20 Emotion

ROBERT W. LEVENSON, SANDY J. LWI, CASEY L. BROWN, BRETT Q. FORD, MARCELA C. OTERO, AND ALICE VERSTAEN

INTRODUCTION

Emotion has historically played a central role in psychophysiological research, with rich traditions focusing on both central and peripheral nervous system measures. A central tenet of most functionalist/evolutionary theories is that emotions prepare the organism for dealing effectively and efficiently with threats, challenges, and opportunities (Levenson, 1994). Thus, research has arisen around the actions that occur (the "motion" part of emotion), which are largely subserved by the somatic nervous system, and the metabolic support for these actions, which is largely subserved by the autonomic nervous system (ANS). In this chapter, we focus primarily on the role the ANS plays in emotion and the ways it can best be studied.

THEORETICAL UNDERPINNINGS

Emotion research has been strongly influenced by a number of opposing theoretical positions, some of which have been debated for over a century: (a) discrete versus dimensional; (b) hard-wired versus socially constructed; and (c) universal versus culture-specific. Although psychophysiological research is often viewed as being primarily data-, phenomenon-, and methodology-driven, these theoretical debates have had important influences on the ways this research is conducted. Moreover, psychophysiological studies have provided valuable data that are often used (and misused) in theoretical debates about the nature of emotion.

Arguably most important for psychophysiological research is the discrete versus dimensional debate, which centers on the *differences* among emotion. In discrete emotions theories, a limited number of distinct emotions can be distinguished from each other in terms of structural features (e.g., facial expression, ANS activity) and functions (e.g., preparation for fight, preparation for flight). Discrete emotions are often seen as "natural kinds" (Matsumoto & Willingham, 2006; Panksepp, 2000), with their sources found in the structure of the natural world. In contrast, dimensional theories do not envision distinct emotions, but rather allow for a large (perhaps unlimited) number of emotional states that are located within a dimensional space defined by one or more descriptors. Dimensional approaches that are prominent in the psychophysiological literature include: (a) a two-dimensional model that includes valence (negative–positive) and arousal (low–high), and (b) a single-dimensional model comprised by a motivational or action tendency dimension (approach–avoidance). Although discrete and dimensional models can be combined (e.g., locating a discrete emotion such as fear in negative valence/high arousal dimensional space), these theoretical models have often led to very different research paradigms.

The hard-wired versus social construction debate centers on the *sources* of differences among emotions. On one side of this debate are those who envision the relationships between antecedent conditions, appraisals, and activation of physiological systems to be hard-wired (shaped by evolution and built into the structure of the nervous system). On the other side are those who believe these relationships are socially constructed (created *de novo* in ways that reflect prevailing beliefs, traditions, and conditions). Often the theoretical landscape in emotion is dichotomized into an evolutionary, hard-wired camp (e.g., Ekman, Friesen, & Ellsworth, 1972a; Levenson, 1994; Panksepp, 1998) and a social constructionist camp (e.g., Barrett, 2009; Mesquita, Barrett, & Smith, 2010; Schachter & Singer, 1962). However, closer examination reveals important areas of overlap. For example, Ekman's position is often seen as exemplifying the hard-wired camp, yet it is also the source for the notion of "display rules" (i.e., culturally determined modulation of emotional facial displays; Ekman, Friesen, & Ellsworth, 1972a; Friesen, 1972), which is one of the most widely accepted forms of social construction. Another area of overlap is Barrett's view that emotions are constructed from evolutionary hard-wired experiences of core affect (Barrett, 2006).

