

CHAPTER 24

**Social Psychophysiology:
Bioelectrical Measurement,
Experimental Control, and
Analog-to-Digital Data Acquisition**

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INTRODUCTION

Social psychophysiological research is distinguished by its integrative analysis of physiological and social factors and systems (cf. Cacioppo, 1982; Cacioppo & Petty, 1981a; Schwartz & Shapiro, 1973; Shapiro & Schwartz, 1970). Contributions to this book attest to the advances that have been made in understanding how physiological mechanisms are affected by social factors, explaining complex social behaviors that are affected by both situational and internal (e.g., detected physiological) events, and constructing testable and more precise social psychological predictions. This approach also promises to lead to the development of more realistic social psychological theories resulting from investigators considering the physiological substrates of overt behavior and the biological limitations to which their abstract theories must ultimately adhere.

Electrophysiological measures can be expected to yield unambiguous information, however, only if recorded properly and obtained within an experimental design that exposes the contingencies between the bioelectrical events and social psychological constructs. Obtaining valid and reproducible bioelectrical measurements is a small technical wonder in itself. "You've got to pull out a low-level voltage from high-level noise, build or employ equipment to survive anything from liquid spills to high-voltage pulses and—most important—make sure the patient is protected from electrical hazard while you're about it" (Svetsz & Duane, 1975, p. 68). In the

first portion of this chapter, we elaborate on some of the basics of electrophysiological measurement that were broached in preceding chapters. Next, we outline issues regarding the experimental context and survey potentially confounding variables. Afterward, we describe a flexible yet relatively inexpensive laboratory for social psychophysiological research that we have developed at the University of Iowa, and the procedures for experimental control and analog-to-digital data acquisition that we have adopted are explained. The description of the Iowa laboratory is used to illustrate in concrete terms some of the issues and decisions that are raised in this and the preceding two chapters. We end the chapter by discussing a few nonelectrophysiological procedures for social psychophysiological research.

BIOELECTRICAL MEASUREMENT

Bioelectrical signals generally range in magnitude from a millivolt (mV), such as might result from the ventricular contraction of the heart, to a few microvolts (μV), such as might result from the muscle action potentials of a small skeletal muscle. Extracting these signals can be difficult because the person in a laboratory is basked in about 10 V of electrical "noise," which arises from surrounding electrical sources (e.g., lighting, power lines, motors, transformers) and from the similar coupling of the body and apparatus to powerline grounds (Svetz & Duane, 1975).

Bioelectrical signals can be classified as spontaneous or event-related, and as tonic or phasic. *Spontaneous or nonspecific activity* refers to bioelectrical events that occur in the absence of a designated or identified stimulus. For instance, subjects may vary in their responding to the experimenter or laboratory. Unless attributes of the experimenter or laboratory are manipulated or assessed in some manner (e.g., Fankin & Campbell, 1955), the physiological responses to these stimuli would be included in the category called spontaneous or nonspecific, since these would be among the physiological responses that appeared "unrelated" to specific stimuli or experimental events. The opposite of a spontaneous physiological response is an *event-related response*, which can be characterized by a stable temporal relationship to an actual or anticipated stimulus. An event-related physiological response is sometimes said to be "evoked" or "elicited."

Orthogonal to the classification of a response as spontaneous or event-related is the categorization of a physiological response as phasic or tonic. *Phasic physiological responses* refer to short-term bioelectrical events that return to their prior level of activity. When a bioelectrical event persists and appears not as a transient shift, but rather as an adjustment in the level of activity, the change in activity would indicate a change in *tonic physiological response*. A sudden quickening of the heart beat when concentrating on a difficult task would clearly classify as a phasic change as long

as heart rate returned to its normal (i.e., prestimulus) level within a matter of seconds. The distinctions between tonic and phasic physiological responses can at times be difficult to determine in practice, and interested readers might wish to consult the discussion of phasic responses by McHugo and Lanzetta (Chapter 23, this volume) and texts on techniques in psychophysiology for the details of these distinctions for any given system of response (e.g., Brown, 1967; Greenfield & Sternbach, 1972; Martin & Venables, 1980; Stern, Ray, & Davis, 1980; Venables & Martin, 1967).

But how are bioelectrical signals recorded in the first place? We turn to this question next.

The Laboratory Context

In many pioneering and some contemporary studies in social psychophysiology, little attention has been given to the laboratory context. A polygraph has been wheeled into a room accommodating a subject, electrodes or transducers were applied to the subject, and bioelectrical recordings were obtained from the subject. This procedure may seem expedient, particularly if a sound experimental design is employed, but at a minimum extraneous sources of electrical and auditory noises threaten the sensitivity and validity of the psychophysiological measures obtained. In this section we briefly summarize the major considerations that should be given when developing a laboratory for social psychophysiological research. Although there are a few sources of helpful information that readers may wish to consult (e.g., manufacturers' literature), we found Gale and Smith's (1980) compilation of the suggestions of a large sample of the members of the Society for Psychophysiological Research and of the Psychophysiological Group of Great Britain to be a particularly valuable resource.

According to Gale and Smith (1980), there are five areas of concern: extraneous auditory noise, extraneous electrical noise, extraneous psychosocial noise, computer installation, and technical assistance.

Extraneous Auditory Noise

As Gale and Smith (1980) note, the principal sources of disturbing auditory noise are (1) traffic outside the building (e.g., automobiles, airplanes, students passing between bars), (2) traffic inside the building (e.g., students passing between classes; sounds from adjacent animal, children, or group processes labs), (3) machinery (e.g., elevators, typewriters, telephones, workshops), (4) the building (e.g., water running through pipes, rain or winds striking the exterior of the building), and (5) the control room of the laboratory (e.g., experimenters, slide projectors, relays, computer printers). The decision regarding the location of the laboratory can minimize the problems arising from the first four sources of noise. In

addition, with the advent of closed-circuit television, the control room and subject's chamber can be separated by a wall and sound-attenuating material rather than by large observation windows. Apparatus, such as the polygraph, computer, slide projector, and tape deck, can be placed in the control room to minimize the sounds that they might produce while in use. For instance, we found that the sound made by a slide projector was disturbing to (i.e., elicited autonomic responses from) subjects sitting in an otherwise quiet environment. At present, our subject's chamber and control room are located adjacently at the end of a hallway of social psychological laboratories, and we use a small projection window to present visual stimuli from the control room to subjects in their quarters. All the cables that pass between the rooms do so through conduits that are stuffed with foam. These arrangements have been the most important and effective of those available to attenuate distracting and extraneous sounds in the subject's room.

