Evaluation apprehension. Naive subjects may be apprehensive about participating in research involving the use of electrodes and electrical recording equipment. Such apprehension, although possibly of interest in its own right (Fridlund, Hatfield, Cottam, & Fowler, 1986), can create a level of tension or hypervigilance in the subject that is unrepresentative and that can obscure the effects of the experimental treatments. This apprehension is in addition to the potential apprehension that subjects may feel about being evaluated by experimenters who are presumably experts in human behavior. Rosenthal (1966) suggested that this "evaluation apprehension" may also lead subjects to distort their actions in a socially desirable fashion. If an experimenter's behavior or experimental treatment makes subjects especially anxious or aware that they are being evaluated, then the data may be significantly biased.

Procedures for minimizing evaluation apprehension have been suggested and, in addition to those outlined in the preceding section, include: (1) providing a tour of portions of the laboratory to prospective subjects while explaining the principles underlying bioelectrical recording, briefly demonstrating hook-up procedures, and briefing them on the tasks and procedures involved in the study prior to seeking informed consent or scheduling them for participation; (2) allowing time before the beginning of the experimental procedures for subjects to adapt to the laboratory; (3) using buffer trials or stimuli to allow adaptation to the experimental procedure; (4) employing a closed-loop baseline to ensure subjects are not tense or aroused before initiating the next trial; and (5) minimizing the sense subjects have that they are being "observed" or evaluated, for instance, by automating procedures, assuring subjects that their responses are anonymous, and using hidden cameras when visually monitoring subjects.

Subject variables as potential independent variables. Finally, various attributes of the subjects can affect EMG measures and, therefore, are important to assess or control by means of the experimental design. These attributes include age; intramuscular temperature, which can be affected by muscle activity as well as ambient temperature; and muscle strength, which is correlated with sex (cf. Goldstein, 1972).

11.3.3.2 *Social determinants of somatic actions*

In the previous section, we saw that the nature of the interaction between the experimenter and subject is a source of both bias in psychophysiological research and a means for its solution. In this section, we briefly review illustrative research demonstrating how social factors can also moderate the influence of nonsocial factors on EMG responses.

Display rules. The classic observations of Charles Darwin (1873/1872) suggested that facial expressions of emotion were universal. The study of emotions was advanced yet further when, building on the pioneering observations of Darwin, it was found that (1) individuals perform at better than chance levels when matching emotion terms to photographs of faces held to represent happiness, sadness, surprise, anger, disgust, and fear; (2) the inductions of states in which individuals report positive and negative emotions are associated with distinctive facial actions; (3) cultural influences can alter significantly these outcomes; (4) displays similar to those of the adult can be found in neonates and the blind as well as sighted adults; (5) specific patterns of activity in the autonomic nervous system are observed when facial prototypes connoting emotion are constructed muscle by muscle and by reliving past experiences reported as emotional; and (6) variability in emotional expressions observed across individuals and cultures could be attributed to factors such as differences in which emotion was evoked or the sequence or blend of emotions evoked and to cultural prescriptions regarding facial display of emotions (e.g., see Ekman, 1973, 1982; Ekman & Friesen, 1978; Ekman, Levenson, & Friesen, 1983; Ekman et al., 1987; Izard, 1971, 1977; Steiner, 1979; Tomkins, 1962).

According to Ekman's notion of display rules, a given emotion will not always be displayed in the same fashion due to the influence of personal habits, situational pressures, and cultural norms. In an early study on display rules, Japanese or American students were exposed to a disgusting film while being videotaped unobtrusively or with an authoritarian experimenter present (Ekman, 1972; Friesen, 1972). Results revealed that both the Japanese and American students displayed revulsions while viewing the film in solitude, but the Japanese students masked their feelings of revulsion by smiling during the film when the experimenter was present (cf. Fridlund, in press).

The influence of an observer on people's facial expressions of emotion emphasizes the dual role played by muscular responses. Because the skeletomotor system is the only means individuals have of approaching, avoiding, or modifying physical elements in their environment, one might expect that somatic responses in part reflect or serve to gratify certain goals or desires. An individual who accidentally touches a hot platter is likely to exhibit a rapid withdrawal, just as an individual who begins to ingest wretched food is likely to express disgust and rapidly expel the offending food (Darwin, 1873/1872).

The skeletomotor system is also the primary means individuals have of communication and effecting change in the social environment. Not surprisingly, therefore, somatic responses such as facial expressions can be affected strongly by the perceived presence of observers. Kraut and Johnson (1979), for instance, related the observed frequency of smiling to simultaneously occurring events in a wide range of naturalistic settings (e.g., bowling alleys, public walkways, hockey arenas). Their results indicated that people were most likely to smile while speaking with other people; they were significantly less likely to smile perceptibly when an event caused them to experience positive emotions (e.g., bowling a strike) when their faces were unobserved than observed (see, also, Fridlund, in press).

Social facilitation and social loafing. Facial expressions of emotion are not the only somatic responses that are affected by the presence of observers. Chapman (1974), for instance, monitored EMG activity over the forehead region as subjects listened to a story while unobserved, watched by a concealed observer, or watched by an unconcealed observer. Chapman found that EMG activity over the forehead region was higher during the story when the subject was observed than when unobserved and slightly though not significantly higher when the observer was present than when concealed. Groff, Baron, and Moore (1983) further demonstrated that the presence of observers led to more vigorous motor responses. These data fit well with observations dating as far back as 1898 demonstrating that an individual's performance on a task can be altered dramatically simply by moving the task from a nonsocial to a social context. Triplett (1898) is credited with being the first to notice that individuals perform well-practiced actions (e.g., bicycle riding) more quickly or vigorously when others were engaged in the same task rather than when alone, and Meumann (1904; cited in Cottrell, 1972) several years later reported the same effect occurred as a result of simple observation. Zajonc (1965) organized much of this research with his proposal that the presence of conspecifics lowered the threshold for the single most likely response to a task. Hence, according to Zajonc's theory of social facilitation, coactors or audiences facilitate the performance of easy tasks and impair the performance of difficult tasks (see review by Geen & Gange, 1977). The important point here is that not only performance but also physiological responses such as EMG activity over the forehead region and the vigor of a forearm flexion have been found to vary as a function of the presence of observers (cf. Cacioppo & Petty, 1986, pp. 658–664).

The presence of others has also been shown to lessen rather than heighten effort and the vigor of somatic responses when by their presence an individual is rendered anonymous or unaccountable for her or his performance. Latane, Williams, and Harkins (1979) have dubbed this effect "social loafing." In an illustrative series of studies, Latane et al. (1979) instructed subjects to clap or shout as loudly as possible. On some trials, subjects were led to believe their individual performance was being monitored, whereas on other trials they were led to believe their performance was being pooled with those of varying numbers of other subjects. On all trials, subjects heard a masking noise through headphones as they clapped or shouted, so they could not tell how loudly they or others were performing. Results revealed that subjects expended more physical effort (i.e., clapped or shouted more loudly) when they believed they were personally accountable for their performance than when they were able to diffuse their responsibility for performing the task. Hence, the presence of others can enhance or reduce muscular responses depending on whether the presence of others increases or decreases the threat of social sanctions or embarrassment based on one's performance.

Mimicry. Mimicry here refers to the elicitation of a localized motor response through witnessing the same response being performed by another. Evidence for motor mimicry includes such demonstrations as wincing at another's pain (Vaughan & Lanzetta, 1980), straining at another's effort (Markovsky & Berger, 1983), and smiling at another's evident delight (Dimberg, 1982). Motor mimicry in psychology has traditionally been conceptualized as primarily intrapersonal, representing either primitive empathy, a conditioned emotional response based on one's direct experience, or an expression of vicarious emotion (Allport, 1968). Consistent with this emphasis, Dimberg (1982) reported that subtle decreases in EMG activity over the *corrugator supercilii* muscle region and increases in EMG activity over the *zygomaticus major* muscle region were observed when subjects viewed pictures of smiling faces, whereas the opposite pattern of facial EMG activity was observed when subjects viewed pictures of angry faces. Englis, Vaughan, and Lanzetta (1982) provided evidence that counterempathic as well as empathic responses could manifest in subtle changes in facial EMG activity.

A recent pair of studies by Bavelas, Black, Lemery, and Mulleit (1986) suggests the intensity of *visible* motor mimicry is influenced strongly by the communicative significance of the mimesis as well. For instance, in one study the victim of what appeared to be a painful injury was either increasingly or decreasingly visible to the observing subject. Results revealed that the subject's motor mimicry was significantly affected by the visibility of the victim. Thus, the research on mimicry is consistent with the preceding suggestion that social factors can influence somatic responding in the service of interpersonal (i.e., communicative) goals as well as personal feelings and emotions.

RESPONSE PARAMETER	RESPONSE ORIGIN: Endogenous	RESPONSE ORIGIN: Exogenous
Dependent variable	Double dissociation	Reflex probe
Independent variable	Conditional probability	Manipulated response

Figure 11.7. Illustrative paradigms in psychophysiological research involving skeletomotor system.

11.4 INFERENTIAL CONTEXT

Understanding the physiological basis of EMG and the electrical principles underlying its measurement is important in conducting meaningful research, but it is not sufficient. As Shapiro and Crider (1969, p. 3) noted:

> In the most concrete sense, physiological variables are measures of nothing but themselves, and cannot be taken as ready-made indicators of...psychological constructs. A response measure, whether of overt or covert functioning, has meaning only in the context of observation.

General discussions of the issues involved in moving from physiological data to psychological or behavioral inferences have been provided by Cacioppo and Tassinary (chapter 1) and Strube (chapter 2). In this section, we review several general and promising paradigms in psychophysiological studies of EMG activity. In so doing, we also highlight some of the information about cognitive, emotional, and behavioral processes that has come from EMG studies.

11.4.1 *Psychophysiological paradigms*

One of the challenges in psychophysiological research is to create paradigms that allow strong inferences about psychological constructs based on physiological responses. Much of the variety and complexity in the experimental paradigms in this area can be characterized in terms of a 2 (Somatic Response as the Dependent vs. Independent/Blocking Variable) × 2 (Endogenous vs. Exogenous Origin of Somatic Response) multidimensional space (Figure 11.7). Within these general paradigms, answers have been sought to questions regarding the psychological, behavioral, and health significance of somatic activity and the extent to which skeletomotor activity reflects specific or global activation, phasic activation, tonic activation, or modulated thresholds for activation; and characteristics of the stimulus situation or the individual's disposition.

11.4.1.1 *Outcome paradigms*

Outcome paradigms are the simplest and most prevalent in psychophysiology. Although variations include the double-dissociation paradigm and the double-dissociation with constant stimuli paradigm (see subsequent discussion), the essence of the outcome paradigm, as illustrated in Figure 11.7, is that a psychological or behavioral process is manipulated while one or more physiological (e.g., EMG) responses are monitored. Edmund Jacobson's (e.g., 1932) original EMG studies summarized at the beginning of this chapter are cases in point as are studies based on the logic of the subtractive and additive factors methods (see Cacioppo & Tassinary, chapter 1).

Studies conducted within this general paradigm on phasic EMG responses since Jacobson have found that, despite large variations within and across individuals in skeletomotor response, reliable and oftentimes minute patterns of EMG activity accompany thought, emotion, and imagery. Cacioppo and Petty (1981a) summarized this research as follows: (1) there are foci of somatic activity in which changes mark particular psychological processes (e.g., emotion and the mimetic muscles, language processes, and the musculature employed in speech); (2) inhibitory as well as excitatory changes in somatic activity can mark a psychological process; (3) changes in somatic activity are patterned temporally as well as spatially; (4) changes in somatic activity become less evident as the distance of measurement from the focal point increases; and (5) foci can be identified a priori by (a) analyzing the overt reactions that initially characterized the particular psychological process of interest but appeared to drop out with practice and (b) observing the somatic sites that are involved during the "acting out" of the particular psychological process of interest.

