

## CHAPTER 11

# *The Psychophysiology of Emotion*



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Humans have walked the surface of the earth for about 2 million years, and for all but the last 2,000 or 3,000 years, humans have been hunter-gatherers (Ackerman, 1990). In a strikingly brief span, human civilization has achieved the engineering of the Great Pyramids, the elegance of Beethoven's Ninth Symphony, the refinement of Dom Perignon, the efficiency of mass production, the triumph of modern medicine, the cognizance of heterotic string theory, and the wonder of space exploration. Perhaps we can be excused for tending to see our achievements as the outcome of pure reason and our distant past "through a reverse telescope that compresses it: a short time as hunter-gatherers, a long time as 'civilized' people" (Ackerman, 1990, p. 129).

Despite the constraints of civilization, however, humans are also the source of less rarified achievements: the relentless exploitation of fossil fuels and rainforests, the apocalyptic peril of biological and nuclear warfare, and the savage horror of torture and genocide, to name but a few. We may sing in choirs and bridle our rages behind placid countenances, but we patrol the world under the auspices of an affect system sculpted over millennia of evolutionary forces.

Emotions are shared across species—an observation that has long fueled the concern that emotions are an obstacle to fulfilling human potential (Brazier, 1960). We may sit in quiet repose contemplating the diversity of the linguistic expressions for emotions, but emotions predate language and the human species.

Individuals are revered for cultivated tastes and seemingly dispassionate responses to life's challenges. Yet emotions, however archaic in origin, saturate human existence throughout the lifespan. Emotions guide, enrich, and ennoble life; they provide meaning to everyday existence; they render the valuation placed on life and property. Emotions promote behaviors that protect life, form the basis for the continuity in life, and compel the termination of life. They can be essential ingredients for, as well as overwhelming obstacles to, optimizing human potential, and they often serve as the engines for intellectual development. Given their evolutionary heritage and daily currency, there is little wonder that emotions have preoccupied humankind throughout recorded history, and there is little doubt that emotions are both biologically rooted and culturally molded.

Affect and emotion in human studies have

been treated as the conscious subjective aspect of an emotion considered apart from bodily changes (e.g., Osgood, Suci, & Tannenbaum, 1957; Green, Salovey, & Truax, 1999; cf. Cacioppo, Gardner, & Berntson, 1999; LeDoux, 1996). Like the organization and processes underlying the undeniable percept that the sun circles the earth, however, the organization and processes underlying affective experiences may be far subtler than their apparent manifestations might lead one to suspect (Cacioppo, Gardner, & Berntson, 1997). Although rich in emotional terms (Clore, Ortony, & Foss, 1987; Frijda, Markam, Sato, & Wiers, 1995; Russell, 1978), language sometimes fails to capture affective experiences—especially intense affective experiences—so metaphors become more likely vehicles for rendering these conscious states of mind (Fainsilber & Ortony, 1987; Ortony & Fainsilber, 1989; Hoffman, Waggoner, & Palermo, 1991).

Affective reports have also long been recognized as subject to a host of motivational influences and contextual distortions, as well as being only modestly related to other aspects of affective reactions, such as somatovisceral events and behavior. Dating back to Freud, research from clinical psychology has underscored the dissociation between reportable aspects and affective states (e.g., Bradley, 2000; Davidson, 1998; Lang, 1971); research in neuropsychology and the neurosciences has shown that emotional feelings are neither necessary nor sufficient for the evocation of emotional processes (Gazzaniga & LeDoux, 1978; Tranel & Damasio, 2000); and research from social and cognitive psychology has shown that emotions are capable of being elicited quickly, effortlessly, automatically, or even unconsciously upon exposure to the relevant stimulus (e.g., Bargh, Chaiken, Gendler, & Pratto, 1992; Pratto & John, 1991). Zajonc (1980) observed:

When we meet a stranger, we know within a fraction of a second whether we like the person or not. The reaction is instantaneous and automatic. Perhaps the feeling is not always precise, perhaps we are not always aware of it, but the feeling is always there. . . . Perhaps we have not developed an extensive and precise verbal representation of feeling just because in the prelinguistic human this realm of experience had an adequate representation in the nonverbal channel . . . if affect is not always transformed into semantic content but is instead often encoded in, for example, visceral or muscular symbols, we would expect informa-

tion contained in feelings to be acquired, organized, categorized, represented, and retrieved somewhat differently than information having direct verbal referents. (pp. 157–158).