The control and subject's rooms can be constructed to attenuate the remaining noise. Gale and Smith (1980) indicate that soundproofing tiles and other fabric inside the subject's chamber are ineffective in attenuating sounds coming from outside the chamber and suggest that soft lining (e.g., thick curtains) be installed around the source of the noise (e.g., in the control room) to reduce echo and transmissions to the subject's room.

Achieving reasonable sound attenuation is not difficult or expensive, particularly if the laboratory can be located in a quiet part of the building. Complete sound attenuation, however, is not only very expensive, but can be dissettling to subjects. Hence, a careful decision about where to locate the laboratory, a modest investment to insulate the equipment in the control room, and a limited investment to insulate the subject's chamber from other intrusive noises are probably best for most purposes.

Extraneous Electrical Noise

The need to reduce or eliminate external electrical interference is another consideration when selecting the location of the laboratory. Major sources of electrical interference include elevators, workshops (e.g., arc welding), flickering neon lamps, motor relays, fluorescent lights and dimmers, and ventilation control systems (Gale & Smith, 1980). To some extent, the differential amplifiers used commonly in electrophysiological recording serve to attenuate these confounding electrical signals. Differential amplifiers are so named because they take the difference between the two input signals obtained from the electrodes or transducer and magnify this difference. Theoretically, the electrical signals ("noise") that appear at both inputs simultaneously have no effect on the output of the amplifier. In practice, unfortunately, differential amplifiers are imperfect in function, and low-level bioelectrical events can be lost in the sea of electrostatic noise that emanates from external electrical sources (for more details on

amplifiers, see McGuigan, Chapter 22, this volume). Accordingly, locating the laboratory away from major sources of external electrical interference can reduce the problem as well as minimize the need for expensive apparatus, such as shielding around the subject's room (see McGuigan, Chapter 22).

Ideally, lighting and equipment should be powered by a dc rather than an ac supply; at a minimum, incandescent rather than fluorescent room lighting should be employed, as these procedures will aid in minimizing extraneous electrical interference in psychophysiological recordings. Carpeting in and around the laboratory should be the electrically groundable type, as electrostatic discharges can be detrimental to microcomputer and control-logic equipment. Finally, and importantly, proper grounding procedures, which are discussed in detail in Chapter 22 (see also Gale & Smith, 1980; Stern *et al.*, 1980), are necessary to attenuate extraneous electrical interference and to ensure the safety of the subject and experimenter.

Extraneous Psychosocial Noise

The laboratory artifacts that plague social psychologists in studies of overt behavior (e.g., demand characteristics, evaluation apprehension, experimenter bias) are no less a problem in social psychophysiological research, since reliable and valid measures of social psychological constructs are the object of study in both settings. The presence of electrical instrumentation, cables, and bioelectrical sensors can exacerbate the investigator's problem of involving the subject in the experimental task *per se*, for although psychophysiological measures are noninvasive, they can most certainly be obtrusive. Social psychologists, who have nearly perfected the instructional manipulation (cf. Aronson & Carlsmith, 1969), are quick to appreciate the care with which the experimental instructions and task must be prepared. Less obvious, perhaps, is the importance of the experimenters being skilled technicians in the laboratory. The behavior of the experimenters in a social psychophysiological study can be a major determinant of the ease with which subjects can adapt to the sensors that are attached and the electrical equipment they know stands nearby. Subjects generally find the sensors, electroconductive gels, adhesives, and so forth, to be novel. If the experimenters appear unknowledgeable about procedures or apparatus, or incompetent in performing their task, the subjects may become anxious about their own safety and, consequently, become less attentive to the various experimental stimuli. Thus, the sensitivity and reliability of the electrophysiological responses to the experimental treatments can be enhanced greatly by training experimenters in the technical aspects of psychophysiological recording and the social aspects of establishing rapport with the subject while remaining objective and detached. Finally, double-blind procedures can be used to minimize

experimenter bias and are feasible to employ if the critical experimental instructions can be automated or delivered from the control room following the preparation of the subject.

Ideally, the preparation of the subject for electrophysiological recordings is done in a separate room that is carpeted (to help minimize noise and echos), painting in a soothing (e.g., pastel) color, and furnished in a comfortable style (e.g., minimal electrical wiring in view, paintings on the walls) to attenuate any anxieties he or she may have about participating in the study. Although some equipment is unavoidable in this room, the less intimidating or unusual the room appears to the subject, the more quickly he or she will adapt to the setting and respond solely to the experimental treatments. Of course, when the subject is ultimately led to the testing room, another period of adaptation will be required. Again, the less intimidating or unusual the room appears to the subject, the more quickly he or she will adapt to the extraneous environmental factors.

Computer Installation

The large quantities of data involved and the need for precise, flexible, and sophisticated manipulations of experimental treatments have made the use of computers in social psychophysiological research particularly attractive. There are, however, several issues that might be considered when selecting and interfacing a computer to the polygraph. Obvious concerns such as space, adequate power, air conditioning and humidifying equipment, and cables and conduits for interfacing the computer to the other equipment in the laboratory can create major problems for installation if overlooked (Gale & Smith, 1980). Additional issues that we faced while developing a microcomputer-based laboratory for social psychophysiological research are detailed in the following major section of this chapter.

Technical Assistance

Many researchers who wish to employ electrophysiological equipment have extensive expertise that do not intersect with electronics. For this reason, technical assistance in developing and maintaining a laboratory is common. However, the need for technical assistance can be reduced substantially by investing 6 months in the intensive study of electronics and computer systems (Gale & Smith, 1980). Although one is unlikely to learn enough in 6 months to do without technical assistance, the selection of, and communication with, those providing the technical support can be greatly improved by such study. Of course, consulting with knowledgeable colleagues can also be helpful. Moreover, outline what skills you need, or what technical tasks are at hand, *before* seeking technical support. The technician is likely to know less about the requirements and limitations of your particular research objective than you know about (or are willing to learn about) electronics.