In an illustrative study, Shaw (1940) instructed subjects to lift or imagine lifting weights. He found that the amplitude of EMG activity over the preferred arm increased as subjects lifted heavier and heavier weights; this same trend held when subjects imagined lifting the weights. Similarly, Schwartz and his colleagues (e.g., Schwartz et al., 1976; cf. Schwartz, 1975) found that clinically (dysphorically) depressed subjects displayed higher levels of EMG activity over the brow (*corrugator supercilii*) muscle region and lower levels of EMG activity over the cheek (*zygomaticus major*) muscle region when they imagined unpleasant experiences than when they imagined pleasant ones. Nondepressed subjects displayed patterns similar to those produced by the depressed subjects, but the pattern accompanying pleasant imagery was accentuated and the pattern accompanying unpleasant imagery was attenuated in the normal subjects. Furthermore, when the subjects were asked to imagine their typical day, normal subjects displayed a pattern similar to that evinced when they imagined a pleasant experience, whereas depressed subjects displayed a pattern similar to that exhibited while they imagined an unpleasant experience.

Although the early and contemporary EMG research in psychophysiology focused primarily on specific phasic changes in EMG activity, much of the research from 1940 to 1975 focused on general or tonic changes in tension, activation, or arousal (e.g., see reviews by Duffy, 1962; Goldstein, 1972; Malmo, 1959, 1975). Germana (1974), for instance, suggested that although skilled or habitual actions are characterized by a well-orchestrated patterning of skeletomotor activity, response uncertainty leads to a general activation of the musculature. Germana further suggested that the basic significance of this general activation across functionally

disparate muscle regions is extensive preparation for overt behavior. Finally, the two conditions identified by Germana as being likely to produce response uncertainty, and consequent somatic activation, were novel stimuli and conditioned stimuli during the initial stages of conditioning. Interestingly, recent research provides some support for Germana's suggestion that the pattern of activation of the musculature during response uncertainty contributes to "a greater equalization within the distribution of behaviorally selective probabilities" (e.g., see Coles et al., 1985; see, also, Coles, Gratton, & Fabiani, chapter 13).

Malmo (e.g., Davis & Malmo, 1951; Malmo, 1965, 1975; Wallerstein, 1954), in contrast, used EMG gradients to depict variations across time in tonic muscle tension. Malmo (1965) summarized his findings as follows: (1) EMG gradients are observed in certain muscles, namely, those that are chronically the most reactive within an individual or those whose actions (or whose paired muscles' actions) are specifically required by the situation, and (2) the steepness of the EMG gradient throughout the entire course of the sequence reflects the stress or effort involved in the entire sequence from beginning to end.

In an illustrative study, subjects played a video game that required they stop a "ball" from passing across the screen by maneuvering a video "bat" to intercept the ball (Svebak, Dalen, & Storfjell, 1981). Subjects rotated a knob held between the thumb and index finger to control the location of the bat. Two versions of the game were employed. In the *easy* version, an unimpeded ball bounced across the screen in approximately 3 s, whereas in the *difficult* version the ball traveled at approximately twice this rate. Both versions required the subject to engage in continuous performance for 150 s, and EMG activity was recorded over the forearm flexor of the passive arm during baseline and task periods. Results revealed the EMG gradient associated with the difficult game was steeper than that associated with the easy game.

In a similar vein but on a shorter time scale, Davis (1940) recorded EMG activity over several muscle regions (e.g., forearm extensors) as subjects performed a choice reaction time task under unwarned, fixed-foreperiod or variable-foreperiod conditions. Davis observed that EMG activity was higher in the foreperiod when the subject was warned than unwarned; EMG activity began to rise approximately 200–400 ms following the warning signal and continued to rise until the overt response was completed; and EMG activity was higher (and reaction time shorter) with a fixed than variable foreperiod. Davis concluded that the EMG responses during the foreperiod reflected a set for motoric response.

Despite these encouraging findings, there is no more consensus within the EMG field than within other fields of psychophysiology regarding which measure best reflects general motivation, tension, or activation. Meyer (1953) suggested eyeblink rate provided the best overall measure of generalized tension. Consistent with the notion that sympathetico-tonia resulted in scleral dryness and increased blinking, Meyer, Bahrick, and Fitts (1953) reported that individuals who score high on anxiety inventories also have high blink rates. However, Rossi (1959) found a similar relationship between manifest anxiety scores and EMG activity over forearm extensors. Similarly, Davis, Malmo, and Shagass (1954) administered white-noise blasts at 1-min intervals to two groups of subjects: individuals with anxiety disorders and normals. Results revealed that although the noise blast evoked a slightly larger EMG response over the forearm extensor region in the anxious than normal individuals, the more significant difference occurred immediately following the stressor. The elevation in EMG activity in normals was sharply delimited, returning to basal levels within seconds of the termination of the noise burst, whereas the elevation in EMG in the anxious subjects lingered.

Fridlund et al. (1986) recently replicated and extended these molar findings using EMG measures over the head, neck, and limbs. Subjects first rested quietly for 15 min and then were exposed to 5 min of 105 dB binaural white-noise stimulation. High-, in contrast to low-, anxious subjects exhibited higher levels of EMG activity primarily over the head and neck preceding the stimulus and more generally during the stimulus. Within-subjects principal components analyses of EMG activity during these periods failed to reveal evidence for a general, intercorrelated tensional factor; instead, the EMG elevations in the highly anxious subjects consisted largely of uncorrelated response bursts. They believed the EMG responses indicated anxious hypervigilance.

Woodworth and Schlosberg (1954, pp. 173–179) made the interesting suggestion that EMG activity, particularly in the neck (e.g., splenius), may be an indicator of the level of activation due to the possibility that a disproportionate share of proprioceptive impulses to the central nervous system originated in this muscle region. This suggestion is interesting in light of the sparse evidence for the notion of a coherent tensional factor (e.g., see Fridlund, Fowler, & Pritchard, 1980). Consistent with Woodworth and Schlosberg's suggestion, Eason and White (1961) had subjects perform a variety of vigilance tasks (e.g., rotary tracking) while recording EMG activity over the *splenius* and *trapezius* of the neck, *trapezius* of the shoulder, and the *deltoid* and *biceps* of the right arm. The major finding in these studies was that the general level of EMG activity (most consistently that recorded over the neck muscles) varied as a function of the effort subjects expended on tasks.

In summary, substantial increases in task difficulty, the subjective effort expended on tasks, or stressors have been found to lead to elevated EMG activity over the neck in seated subjects during vigilance tasks and in task-relevant musculature in general. In addition, an inhibition of EMG activity over irrelevant musculature is sometimes observed during such tasks, particularly when the response to the task is well practiced (e.g., see Germana, 1974; Goldstein, 1972). Although these findings contradict the simple-minded view of general tension or arousal, this research clearly indicates that muscle tonus can be an informative outcome measure:

> The literature of muscle tonus has been burdened in the past and is still being burdened by observations which have not taken into account the functional significance of tonic activity. Tonic manifestations have been sought for indiscriminately in all muscles, at all times, and not infrequently the operative procedure of the investigator has caused the very tonicity he has sought for to vanish. (Fulton, 1926, p. 384)

11.4.1.2 *Double-dissociation paradigm*

Whether EMG changes reflect specific actions and patterns or general somatic changes often has important theoretical implications. The *double-dissociation paradigm* from physiological psychology (Teuber, 1955) can therefore be particularly powerful in EMG research. This paradigm is so named because: (1) one or more treatments that should evoke a specific somatic action or pattern is contrasted with one or more treatments that should not evoke the target action or pattern and (2) one or more measures of the target somatic response are included as well as one more measures of nontarget somatic response. The former establishes discriminant validity of the treatments, whereas the latter demonstrates the discriminant validity of the responses.

To illustrate, there has long been a hypothesis that silent-language processing is associated with increased activation of the speech (e.g., perioral) musculature (see McGuigan, 1978). As McGuigan (1970) noted, there are a number of studies demonstrating that EMG activity over the perioral musculature increased from basal levels when individuals engaged in silent-language processing. These results alone are not particularly informative because such a psychophysiological outcome could be attributed to aspects of the task that had nothing to do with language processing (e.g., orthographic or auditory analyses may be associated with a tensing of the lips) or to general increases in tension or arousal (e.g., due to the motivation or apprehension that stemmed from the presentation of the task). The inclusion of nonlanguage as well as language tasks speaks to the first of these interpretational problems, and the measurement of EMG activity over nontarget as well as target sites speaks to the second.

In most applications of the double-dissociation paradigm, different subjects or stimuli are used to achieve treatments that theoretically should and should not evoke a specific somatic action or pattern. In a particularly comprehensive series of studies, for instance, McGuigan and Bailey (1969) recorded EMG activity over the chin, tongue, and forearm muscle regions while subjects silently read, memorized prose, listened to prose, listened to music, and attentively listened to "nothing." Results revealed that EMG activity over the perioral musculature increased dramatically while subjects performed silent-language tasks.

Double dissociation with constant stimuli. Although the outcome observed by McGuigan and Bailey (1969) is consistent with the hypothesis that silent-language processing leads to increased perioral EMG activity, Cacioppo and Petty (1979b, 1981b) noted that the grounds for such an inference would be strengthened further if the subjects and the physical characteristics of the target stimuli were held constant within the double-dissociation paradigm. In an illustrative study, EMG activity was monitored over the *inferior orbicularis oris* and the *superficial forearm flexor* muscle regions while subjects responded to questions about visual presentations of trait adjectives (Cacioppo & Petty, 1979b). The treatment condition was varied by what subjects were asked about a set of stimuli rather than by varying subjects or stimuli. Specifically, half the questions required that subjects perform a semantic analysis of the stimulus word (e.g., "Is the following descriptive of you?"), whereas half did not (e.g., "Is the following printed in uppercase letters?"). In addition, half of the trait adjectives within each treatment condition were self-descriptive, and half were not; half were printed in uppercase letters and half in lowercase letters; and half of the questions for each type of task called for a button press signifying yes, whereas half called for a button press signifying no. Results revealed EMG activity over the perioral region was greater during the language than nonlanguage task, whereas EMG activity over the nonpreferred forearm did not differ as a function of task. Because the type of stimulus presented or type of subject tested did not vary along with the extent of silent-language processing presumed to be manipulated in this double-dissociation design, one can be somewhat more confident that silent-language processing involving short-term memory leads to increased EMG activity over the perioral region.

11.4.1.3 *Conditional probability paradigm*

Most psychologists, like many psychophysiologists, have sought to use physiological data to infer psychological or behavioral constructs such as anxiety, emotion, and depression. In this effort, the target physiological events have been identified as those that have been shown to vary as a function of the theoretical construct of interest. Electromyographic activity over the forehead region has been of interest, for instance, because anxiety and tension are often accompanied by increased EMG activity over this site. However, knowing that the manipulation of a psychological or behavioral factor leads to a particular somatic response does not logically imply that this somatic response indexes the psychological or behavioral factor (see Cacioppo & Tassinary, 1989). Chapter 1 outlined how probability theory can be used to guide the construction of comparison conditions. Briefly, let Ψ represent the abstract construct of interest and Φ represent skeletomotor activity. It should be clear from probability theory that $P(\Psi/\Phi)$ cannot be assumed to equal $P(\Phi/\Psi)$, as they can differ dramatically. In fact, however, $P(\Psi/\Phi) = P(\Psi, \Phi)/[P(\Psi, \Phi) + P(\text{Not} - \Psi, \Phi)]$. Hence, it can be seen that the utility of the target skeletomotor response to serve as an index of an abstract construct is weakened by the occurrence of the skeletomotor response in the absence of the construct of interest (see chapter 1).

Although one cannot logically identify all possible factors that might influence the target skeletomotor response/pattern, the preceding formula makes it clear that information about the value of a target physiological response/pattern as an index of a construct can be gained by quantifying the extent to which the construct of interest is present given the presence of the target physiological response. That is, one can block on the presence or absence of the target skeletomotor response (or on variations of the target physiological response) and analyze the extent to which the construct of interest is evident. In so doing, an endogenous skeletomotor response pattern is used as a blocking variable (see Figure 11.7).