Zajonc's point that interpersonal judgments and emotional experiences are fundamentally organized in terms of the dimension(s) of positivity and negativity has strong empirical support (see review by Cacioppo & Gardner, 1999). His proposition that emotion is meaningfully associated with, and possibly encoded in, somatovisceral events is more speculative; however, at least when limited to positive and negative processes, it has received preliminary support (Cacioppo, Priester, & Berntson, 1993). The study of the somatovisceral links to emotion, however, has perhaps been fueled most by the common experience that different visceral sensations underlie different emotions. If individuals were to say that they felt butterflies in their stomachs or that they felt they were ready to boil, few observers would fail to understand that the individuals were experiencing fear and anger, respectively. These interoceptive sensations are so distinct and compelling that it is hard to believe that these emotions are *not* differentiated peripherally as well as centrally. In this chapter we examine the psychophysiology of emotions, with a special emphasis on subtle mechanisms by which somatovisceral events may contribute to human emotions. Because of the centrality of hedonic tone in studies of emotion, we examine both the physiological differentiation of discrete emotions and the differentiation of positive and negative states.

## HEURISTIC PERSPECTIVES

More than a century ago, William James (1884, 1890/1950) argued that emotional feelings are consequences rather than antecedents of peripheral physiological changes brought about by some stimulus. James (1884) also viewed emotions as being multiply determined. Individuals may recall earlier emotional episodes, including their feelings, and in so doing they may reexperience the emotion. If the remembered emotion was weak originally (e.g., it involved little or no somatovisceral activation), reexperiencing the emotion may occur in the absence of significant peripheral bodily disturbances. James (1884) therefore stated at the

outset that "the only emotions I propose expressly to consider here are those that have a distinct bodily expression" (p. 189). James maintained that within this class of emotional phenomena, discrete emotional experiences can be identified with unique patterns of bodily changes, and that the perception of one of these specific patterns of peripheral physiological changes is the emotional experience.

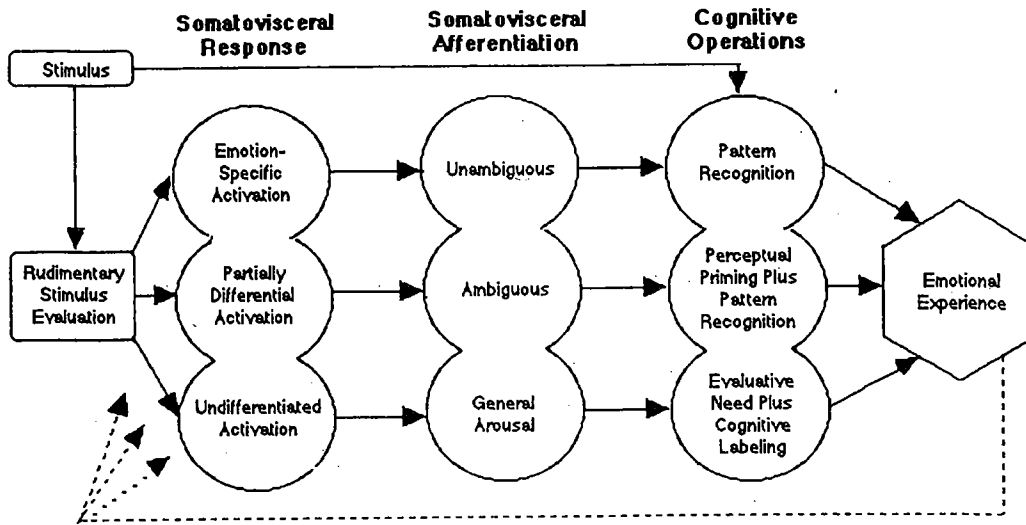
James's (1884) hypothesis that autonomic nervous system (ANS) activity produces the percepts of discrete emotional states implies that emotion-specific somatovisceral patterns generate emotional experiences, and that a somatovisceral pattern begins before the experience of the corresponding emotion. In an early critique of this position, Cannon (1927) provided evidence from animal studies that autonomic events are too slow, too insensitive, and too undifferentiated to contribute to emotions. This critique appeared devastating and led to the notion that emotional experience is the exclusive province of central networks. Consistent with this notion, research on the influence of cognitive appraisals in emotion (e.g., Ellsworth, 1994) and on emotions in the spinal-cord-injured (e.g., Chwalisz, Diener, & Gallagher, 1988) suggests that afferent information from peripheral activity is not a necessary condition for emotional experience. Recently, however, the pendulum appears to have begun to swing in the other direction, as investigations suggest that autonomic processes *can* contribute to the encoding and recall (if not the experience) of emotional information (e.g., see review by Cahill, 1996; see also Demaree & Harrison, 1997).