There also appears to be a strong lure of hardware and fancy equipment, particularly (though not exclusively) to those providing technical support:

Psychophysiology does have its own brand of sophisticated alchemy, of course; there are now several manuals of a very technical nature, which discuss (in what may appear to the outsider as obsessional and excruciating detail) problems of electronic circuitry, electrode preparation and placement, waveform analysis, computer storage of data, and so on. My view is that this sophistication has been misplaced, since technical aspects have often been overemphasized at the expense of the art of *experimentation*. (Gale, 1973; italics added)

It is expedient, therefore, to inform the technicians that modifications in an operating system (e.g., replacing floppy disks with a hard disk storage system) must be accomplished in a manner that minimizes the disruptions of ongoing research so that you are able to maintain, for the most part, an uninterrupted program of research on social variables. (We have found that the projected "downtime" for design modifications is generally badly underestimated.)

Psychophysiological Data Collection

Overview

As outlined in Chapter 22, collecting physiological measures can be examined in four major stages: (1) sensing, (2) amplifying, (3) recording, and (4) quantifying. To review briefly, *sensing* involves the selection and application of the appropriate electrodes or transducers required to detect the desired bioelectrical signal while attenuating background electrical noise. Once a signal has been detected, enhancement of the signal and attenuation of the background noise is accomplished during the *amplification* stage using, for example, differential amplifiers. In the *recording* stage, the physiological analog signals are stored using chart-and-pen recorder and/or FM tape recorders. Laboratory computers are increasingly employed to digitize analog signals and record these values as the ultimate object of statistical analyses (Law, Levey, & Martin, 1980).

Representative Problems and Sources of Artifacts

One complication in the interpretation of physiological measures is that large differences exist among individuals in the stability and reactivity of their physiological responses. This idiosyncratic source of variance can be diminished by collecting and correcting for prestimulus differences in responding and/or by treating your major independent variables as within-subject factors in mixed-factor experimental designs. In between-subjects designs, of course, a physiological response is measured as a function of

factors that are varied between subjects. In within-subject designs, the baseline physiological level is established prior to each trial or block of trials, physiological changes are measured relative to the pretrial baseline level, and treatments are varied within or between blocks of trials. We have attempted to blend the best of each in mixed-factor designs wherein we conduct two versions or "replications" of each experiment, with replications treated as a between-subjects factor and differing primarily in the ordering of the experimental stimuli (e.g., Cacioppo & Petty, 1981b).¹ Each replication includes multiple practice and experimental trials, which, in turn, consist of epochs such as a variable-length intertrial interval (the last several seconds of which serve as the baseline interval for that trial), the pretaped announcement of a question or forewarning, a postwarning/prestimulus (wait) interval, the presentation of the test stimulus for the primary task (e.g., a decisional problem, a controversial editorial), and a brief post- (overt) response interval. The partitioning of a trial is not invariant, but rather can be accomplished in whatever manner best suits an investigator's goals.

A second methodological procedure useful in social psychophysiological research is the paced or time-locked procedure (Kahneman, Tursky, Shapiro, & Crider, 1969; see Shapiro & Schwartz, 1970). In the time-locked procedure, the subject is given information and responds at specified moments during a recording trial (e.g., at a slide change). Moment-by-moment physiological responses throughout the trial are recorded. Subsequently, average physiological response profiles are determined for each subject and condition. The averaging procedure can actually serve to magnify small but consistently positive or negative bioelectrical events that are masked in a random distribution of "noise" (e.g., the averaged electrocortical potential or contingent negative variation—see Chapter 22). In other instances, the time-locked procedure simply aids discriminating between tonic and phasic activity, differentiating the experiment's event-related responses from spontaneous responses, and assessing the covariation among responses obtained from several modalities (e.g., physiological, verbal, motoric) by providing a clearer picture of the form and time course of the physiological responses.

Third, there are generally low intercorrelations among physiological responses (Lacey, 1959, 1967) except following particularly novel or intense stimuli (e.g., a gun shot—Darrow, 1929; see Lang, 1971; Lazarus,

1. Inclusion of "Replications" as a factor allows one to generalize more confidently from findings that emerge across the replications to other sequences of treatments. Generalization is limited only if the Replication factor interacts with a within-subject factor. This mixed design also allows investigators to standardize the psychophysiological data within subjects, for although this standardization procedure may eliminate a main effect attributable to the Replication factor, it does not eliminate interactions involving the Replication and within-subject factors.

1966; Mewborn & Rogers, 1979). One implication of this dispersion of physiological activity is that a multivariate analysis of a profile of physiological responses may yield information about patterns of physiological responses that is not apparent in univariate analyses (see Fridlund & Izard, Chapter 9, this volume; Schwartz, 1982). McHugo and Lanzetta (Chapter 23, this volume) provide a summary of the various multivariate procedures currently employed in psychophysiological research.

Fourth, potentially confounding influences are inherent when comparing two distinct populations, such as people who differ in public self-consciousness (see Scheier, Carver, & Matthews, Chapter 18) or extraversion (see Geen, Chapter 13). In all likelihood, there are differences between the two populations other than the variable of interest, and these differences may be capable of influencing psychological and physiological responses (Pollin, 1962). There theoretically will always be differences between groups unless the groups are constituted randomly, and ultimately, the only means of increasing the reasonableness of the argument that a dispositional or group characteristic is responsible for a particular manner of physiological responding is to manipulate this characteristic.

Finally, social-developmental or longitudinal studies employing electrophysiological measures are complicated by the effects of seasonal environmental variables on physiological responses.² Lengthier periods of acclimatization than might normally precede an experimental session, range corrections (Lykken, Rose, Luther, & Maley, 1966), transformations to normalize the data (see Levey, 1980), and within-subject comparisons for longitudinal studies can be utilized to minimize the variance in physiological responding that is attributable to seasonal or irrelevant environmental factors.

EXPERIMENTAL CONTROL AND ANALOG-TO-DIGITAL DATA ACQUISITION: AN ILLUSTRATION OF A MICROCOMPUTER-BASED LABORATORY

As the instrumentation and recording procedures in psychophysiology become more standardized, and the experimental control of potent factors in the setting becomes more complete, reproducible chart-and-pen (analog) records of subtle physiological responses to a stimulus are increasingly attainable. *The acquisition of comparable analog records of physiological responding is*

2. Wegner (1962), for instance, reported that these factors almost ended his psychophysiological research:

The school-age subjects of the Fels Research Institute came for biannual testing. My first two sets of data showed little correspondence, even though an air-conditioned laboratory has been employed during the summer. Fortunately, I continued work in the second winter and found winter-to-winter consistencies that were not reflected in the summer data. (p. 106)

not sufficient, however, for achieving psychophysiological results that are comparable across laboratories or studies. Psychophysiological data are not analyzed in their analog form, but rather they are digitized and summarized using descriptive statistics. The manner (e.g., sampling rate) in which the analog data are digitized, the nature of the parameters (e.g., amplitude, magnitude, variance) extracted from the digital representation of the analog signal, the manner in which a given set of parameters is extracted (e.g., using reciprocals, range corrections, transformations), and the nature of the inferential statistics employed when analyzing the extracted parameters can each affect the final results obtained and the conclusions drawn.