Cacioppo et al. (1988) utilized a conditional probability paradigm to examine the extent to which specific forms of EMG response over the brow region indexed variations in emotions evoked during an interview. As noted in the preceding, previous research has demonstrated that mild negative emotional imagery and unpleasant sensory stimuli tends to lead to more EMG activity over the brow (*corrugator supercilii*) and less EMG activity over the cheek (*zygomaticus major*) and ocular (*orbicularis oculi*) muscle regions than mild positive imagery and stimuli. This previous research did *not* address whether facial EMG responses provided a sensitive and specific index of emotions, however, since there is a multiplicity of events that can change facial EMG activity. To address this question, Cacioppo et al. (1988) obtained facial EMG and audiovisual recordings while individuals were interviewed about themselves. Afterward, individuals were asked to describe what they had been thinking during specific segments of the interview marked by distinctive EMG responses over the brow region in the context of ongoing but stable levels of activity elsewhere in the face. Consistent with the notion that expressive/behavioral components of emotion are "*sometimes brought unconsciously into momentary action by ludicrously slight causes*" (Darwin, 1873/1872, p. 184), minute EMG responses over the *corrugator supercilii* muscle region were observed to covary with subtle variations in emotion during the interview even though the overt facial expressions evinced by subjects were rated similarly across conditions by observers. Furthermore, it was reasoned that certain forms of EMG response, such as jagged bursts rather than graded increases and decreases in EMG activity, would be especially predictive of variations in emotion due to theoretical differences in $P(\text{Not-}\Psi, \Phi)$.[9] Support for this reasoning was also found. These results illustrate the power of the conditional probability paradigm and provide evidence that specific patterns of facial EMG response can actually *index* variations in emotion, at least within this limited context (see, also, Fridlund et al., 1984).

Interestingly, a classic study by Max (1935) can be viewed within this paradigm as well. Max hypothesized that EMG activity would increase during problem solving and that this activity would be evident not only in the speech musculature of normal speaking individuals, but also in the hands of deaf mutes (since their speech originated in their fingers). In a test of this reasoning, EMG activity was recorded over the arm and finger muscles as normal and deaf subjects slept. Max observed a general decrease in EMG activity as subjects fell asleep, and occasional bursts of EMG activity were observed over the finger muscles during their sleep. When the latter occurred, subjects were awakened and were asked to report if and what they had been dreaming. Max (1935) found that EMG activity over the finger muscles was associated with dreaming in the deaf subjects but not in the normals.

Shimizu and Inoue (1986) recently completed a study of sleep and dreams that bears on the utility of perioral EMG activity as a marker of silent-language processing in normals as well. Electroencephalographic (EEG), electrooculographic (EOG), perioral EMG, and nonoral EMG activity were recorded as subjects slept. Subjects were awakened during either rapid eye movement (REM) or Stage 2 sleep, as determined by inspection of the EEG and EOG recordings. When subjects reported dreaming, subjects were asked whether or not they had been speaking in their dreams. Dream recall during REM sleep occurred in approximately 80% of the awakenings, and it occurred during Stage 2 sleep in approximately 28% of the awakenings. Awakenings without dream recall were excluded from further analyses, as were awakenings preceded by phasic discharges in the perioral musculature that were accompanied by any whispering or vocalization. Results revealed that when phasic discharges over the perioral musculature were observed within the 30 s preceding the awakening, subjects reported having been speaking in their dreams in 88% of the awakenings from REM sleep and 71% of the awakenings during State 2 sleep. Moreover, when phasic discharges over the perioral musculature were not observed within the 30 s preceding the awakening, subjects reported having been speaking in their dreams in only 19% of the awakenings from REM sleep and in none of the awakenings during Stage 2 sleep.

In summary, previous research has indicated that situations in which subjects report negative emotional reactions are accompanied by EMG activity over regions of the mimetic muscles (e.g., the brow) and that silent-language and numeric tasks that load working memory influence the EMG activity over the speech muscle region. The research reviewed in this section further suggests that EMG discharges over the brow and over the muscle regions involved in speech can be used in at least some situations (see chapter 1) to mark episodes of affect and silent-language processing, respectively.

11.4.1.4 *Reflex paradigms*

We have made the case throughout the chapter that the skeletomotor system is a primary means through which the organism interacts with its environment. A detailed discussion of how environmental information is transformed into observable skeletomotor activity is beyond the scope of this chapter, although the interested reader is referred to the excellent tutorial by Gallistel (1980). Other theoretical discussions of traditional and recent approaches to this problem can be found in Asby (1960) and Kugler and Turvey (1987), respectively. However, in order to convey some of the issues involved, we first describe what is arguably the simplest internal mechanism for mediating organismic–environmental transactions (i.e., the monosynaptic reflex) and then briefly describe how this mechanism can be used to probe ongoing psychophysiological processes. The reader further interested in the history of the reflex is encouraged to consult the monographs by Fearing (1930) and Liddell (1960).

Definition. Reflexes generally refer to any automatic reaction of the nervous system to stimuli impinging upon the body or arising within it (Merton, 1987). Although there have been clear analytical attempts to define the concept of the reflex in precise logical and empirical terms from within both physiology (Sherrington, 1923/1906) and psychology (Skinner, 1931), the definition of the reflex and the functional significance of reflexes in the intact organism remain active topics of research (e.g., Berkinblit, Feldman, & Fukson, 1986).

From a physiological perspective, reflexes can be defined as a discrete type of behavior mediated by a reflex arc, thus providing both functional and structural constraints on the definition (Gallistel, 1980). Structurally, a reflex arc is an anatomical entity consisting of (1) receptors, tuned to transduce to specifiable classes of environmental stimuli into neural signals; (2) sensory neurons, which conduct the output signals from the receptors to the central nervous system (CNS); (3) mediators, either a single synapse or a small set of interneurons, that relay the sensory output to an appropriate subset of motoneurons or neurohumoral cells; (4) motoneurons/neurohumoral cells, which conduct the signal from the CNS to particular effectors; and (5) the effectors themselves, which impact on the environment as a function of neural and/or hormonal input.

Functionally, four conditions must be met in order for a particular behavior to be classified as reflexive. First, the effector response to any single sensory stimulus of sufficient intensity to actually elicit a response must rise to a single peak and then decline rapidly. Second, response duration and amplitude must be determined strictly by the intensity of the elicitor and current states of the intervening synapses and effector organs. Third, signal conduction can proceed in only one direction ("the irreversibility of conduction"). And finally, the actual result of the activation of the effectors cannot directly modify subsequent effector output (i.e., there should be no feedback from the effectors to any part of the reflex arc).

From a psychological perspective, Skinner (1931) argued that the concept of the reflex is fundamentally both behavioral and statistical and that it reduces simply to "the observed correlation of the activity of an effector (i.e., a response) with the observed forces affecting a receptor (i.e., a stimulus)" (p. 438). He argued that the functional attributes of unlearned, unconscious, and involuntary as well as any physiological attributes so often claimed to define a reflex were actually incidental properties of the class of reflexes that were first discovered and investigated by neurophysiologists. Generalizing the concept beyond its historical beginnings, he partitioned the experimental study of the reflex into two parts. First, there is the investigation of the correlation between a specifiable stimulus class (*S*) and response class (*R*), that is, the latency, threshold, and range of variation in *S* and *R* over which the correlation holds. Second, there is the investigation of variations in these characteristics as a function of third variables. This latter investigation would include assessing changes in reflex strength (i.e., the magnitude of the correlation) as a function of variables such as motivation, drive, response preparation, and so on.

Reflex probe technique. Since the turn of the century, the scientific study of the reflex has proceeded in two directions. Disciplines concerned with the control of movement (e.g., neurophysiology, physiological psychology, psychology) have generally followed the tradition of Sherrington (1923/1906) and examined reflexes as integral to the regulation of behavior. Predicated on this view of the reflex as a relatively invariant unit of behavior, the accompanying research and theory focuses on specifying the rules by which reflexes combine to generate coordinated, goal-directed movements.

In neurology and psychophysiology, however, the reflex is viewed in a manner more consistent with the behaviorist generalization of the concept articulated by Skinner. In the field of neurology this conceptualization led initially to widespread confusion, with the early part of the century referred to as an open season for the "hunting of the reflex" (Wartenberg, 1946). During this time, any stimulus–response correlation was "fair game" to be named and reified. An unfortunate result was that many reflexes were "discovered" by one author after another, each time renamed and claimed to be unique.

However, it is now possible to use parameters of reflex responses as markers of CNS function (Kimura, 1973) because of increasingly detailed information about the neural circuits mediating specific reflexes (Ongerboer de Visser, 1983) and the development of standardized testing conditions (Bickerstaff, 1975; Desmedt, 1973; Hugon, 1973). For example, Kimura, Giron, and Young (1976) divided 81 Bell's palsy patients into two groups based on temporal changes in the electrically elicited direct and reflex blink responses. Direct blinks were those evoked by the stimulation of the motoneuron axons, whereas reflex blinks were those evoked by sensory nerves. The results were striking: All of the 56 patients who maintained direct motor responses until the recovery of the blink reflex experienced at least a 50 percent recovery of facial nerve function at the end of 2 months, whereas none of the 25 patients who had lost direct blink responses prior to reflex recovery demonstrated any indication of facial nerve function at the end of 2 months.

As a tool in the investigation of psychological processes, surface electromyography provides an ongoing record of muscular activity while minimally interfering with the behavior under study. The unique advantage of the reflex probe technique, however, is that it allows estimation of changes in the excitability of spinal and brainstem motor structures that may be manifest in neither overt behavior nor in peripheral EMG activity. The use of the reflex as a probe into ongoing psychological processes further exemplifies the examining of variations in reflex characteristics as a function of third variables. Although Skinner (1931) intended this experimental procedure to be used to quantify the influences of external variables on the reflex behavior of intact organisms, that logic of the situation allows one to use variations in reflex strength as an indicant of internal psychological processes as well. In the former case the focus is on the description of behavior, whereas in the latter case one infers the operation of either intervening variables or hypothetical constructs.

Early investigations of reflexes revealed that psychological factors (i.e., attention) could impact on aspects of reflex response. Clinical neurologists looked upon these influences as nuisance variables, factors that could increase the likelihood of both false positives and false negatives in their diagnosis of CNS function. However, the enormous potential to use such procedures in psychophysiological investigations was apparent from the turn of the century (Dodge, 1911; Sherrington, 1923/1906). Surprisingly, for reasons that remain somewhat unclear (see Ison & Hoffman, 1983), the use of this technique was sporadic until the mid-1960s and early 1970s.

The power of the reflex probe technique for psychophysiological inference can be most clearly seen in the work on attentional proceses (e.g., Anthony, 1985; Graham, Stock, & Zeigler, 1981) and on response preparation (e.g., Boelhouwer, Bruggemans, & Brunia, 1987; Brunia, 1984). For example, Anthony (1985) reviews numerous experiments on the modulation of the blink reflex by manipulations affecting attention. The general conclusion from such studies is that the amplitude and/or latency of the blink can be used in specific situations to measure how attention is allocated to different sensory modalities. Specifically, in paradigms in which the subject is warned of an impending target stimulus, the amplitude of the blink is reliably enhanced or suppressed in the warning interval as a function of the match or mismatch, respectively, between the modalities of the two stimuli. In addition, reliable changes in the degree of facilitation or inhibition across the warning interval suggest that the selective allocation of attention may begin as early as the onset of the warning stimulus but that the rate of allocation speeds up dramatically approximately 2 s before the onset of the target stimulus (cf. Davis, 1940).

11.4.1.5 *Manipulated response paradigms*

Questions about the contributions of skeletomotor actions to psychological states or processes have typically been addressed by manipulating skeletomotor actions to achieve the desired configuration, verifying the configuration using some observational procedure such as Ekman and Friesen's (1978) facial action coding system and measuring the outcome variables of interest (e.g., subjective states, autonomic responses; see Figure 11.7). Although skeletomotor actions have occasionally been manipulated through operant conditioning procedures (e.g., Hefferline, Keenan, & Harford, 1959; McCanne & Anderson, 1987), the most common approaches have been to instruct subjects either to exaggerate/suppress general skeletomotor configurations or to achieve a particular pose by varying the actions of individual muscles (e.g., see reviews by Laird, 1984; Matsumoto, 1987).

Muscle-by-muscle induction paradigm. In an illustrative study utilizing the muscle-by-muscle induction variant of this general approach, Ekman et al. (1983) instructed individuals to contract individual muscles until prototypes of the expressions of happiness, sadness, fear, anger, disgust, or surprise were constructed. The construction of each emotional expression was preceded by the construction of an equally effortful nonemotional expression. Each expression was held for 10 s and was subsequently verified as having been achieved by the experimenter. Averaged data during emotional faces minus that during nonemotional ones revealed that the anger face was associated with elevated heart rate and palmar skin temperature, fear and sad faces were associated with elevated heart rate and relatively low levels of palmar skin temperature, and the remaining expressions were associated with relatively low levels of heart rate and skin temperature.