To the extent that emotional experiences are multiply determined, the experience of a discrete emotion can occur in the absence of the "corresponding" somatovisceral pattern, even if somatovisceral afference can be an antecedent of the emotion. A recent neurobiological model of anxiety emphasizes the reciprocal relations between ascending and descending systems (Berntson, Sarter, & Cacioppo, 1998). This model recognizes not only that affective states may be primed by either top-down (cognition) or bottom-up (visceral reactivity) processes, but that these alternative activational modes may mutually reinforce one another (e.g., as in panic disorder). For this reason, it is more informative to ask under what conditions and for what emotions differential physiological activity is observed than to search for an invariant re-

lationship between emotional experience (or expressions) and physiological response. For instance, Schachter and Singer (1962) shaped thinking about emotions when they suggested that undifferentiated autonomic activity *can* subserve discrete emotions. The mechanism by which this is accomplished, according to Schachter and Singer (1962; see also Mandler, 1975; Reisenzein, 1983), is the perception of neutral, unexplained physiological arousal, which creates an "evaluative need" and motivates the individual to understand and label cognitively the arousal state. The consequent attributional processes were thought to produce discrete feeling states and influence emotional behavior.

Figure 11.1 depicts a general framework summarizing mechanisms by which somatovisceral afference may influence emotional experience (Cacioppo, Berntson, & Klein, 1992). At one end of the continuum (Figure 11.1, top left column), discrete emotional experiences result from the apperception of distinct somatovisceral patterns (e.g., Ekman, Levenson, & Friesen, 1983; James, 1884; Levenson, 1988; Levenson, Ekman, & Friesen, 1990). At the other end of the continuum (Figure 11.1, bottom left column), discrete emotional experiences derive from attributional processes that are initiated by the perception of undifferentiated physiological arousal (e.g., Mandler, 1975; Schachter & Singer, 1962). Falling between these extremes is yet another process by which peripheral bodily reactions may contribute to emotional experience—"somatovisceral illusions," an active perceptual process by which an ambiguous pattern of somatovisceral afference is disambiguated to produce an immediate, spontaneous, and indubitable emotional percept (Figure 11.1, middle left column).

The essential feature of the proposition that discrete emotions can result from somatovisceral illusions can be illustrated by analogy using the ambiguous visual figure depicted in Figure 11.2 (see Cacioppo, Berntson, & Klein, 1992, for a more complete description of the model). Even though there is only one set of visual contours and features in Figure 11.2, top-down processes make it possible for a person looking at this picture to see or experience two very different perceptual images: a young woman facing left or an old woman facing right. Once these images have been identified, the viewer may find that he or she can alternate quickly between seeing these discrete images,



**FIGURE 11.1.** The somatovisceral afference model of emotion (SAME). The same pattern of somatovisceral activity has been associated with surprisingly different emotions, and the same emotion has been associated with quite different patterns of somatovisceral activity. These results have been viewed as evidence against the importance of somatovisceral afference in emotion. The SAME, depicted above and described in the text, encompasses both of these findings while emphasizing the instrumental role of somatovisceral afference and cognitive/perceptual processes in producing emotion. From Cacioppo, Berntson, and Klein (1992). Copyright 1992 by Sage Publications. Reprinted by permission.

but cannot see both at once. That is, the same visual afference can lead to two different, discrete, and indubitable perceptual experiences, just as the same physiological afference may lead to two different, discrete, and indubitable emotions.

Ambiguous visual figures such as the one depicted in Figure 11.2 are constructed by using elements from two (or more) unambiguous images in such a way that the figure created by overlapping or slightly modifying the elements of the unambiguous images can be interpreted in multiple discrete ways (Sekuler & Blake, 1985). Because the same sensory information in an ambiguous figure can produce such strikingly different, immediately obvious, and unambiguous perceptions, Leeper (1935) referred to ambiguous figures as "reversible illusions." There is little reason to suppose that somatovisceral illusions can not operate similarly. The active perceptual processes underlying reversible visual illusions are not limited to visual information processing, but can also operate on interoceptive (e.g., visceral) and proprioceptive (e.g., postural, facial, vocal) input. Indeed, the architecture of the somatovisceral apparatus may be better suited to produce ambiguous afference than is the visual system (Reed, Harver,

& Katkin, 1990). For instance, in the perception of ambiguous visual figures, the stimulus is a visual array outside the body. However, the central nervous system serves to create and interpret both the stimulus and the response to somatovisceral information. In this regard, visual processes are somewhat more like somatic instrumental processes than like visceral processes. Both of the former differ from visceral perception, for instance, in the distinctiveness of the reafference. In the somatic case, the accuracy of response is readily ascertainable, and correctable, by somatosensory and visual feedback. In the visceral domain, there is no "intended" outcome in the conscious sense (although there are target outcomes in an automatic or homeostatic sense). In the case of all three, feedback can importantly shape subsequent action without conscious awareness. Hence visceral perception differs from somatic and visual perception in that there is no discrete criterion (or "correct" perception) for which an individual is consciously looking. For this reason, visceral afference may be particularly prone to misperceptions and "illusions." Furthermore, it seems likely that events as important and commonplace as the emotions have cognitive representations that include somato-