A simple example should illustrate. The integrity of an analog waveform can be retained in a digital array only if the rate of analog-to-digital (A/D) conversion is at least twice as fast as the fastest frequency in the analog signal (see Figure 24-1). Obviously, the array of digital values needed to represent transient physiological responses can become large quickly, and human errors, either in the A/D calculations or in the transcriptions, can become quite likely.

Computers in psychophysiological research have proven to be a powerful tool, for several reasons. First, the experimental control and timing of events can be very specific, simplifying the process of signal averaging and the detection of event-related physiological responses. Second, the A/D conversions can be programmed to occur tirelessly and reliably at high speeds if necessary. Third, response detection and parameter extraction through the use of computers require a formal explication of procedures, rendering these procedures (in the form of computer programs) open for public scrutiny and replication. Fourth, as evidenced in several of the preceding chapters (e.g., see Chapters 13 through 15), whether physiological activity is thought to vary as a function of social factors depends in part on what physiological effector is monitored and what parameters are extracted. For instance, Moore and Baron (Chapter 15) report that the mere presence of others typically has no effect on heart rate, but, occasionally at least, it has an excitatory effect on skin conductance responses. The overall physiological effects of the mere presence of others is difficult to determine from these data, since seldom is more than one parameter examined in any given study. However, the processing speed of computers has substantially reduced the cost of recording multiple measures simultaneously and extracting several parameters from each (e.g., skin conductance level, skin conductance response amplitude), so that the effects of social factors on physiological systems can be more accurately determined. Moreover, the study of the reciprocal influence of social and physiological systems is aided by the simultaneous recording of people's reportable, behavioral, and physiological responses. Again, laboratory computers are proving to be of assistance, as they can often provide the needed speed, reliability, and storage capacity for the volumes of data obtained.

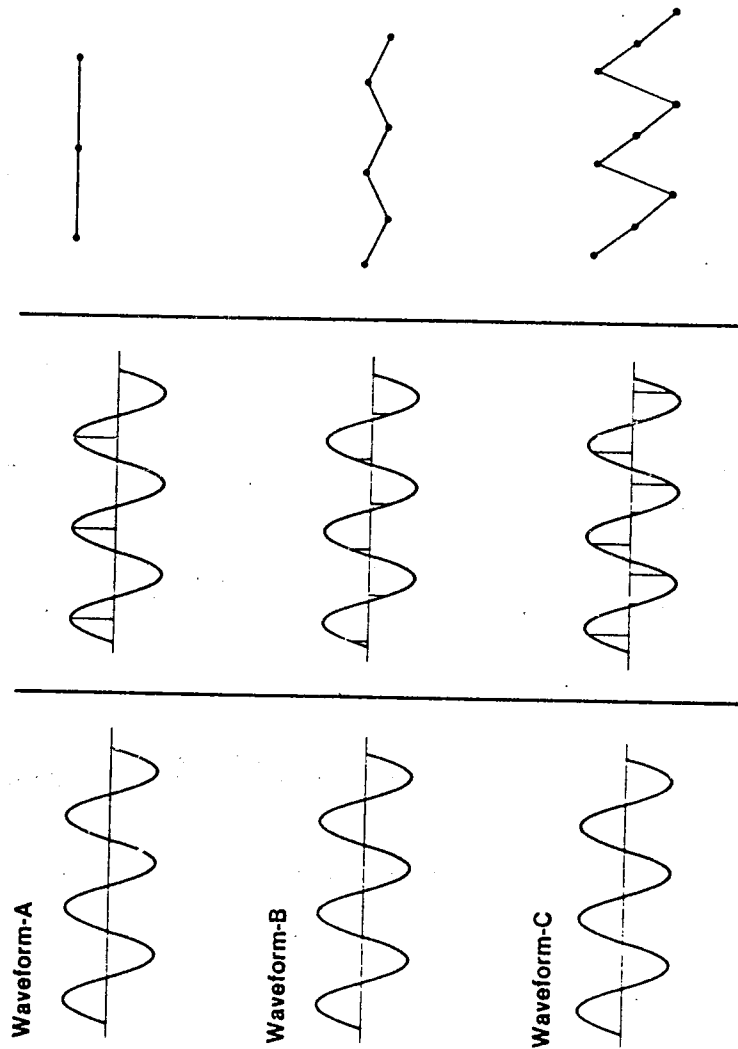


FIGURE 24-1. Three identical analog signals are illustrated in the left panel. In the middle panel, these signals are reproduced with vertical lines representing analog-to-digital (A/D) conversions. The rate of A/D conversion is equal to the frequency of the fastest component of the analog signal in waveform A in the middle panel, twice the frequency of the fastest component of the analog signal in waveform B of the middle panel, and three times the frequency of the fastest component of the analog signal in waveform C. In the right panel, the analog signals are reproduced from the digital arrays obtained from the A/D conversions depicted in the middle panel. The waveforms reproduced in the right panel, rather than the original waveforms in the left panel, form the basis for data processing and analysis, thereby illustrating that the rate of A/D conversion is one of several technical factors independent of bioelectrical measurement that govern the comparability of results across psychophysiological studies.

In this section of the chapter we describe a relatively inexpensive and flexible microcomputing system developed specifically to control social psychophysiological experiments, collect analog and digital data, and extract dependent variable measures for the reportable, physiological, and motoric states. Readers not interested in using computers in psychophysiological research may wish to forgo this discussion and proceed directly to the following section, "Nonelectrophysiological Procedures."