The universal versus culture-specific debate centers on the *consistency* of particular features of emotion (e.g., facial expression, antecedent appraisals, ANS patterning) across cultures, ethnic groups, and nationalities. This

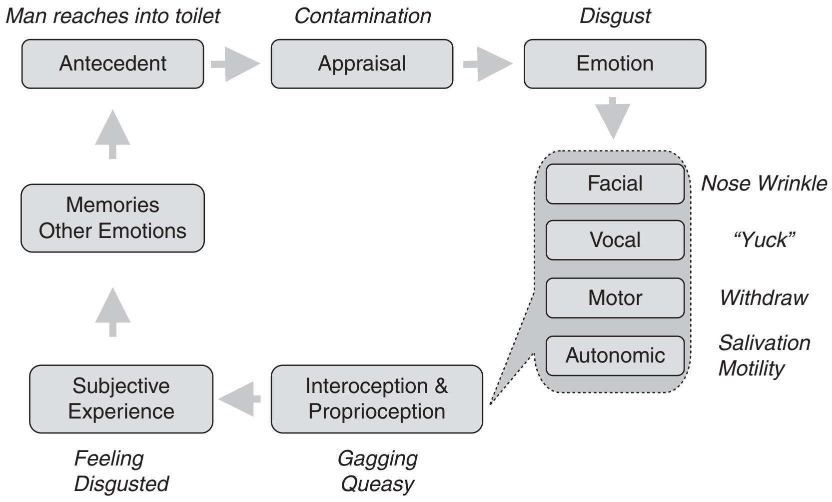

Figure 20.1 Model of emotion elicitation (based on Levenson, 2014).

debate is sometimes conflated with the hard-wired versus social construction debate; however, it is important to recognize that a feature of emotion can be consistent across all studied cultures (e.g., colors associated with qualities of emotions; D'Andrade & Egan, 1974) but not necessarily hard-wired. Rather, the observed consistency could result from multiple cultures independently constructing that feature in a similar way based on similar experiences. The universal versus culture-specific debate (e.g., Ekman, 1994; Russell, 1994) has largely been dominated by studies of the *recognition* of emotional facial expressions across cultures (Ekman, Sorenson, & Friesen, 1969; Gendron, Roberson, van der Vyver, & Barrett, 2014; Izard, 1971; Sauter, Eisner, Ekman, & Scott, 2010). A much smaller literature has examined cross-cultural and cross-national consistencies in the *production* of emotional expressions (e.g., Matsumoto & Willingham, 2006; Tracy & Matsumoto, 2008). Finally, there are also small but influential literatures examining the consistency of physiological features of emotion across cultures and ethnic groups that have examined *actual* peripheral physiological responding (e.g., Lazarus, Opton, Tomita, & Kodama, 1966; Levenson, 1992; Vrana & Rollock, 2002) or *beliefs* about physical changes that accompany different emotions (Scherer & Wallbott, 1994).

THE CLASSIC PARADIGM

A research participant arrives at the psychophysiology laboratory and has sensors attached for monitoring aspects of autonomic and somatic nervous system activity. After sitting quietly for a while and adjusting to the room, the experiment begins. On the first trial, there is a one-minute rest period followed by an excerpt from a movie in which a young man is gagging as he reaches into an extremely filthy toilet to recover something inside. The research participant responds to this film with large changes in facial activity, motor response, and autonomic nervous system activity. After a few minutes, the screen goes dark and the participant's responses gradually dissipate. The participant is then asked to rate her or his emotional experience during the film.

This scenario, which is based on a recent study conducted in our laboratory (Eckart, Sturm, Miller, & Levenson, 2012), or something very much like it, is repeated every day in laboratories around the world that study the psychophysiology of emotion. Over the years, theories of emotion have evolved in important ways: physiological measures have become more sensitive and diverse, psychophysiological recording equipment has dramatically decreased in size and increased in capabilities, the selection of emotion-eliciting stimuli has become more sophisticated, and measures of emotional experience have become more refined. Nonetheless, this experimental procedure is remarkably similar to what was done in psychophysiological studies of emotion conducted over a half century ago (e.g., using the death scene in the Disney movie *Bambi* to elicit emotion, measuring ANS responding during the film, and afterwards, asking participants about their subjective emotional experience; Sternbach, 1962).