Research utilizing the muscle-by-muscle induction paradigm has sometimes yielded inconsistent results (e.g., Tourangeau & Ellsworth, 1979; cf. Tassinary et al., 1989). Methodological issues that could contribute to inconsistent results and flawed interpretations include improper controls for somatic tension or effort; floor and ceiling effects in emotional responding; and the specification and construction of the appropriate configuration of skeletomotor actions, at appropriate levels of intensity overall and relative to one another, with naturalistic durations and appropriate forms of response across time. Interested readers might wish to see relevant commentaries by Cacioppo and Petty (1986), Fridlund (1988), Hager and Ekman (1981), Laird (1984), and Matsumoto (1987).

Exaggeration–suppression paradigm. Vaughan and Lanzetta (1981) employed the exaggeration–suppression variant of this paradigm to assess the possible influence of facial expressions on vicarious emotional arousal. Subjects were exposed to a videotaped model displaying pain, ostensibly from receiving electric shocks. One group of subjects was instructed to *inhibit* any facial expressions when the model was shocked, a second group was instructed to *amplify* their facial expressions when the model was shocked, and a third (*control*) group received no instructions about modulating their facial expressions. Results revealed that the amplify group exhibited larger skin conductance responses, heart rate increases, and facial EMG activity in response to the model's display of pain than the other two groups, which did not differ from one another.

Based on the emerging research showing that manipulations of overt facial expressions can influence affective responses, Wells and Petty (1980) tested the hypothesis that affectively relevant bodily movements could also influence attitudinal responses toward a persuasive appeal. Specifically, head movements (nodding in agreement or disagreement) were chosen for study because of their strong association with agreeing and disagreeing responses in a wide variety of cultures (Eibl-Eibesfeldt, 1972). Darwin (1873/1872), in fact, suggested that head shaking has a universal negative meaning that originated from food refusal.

In their study, subjects were led to believe that they were participating in consummer research on the sound quality of stereo headphones; in particular, how the headphones tested (e.g., in terms of sound quality, comfort) when listeners were engaged in movement (e.g., walking, dancing, jogging). One group of subjects was told that they should move their heads up and down once per second to test the headphones (vertical head movements condition), a second was told to move their heads from side to side once per second (horizontal head movements condition), and a third (control) group was told nothing about head movements. After subjects were given the instructions, a tape from a purported campus radio program was played. The tape began and ended with music, and a "station editorial" was introduced between the two musical selections. Subjects either heard an editorial in favor of raising tuition at their university or one in favor reducing tuition. The key dependent measure was what subjects indicated tuition at their university should be. Results revealed that although subjects believed the appropriate level of tuition was higher following the "increase tuition" than "decrease tuition" editorial, a significant interaction revealed that subjects in the vertical-head-movements condition advocated more tuition than subjects in the horizontal-head-movements condition following the "increase tuition" message, and the opposite occurred following the "decrease tuition" message; in both instances, judgments by subjects in the control condition fell between these two. That is, vertical head movements led to greater agreement with the message in both cases than did horizontal head movements. Whether these results reflect the effects of peripheral feedback per se or of memories and cognitive sets that might have been evoked by the head movements remains to be determined.

11.4.2 *Range of applications*

As we describe throughout this chapter, the surface EMG technique is valuable in studying a variety of psychological and behavioral processes. The technique also finds wide use in clinical practice, research, and forensics. We list a few general areas to illustrate the breadth of its application.

11.4.2.1 *Headache and stress reduction*

A popular use of surface EMG detection is in clinical biofeedback for tension headache and stress reduction. This use stemmed from a clinical report by Budzynski and Stoyva (1969), who used EMG activity from a bilateral forehead site over the *lateral frontalis*. In the typical clinical regimen, patients hear tones or clicks whose pitch or rate varies with the envelope of the smoothed, rectified electromyogram; patients learn to lower the tone or click rate by relaxing their muscles. Budzynski and Stoyva promulgated "frontalis EMG biofeedback" as a treatment for muscle contraction ("tension") headache, but this procedure was soon extended to general stress management (e.g., Stoyva & Budzynski, 1974).

Budzynski and Stoyva chose the *frontalis* site because they claimed that muscle tention there was uniquely indicative of whole-body tension. This rationale was eventually discredited, both in normals (Alexander, 1975; Fridlund, Cottam, & Fowler, 1982; Fridlund et al., 1980; Shedivy & Kleinman, 1977; Whatmore, Whatmore, & Fisher, 1981) and in anxious students (Fridlund et al., 1986).

The rash of frontalis EMG biofeedback studies published in biofeedback's halcyon days consisted mostly of case reports and uncontrolled clinical trials (see Alexander & Smith, 1979, for review), and the claimed incremental efficiacy over simple relaxation or meditation techniques is in doubt. The few studies that were done with adequate controls indicated the EMG biofeedback for stress control is equivalent in efficacy to the panoply of stress-reduction techniques. By 1980, an NIMH report on claims for EMG biofeedback's unique efficacy in headache and stress management was skeptical (NIMH, 1980). Moreover, the last ten years have seen a devaluation of the role of muscle tension in "tension" headache (Chun, 1985), and an emphasis on vascular dysfunction, secondary ischemia, and nocigenic metabolites in the etiology (Pikoff, 1984). Clinicians now tend to use "frontalis EMG biofeedback" as a variant of relaxation training.

Psychosomatic medicine researchers in the 1940s and 1950s were interested in painful, idiopathic muscular contractions occurring in stress or conflict (Malmo, 1965; Malmo & Shagass, 1949a, b; Malmo, Shagass, Belanger, & Smith, 1951; Malmo, Shagass, & Davis, 1951; Malmo & Smith, 1955). These examples of "symptom specificity" have occasionally been treated with EMG biofeedback to relax the muscles. However, these idiopathic contractions are today regarded most often as

secondary to any number of disorders, including joint disturbance (e.g., temporomandibular joint disorder), major depression, Briquet's syndrome, anxiety disorders, or infectious illness. Treatment of the primary disorder is the preferred intervention.

11.4.2.2 *Physical medicine and rehabilitation*

Basmajian (1963) confirmed early the supposition that given sufficiently precise feedback, individuals could learn to control single motor units. His finding, and his pioneering application of EMG biofeedback methods in physical medicine, soon led to the widespread use of surface EMG to enhance recovery of function in muscles that were rendered nonfunctional by stroke, illness, and accidents (Basmajian & DeLuca, 1985). In the rehabilitation setting, feedback derived from the surface EMG signal is used, depending upon the disorder, either to relax or tense spastic muscles (e.g., chronic unilateral neck spasms; spastic cerebral palsy; see DeBacher, 1979) or to activate atrophied or functionally denervated muscles (e.g., hemiplegia from stroke; Basmajian, Kukulka, Narayan, & Takebe, 1975). Following facial anastomosis surgery (graft of a facial nerve branch from the functional side of the lower face to the nonfunctional side, often after a stroke has induced hemiparesis), biofeedback is often used to restore bilateral symmetry to the hemiparetic face.

Electromyographic biofeedback in rehabilitation is now standard procedure, and there were early reports of incremental efficacy over standard physical therapy (see Fernando & Basmajian, 1978). Despite this early enthusiasm, it is still not clear that the mechanism of the EMG biofeedback is the source of its putative efficacy. Most individuals with neuromuscular disability are chronically depressed, and their hopes for success of the biofeedback often ameliorate the depression and rejuvenate their efforts in physical therapy.

11.4.2.3 *Forensic polygraphy*

Canny criminal suspects who undergo a polygraph test often use a variety of countermeasures to foil the test. By pressing their toes hard against the floor or biting their tongues, they can generate autonomic responses that confuse the polygraph examiner (Honts, Hodes, & Raskin, 1985; Reid & Inbau, 1977). Recently, Honts, Raskin, and Kircher (1983) found that surface EMG detected from the examinee's gastrocnemius (anterior thigh) and temporalis (temple) muscles permitted detection of 90 percent of experimental subjects who used tongue biting or toe pressing to defeat the test. Using surface EMG is not routine in polygraphy because of both its novelty and the added expense of the EMG equipment. We expect that it will become used more widely.

11.4.2.4 *Polysomnography*

In studies of sleep, the onset of paradoxical or rapid eye movement (REM) sleep is reliably accompanied by a loss of normal muscle activity in the face and limbs. This loss of tension is thought to block the acting out of dreams. In both clinical and research polysomnography (i.e., measurement during sleep of physiological responses like heart rate, sweat gland response, respiration, eye movement, etc.; see Rechtschaffen & Kales, 1968), surface EMG is typically recorded from the chin, over the *mentalis* muscle (whose action elevates the chin boss). Changes in activity over this site corroborate transitions to and from paradoxical sleep (Kupfer & Reynolds, 1983). Surface EMG has also been used to study: (1) leg spasms in nocturnal myclonus ("restless legs syndrome"); (2) abdominal actions in airway apneas (breathing difficulties due to paradoxical sleep-related epiglottal collapse); and (3) nocturnal bruxism, or tooth grinding (see Association of Sleep Disorders Centers, 1979; Guilleminault, 1982; Hauri, 1977).

11.4.2.5 *Miscellaneous*

Surface EMG is a viable, precise way of measuring muscular contraction in an ongoing fashion in many situations wherein observation is too imprecise or awkward. In addition to those uses we detailed, we just mention a few more: (1) measuring eyeblink rates and amplitudes in conditioning and vigilance studies; (2) determining muscle tension in ergonomic design and man–machine interface studies; (3) timing and quantifying precisely the onset of responses in reaction time tasks, including incipient responses that precede the overt response; (4) corroborating timing or force irregularities in neurological finger-tapping tasks; and (5) discerning the specific muscles that maintain posture, coordinate gait, and participate in skilled acts.

With the decreasing expense of the instrumentation required for sensitive and precise EMG measurement, the availability of guidelines and standards, and the emergence of conceptual frameworks and paradigms to aid in the interpretation of EMG responses, the surface EMG technique should find even wider application.

11.5 CONCLUSION

The skeletomotor system has been central to the field of neurophysiology since Francesco Redi's indirect observation in 1666 that living muscles generate electrical current. The centrality of the skeletomotor system within the field of psychology is illustrated by William James's (1890) early suggestion that the "Will" (i.e., an idea or image) triggers the waiting musculature:

> We may then lay it down for certain that every representation of a movement awakens in some degree the actual movement which is its object; and awakens it in a maximum degree whenever it is not kept from doing so by an antagonistic representation present simultaneously to the mind.... We do not have a sensation or a thought and then have to *add* something dynamic to get a movement. (pp. 526–527)

Moreover, the concepts of muscle activation, muscle tension, and skeletomotor patterning have long been related to thinking (e.g., Jacobson, 1932; James, 1890; McGuigan, 1978), feeling (e.g., Darwin, 1873/1872; James, 1884), behaving, imagined or real (e.g., Jacobson, 1932; Shaw, 1940), sleeping (e.g., Larson & Foulkes, 1969; Max, 1935), and learning (e.g., Bills, 1927; Courts, 1942) and to the constructs of motivation (e.g., Bartoshuk, 1955; Malmo, 1965), arousal or activation (e.g., Kennedy & Travis, 1948; Woodworth & Schlosberg, 1954), attention (e.g., Lynn, 1966; Pavlov, 1927), personality (e.g., Goldstein, 1964), psychosomatic disease (e.g., Malmo, Shagass, & Davis, 1950; Malmo, 1975), and psychopathology and psychotherapy (e.g., Jacobson, 1938).