Hardware Configuration

The hardware configuration of the Iowa Social Psychophysiological Laboratory is displayed in Figure 24-2. Although the microcomputers employed in this laboratory are typically marketed as personal (hobby) computers, their design allows their conversion to a powerful laboratory computer. Specifically, we employ the general hardware configuration of the Apple II/FIRST system developed and described by Scandrett and Gormezano (1980). Our system consists of two 16-sector Apple II Plus microcomputers, each augmented by an AM9511 floating-point processor and 8253 programmable counter/timer configured to provide a real-time clock. Each microcomputer is equipped with 48K of memory, a random access memory card that provides up to an additional 16K of memory; two 5¼-inch minifloppy disk drives, and a 9-inch video monitor. The primary microcomputer (see Figure 24-2) is additionally equipped with a 16-channel 8-bit A/D converter, a 16-channel 8-bit D/A converter, and two 8255 programmable peripheral interface (PPI) chips providing a pair of 24-bit digital input/output (I/O) buffers, which are used for experimental control and digital data acquisition. At present, up to eight physiological (analog) responses may be sensed and recorded simultaneously from a human subject.³ The channels in the system include one dc channel for electrodermal (EDA) input, six ac channels for EMG or EEG inputs, and one channel for moment-by-moment heart rate input. Other input devices include a hand-held potentiometer for subjects to indicate their moment-by-moment subjective state, up to 11 reaction-time keys for discrete behavioral responses, and a panel of 10 switches for entry of judgments, ratings of attitudes, and decisions in choice situations. Output devices that can be switched on or off include a slide projector, the paper drive on the polygraph, a display panel containing a row of five lights, a large-dial galvanometer for use in providing veridical or bogus feedback, two tone generators, and a tape deck. In addition, a probe stimulus may be presented

3. The typical sampling rate employed is 100 observations per channel per second, which can quickly yield more data than can be stored internally in the computer. Hence, data must be transferred periodically from the computer to the hard disk. By using "virtual arrays" during data collection, this transfer of data from the primary microcomputer to the hard disk essentially becomes invisible to the subject and user.

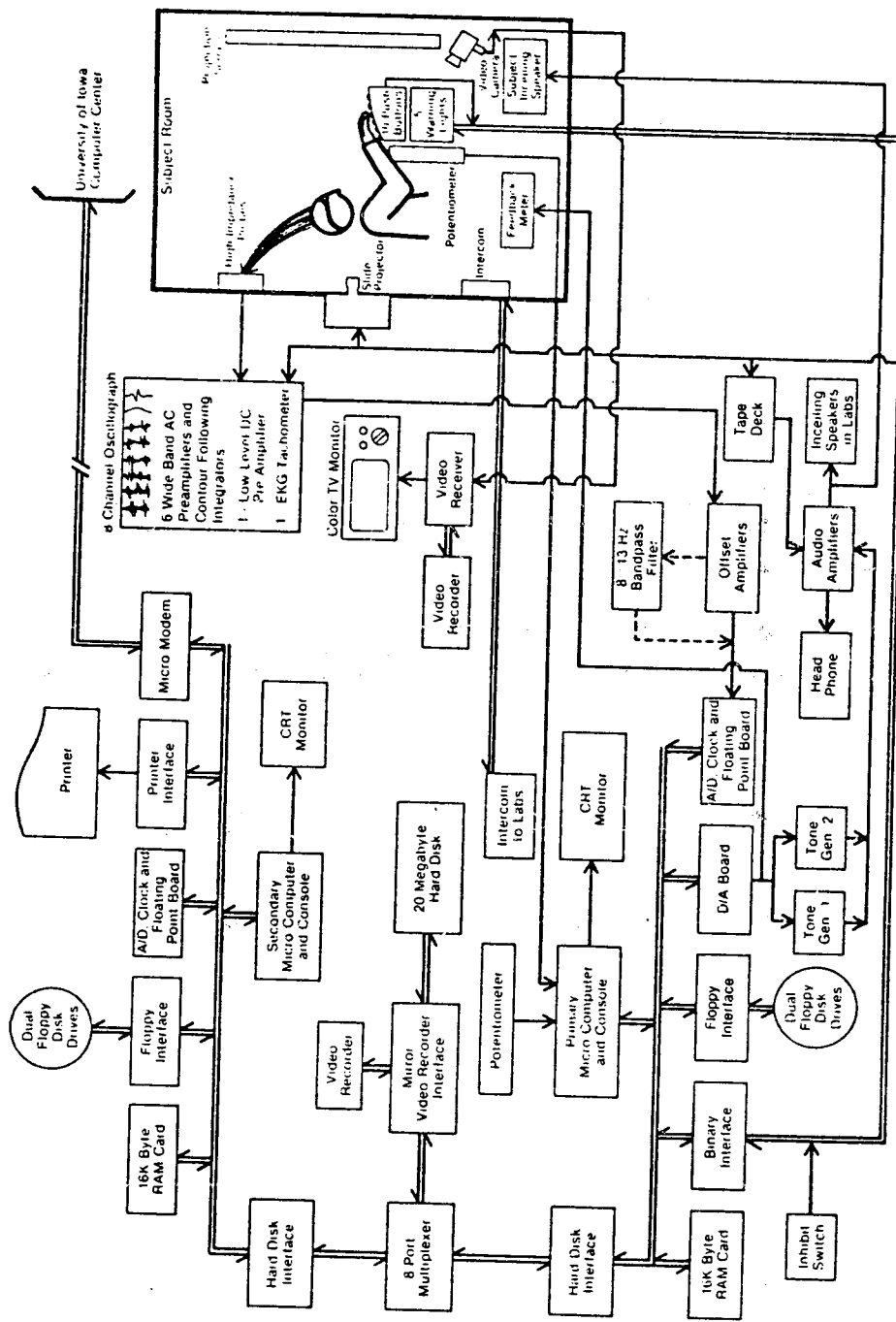


FIGURE 24-2. Hardware components of a social psychophysiological laboratory. Adapted from Cacioppo (1982).

during the task epoch on some trials. The probe stimulus (e.g., a brief tone) initiates a secondary task that subjects perform by pressing a reaction-time key as quickly as possible whenever the stimulus is presented. Subjects' reaction time to the probe stimulus is used as an independent measure of the proportion of the individual's total available processing capacity that he or she utilizes while performing the primary task (e.g., see Tyler, Hertel, McCallum, & Ellis, 1979). The primary microcomputer serves to time the presentation of the stimuli and demarcate the epochs while also identifying and recording physiological, attitudinal, and behavioral responses obtained during or following a trial. The secondary microcomputer, which can serve as a backup for the primary microcomputer, is typically dedicated to data processing and analysis. The secondary microcomputer is specially equipped with a printer/plotter and a micromodem that provides an interface to the university mainframe computer system (see Figure 24-2).

