychological domain (Ψ) and elements in the physiological domain (Φ).

- 4 A many-to-many relation, meaning two or more psychological elements are associated with the same (or an overlapping) subset of elements in the physiological domain.
- 5 A null relation, meaning there is no association between an element in the psychological domain and that in the physiological domain.⁴

Of these possible relations, only the first and second allow a formal specification of psychological elements as a function of physiological elements (cf. Coombs, Dawes, & Tversky, 1970, pp. 351-371). This is important because, as we have noted, psychophysiological research typically involves the manipulation of (or blocking on) elements in the psychological domain and the measurement of elements in the physiological domain. The grounds for inductive reasoning in psychophysiology, therefore, can be strengthened if a way can be found to specify the relationship between the elements within Ψ and Φ in terms of a one-to-one relationship. Although somewhat involved, this is often possible.

1.4.1.2 *Physiological elements as spatial and temporal response profiles*

First, a one-to-one relation can exist, such that an element in the psychological set is associated with one and only one element in the physiological set. Such relationships provide strong grounds for inference but are not common cross-situationally at present in psychophysiology (e.g., see Coles et al., 1987; Donchin, 1982). The functional opposite of the one-to-one relation is the null relation, which means that the element in the physiological domain is unrelated to and, hence, harbors no information about the element in the psychological domain. A third form of relation between elements in the psychological and physiological