**FIGURE 11.2.** This ambiguous figure is called "My wife and mother-in-law" and is constructed from overlapping unambiguous elements. The perceptual system tends to group like or related information together. Rather than presenting some odd mixture of the two alternative pictures, partial identification of a young woman or an old woman in this figure supports a stable perception of a single coherent image. The identification of wholes and of parts is reciprocally supportive, contributing further to the locking-in process. A shift in gaze is not necessary for a perceptual change to occur. In what may be analogous to discrete emotional feelings' being spawned by the same ambiguous pattern of somatovisceral information, ambiguous visual figures demonstrate that discrete images can derive from the same ambiguous pattern of visual information. From Boring (1930).

visceral attributes. Thus several important features required for the production of somatovisceral illusions are plausibly in place.

The nodes along the continuum in the left column of Figure 11.1 represent important transitions in the constitution of the autonomic response, but the openings between these nodes underscore the continuous nature of this dimension. The pattern of somatovisceral activation produces a parallel continuum of somatovisceral sensory input to the brain. The arrows between nodes denote the major pathways for in-

formation flow (Cacioppo, Berntson, & Klein, 1992). The extent of the cognitive elaboration of the somatovisceral afference required to produce an emotional experience ranges from simple informational analyses such as pattern recognition (e.g., James's theory of emotion as the perception of discrete patterns of somatovisceral afference) to much more complex attributional analyses and hypothesis testing (e.g., Mandler's theory of emotion), with simple cognitive appraisals of the stimulus and perceptual priming of an emotion schema falling between these two endpoints. Note that quite different patterns of somatovisceral afference (see Figure 11.1, left column) can lead to the same emotional experience via three very different psychophysiological mechanisms (see Figure 11.1, right column), whereas the same pattern of somatovisceral afference can lead to discrete emotional experiences by two distinct psychophysiological mechanisms: (1) somatovisceral "illusions" when the afference is ambiguous and an emotion schema has been primed (see Figure 11.2); and (2) cognitive labeling when the perception of the afference is undifferentiated with respect to an emotion and there is an evaluative need. The framework outlined in Figure 11.1 argues against the tendency to view the psychophysiological mechanisms underlying emotion in terms of a simple central-peripheral dichotomy. It also is in accord with robust findings in the literature that discrete emotional percepts can occur even when the autonomic changes do not discriminate fully the emotions that are experienced, and that autonomic activation can alter the intensity if not the nature of emotional experience. In the sections that follow, we examine the nature of the expressive patterns associated with discrete emotions.

## FACIAL ELECTROMYOGRAPHY

Scientific studies of the link between facial expressions and emotions originated with Darwin's (1872) seminal analysis and were reinvigorated by Tomkins's (1962) proposition that facial movement and feedback play an important role in the experience of emotion. Tomkins suggested that high-speed filming could be used to perform microscopic analyses of facial expressions and emotion. These proposals led to important methodological advances in the coding of facial expressions (e.g., Ekman &

Friesen, 1978; Izard, 1971, 1977). Building on this foundation, investigators have provided provocative evidence that (1) at least some discrete emotions are associated with distinct overt facial expressions; (2) induced states in which individuals report positive and negative emotions are associated with distinctive facial actions; and (3) displays similar to those of adults can be found in neonates and the congenitally blind, suggesting that these displays are inherently linked with basic emotions (e.g., see Ekman, 1973; Ekman & Friesen, 1978; Izard, 1977).

Although facial expressions may seem intuitively to reveal the nature of underlying emotions, many emotional and affect-laden information processes are not accompanied by visually perceptible facial actions. This fact has limited the utility of analyses of facial actions in understanding emotions. Furthermore, although observers across cultures attribute the same emotional meaning to the expressions of happiness, sadness, fear, anger, surprise, and disgust, these attributions are not perfect (Russell, 1994). Complicating research in this area, the specific emotion that is evoked by a stimulus may vary across individuals and cultures. Finally, individuals can invoke display rules to mask or hide the emotion they are feeling, and observers can confuse the meaning of expressions (e.g., fear and surprise; Ekman, 1973; cf. Cacioppo, Bush, & Tassinari, 1992). For these reasons, the coding of overt facial expressions can be a less than perfect measure of affective state. An important complement to visual inspection of facial expression has been the measurement of patterns of activity in facial muscles. This technique—facial electromyography (EMG)—has made it possible to index muscle activity even in the absence of observable facial expressions (Cacioppo & Petty, 1981; Cacioppo, Tassinari, & Fridlund, 1990).