Despite the availability of 64K of memory in each microcomputer, memory limitations have proven to be a problem. Hence, we acquired a 20-megabyte hard disk, which can be accessed concurrently by users at both the primary and secondary microcomputers. The 20-megabyte hard disk has removed any serious restrictions on the size of the experimental programs or arrays of data employed during an experimental session. The 20-megabyte disk can eventually become cluttered with programs and data from previous sessions unless provisions are made for transferring files from the hard disk to a long-term storage medium. As depicted in Figure 24-2, we have interfaced a videorecorder to a hard disk, which allows us to store and retrieve volumes of information using compact videocassettes.

Software System

The software system that we employ is called FIRST and is an adaptation by Scandrett (Scandrett & Gormezano, 1980) of FORTH (Moore, 1974), which is an interactive, high-level language developed for use on computers with severely limited memory size (e.g., 8K words). Like FORTH, FIRST is a dictionary-based language, but FIRST is specifically tailored for the most efficient laboratory use of the modified microcomputers that we employ.

The basic FIRST language consists of a dictionary of about 450 words which can be executed by entry on the keyboard. The available functions support a monitor, a disk operating system, an efficient compiler, a macro assembler, a well-developed text editor, high-resolution graphic capabilities, keyboard input and video output facilities for numerical and character string data, and routines for line printer operations and hard-copy graphics.

FIRST provides for hardware multiplication and division of 16- and 32-bit integers as well as 32-bit floating-point operations. These include a

full selection of transcendental functions (direct trigonometric, inverse trigonometric, log, exponent, square root). Numerical calculations are particularly rapid due to the use of the AM9511.⁴ Compiling time in FIRST is short, which expedites debugging a program (the full language can be reassembled in a matter of seconds), and the modular nature of programming in FIRST allows small portions of a program to be written and tested with much greater ease than in BASIC or from an EDITOR/ASSEMBLER. Once written and tested, a set of FIRST instructions can be represented by a single word, which acts much like a call for a machine-language subroutine in BASIC.

FIRST, therefore, provides the ability to define new functional words as combinations of previously defined words. After a new word has been added to the dictionary, it can be used as a component of still newer words. A FIRST program is thus developed in a hierarchical manner, starting with the 450 words in the FIRST language and building new intermediate words. For example, the word SLDCH, which stands for slide change, advances the slide projector carousel one time, and is one of many specially designed words that links the primary microcomputer to the peripheral equipment. These intermediate words are combined into still more comprehensive words, which define the sequence of operations to be performed. For instance, the word TRIALA, which represents one of several different types of trials to which a subject might be exposed, is comprised of a series of words (or subroutines) defined previously in the program that deals with specific and distinct aspects of this particular type of trial (e.g., timing of slide changes, inclusion of probe stimulus, A/D recording). Entering the most comprehensive word (e.g., RUN) executes the series of subroutines that constitute a complete session.

No formal distinction is made between the operating system, the compiler, and the program. Every program is essentially a new language designed to be the most suitable for the control and computational demands of a particular experiment. Each program need not be built from scratch, however, but rather a new program typically requires changes only at the upper levels of the language (e.g., definition of Trial words). The intermediate words that control output devices such as the tape recorder and slide projector and sample input devices such as the polygraph channels and subject's keyboard, once written, can be used in any

4. All numerical calculations are done in R.P.N. (reverse Polish notation) on a 4-byte-wide, 256-byte-deep software stack. Entering a numerical value pushes that number on to the top of the arithmetic stack, and arithmetic operators operate on the stacked values. Because of easy, compiled-in-stack manipulations, large stack scratch space, and extensive use of the floating-point processor hardware, FIRST completely supersedes the functions usually provided by the Applesoft (floating-point) BASIC or integer BASIC by both its very high processing speed and its flexibility.

program. Similarly, the intermediate words written to sample A/D input from EDA, EMG, EEG, HR, potentiometers, and so forth, can be reused, much as one reuses subroutines in other programming languages. In addition, the intermediate words that control timing are written as variables so that changes in the duration of epochs and stimuli within epochs may be accomplished by simple editing of experimental parameters.

Applications: An Illustration

Prior to an experimental session, the experimenter loads a test program, which is used to calibrate the polygraph, A/D chip, and so forth. Following calibration and checks of input and output devices, the experimenter loads an interactive program that displays the current experimental setup (e.g., A/D sampling rate, instruction and stimulus epochs in milliseconds, number of practice and experimental trials, and filtering characteristics for each of the eight physiological channels) and permits changes to be entered on the keyboard. These values are stored for later use in parameter extraction and analysis programs, executed from the secondary microcomputer. The program pauses at various points to permit the experimenter to provide preexperimental instructions, obtain preexperimental response (e.g., questionnaire) measures, and apply physiological sensors, and await the subject's adaptation to the laboratory. When all is ready for the experiment to begin, the experimenter enables the program that controls the presentation of specific, prerecorded instructions to the subject, followed by a pretreatment baseline and a series of practice and experimental trials. The A/D counts from each channel are sampled every 10 msec, and these digitized values are recorded on disk. If instructional manipulations or the presence of others are involved, these procedures can be either automated using audio- or videorecording equipment or performed "live" as part of the programmed sequence of events.

Following an experimental session, a separate program is employed using the secondary microcomputer to extract the appropriate parameters from the signals recorded on each channel. For example, the extracted measures for channels with integrated EMG input include the number and amplitude of the peak responses emitted during each epoch (e.g., pre-stimulus, stimulus), the magnitude of the integrated EMG activity in microvolts per second evinced during each epoch, the variability of the integrated EMG activity, and so forth. The data obtained from the parameter extraction program can then be summarized across trials by another program and input into classification (data processing and analysis) programs.

We are now in the process of developing a library of generalized programs for experimental control/data acquisitions, parameter extrac-

tion, signal analysis, statistical analysis, and data plotting. An example of a signal analysis algorithm that has been programmed in FIRST is a fast Fourier transform routine, whereas an example of a statistical routine program is FANOVA, a mixed design analysis of variance program.⁵ When especially complex or unusual analyses are desired, we transfer the data at 300 baud over a standard telephone line (via a micromodem) to the university mainframe computer.

A considerable setup time for a computerized laboratory for social psychophysiological research can probably be expected. Acquisition and construction of the hardware configuration can often be slowed by the need for components not available locally. Development of the interfaces, subroutines, and prototype programs for experimental control/data acquisition and data analysis can be particularly time consuming, but can be facilitated by perusing similar programs developed in other laboratories. Fortunately, you can expect the daily operation and modification of established prototype programs to require less time and expertise than does the initial programming.