Early theories attempted to explain many psychological processes entirely in

terms of peripheral skeletomotor actions. This resulted in an exciting and active period for psychophysiology, but the disconfirmation of categorical predictions made by these motor theories was inevitable, resulting in a brief downturn in interest in transient or weak skeletomotor actions. Nonetheless, many interesting results from this early period have been replicated, however, and coupled with advances in signal acquisition and analysis, these data are being incorporated within theoretical frameworks highlighting the integrated actions of the central and peripheral nervous systems. As illustrated in this chapter, contemporary EMG studies are diverse. Among the key directions are: (1) the spatial and temporal patterning that characterizes specific organismic–environmental transactions; (2) incipient actions of the skeletomotor system and their relation to ongoing psychological processes; (3) surface EMG in studies of the potential influence of striated muscle actions and patterns on supraphysiological constructs such as thought, emotion, and motivation; (4) the diagnosis and therapeutic use of EMG in psychopathology and psychosomatic disorders; and (5) interactions between the skeletomotor and other physiological systems (see, also, Papillo & Shapiro, chapter 14; Coles et al., chapter 13). These directions, we believe, bode well for EMG research in psychology.

NOTES

Preparation of his chapter was supported by National Science Foundation Grant Nos. BNS-8414853, BNS-8706156, and BNS-8940915.

1 Interested readers may wish to consult Fulton (1926), Wu (1984), and Brazier (1959) for additional details about the history of muscle physiology and electromyography. Readers interested in additional details about the physical basis and neural control of muscle contraction are encouraged to consult the recent works of Hoyle (1983) and Loeb and Gans (1986), and those interested in more information about related clinical applications are encouraged to consult Monnier (1970).

2 This was also the first evidence of the injury current in muscles, which is the current flow resulting from the potential difference between injured and intact tissue (Wu, 1984). Extensive study of this phenomenon during the nineteenth century resulted in the discovery of the action potential.

3 Volta's study of muscle actions contributed significantly to his inventing the first electric battery. Volta's battery was constructed by interposing layers of two different metals and pasteboards and soaking them in salt water. Volta asserted that this "artificial electric organ" was essentially the same as the natural electric organ of the torpedo or electric eel (Wu, 1984).

4 It is the closer spacing that can be achieved with small electrodes, not their higher electrode impedances, which enables greater recording selectivity: "Only closely spaced bipolar electrodes with differential amplification can make such recordings spatially selective" (Loeb & Gans, 1986, p. 24).

5 One important implication is that a failure to find significant treatment differences in EMG activity could be due to the selection of an inappropriate recording bandpass rather than to an actual absence in EMG activity across treatments. It is often advisable, therefore, to use a wide bandpass (e.g., 10–500 or 1,000 Hz) when recording EMG activity and subsequently apply filters to copies of the stored data.

6 The rms of the EMG signal can be calculated by summing the squares of each EMG amplitude within a recording bin, and performing the square root (see Marshall-Goodell et al., chapter 4). The rms is superior to mean amplitude as a measure of sinusoidal alternating current, and Basmajian and DeLuca (1985) have extended this argument to motor unit action potentials as well. It is of interest to note that the measures of mean amplitude, rms amplitude, and total electrical energy are closely related mathematically, with each emphasizing a different aspect of the amplitude distribution of a waveform. Interested

readers may wish to consult Cacioppo and Dorfman (1987). For alternative forms of averaging, see Basmajian and DeLuca (1985), Fridlund and Cacioppo (1986), or Dorfman and Cacioppo (chapter 20).

7 One common practice is to conduct analyses on standardized scores but present means of the raw data. It should be clear, however, that this practice can also be misleading in instances such as that depicted in Table 11.1. Finally, although the example discussed in the text focused on the use of standard scores to achieve a "comparable" metric across subjects, it is simple to demonstrate that the same limitations can arise when using standard scores to obtain comparability across recording sites.

8 For instance, Cacioppo, Petty, et al. (1986) placed electrodes on the side and back of the head and neck as well as on subjects' face and body; and subjects were told that the electrodes were placed around their brain to help isolate and identify the neural processes involved in processing pictorial stimuli through a process of triangulation. To the extent that the electrodes on the body and the dummy electrodes on the neck and head diverted subjects' attention from their voluntary facial actions, which debriefing suggested they did, then this explanation was factually accurate.

9 For instance, gradual rises and falls in EMG activity over the brow region were suggested to reflect paralinguistic signals as well as emotions, whereas more ballistic EMG responses over the brow region were depicted as less likely to serve as paralinguistic signals during an interview.

REFERENCES

Alexander, A. B. (1975). An experimental test of assumptions relating to the use of electromyographic biofeedback as a general relaxation technique. *Psychophysiology, 12,* 656–662.

Alexander, A. B., & Smith, D. D. (1979). Clinical applications of EMG biofeedback. In R. J. Gatchel & K. P. Price (Eds.), *Clinical applications of biofeedback: Appraisal and status* (pp. 112–133). New York: Pergamon.

Allport, G. W. (1968). The historical background of modern social psychology. In G. Lindzey & E. Aronson (Eds.), *The handbook of social psychology* (2nd ed.). Menlo Park, CA: Addison-Wesley.

Anson, B. J. (1966). *Morris' human anatomy* (12th ed.). New York: McGraw-Hill.

Anthony, B. J. (1985). In the blink of an eye: Implications of reflex modification for information processing. *Advances in Psychophysiology: A Research Annual, 1,* 167–218.

Ashby, W. R. (1960). *Design for a brain: The origin of adaptive behavior.* New York: Wiley.

Association of Sleep Disorders Centers. (1979). Diagnostic classification of sleep and arousal disorders (1st ed.). *Sleep, 2,* 1–137.

Bartoshuk, A. (1955). Electromyographic gradients as indicants of motivation. *Canadian Journal of Psychology, 9,* 215–230.

Basmajian, J. V. (1963). Control and training of individual motor units. *Science, 141,* 440–441.

Basmajian, J. V., & DeLuca, C. J. (1985). *Muscles alive: Their functions revealed by electromyography* (5th ed.). Baltimore: Williams & Wilkins.

Basmajian, J. V., Kukulka, C. G., Narayan, M. G., & Takebe, K. (1975). Biofeedback treatment of foot-drop after stroke compared with standard rehabilitation technique: Effects on voluntary control and strength. *Archives of Physical Medicine and Rehabilitation, 56,* 231–236.

Bavelas, J. B., Black, A., Lemery, C. R., & Mullett, J. (1986). "I *show* how you feel": Motor mimicry as a communicative act. *Journal of Personality and Social Psychology, 50,* 322–329.

Berkinblit, M. B., Feldman, A. G., & Fukson, O. I. (1986). Adaptability of innate motor patterns and motor control mechanisms. *Behavioral and Brain Sciences, 9,* 585–638.

Bickerstaff, E. R. (1975). *Neurological examination in clinical practice.* Oxford: Blackwell Scientific Publications.

Bills, A. G. (1927). Facilitation and inhibition in mental work. *Psychological Bulletin, 34,* 386–309.

Boelhouwer, A. J. W., Bruggemans, E., & Brunia, C. H. M. (1987). Blink reflex magnitude during the foreperiod of a warned reaction time task: Effects of precueing. *Psychophysiology, 24,* 625–631.

Bowditch, H. P. (1871). Uber die Eigenthumlichkeiten der Reizbarkeit welche die Muskelfasern des Herzens zeigen. *Ber. d. Konigl. Sachs. d. Ges. D. Wissen., 23,* 652–689. Cited in Fulton (1926).

Borelli, G. A. (1680). *De motu animalium* (pp. 276–277). Leiden: P. Vander Aa, 1710.

Bramsley, G. R., Bruun, G., Buchthal, F., Guld, C., & Petersen, H. S. (1967). Reduction of electrical interference in measurements of bioelectrical potentials in a hospital. *Acta Polytechnica Scandanavia, Electrical Engineering Series, 15,* 1–37.

Brazier, M. A. (1959). The historical development of neurophysiology. In J. Field (Ed.), *Handbook of physiology: Vol. 1, Section I. Neurophysiology* (pp. 1–58). Washington, DC: American Physiological Society.

Brunia, C. H. M. (1984). Selective and aselective control of spinal motor structures during preparation for a movement. In S. Kornblum & J. Requin (Eds.), *Preparatory states and processes.* Hillsdale, NJ: Erlbaum.

Budzynski, T. H., & Stoyva, J. M. (1969). An instrument for producing deep muscle relaxation by means of analog information feedback. *Journal of Applied Behavior Analysis, 2,* 231–237.

Cacioppo, J. T., & Dorfman, D. D. (1987). Moments in psychophysiological research: Topographical analysis of non-negative bounded waveforms. *Psychological Bulletin, 102,* 421–438.

Cacioppo, J. T., Losch, M. L., Tassinary, L. G., & Petty, R. E. (1986). Properties of affect and affect-laden information processing as viewed through the facial response system. In R. A. Peterson, W. D. Hoyer, & W. R. Wilson (Eds.), *The role of affect in consumer behavior: Emerging theories and applications* (pp. 87–118). Lexington, MA: Heath.

Cacioppo, J. T., Marshall-Goodell, B. S., & Dorfman, D. D. (1983). Skeletal muscular patterning: Topographical analysis of the integrated electromyogram. *Psychophysiology, 20,* 269–283.

Cacioppo, J. T., Marshall-Goodell, B. S., & Gormezano, I. (1983). Social psychophysiology: Bioelectrical measurement, experimental control, and analog-to-digital data acquisition. In J. T. Cacioppo & R. E. Petty (Eds.), *Social psychophysiology: A sourcebook* (pp. 666–692). New York: Guilford Press.

Cacioppo, J. T., Martzke, J. S., Petty, R. E., & Tassinary, L. G. (1988). Specific forms of facial EMG response index emotions during an interview: From Darwin to the continuous flow hypothesis of affect-laden information processing. *Journal of Personality and Social Psychology, 54,* 592–604.

Cacioppo, J. T., & Petty, R. E. (1979a). Attitudes and cognitive response: An electrophysiological approach. *Journal of Personality and Social Psychology, 37,* 2181–2199.

Cacioppo, J. T., & Petty, R. E. (1979b). Lip and nonpreferred forearm EMG activity as a function of orienting task. *Biological Psychology, 9,* 103–113.

Cacioppo, J. T., & Petty, R. E. (1981a). Electromyograms as measures of extent and affectivity of information processing. *American Psychologist, 36,* 441–456.

Cacioppo, J. T., & Petty, R. E. (1981b). Electromyographic specificity during covert information processing. *Psychophysiology, 18,* 518–523.

Cacioppo, J. T., & Petty, R. E. (1983). *Social psychophysiology: A sourcebook.* New York: Guilford Press.

Cacioppo, J. T., & Petty, R. E. (1986). Social processes. In M. G. H. Coles, E. Donchin, & S. Porges (Eds.), *Psychophysiology: Systems, processes, and applications* (pp. 646–679). New York: Guilford Press.

Cacioppo, J. T., Petty, R. E., Losch, M. E., & Kim, H. S. (1986). Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personality and Social Psychology, 50,* 260–268.

Cacioppo, J. T., Petty, R. E., & Marshall-Goodell, B. (1984). Electromyographic specificity during simple physical and attitudinal tasks: Location and topographical features of integrated EMG responses. *Biological Psychology, 18,* 85–121.

Cacioppo, J. T., Petty, R. E., & Marshall-Goodell, B. (1985). Physical, social, and inferential elements of psychophysiological measurement. In P. Karoly (Ed.), *Measurement strategies in health psychology* (Vol. 1, pp. 263–300). New York: Wiley.

Cacioppo, J. T., Petty, R. E., & Morris, K. J. (1985). Semantic, evaluative, and self-referent processing: Memory, cognitive effort, and somatovisceral activity. *Psychophysiology, 22,* 371–384.

Cacioppo, J. T., Petty, R. E., & Tassinary, L. G. (1989). Social psychophysiology: A new look. *Advances in Experimental Social Psychology, 22,* 39–91.