In pioneering research, Schwartz and colleagues demonstrated differences related to emotional imagery in EMG activity over the brow (corrugator supercilii), cheek (zygomaticus major), and perioral (depressor anguli oris) muscle regions. Schwartz, Fair, Salt, Mandel, and Klerman (1976), for instance, asked participants to imagine positive or negative events in their lives. Results revealed that people showed more EMG activity over the brow region and less over the cheek and perioral regions when imagining sad as compared to happy events. Schwartz, Ahern, and Brown (1979) asked sub-

jects to engage in thought and imagery tasks that involved happiness, excitement, sadness, fear, and neutral emotional states. Facial EMG was recorded over two sites, the brow and cheek. The only significant main effects for discrete emotional states indicated higher EMG activity over the cheek and lower EMG activity over the brow during positive than negative emotions.

Although the number of studies is limited, research has consistently shown that EMG activity over the brow (corrugator supercilii, frown muscle) region is lower and EMG activity over the cheek (zygomaticus major, smile muscle) and perioral (orbicularis oculi) muscle regions is higher when emotions that are mildly positive, as opposed to mildly negative, are evoked. These opposing effects are more apparent at the group (nomothetic) level than at the individual (idiographic) level of analysis. In early reports, the facial EMG patterns associated with emotional states were characterized as "miniature representations" of those occurring during overt facial expressions (Schwartz, Fair, Greenberg, Foran, & Klerman, 1975). The evidence for covert emotion-specific facial expressions has been far weaker than the evidence for overt emotion-specific facial expressions, however. In a comprehensive study, for instance, Brown and Schwartz (1980) had participants go through imagery conditions designed to elicit happiness, sadness, fear, and anger at three levels of intensity while EMG activity was recorded over the brow, cheek, forehead, and jaw muscle regions. Results revealed that the imagery of negative emotions (fear, anger, and sadness) was associated with higher EMG activity over the brow muscle regions than was the imagery of the positive emotion (happiness). EMG activity over the cheek region was highest during happy imagery but also was elevated at least somewhat during fear and anger imagery. Whether these latter elevations reflect some participants engaging in miserable or distress smiling (Ekman, Friesen, & Ancoli, 1980), "cross-talk" from other muscles of the middle and lower facial regions, or the putative phylogenetic origin of smiling and laughter in primitive agonistic displays (Andrew, 1963; van Hooff, 1972) is unclear. EMG activity over the jaw and forehead muscle regions did not vary significantly (see also Brown & Schwartz, 1980; Hess, Kappas, McHugo, Lanzetta, & Kleck, 1992; Schwartz et al., 1976). Finally, increasing emotional intensity led to increased

EMG activity, especially over the brow muscle regions during sad, angry, and fearful imagery, and over the cheek muscle region during happy imagery (see, also, Cacioppo, Martzke, Tassinari, & Petty, 1988).

Fridlund, Schwartz, and Fowler (1984), using a unique classification analysis, reported evidence for emotion-specific facial EMG patterns. Subjects were instructed to imagine 48 emotional scenes designed to elicit happiness, fear, sadness, or anger, and EMG activity was recorded over the frontalis, corrugator supercilii, orbicularis oculi, and orbicularis oris muscle regions. A one-way multivariate analysis of variance was performed separately on the data from each subject. The parameter of EMG activity (e.g., mean, peak) that yielded the discriminant function with the clearest separation of emotion categories was selected on a subject-by-subject basis. A linear discriminant analysis differentiated among the emotion categories at better than chance level: Hit rates were 51% for happiness, 49% for sadness and anger, and 38% for fear. Posed expressions were also tested, yielding hit rates ranging from 83% to 89%. The covert facial EMG patterns that best differentiated among the emotions may have varied across subjects, and we have found no subsequent study in which an approach such as this produced evidence for distinctive (and generalizable) incipient facial expressive actions associated with discrete emotional states. Thus the bulk of the evidence to date suggests that the simple differentiation of hedonic tone has a lower threshold for activation than emotion-specific facial displays across individuals. That is, emotions can be characterized as a coalition of normally loosely coupled control mechanisms that are temporally recruited in a hierarchical sequence in order to meet an environmental challenge (imagined or real). The global distinction between hospitable (positive) or hostile (negative) stimuli, which is among the first information extracted from stimuli (Zajonc, 1980), may be one of the first aspects of an emotional response to be reflected in peripheral physiological activation in the form of rudimentary facial efference.