The few problems we have encountered following the establishment of the Iowa laboratory are relatively minor. Although the small size of the microcomputers make them easily portable, movement exacerbates the tendency for the component chips to loosen from their sockets. Particular care might also be taken when moving or handling the hard disk, floppy disks, and/or floppy disk drives, since dust or movement *can* result in a partial or complete loss of the stored data. Investigators should plan on keeping duplicate copies of all program and summary data files, for instance, on floppy disks or videocassettes.

NONELECTROPHYSIOLOGICAL PROCEDURES

The preceding description of a microcomputer-based laboratory for experimental control, A/D data acquisition, and data processing illustrates the kinds of options that might be considered and decisions that must be made when using bioelectrical measures in social psychophysiological research. There are, however, alternative, nonelectrophysiological procedures that are useful in social psychophysiological research. In this section we survey three nonelectrophysiological methods that have shown

5. Since the data array is virtually paged from disk into computer memory, thousands of input values are permitted. Although the number of levels within each factor, including the Subject factor, is essentially unlimited, the total number of different factors permitted by the current version of FANOVA in any mixture of within- and between-subject factors is nine when our high-resolution graphical plotting facilities are simultaneously present in computer memory. (Deletion of the graphics vocabulary permits a modest extension of the number of factors handled by FANOVA.)

particular promise: verbal measures of physiological activity, the misattribution procedure, and exogenous agents that alter physiological activity (e.g., drugs, pacemakers).

Verbal Measures of Physiological Activity

Perhaps the oldest and most straightforward procedure is to ask the subject to describe his or her bodily sensations (cf. Hassett & Danforth, 1982). The James-Lange theory of emotions, for instance, assumed that people could, at a minimum, distinguish the idiosyncratic bodily reactions that accompanied divergent emotional reactions. Studies of the relationship between the electrophysiological and verbal covariants of emotion indicated large discrepancies existed, and the accuracy and validity of verbal reports were implicated (e.g., Syz, 1926; see Blascovich & Katkin, Chapter 17, this volume).

Nisbett and Wilson (1977) have argued more recently that people cannot accurately report the causes (antecedents) of their behavior or emotions. Their critique of verbal reports as data about psychological processes applies to stimuli arising from within an individual's body as well as to those emanating from the external environment. Although the experiments and interpretations offered by Nisbett and Wilson (1977) have been criticized on a number of grounds (see Ericsson & Simon, 1980; Sabini & Silver, 1981; Smith & Miller, 1978; White, 1980), their caveat regarding the interpretation of verbal reports nevertheless warrants commentary. Verbal reports concerning an individual's bodily sensations or states can be viewed as symptomatology data whose accuracy is open to empirical study. As detailed in the chapter by Blascovich and Katkin (Chapter 17), verbal reports of *specific* bodily states (e.g., resting heart rate) and reactions (e.g., increase in heart rate) have proven to be fairly inaccurate. Similarly, the causes of bodily reactions are typically reported inaccurately by people (see Pennebaker, 1982). Nevertheless, the verbal reports of physiological activity can constitute an informative set of data in social psychophysiology as long as they are used to complement rather than replace actual physiological data (e.g., see Pennebaker, Chapter 19, and Scheier *et al.*, Chapter 18).

Although the apparent dissociation between specific verbal and electrophysiological measures of ongoing physiological activity quelled research in this area, investigations of the operant conditioning of visceral activity has led to a renewed interest in proprioception and interoception (Brener, 1977). From the point of view of operant conditioning theorists, an individual's detection of a physiological change need not be accurate as long as it is a perceptible event that is correlated with the physiological change. For instance, individuals may not be able to discriminate between large

changes in heart rate and skin conductance, but nevertheless reliably report being more "aroused" when one or both of these responses occur than when they do not (see Thayer, 1970).

More recently, Mackay (1980) has contended that adjective checklists (e.g., the stress-arousal checklist) provide an integrative measure more representative of general physiological arousal than any single psychophysiological variable. In a review of verbal measures of physiological activity, Mackay (1980) cites two lines of evidence for this proposition. The first derives from research that indicates verbal reports of arousal (e.g., as assessed using adjective checklists) correlate more highly with physiological composites (e.g., heart rate and skin conductance) than do pairs of physiological variables (e.g., Thayer, 1967, 1970). The second line of evidence comes from a deductive rather than inductive research strategy: Subjects are exposed to discernable external stimuli (e.g., noise) that are hypothesized to alter physiological arousal, and verbal measures of physiological arousal are administered. Generally, self-reports of arousal have covaried with the expected effects of the independent variables on physiological activation (see Mackay, 1980). The validity of verbal measures of general physiological arousal, however, is still questionable, for two reasons. First, self-report measures of arousal may be more highly correlated with the average of several physiological measures of arousal than with any single physiological measure (or than are any two physiological measures) of arousal because of the reduction in measurement error that is achieved by using multiple measures to gauge a common construct. Second, Zillmann (see Chapter 8, this volume) has clearly demonstrated that following exercise reportable arousal subsides more quickly than does changes in blood pressure. Hence, independent variables that excite specific effector systems may also alter verbal reports of arousal, but this convergence is apparently lost soon afterward (see also Lang, 1971).

At this point, the validity of verbal measures of actual physiological activity cannot be accepted without strong reservations. Nevertheless, the basic independence among the physiological, reportable, and behavioral responses to experimental treatments provides a wealth of information that can be tied empirically and theoretically to social behaviors (e.g., see Fazio & Cooper, Chapter 5).⁶ Thus, verbal measures of physiological activity (or activation) should not be taken as an index of physiological activity *per se*, but rather as an index of a reportable state that may or may not be related highly to the targeted physiological process.

6. Although the change in reportable states is assumed to be based in a physiological change, it is an error to equate the two since (1) numerous physiological changes go unnoticed (e.g., Cacioppo & Petty, 1982; see Cacioppo & Petty, Chapter 1), (2) situational factors can alter the bodily sensations that are perceived (see Pennebaker, 1982; Scheier *et al.*, Chapter 19), and (3) the same reportable state may be accomplished by a variety of physiological mechanisms (Schwartz, 1982).