Cacioppo, J. T., & Tassinary, L. G. (1989). The concept of attitude: A psychophysiological analysis. In H. L. Wagner & A. S. R. Manstead (Eds.), *Handbook of psychophysiology: Emotion and social behaviour*. Chichester: Wiley.
Cavallo, T. (1786). *A complete treatise on electricity, in theory and practice* (3rd ed., Vol. 2). London: C. Dilly. Cited in Wu (1984).
Chapman, A. J. (1974). An electromyographic study of social facilitation: A test of the "mere presence" hypothesis. *British Journal of Psychology, 65*, 123–128.
Christie, M. J., & Todd, J. L. (1975). Experimenter-subject-situational interactions. In P. H. Venables & M. J. Christie (Eds.), *Research in psychophysiology*. London: Wiley.
Chun, W. X. (1985). An approach to the nature of tension headache. *Headache, 25*, 188–189.
Coles, M. G. H., Gratton, G., Bashore, T. R., Eriksen, C. W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 529–553.
Compton, R. W. (1973). Morphological, physiological, and behavioral studies of the facial musculature of the Coati (Nasua). *Brain, Behavior, and Evolution, 7*, 85–126.
Cooper, R., Osselton, J. W., & Shaw, J. C. (1980). *EEG technology* (3rd ed.). London: Butterworth.
Cottrell, N. B. (1972). Social facilitation. In C. G. McClintock (Ed.), *Experimental social psychology*. New York: Holt, Rinehart & Winston.
Courts, F. A. (1942). Relations between muscular tension and performance. *Psychological Bulletin, 39*, 347–367.
Daniels, L., & Worthingham, C. (1986). *Muscle testing: Techniques of manual examination* (5th ed.). Philadelphia: Saunders.
Darwin, C. (1873). *The expression of the emotions in man and animals*. New York: Appleton. (Original work published 1872.)
Davis, J. F., & Malmo, R. B. (1951). Electromyographic recording during interview. *American Journal of Psychiatry, 107*, 908–916.
Davis, J. F. (1952). *Manual of surface electromyography*. Montreal: Laboratory for Psychological Studies, Allan Memorial Institute of Psychiatry.
Davis, J. F., Malmo, R. B., & Shagass, C. (1954). Electromyographic reaction to strong auditory stimulation in psychiatric patients. *Canadian Journal of Psychology, 8*, 177–186.
Davis, R. C. (1940). Set and muscular tension. *Indiana University Publications, Science Series*, No. 10.
DeBacher, G. (1979). Biofeedback in spasticity control. In J. V. Basmajian (Ed.), *Biofeedback – Principles and practice for clinicians*. Baltimore: Williams & Wilkins.
Desmedt, J. E. (1973). A discussion of the methodology of the Triceps Surae T- and H-reflexes. In J. E. Desmedt (Ed.), *New developments in electromyography and clinical neurophysiology* (Vol. 3). Basel: Karger.
Dimberg, U. (1982). Facial reactions to facial expressions. *Psychophysiology, 19*, 643–647.
Dodge, R. B. (1911). A systematic exploration of a normal knee jerk, its technique, the form of muscle contraction, its amplitude, its latent time and its theory. *Zeitschrift für Allgemeine Physiologie, 12*, 1–58.
Du Bois-Reymond, E. (1849). *Untersuchungen ueber thiersiche elektricitaet* (Vol. II, 2nd part). Berlin: Reimer-Verlag. Cited in Basmajian & DeLuca (1985).
Duchenne, G. B. (1959). *Physiology of motion: Demonstrated by means of electrical stimulation and clinical observations and applied to the study of paralysis and deformities* (E. Kaplan, Trans. & Ed.). Philadelphia: Lippincott. (Original work published 1867.)
Duffy, E. (1962). *Activation and behavior*. New York: Wiley.
Eason, R. G., & White, C. T. (1961). Muscular tension, effort, and tracking difficulty: Studies of parameters which affect tension levels and performance efficiency. *Perceptual and Motor Skills, 12*, 331–372.
Eibl-Eibesfeldt, I. (1972). Similarities and differences between cultures in expressive movement. In R. A. Hinde (Ed.), *Nonverbal communication*. Cambridge: Cambridge University Press.
Ekman, P. (1972). Universal and cultural differences in facial expressions of emotion. In J. Cole (Ed.), *Nebraska symposium on motivation*, (Vol. 19, pp. 207–218). Lincoln: University of Nebraska Press.
Ekman, P. (1973). *Darwin and facial expression: A century of research in review*. New York: Academic Press.
Ekman, P. (1982). Methods for measuring facial action. In K. R. Scherer & P. Ekman (Eds.), *Handbook of methods in nonverbal behavior research* (pp. 45–90). Cambridge: Cambridge University Press.

Ekman, P. (1985). *Telling lies: Clues to deceit in the marketplace, politics, and marriage*. New York: Norton.
Ekman, P., & Friesen, W. V. (1975). *Unmasking the face*. Englewood Cliffs, NJ: Prentice-Hall.
Ekman, P., & Friesen, W. V. (1978). *Facial action coding system (FACS): A technique for the measurement of facial actions*. Palo Alto, CA: Consulting Psychologists Press.
Ekman, P., Friesen, W. V., O'Sullivan, M., Chan, A., Diacoyanni-Tarlatzis, I., Heider, K., Krause, R., LeCompte, W. A., Pitcairn, T., Ricci-Bitti, P. E., Scherer, K., Tomita, M., & Tzavaras, A. (1987). Universals and cultural differences in the judgments of facial expressions of emotion. *Journal of Personality and Social Psychology, 53*, 712–717.
Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science, 221*, 1208–1210.
Englis, B. G., Vaughan, K. B., & Lanzetta, J. T. (1982). Conditioning of counter-empathic emotional responses. *Journal of Experimental Social Psychology, 18*, 375–391.
Faulkenberry, L. M. (1977). *An introduction to operational amplifiers*. New York: Wiley.
Fearing, F. (1930). *Reflex action: A study in the history of physiological psychology*. Baltimore: Williams & Wilkins.
Fernando, C. K., & Basmajian, J. V. (1978). Biofeedback in physical medicine and rehabilitation. *Biofeedback and Self-Regulation, 3*, 435–455.
Foley, M. G. (1954). *Galvani: Effects of electricity on muscular motion*. Norwalk, CT: Bundy Library.
Fridlund, A. J. (1979). Contour-following integrator for dynamic tracking of electromyographic data. *Psychophysiology, 16*, 491–493.
Fridlund, A. J. (1987). Advances in analyzing the facial electromyogram. *Face Value, 1*, 4–5.
Fridlund, A. J. (in press). Evolution and facial action in reflex, emotion, and paralanguage. In P. K. Ackles, J. R. Jennings, & M. G. H. Coles (Eds.), *Advances in psychophysiology* (Vol. 4). Greenwich, CT: JAI Press.
Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23*, 567–589.
Fridlund, A. J., Cottam, G. L., & Fowler, S. C. (1982). In search of the general tension factor: Tensional patterning during auditory stimulation. *Psychophysiology, 19*, 136–145.
Fridlund, A. J., & Fowler, S. C. (1978). An eight-channel computer-controlled scanning electromyograph. *Behavior Research Methods & Instrumentation, 10*, 652–662.
Fridlund, A. J., Fowler, S. C., & Pritchard, D. A. (1980). Striate muscle tensional patterning in frontalis EMG biofeedback. *Psychophysiology, 17*, 47–55.
Fridlund, A. J., Hatfield, M. E., Cottam, G. L., & Fowler, S. C. (1986). Anxiety and striate-muscle activation: Evidence from electromyographic pattern analysis. *Journal of Abnormal Psychology, 95*, 228–236.
Fridlund, A. J., & Izard, C. E. (1983). Electromyographic studies of facial expressions of emotions and patterns of emotions. In J. T. Cacioppo & R. E. Petty (Eds.), *Social psychophysiology: A sourcebook* (pp. 243–286). New York: Guilford Press.
Fridlund, A. J., Price, A. W., & Fowler, S. C. (1982). Low-noise, optically isolated electromyographic preamplifier. *Psychophysiology, 19*, 701–705.
Fridlund, A. J., Schwartz, G. E., & Fowler, S. C. (1984). Pattern recognition of self-reported emotional state from multiple-site facial EMG activity during affective imagery. *Psychophysiology, 21*, 622–637.
Fridlund, A. J., Tassinary, L. G., & Cacioppo, J. T. (1988). On the utility of non-polarizing electrodes in human surface electromyographic recording. *Psychophysiology, 25*, 488.
Friesen, W. V. (1972). *Cultural differences in facial expression in a social situation: An experimental text of the concept of display rules*. Unpublished doctoral dissertation, University of California, San Francisco.
Fulton, J. F. (1926). *Muscular contraction and the reflex control of movement*. Baltimore: Williams & Wilkins.
Gale, A., & Baker, S. (1981). *In vivo* or *in vitro*? Some effects of laboratory environments, with particular reference to the psychophysiological experiment. In M. J. Christie & P. G. Mellet (Eds.), *Foundations of psychosomatics*. Chichester: Wiley.
Gale, A., & Christie, B. (1987). *Psychophysiology and the electronic workplace* (pp. 3–15). Chichester: Wiley.
Gallistel, C. R. (1980). *The organization of action: The new synthesis*. Hillsdale, NJ: Erlbaum.

Galton, F. (1884). Measurement of character. *Fortnightly Review, 42,* 179–185.

Galvani, L. (1952). *Dell'uso e dell'attivita dell'arco conduttore nelle contrazione dei muscoli, Supplemento al trattato.* Bologna: A. S. Tomaso d'Aquino. *Galvani-Volta* (B. Dibner, Trans.). Norwalk, CT.: Burndy Library. (Original work published in 1794.)

Galvani, L. (1953). *De viribus electricitatis in motu musculari.* Bologna: Typographia Instituti Scientiarum. (R. M. Green, Trans.) *Commentary on the effect of electricity on muscular motion.* Cambridge, MA: Elizabeth Licht. (Original work published in 1791.)

Gans, C., & Gorniak, G. C. (1980). Electromyograms are repeatable: Precautions and limitations. *Science, 210,* 795–797.

Geen, R. G., & Gange, J. J. (1977). Drive theory of social facilitation: Twelve years of theory and research. *Psychological Bulletin, 84,* 1267–1288.

Germana, J. (1974). Electromyography: Human and general. In R. F. Thompson & M. M. Patterson (Eds.), *Bioelectric recording techniques: Part C: Receptor and effector processes* (pp. 155–163). New York: Academic Press.

Ghez, C. (1985). Introduction to the motor systems. In E. R. Kandel & J. H. Schwartz (Eds.), *Principles of neural science* (2nd ed., pp. 429–442). New York: Elsevier.

Goldstein, I. B. (1964). Role of muscle tension in personality theory. *Psychological Bulletin, 601,* 413–425.

Goldstein, I. B. (1972). Electromyography: A measure of skeletal muscle response. In N. S. Greenfield & R. A. Sternbach (Eds.), *Handbook of psychophysiology* (pp. 329–366). New York: Holt, Rinehart & Winston.

Gotch, F. (1902). The submaximal electrical response of nerve to a single stimulus. *Journal of Physiology, 28,* 395–416.

Graham, F. K., Strock, B. D., & Zeigler, B. L. (1981). Excitatory and inhibitory influences on reflex responsiveness. In W. A. Collins (Ed.), *Aspects of the development of competence: The Minnesota symposia on child psychology* (Vol. 14, pp. 1–38). Hillsdale, NJ: Erlbaum.

Graham J. L. (1980). A new system for measuring nonverbal responses to marketing appeals. *1980 AMA Educator's Conference Proceedings, 46,* 340–343.

Grieve, D. W., & Cavanaugh, P. R. (1973). The quantitative analysis of phasic electromyograms. In J. E. Desmedt (Ed.), *New developments in electromyography and clinical neurophysiology* (Vol. 2, pp. 487–496). Basel: Karger.

Groff, B. D., Baron, R. S., & Moore, D. L. (1983). Distraction, attentional conflict, and drivelike behavior. *Journal of Experimental Social Psychology, 19,* 359–380.

Guilleminault, C. (Ed.) (1982). *Sleeping and waking disorders: Indication and techniques.* Menlo Park, CA: Addison-Wesley.

Hager, J. C., & Ekman, P. (1981). Methodological problems in Tourangeau and Ellsworth's study of facial expression and experience of emotion. *Journal of Personality and Social Psychology, 40,* 358–362.

Harris, R. (1975). A primer of multivariate statistics. New York: Academic.

Hauri, P. (1977). *The sleep disorders.* Kalamazoo, MI: Upjohn Pharmaceuticals.

Hayes, K. J. (1960). Wave analyses of tissue noise and muscle action potential. *Journal of Applied Physiology, 15,* 749–752.

Hefferline, R. F., Keenan, B., & Harford, R. A. (1959). Escape and avoidance conditioning in human subjects without their observation of the response. *Science, 1,* 1338–1339.