Although facial EMG research has proven to be a sensitive measure of hedonic tone, most psychophysiological research on discrete emotions has focused on the ANS. This emphasis is attributable to several factors. First, and as noted above, different emotions appear to be associated with signature visceral sensations (e.g.,

feeling steamed when one is angry, feeling butterflies in one's stomach when one is frightened). Second, whether or not visceral responses contribute to emotional experiences, they are clearly involved in emotion—as, for instance, demonstrated by the visceral changes that are observed when central networks associated with emotions are activated (LeDoux, 1996). Third, emotions, like the viscera, are common to all animals and fall largely outside of direct voluntary control. Consequently, the links between emotions and the ANS have been the topic of much research. Much of this research has been influenced by James's (1884) proposal that peripheral physiological changes are antecedents rather than consequences of the perception of emotional experience. Because of the close links between emotions and ANS activity, many researchers have focused their search for emotion-specific patterning on the ANS. We turn to this research next.

#### AUTONOMIC ACTIVITY

Early research on autonomic activity and affective reactions appeared to be characterized by a lack of replicability or generalizability. Despite the lack of consistency in early findings, the notion that visceral responses differentiate discrete emotions remained popular. In an important development in this area, Ekman, Levenson, and colleagues (Ekman et al., 1983; Levenson, 1988) attributed much of the inconsistency in prior results to various methodological problems. Among the problems they cited are the failure to verify independently that an emotional state has been aroused (e.g., through self-report or behavioral observation); the failure to equate the intensity of the emotions; and the mistiming of physiological recordings, given the likely onset and offset of the emotion. Furthermore, Ekman, Levenson, and colleagues argued that differentiation requires simultaneous examination of a number of indices of ANS activity. They maintained that emotion-specific autonomic differentiation would be obtained if these shortcomings were eliminated.

Ekman's group first presented evidence for the differentiation of discrete emotions in an article in *Science* in 1983 (Ekman et al., 1983). Heart rate, left- and right-hand finger temperature, skin resistance, and forearm flexor muscle tension were recorded during the manipulation of the emotional states of anger, fear, sadness,

happiness, surprise, and disgust. One method for evoking emotions involved a directed facial action task, in which a participant was induced to form a facial expression associated with a discrete emotion through muscle-by-muscle contraction instructions that omitted any reference to the emotional state. For example, a participant might be told to pull the eyebrows down and together, to raise the upper eyelid, to push the lower lip up, and to press the lips together. These instructions corresponded to the facial expression associated with anger.

Emotion was also evoked in this experiment with an imagery task, in which participants were asked to relive a past emotional experience for 30 seconds. Physiological responses during a relived emotion period were compared to a nonimagery resting baseline, revealing higher skin resistance during sadness than during fear, anger, or disgust. Together, the results from the two emotion induction techniques generated considerable enthusiasm for the idea of emotion-specific autonomic patterning, especially because emotions of the same valence (e.g., anger and fear) appeared distinguishable. Similar results were obtained by Levenson et al. (1990), using the directed facial action task, leading these researchers to propose that each discrete emotion is associated with an innate affect program whose role is to coordinate changes in the organism's biological states. They further argued that these changes are directed at supporting the behavioral adaptations and motor programs most likely associated with a particular emotion (e.g., fleeing in the case of fear), and can be recorded as emotion-specific changes in ANS activity (Levenson et al., 1990).

There is now a significant body of research relevant to this hypothesis, and several reviews have been performed (Cacioppo, Klein, Berntson, & Hatfield, 1993; Cacioppo, Berntson, Klein, & Poehlmann, 1997; Zajonc & McIntosh, 1992). These reviews reveal that whereas some reliable autonomic differentiation has been obtained across studies, the results are far from definitive regarding emotion-specific autonomic patterning. Table 11.1 lists in chronological order published research that has contrasted the effects of at least two discrete emotions on two or more autonomic measures in humans.

We (Cacioppo, Berntson, et al., 1997) conducted a meta-analysis providing data relevant to the question of whether emotion-specific au-

tonomic patterning exists. We updated the database (see Table 11.1) and repeated the meta-analyses based on this more complete dataset. Our inclusion criteria yielded numerous effect sizes involving 22 measures across almost two dozen studies. A word of caution is in order before we turn to the results. These meta-analyses allow one to examine statistically the differentiation of discrete emotions by individual measures. It is possible that discrete emotions differ in terms of the patterns of autonomic responses associated with each, even if no single measure is found to differentiate these emotions. Still, the literature is replete with claims of differentiating emotions using individual autonomic measures, and meta-analyses provide a more rigorous test of such assertions. Furthermore, a meta-analytic approach to this literature points to particularly fertile areas of research as well as to barren areas.