The Misattribution Paradigm

A second procedure that has been effective in social psychophysiological research is misattribution. The most common sequence of events involves the subject ingesting a placebo that he or she believes has specific (experimenter-specified) side effects. This misattribution procedure is based on the principle that people search for causes of an unexplained internal state, such as a sudden feeling of tension or arousal (see Chapters 5 through 8). In their search, people consider external as well as internal causes and sometimes misattribute the true cause of a felt bodily state (e.g., increased sympathetic activity, epinephrine in the bloodstream), to something that *seems* to be a reasonable cause at the time (e.g., a pill they recently ingested). Of course, only when a stimulus can have the same effects on a person as he or she is experiencing at the moment will misattribution be likely to occur (see Zillmann, Chapter 8). The nature of the internal state that the people are experiencing, therefore, can be inferred indirectly by determining the type of "side effect" that elicits misattribution. Thus, in the misattribution paradigm, subjects are either exposed or not to treatments that are believed to affect physiological responding and are either exposed or not to a possible external cause for the consequent bodily sensations.

Several studies in the area of cognitive dissonance, for instance, used misattribution procedures to investigate the sensations associated with the state of cognitive dissonance (see Fazio & Cooper, Chapter 5). A study by Higgins, Rhodewalt, and Zanna (1979) nicely illustrates the procedure. Subjects were told that they were to ingest a pill (a placebo) as part of a study on visual acuity. Subjects were told that the pill might cause them to feel "unpleasantly sedated" (unaroused-unpleasant), "relaxed" (unaroused-pleasant), "tense" (aroused-unpleasant), "pleasantly excited" (aroused-pleasant), or nothing in particular (no-side-effects control group). These subjects voluntarily wrote a persuasive message advocating a position with which they initially disagreed while they believed they were waiting for the pill to take full effect. Higgins *et al.* (1979) found the placebo with the possible side effect of making the person feel "tense" lessened attitude change. More important, however, they found that a pill described as possibly causing a feeling of unpleasant sedation blocked attitude change even more completely. Overall, the characteristic of felt unpleasantness (or stress) was more effective in eliciting the misattribution of dissonance to the pill (and the consequent reduction of pressures to change one's attitude) than was the characteristic of felt arousal (cf. Fazio & Cooper, Chapter 5). Of course, there may be large discrepancies between the nature of and the sensations from one's bodily responses. Cognitive dissonance may have sympathetic-like physiological effects, but feel most like a state of unpleasant tension. Hence, the nonelectrophysiological and electrophysiological procedures that we have discussed thus far can pro-

vide complementing rather than redundant information (Cacioppo & Petty, 1982b).

Exogenous Agents That Alter Physiological Activity

A third procedure that has occasionally been employed in social psychology involves utilizing exogenous agents that alter physiological activity in well-defined ways (e.g., Cacioppo, 1979; Schachter, 1971). For example drugs might be administered to enhance or attenuate a physiological reaction that presumably mediates a socially significant behavior (e.g., helping, attitude change). One of the best known studies of this type is Schachter and Wheeler's (1962) study of emotional plasticity. Subjects were told that they were in a study of the effects of vitamins on vision. Subjects were injected with either epinephrine, a saline solution (placebo), or chlorpromazine (a peripherally active agent that diminishes the activation of sympathetically innervated structures). Subjects were misinformed about the nature of the injection, however; all were told that, following the prick of the injection, they would feel no side effects from the drug. Subjects were exposed to a comedy film shortly thereafter. (The exact time period between injection and film presentation was adjusted so that the effects of the drug would occur shortly after the start of the film.) Schachter and Wheeler (1962) found that subjects injected with epinephrine or the placebo tended to act more amused during the film than did subjects injected with chlorpromazine. Although the theoretical support this study provided for Schachter and Singer's (1962) theory of emotional plasticity has been questioned (e.g., see Zillmann, 1978), the merits of this innovative methodology persist (e.g., Cooper, Zanna, & Taves, 1978).

CONCLUSION

This chapter has focused on the nature and measurement of bioelectrical activity, and on computer control and A/D data acquisition. The discussion was designed to provide a basic understanding of the general issues involved in and instrumentation available for electrophysiological recording. Discussion was not focused on any one physiological recording procedure [e.g., average evoked potential (AEP) recording], although sources for this information were suggested. Discussion of the nature of bioelectrical activity stressed the importance of laboratory construction, sound and electrical insulation, psychosocial considerations, laboratory safety, and experimental design. It was noted that an important and physiologically significant event could be masked by electrical artifacts. Sources of electrical artifacts and potentially confounding variables were, therefore, described, and a few procedures for their elimination were indicated.

Bioelectrical measurement was segmented for purposes of exposition into four stages: sensing, amplifying, recording, and quantifying (see also

McGuigan, Chapter 22, and McHugo & Lanzetta, Chapter 23). Sensing was used to refer to the transformation of a physiological event to a valid, electrical representation that could be transmitted to amplification equipment. Since the electrical signals of interest to most investigators are extremely small (e.g., 1 mV), a magnification of the signal is required. This step was referred to as amplification. The third stage, recording, referred to the attainment of a permanent record of the detected stream of physiological events. The final stage discussed was quantification (signal processing and analysis). Issues considered during the quantification of bioelectrical signals include transformations of the data, utilization of procedures to check and correct for preexisting differences in physiological responses across groups, and selection of appropriate statistical procedures for deriving or testing hypotheses.

A specific microcomputer-based laboratory for social psychophysiological research was described to illustrate the kinds of options available and the kinds of decisions that might be made to obtain electrophysiological recordings. This system was established specifically to control social psychophysiological experiments, collect analog and digital data, and extract dependent variable measures for the monitored physiological, reportable, and motoric responses. The inexpensive laboratory microcomputer employed has been augmented by a hardware floating-point processor, additional memory, and an A/D converter chip. In addition, a software system (FIRST) was developed specifically for psychological experimentation and A/D data acquisition was described. FIRST is an interactive, high-level, structured programming language that, thus far, has been sufficiently fast that repeated tedious machine-language programming has seldom been needed for stimulus control and data acquisition.

The final section surveyed nonelectrophysiological procedures that have been used in social psychophysiological research. Three procedures were surveyed: verbal reports of bodily state, misattributional procedures, and exogenous agents that alter an individual's physiological state. The survey of these procedures indicated that each complements rather than replaces electrophysiological procedures, as the electrophysiological and nonelectrophysiological procedures appeared to provide only partially redundant information about the role of physiological and situational factors in social behavior.

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