Helmer, R. J. (1986) A test-signal generator for low-frequency instrumentation. *Behavior Research Methods, Instruments, and Computers, 18,* 372–376.

Henneman, E. (1980a). Organization of the motoneuron pool: The size principle. In V. E. Mountcastle (Ed.), *Medical physiology* (14th ed., Vol. 1, pp. 718–741). St. Louis: Mosby.

Henneman, E. (1980b). Organization of the motor systems: A preview. In V. E. Mountcastle (Ed.), *Medical physiology* (14th ed., Vol. 1, pp. 669–673). St. Louis: Mosby.

Henneman, E. (1980c). Skeletal muscle: The servant of the nervous system. In V. E. Mountcastle (Ed.), *Medical physiology* (14th ed., Vol. 1, pp. 674–702). St. Louis: Mosby.

Hinsey, J. C. (1940). The hypothalamus and somatic responses. In J. F. Fulton, S. Walter, & A. M. Frantz (Eds.), *Research publications of the Association for Research in Nervous and Mental Disease* (Vol. 20, pp. 657–685). Baltimore: Williams & Wilkins.

Honts, C. R., & Hodes, R. L. (1982). The effects of multiple physical countermeasures on the detection of deception. *Psychophysiology, 19,* 564–565.

Honts, C. R., Hodes, R. L., & Raskin, D. C. (1985). Effects of physical countermeasures on the physiological detection of deception. *Journal of Applied Psychology, 79,* 177–187.

Honts, C. R., Raskin, D. C., & Kircher, J. C. (1983). Detection of deception: Effectiveness of physical countermeasures under high motivation conditions. *Psychophysiology, 20,* 446–447.

Hoyle, G. (1983). *Muscles and their neural control.* New York: Wiley.

Hugon, M. (1973). Methodology of the Hoffman reflex in man. In J. E. Desmedt (Ed.), *New developments in electromyography and clinical neurophysiology* (Vol. 3, pp. 277–293). Basel: Karger.

Humboldt, F. H. A. von (1797). *Versuche uber die gereizte Muskel- und Nervenfaser nebst Vermuthungen uber chemischen Processes des Lebens in der Thier und Pflanzwelt* (Vol. 1). Poznan: Decker. Cited in Fulton (1926).

Humphrey, G. (1951). *Thinking.* New York: Wiley.

Isley, C. L., & Basmajian, J. V. (1973). Electromyography of the human cheeks and lips. *Anatomical Record, 176,* 143–148.

Ison, J. R., & Hoffman, H. S. (1983). Reflex modification in the domain of startle: II. The anomalous history of a robust and ubiquitous phenomenon. *Psychological Bulletin, 94,* 3–17.

Izard, C. E. (1971). *The face of emotion.* New York: Appleton-Century-Crofts.

Izard, C. E. (1977). *Human emotions.* New York: Plenum Press.

Jacobson, E. (1925). Voluntary relaxation of the esophagus. *American Journal of Physiology, 72,* 387–394.

Jacobson, E. (1927). Action currents from muscular contractions during conscious processes. *Science, 66,* 403.

Jacobson, E. (1930a). Electrical measurements of neuromuscular states during mental activities: I. Imagination of movement involving skeletal muscle. *American Journal of Physiology, 91,* 567–608.

Jacobson, E. (1930b). Electrical measurements of neuromuscular states during mental activities: II. Imagination and recollection of various muscular acts. *American Journal of Physiology, 94,* 22–34.

Jacobson, E. (1930c). Electrical measurements of neuromuscular states during mental activities: III. Visual imagination and recollection. *American Journal of Physiology, 95,* 694–702.

Jacobson, E. (1930d). Electrical measurements of neuromuscular states during mental activities: IV. Evidence of contraction of specific muscles during imagination. *American Journal of Physiology, 95,* 703–712.

Jacobson, E. (1931a). Electrical measurements of neuromuscular states during mental activities: V. Variation of specific muscles contracting during imagination. *American Journal of Physiology, 96,* 115–121.

Jacobson, E. (1931b). Electrical measurements of neuromuscular states during mental activities: VI. A note on mental activities concerning an amputated limb. *American Journal of Physiology, 96,* 122–125.

Jacobson, E. (1931c). Electrical measurements of neuromuscular states during mental activities: VII. Imagination, recollection and abstract thinking involving the speech musculature. *American Journal of Physiology, 97,* 200–209.

Jacobson, E. (1932). Electrophysiology of mental activities. *American Journal of Psychology, 44,* 677–694.

James, W. (1884). What is an emotion? *Mind, 9,* 188–205.

James, W. (1890). *The principles of psychology.* New York: Holt.

Johnson, L. C., & Lubin, A. (1972). On planning psychophysiological experiments: Design, measurement, and analysis. In N. S. Greenfield & R. A. Sternbach (Eds.), *Handbook of psychophysiology* (pp. 125–158). New York: Holt, Rinehart & Winston.

Kahn, F. (1943). *Man in structure and function* (George Rosen, Trans.) (Vol. 1). New York: Knopf.

Kandel, E. R., & Schwartz, J. H. (1985). *Principles of neural science* (2nd ed.). New York: Elsevier.

Kendall, P. T., & McCreary, E. K. (1980). *Muscles: Testing and function* (3rd ed.). Baltimore: Williams & Wilkins.

Kennedy, J. L., & Travis, R. C. (1948). Prediction and control of alertness: II. Continuous tracking. *Journal of Comparative and Physiological Psychology, 41,* 203–210.

Kimura, J. (1973). The blink reflex as a test for brainstem and higher central nervous system function. In J. E. Desmedt (Ed.), *New developments in electromyography and clinical neurophysiology* (Vol. 3). Basel: Karger.

Kimura, J., Giron L. T., & Young, S. M. (1975). Electrophysiological study of Bell's palsy: Electrically elicited blink reflex in assessment of prognosis. *Archives of Otolaryngology, 102,* 140–143.
Komi, P. V., & Buskirk, E. R. (1970). Reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. *Electromyography, 10,* 357–367.
Kraut, R. E., & Johnson, R. E. (1979). Social and emotional messages of smiling: An ethological approach. *Journal of Personality and Social Psychology, 37,* 1539–1553.
Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement.* Hillsdale, NJ: Erlbaum.
Kupfer, D. J., & Reynolds, C. F. (1983). Sleep disorders. *Hospital Practice,* February, 101–109.
Kuypers, H. G. J. M. (1982). A new look at the organization of the motor system. In H. G. J. M. Kuypers & G. F. Martin (Eds.), *Progress in brain research: Anatomy of descending pathways to the spinal cord* (Vol. 57, pp. 381–403). Amsterdam: Elsevier.
Laird, J. D. (1984). The real role of facial response in the experience of emotion: A reply to Tourangeau and Ellsworth, and others. *Journal of Personality and Social Psychology, 47,* 909–917.
Langley, L. L., Telford, I. R., & Christensen, J. B. (1974). *Dynamic anatomy and physiology* (4th ed.). New York: McGraw-Hill.
Larson, J. D., & Foulkes, D. (1969). Electromyogram suppression during sleep, dream recall and orientation time. *Psychophysiology, 5,* 548–555.
Latane, B., Williams, K. D., & Harkins, S. G. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37,* 822–832.
Lawrence, J. H., & DeLuca, C. J. (1983). Myoelectrical signal vs. force relationship in different muscles. *Journal of Applied Physiology, 54,* 1653–1659.
Levey, A. B. (1980). Measurement units in psychophysiology. In I. Martin & P. H. Venables (Eds.), *Techniques in psychophysiology.* Chichester: Wiley.
Liddell, F. O. T. (1960). *The discovery of the reflexes.* Oxford: Clarendon.
Lindstrom, L. R. (1970). *On the frequency spectrum of EMG signals.* Technical Report, Research Laboratory of Medical Electronics, Chalmers Institute of Technology, Goteborg, Sweden.
Lippold, O. C. J. (1967). Electromyography. In P. H. Venables & I. Martin (Eds.), *Manual of psychophysiological methods* (pp. 245–298). New York: Wiley.
Loeb, G. E., & Gans, C. (1986). *Electromyography for experimentalists.* Chicago: University of Chicago Press.
Lorenzini, S. (1678). *Osservazioni intorno alle Torpedini* (J. Davis, Trans.). Florence: l'Onofri. [*The curious and accurate observations of Mr. Stephen Lorenzini of Florence,* pp. 66–72. London: Jeffery Wale, 1705.]
Lucas, K. (1909). The "all-or-none" contraction of amphibian skeletal muscle. *Journal of Physiology, 38,* 113–133.
Lynn, R. (1966). *Attention, arousal and the orientation reaction.* Oxford: Pergamon.
Malmo, R. B. (1959). Activation: A neuropsychological dimension. *Psychological Review, 66,* 367–386.
Malmo, R. B. (1965). Physiological gradients and behavior. *Psychological Bulletin, 64,* 225–234.
Malmo, R. B. (1975). *On emotions, needs, and our archaic brain.* New York: Holt, Rinehart & Winston.
Malmo, R. B., & Shagass, C. (1949a). Physiologic studies of reaction to stress in anxiety and early schizophrenia. *Psychosomatic Medicine, 11,* 9–24.
Malmo, R. B., & Shagass, C. (1949b). Physiologic study of symptom mechanisms in psychiatric patients under stress. *Psychosomatic Medicine, 11,* 25–29.
Malmo, R. B., Shagass, C., & Davis, F. H. (1950). Symptom specificity and bodily reactions during psychiatric interview. *Psychosomatic Medicine, 12,* 362–376.
Malmo, R. B., Shagass, C., & Davis, J. F. (1951). Electromyographic studies of muscular tension in psychiatric patients under stress. *Journal of Clinical & Experimental Psychopathology, 12,* 45–66.
Malmo, R. B., & Smith, A. A. (1955). Forehead tension and motor irregularities in psychoneurotic patients under stress. *Journal of Personality, 23,* 391–406.
Markovsky, B., & Berger, S. M. (1983). Crowd noise and mimicry. *Personality and Social Psychology Bulletin, 9,* 90–96.
Matsumoto, D. (1987). The role of facial response in the experience of emotion: More