Consistent with Ekman et al.'s (1983) finding, greater heart rate acceleration was obtained to anger, fear, and sadness as compared to disgust. There was also a tendency for happiness to be associated with greater heart rate acceleration than disgust. However, disgust was associated with the same heart rate response as control conditions; indeed, disgust did not differ from control conditions on any autonomic measure. The meta-analysis also revealed heart rate responses to be larger in (1) anger than happiness, (2) fear than happiness (which also differed on finger pulse volume), and (3) fear than sadness (which also differed on respiration rate). Emotion-specific differentiation for cardiorespiratory measures other than heart rate was less reliable (e.g., measures of bodily tension, facial temperature, respiration amplitude, inspiration volume, or cardiac stroke volume; (Cacioppo, Berntson, et al., 1997). The only other replicable autonomic differentiation noted by Levenson et al. (1990; Levenson, Carstensen, Friesen, & Ekman, 1991) was that finger temperature decreased less in anger than in fear. Meta-analyses revealed that this effect did not achieve statistical significance when the results of all studies were considered. A study by Boiten (1996) also raises the possibility that at least some of the cardiac differentiation of emotions that has been observed may be secondary to effort and respiratory changes.

Several other reliable results emerged from our meta-analyses. Consistent with prior claims, diastolic blood pressure was higher in anger than in fear, but meta-analyses also re-



TABLE 11.1. Studies Comparing Two or More Physiological Measures as a Function of Two or More Discrete Emotions

Study	Age range (mean or mode)	Emotions [Induction]	Dependent variables
Ax (1953)	21-55 (27) <i>n</i> = 43*	Anger, fear [Real life]	SBP, DBP, SV, HR, FCT, FT, NNSCR, NMTP, SCL, EMG, RR
Funkenstein, King, & Drollette (1954)	19-24 <i>n</i> = 52*	Anger in (21 Ss), anger out (22 Ss), fear (anxiety; 9 Ss) [Psychological stressor]	HR, SBP, DBP, SV, CO
Schachter (1957)	(Normotensives, 38; potential hypertensives, 41; hypertensives, 42) <i>n</i> = 48 <sup>a</sup>	Anger, fear, pain [Real life]	HR, SBP, DBP, FCT, HT, SCL, EMG, II, RR, SV, CO, TPR
Sternbach (1962) <sup>b</sup>	All 8 years old <i>n</i> = 10	Fear, happiness, humor, sadness [Film]	SRL, gastric motility, RR, HR, EOG, FPV
Averill (1969)	17-24 (18) <i>n</i> = 54	Happiness, sadness, control [Film]	HR, SBP, DBP, FCT, FT, SCL, FPV, NNSCR, RR, RI
Tourangeau & Ellsworth (1979)	Undergrads <i>n</i> = 123	Fear, sadness, neutral [Film <sup>c</sup> ] crossed with fear, sadness, neutral expression, undirected as to expression [DFA]	HR, SRL, NNSCR
Schwartz, Weinberger, & Singer (1981)	Undergrads <i>n</i> = 32	Anger, fear, happiness, sadness, relaxation, control [Imagery <sup>d</sup> ]	HR, SBP, DBP
Roberts & Weerts (1982)	Undergrads <i>n</i> = 16 <sup>e</sup>	Anger, fear, neutral [Imagery]	HR, SBP, DBP
Ekman, Levenson, & Friesen (1983) <sup>e</sup>	Nonundergrads <i>n</i> = 16 Only "best faces" and "best imagery" trials were reported	Anger, disgust, fear, happiness, sadness, surprise [DFA, relived emotion]	HR, FT, SRL, EMG
Stemmler (1989)	(23) <i>n</i> = 42	Anger, fear, happiness, control [Real life, imagery]	HR, FT, SCL, EMG, MVT (finger and head acceleration), RR, PTT, FPV, BV, NNSCR, FCT
Tassinari, Cacioppo, & Geen (1989)	Undergrads and grads <i>n</i> = 15	Anger, happiness, control [DFA]	SCL, HR
Levenson, Ekman, & Friesen (1990)	18-30 <i>n</i> = 62 <sup>f</sup>	Anger, disgust, fear, happiness, sadness, surprise [DFA]	HR, FT, SCL, EMG, MVT
Levenson, Carstensen, Friesen, & Ekman (1991)	71-83 (77) <i>n</i> = 20* Only "best faces" and "best imagery" were reported	Anger, disgust, fear, happiness, sadness, surprise [DFA, relived emotion]	HR, FT, SCL, MVT
Hess, Kappas, McHugo, Lanzetta, & Kleck (1992)	Undergrads <i>n</i> = 27	Anger, happiness, peacefulness, sadness [Feel, express, feel-and-express]	Facial EMG, SCL, HR

(continued)

TABLE 11.1 (continued)

Study	Age range (mean or mode)	Emotions [Induction]	Dependent variables
Levenson, Ekman, Heider, & Friesen (1992)	16-27 <i>n</i> = 46 <sup>g</sup> Only "best faces" were reported.	Anger, disgust, fear, happiness, sadness [DFA]	HR, FT, SCL, PTT, FPV, RD, RR
Sinha, Lovallo, & Parsons (1992)	21-35 <i>n</i> = 26*	Anger, fear, joy, sadness, neutral state [Imagery]	HR, SBP, DBP, SV, CO, TPR, PEP, LVET
Vrana (1993)	Undergrads <i>n</i> = 50	Anger, disgust, pleasure (happiness), joy [Imagery]	HR, SCL, facial EMG
Boiten (1996)	Undergrads <i>n</i> = 15* Data also broken down into emotional and nonemotional responders	Anger, disgust, fear, happiness, sadness, surprise, nonemotion, standard control [DFA]	RSP ( $T_i$ , $T_e$ , $P_i$ , $T_{tot}$ , $V_t$ , FRC), HR
Sinha & Parsons (1996)	21-35 <i>n</i> = 27 <sup>h</sup>	Anger, fear, neutral [Imagery]	FT, HR, SBD, DBP, SCL, facial EMG
Collet, Vernet-Maury, Delhomme, Dittmar (1997)	19-26 (22) <i>n</i> = 30	Happiness, surprise, sadness, fear, disgust, anger [Imagery]	EDR-Dur, HT, RR, SBF-Nod, SCL
Alaoui-Ismaili, Robin, Rada, Dittmar, & Vernet-Maury (1997)	20-28 (25) <i>n</i> = 44	Happiness, surprise, sadness, ear, disgust, anger [Odorants <sup>i</sup> ]	EDR-Dur, HR, HT, RR, SBF-Nod
Miller & Wood, 1997	8-17 <i>n</i> = 24 <sup>j</sup>	Happiness, sadness, sadness/happiness, neutral [Film <sup>k</sup> ]	HR, HRV, OS

Note. BV, blood volume; CO, cardiac output; DBP, diastolic blood pressure; DFA, directed facial action; EMG, muscle activity; EOG, eyeblink rate; EDR-Dur, electrodermal response duration; FCT, face temperature; FPV, finger pulse volume; FRC, functional residual capacity; FT, finger temperature; HR, heart rate; HRV, heart rate variability; HT, hand temperature; I<sub>i</sub>, inspiratory index; LVET, left ventricular ejection time; MVT, movement; NMTP, number of muscle tension peaks; NNSCR, number of nonspecific skin conductance responses; OS, oxygen saturation of the blood; PEP, pre-ejection period;  $P_i$ , postinspiratory pause; PTT, pulse transit time; RD, respiration depth; RSP, respiration; RI, respiration irregularity; RR, respiration rate; SBF-Nod, nonoscillatory duration of the skin blood flow response; SBP, systolic blood pressure; SCL, skin conductance level; SRL, skin resistance level; SV, stroke volume;  $T_i$ , inspiratory time;  $T_e$ , expiratory time; TPR, total peripheral resistance;  $T_{tot}$ , total cycle duration;  $V_t$ , tidal volume. An asterisk that indicates that participants were selected based on ability to control facial muscles, on ability to produce appropriate imagery, or on whether they experimented the emotions of interest.

<sup>a</sup>18 hypertensives, 8 potential hypertensives, and the same 15 normotensives as in Ax (1953).

<sup>b</sup>Although this study is included in this descriptive table, it is not included in the meta-analyses because no interemotion comparisons were reported.

<sup>c</sup>No significant effects were found for differences in facial expressions during the film.

<sup>d</sup>Participants imagined a scene in which they felt the appropriate emotion as they were (in their imaginations) exercising on a one-step exercise machine.

<sup>e</sup>The DFA results of this study were subsequently incorporated into Levenson et al. (1990).

<sup>f</sup>Article combined results from three experiments: Ekman et al. (1983); a group of 16 Ss selected from 103 screened; and a group of 30 Ss selected from 109 screened.

<sup>g</sup>Participants were from the Minangkabau community in West Sumatra.

<sup>h</sup>Only males with Minnesota Multiphasic Personality Inventory *T*-scores between 30 and 70 were selected.

<sup>i</sup>Ss inhaled vanillin, menthol, eugenol, propionic acid, and dental resin. Vanillin and propionic acid evoked happiness and disgust, respectively; the other odorants did not reliably evoke the intended emotions and were not included in the meta-analyses.

<sup>j</sup>All Ss were asthmatics; no comparison sample was reported.

<sup>k</sup>Ss viewed clips from the film *E.T.: The Extra-Terrestrial*. The sadness/happiness clip was a farewell scene; the data from this condition were not included in the meta-analyses.