methodological problems and a meta-analysis. *Journal of Personality and Social Psychology, 52,* 769–774.
Max, L. W. (1935). An experimental study of the motor theory of consciousness: III. Action-current responses in deaf mutes during sleep, sensory stimulation and dreams. *Journal of Comparative Psychology, 19,* 469–486.
Max, L. W. (1937). An experimental study of the motor theory of consciousness: IV. Action-current responses in the deaf during awakening, kinaesthetic imagery and abstract thinking. *Journal of Comparative Psychology, 24,* 301–344.
McCanne, T. R., & Anderson, J. A. (1987). Emotional responding following experimental manipulation of facial electromyographic activity. *Journal of Personality and Social Psychology, 52,* 759–768.
McGuigan, F. J. (1970). Covert oral behavior during the silent performance of language. *Psychological Bulletin, 74,* 309–326.
McGuigan, F. J. (1978). *Cognitive psychophysiology: Principles of covert behavior.* Englewood Cliffs, NJ: Prentice-Hall.
McGuigan, F. J. (1979) *Psychophysiological measurement of covert behavior: A guide for the laboratory.* Hillsdale, NJ: Erlbaum.
McGuigan, F. J., & Bailey, S. C. (1969). Logitudinal study of covert oral behavior during silent reading, *Perceptual and motor skills, 28,* 170.
McGuigan, F. J., Dollins, A., Pierce, W., Lusebrink, V., & Corus, C. (1982). Fourier analysis of covert speech behavior. *Pavlovian Journal of Biological Science, 17,* 49–52.
McHugo, G., & Lanzetta, J. T. (1983). Methodological decisions in social psychophysiology. In J. T. Cacioppo & R. E. Petty (Eds.), *Social psychophysiology: A sourcebook* (pp. 630–665). New York: Guilford Press.
McHugo, G., Lanzetta, J. T., Sullivan, D. G., Masters, R. D., & Englis, B. G. (1985). Emotional reactions to a political leader's expressive displays. *Journal of Personality and Social Psychology, 49,* 1513–1529.
Merton, P. A. (1987). Reflexes. In R. L. Gregory (Ed.), *The Oxford companion to the mind.* New York: Oxford University Press.
Meyer, D. R. (1953). On the interaction of simultaneous responses. *Psychological Bulletin, 20* 204–220.
Meyer, D. R., Bahrick, H. P., & Fitts, P. M. (1953). Incentive, anxiety, and the human blink rate *Journal of Experimental Psychology, 45,* 183–287.
Monnier, M. (1970). *Functions of the nervous system: Vol. 2. Motor and psychomotor functions* New York: Elsevier.
Mulder, T., & Hulstijn, W. (1984). The effect of fatigue and repetition of the task on the surface electromyographic signal. *Psychophysiology, 21,* 528–534.
National Institutes of Mental Health. (1980). *Biofeedback: Issues in treatment assessment.* NIMH Science Reports, Washington, DC: Author.
Needham, D. M. (1971). *Machina carnis. The biochemistry of muscular contraction in its historical development.* London: Cambridge University Press.
Ongerboer de Visser, B. W. (1983). Anatomical and functional organization of reflexes involving the trigeminal system in man: Jaw reflex, blink reflex, corneal reflex, and exteroceptive suppression. In J. E. Desmedt (Ed.), *Motor control mechanisms in health and disease* (pp. 727–738). New York: Raven Press.
Orne, M. T. (1962). On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. *American Psychologist, 17* 776–783.
O'Dwyer, N. J., Quinn, P. T., Guitar, B. E., Andrews, G., & Neilson, P. D. (1981). Procedures for verification of electrode placement in EMG studies of orofacial and mandibular muscles *Journal of Speech and Hearing Research, 241,* 273–288.
Pavlov, I. P. (1927). *Conditioned reflexes.* New York: Oxford University Press.
Petrofsky, J. S., & Phillips, C. A. (1982). The electromyogram: A potentially attractive tool for the noninvasive assessment of muscle function. In J. A. Herd, A. M. Gotto, P. G. Kaufman & S. M. Weiss (Eds.), *Cardiovascular instrumentation: Proceedings of the working conference on applicability of new technology to biobehavioral research.* Washington, DC: National Heart, Lung, and Blood Institute.
Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.
Pikoff, H. (1984). Is the muscular model of headache still viable? *Headache, 24,* 186–198

Pratt, F. H. (1917). The all-or-none principle in graded response of skeletal muscle. *American Journal of Physiology, 44,* 517–542.
Pratt, F. H., & Eisenberger, J. P. (1919). The quantal phenomena in muscle: Methods with further evidence of the all-or-none principle in graded response for the skeletal fibre. *American Journal of Physiology, 49,* 1–54.
Rajecki, D. W. (1983). Animal aggression: Implications for human aggression. In R. G. Geen & E. J. Donnerstein (Eds.), *Aggression: Theoretical and empirical reviews* (Vol. 1, pp. 189–211). New York: Academic Press.
Rechtschaffen, A., & Kales, A. (Eds.). (1968). *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects.* Washington DC: U.S. Government Printing Office (National Institute of Health Publication No. 204).
Redi, F. (1925). *Esperienze intorno a diverse cose naturali e particolarmente a quelle che ci sono portate dalle Indie* (pp. 47–51). Florence. (Original work published1617.) Reprinted in *Le Piu Belle Pagine di Francesco Redi,* P. Giacosa (Ed.), pp. 105–109. Milan: Fratelli Treves, Editori. Cited in Wu (1984).
Reid, J. E., & Inbau, F. E. (1977). *Truth and deception: The polygraph ("lie detector") technique.* Baltimore: Williams & Wilkins.
Rinn, W. E. (1984). The neuropsychology of facial expression: A review of the neurological and psychological mechanisms for producing facial expressions. *Psychological Bulletin, 95,* 52–77.
Rosenthal, R. (1966). *Experimenter effects in behavior research.* New York: Appleton-Century-Crofts.
Rosenthal, R., & Rosnow, R. (Eds.) (1969). *Artifact in behavioral research.* New York: Academic Press.
Rossi, A. M. (1959). An evaluation of the manifest anxiety scale by the use of electromyography. *Journal of Experimental Psychology, 58,* 64–69.
Scherer, K. R., & Ekman, P. (1982). *Handbook of methods in nonverbal behavior research* (pp. 45–90). Cambridge: Cambridge University Press.
Schmidt, R. F., & Thews, G. (1983). *Human physiology.* Berlin: Springer-Verlag.
Schwartz, G. E. (1975). Biofeedback, self-regulation, and the patterning of physiological processes. *American Scientist, 63,* 314–324.
Schwartz, G. E., Fair, P. L., Salt, P., Mandel, M. R., & Klerman, G. L. (1976). Facial muscle patterning to affective imagery in depressed and nondepressed subjects. *Science, 192,* 489–491.
Seiler, R. (1973). On the function of facial muscles in different behavioral situations: A study based on the muscle morphology and electromyography. *American Journal of Physical Anthropology, 38,* 567–572.
Shapiro, D., & Crider, A. (1969). Psychophysiological approaches to social psychology. In G. Lindzey & E. Aronson (Eds.), *The handbook of social psychology* (Znd ed., Vol. 3). Reading, MA: Aldison-Wesley.
Shaw, W. A. (1940). The relation of muscular action potentials to imaginal weight lifting. *Archives of Psychology,* No. 247.
Sheatz, G. C. (1972). A differential microvolt test signal adjustable to given laboratory requirements. *Psychophysiology, 9,* 658–659.
Shedivy, D. I., & Kleinman, K. M. (1977). Lack of correlation between frontalis EMG and either neck EMG or verbal ratings of tension. *Psychophysiology, 14,* 182–186.
Sherrington, C. S. (1923). *The integrative actions of the nervous system.* New Haven: Yale University Press. (Original work published 1906.)
Shimizu, A, & Inoue, T. (1986). Dreamed speech and speech muscle activity. *Psychophysiology, 23,* 210–215.
Skinner, B. F. (1931). The concept of the reflex in the description of behavior. *The Journal of General Psychology: Experimental, Theoretical, Clinicial, and Historical Psychology, 5,* 427–457.
Smith, R. R., Kier, W. M. (1989). Trunks, tongues, and tentacles: Moving with skeletons of muscle. *American Scientist, 77,* 28–35.
Spencer, H. (1855). *Principles of Psychology* (1st ed.). New York: Appleton.
Sperry, R. (1952). Neurology and the mind-brain problem. *American Scientist, 40,* 291–312.
Steiner, J. E. (1979). Human facial expression in response to taste and smell stimulation. *Advances in Child Development and Behavior, 13,* 257–295.

Sternbach, R. A. (1966). *Principles of psychophysiology.* New York: Academic.
Stoyva, J., & Budzynski, T. (1974). Cultivated low arousal: An anti-stress response? In L. V. DiCara (Ed.). *Recent advances in limbic and autonomic nervous system research* (pp. 370–394). New York: Plenum Press.
Strong, P. (1970). *Biophysical measurements.* Beaverton, OR: Textronix.
Svebak, S., Dalen, K., & Storfjell, O. (1981). The psychological significance of task-induced tonic changes in somatic and autonomic activity. *Psychophysiology, 18,* 403–409.
Tassinary, L. G., Cacioppo, J. T., & Geen, T. R. (1989). A psychometric study of surface electrode placements for facial electromyographic recording: I. The brow and cheek muscle regions. *Psychophysiology, 26,* 1–16.
Tassinary, L. G., Cacioppo, J. T., Geen, T. R., & Vanman, E. (1987). Optimizing surface electrode placements for facial EMG recordings: Guidelines for recording from the perioral muscle region. *Psychophysiology, 24,* 615–616.
Teuber, H. L. (1955). Physiological psychology. *Annual Review of Psychology, 6,* 267–294.
Thompson, R. F. (1967). *Foundations of physiological psychology.* New York: Harper & Row.
Tognacci, L. N., & Cook, S. W. (1975). Conditioned autonomic responses as bidirectional indicators of racial attitude. *Journal of Personality and Social Psychology, 31,* 137–144.
Tomkins, S. S. (1962). *Affect, imagery, and consciousness.* New York: Springer.
Tomovic, R., & Bellman, R. (1970). A systems approach to muscle control. *Mathematical Biosciences, 8,* 265–277.
Tortora, G. J. (1983). *Principles of human anatomy* (3rd ed.). New York: Harper & Row.
Tourangeau, R., & Ellsworth, P. C. (1979). The role of facial response in the experience of emotion. *Journal of Personality and Social Psychology, 37,* 1519–1531.
Triplett, N. (1898). The dynamogenic factors in pacemaking and competition. *American Journal of Psychology, 9,* 507–533.
van Boxtel, A., Goudswaard, P., & Janssen, K. (1983). Absolute and proportional resting EMG levels in muscle contraction and migraine headache patients. *Headache, 23,* 215–222.
van Boxtel, A., Goudswaard, P., & Shomaker, L. R. B. (1984). Amplitude and bandwidth of the frontalis surface EMG: Effects of electrode parameters. *Psychophysiology, 21,* 699–707.
Vaughan, K. B., & Lanzetta, J. T. (1980). Vicarious instigation and conditioning of facial expressive and autonomic responses to a model's expressive display of pain. *Journal of Personality and Social Psychology, 13,* 909–923.
Vaughan, K. B., & Lanzetta, J. T. (1981). The effects of modification of expressive displays on vicarious emotional arousal. *Journal of Experimental Social Psychology, 17,* 16–30.
Vitti, M., Basmajian, J. V., Ouelette, P. L., Mitchell, D. L., Eastman, W. P., & Seaborn, R.D. (1975). Electromyographic investigations of the tongue and circumoral muscular sling with fine-wire electrodes. *Journal of Dental Research, 54,* 844–849.
Volta, A. (1816). Memoria prima sull' elettricita animale. In *Collezione dell'Opere* (Vol. 2). Florence: G. Piatti. (Original work published 1792.) Cited in Wu (1984).
Wallerstein, H. (1954). An electromyographic study of attentive listening. *Canadian Journal of Psychology, 8,* 228–238.
Walsh, J. (1773). Of the electric property of the torpedo. *Philosophical Transactions of the Royal Society, 63,* 461–480.
Wartenberg, R. (1946). *The examination of reflexes: A simplification.* Chicago: Year Book Publishers.
Weaver, C. V. (1977). Descriptive anatomical and quantitative variation in human facial musculature and the analysis of bilateral asymmetry. *Dissertation Abstracts International* (University Microfilms, No. 77-24, 305).
Wells, G. L., & Petty, R. E. (1980). The effects of overt head-movements on persuasion: Compatibility and incompatibility of responses. *Basic and Applied Social Psychology, 1,* 219–230.
Whatmore, G., & Ellis, R. M. (1959). Some neurophysiological aspects of depressed states: An electromyographic study. *Archives of General Psychiatry, 1,* 70–80.
Whatmore, G., Whatmore, N. J., & Fisher, L. D. (1981). Is frontalis activity a reliable indicator of the activity in other muscles? *Biofeedback and Self-Regulation, 6,* 305–314.
Willison, R. G. (1963). A method for measuring motor unit activity in human muscles. *Journal of Physiology, 168,* 35–36.
Willis, W., & Grossman, R. (1977). *Medical neurobiology* (2nd ed.). St. Louis: Mosby.
Winter, D. A., Rau, G., Kadefors, R., Broman, H., & DeLuca, C. J. (1980). *Units, terms, and*

standards in the reporting of EMG research. Report by the Ad Hoc Committee of the International Society of Electrophysiological Kinesiology.

Woodworth, R. S., & Schlosberg, H. (1954). *Experimental psychology*. New York: Holt.

Wu, C. H. (1984). Electric fish and the discovery of animal electricity. *American Scientist, 72,* 598–607.

Zajonc, R. B. (1965). Social facilitation. *Science, 149,* 269–274.

Zajonc, R. B., & Markus, H. (1984). Affect and cognition: The hard interface. In C. E. Izard, J. Kagan, & R. B. Zajonc (Eds.), *Emotions, cognition, and behavior* (pp. 73–102). Cambridge: Cambridge University Press.

Zipp, P. (1982). Recommendations for the standardization of lead positions in surface electromyography. *European Journal of Applied Physiology, 50,* 41–54.