This research paradigm fits nicely with a model of discrete emotion elicitation that I (R.W.L.) have presented previously (see Figure 20.1, based on Levenson, 2014). In this model, inputs from organs of sensation are monitored continuously by phylogenetically ancient brain centers (e.g., amygdala, insula, anterior cingulate) in a rapid appraisal process designed to detect well-defined patterns of sensory input that are particularly relevant for the organism's survival and well-being. When one of these patterns (e.g., visual and/or olfactory cues that denote possible contamination) is detected, an emotion (disgust) is activated. The emotion triggers a highly generalized pattern of associated peripheral nervous system activity in multiple response systems (facial expression, vocalization, motor behavior, ANS) that prepares the organization to respond in a way that should be effective for the individual most of the time, and that alerts conspecifics to the situation and activates their emotional responses.

In this view, emotions have the capacity to "interrupt" ongoing activity throughout the peripheral and central nervous system and quickly reallocate resources to the challenge, threat, or opportunity at hand. While in the service of emotion, patterns of activity across response systems within the ANS (e.g., cardiac, vascular, electrodermal) and between the ANS and other biological systems (e.g., motor programs, vocalization, facial expression) are thought to be *coherent* (i.e., organized rather than chaotic) and *specific* (i.e., optimally tuned to the demands of the prototypic eliciting situation).

In this particular instantiation of the evolutionary/functionalist view, subjective emotional experience is not a core feature of emotion, but rather arises from the processing of afferent information from peripheral nervous system activity (e.g., changes in temperature, pressure, muscle tension; Levenson, 2003). This is an old idea (e.g., James, 1884) that has received additional support from contemporary studies of the peripheral and central nervous systems (Berntson et al., 2011; Craig, 2009). Consistent with this research, proprioceptive and interoceptive information is integrated subcortically in the anterior insula (Craig, 2009) and made available to higher brain centers. To the extent that different emotions have different patterns of associated somatic and visceral activity, they also "feel" different (e.g., the subjective experience of disgust is quite different than the subjective experience of sadness). These subjective feelings create links to memories of other related experiences (e.g., other encounters with other contaminants), stimulate additional emotional responses (e.g., amusement over having had a strong emotional reaction in response to a film), and motivate regulatory, coping, and soothing activities that serve to reduce arousal and restore quiescence.

This model of emotion elicitation suggests four different ways that the peripheral nervous system is critically involved in emotion: (a) preparing the organism for action; (b) signaling conspecifics; (c) providing interoceptive information; and (d) reducing arousal. We turn now to a discussion of psychophysiological research in each of these areas.

PREPARING THE ORGANISM FOR ACTION

A common theme emerges across theories and empirical traditions: emotions activate physiological systems in ways that prepare the organism for action. In the discrete emotions tradition, different emotions are associated with different kinds of action. For example, anger is associated with fighting, while fear is associated with fleeing (e.g., Cannon, 1932). In the dimensional tradition, emotion prepares us to approach positive and beneficial stimuli and avoid negative and harmful stimuli (Arnold, 1960; Craig, 1918; Elliot & Covington, 2001; Tooby & Cosmides, 1990). Despite the common elements of activation and action, studies within these theoretical approaches are often quite different, especially in the ways they elicit emotion (for a general review of emotion elicitation methods, see Coan & Allen, 2007).

Discrete Emotions Tradition

Visual images (whether they are static, as in the case of photographs, or dynamic, as in the case of films) are commonly used to elicit emotions in the discrete emotions tradition. However, the most effective elicitors are arguably those that create conditions that cause participants to experience directly the prototypical antecedent conditions thought to produce particular emotions in the real world. For example, to induce anger, participants can be frustrated, criticized, or exposed to unfair treatment (e.g., Ax, 1953; Herrald & Tomaka, 2002; Mauss, Cook, & Gross, 2007; Prkachin, Mills, Zwaal, & Husted, 2001; Stemmler, Heldmann, Pauls, & Scherer, 2001). To induce fear, participants can be placed in situations that threaten physical or social harm, such as exposure to electric shocks (Ax, 1953) or giving a speech while being evaluated (Pauls & Stemmler, 2003; Stemmler et al., 2001). For disgust, participants can be exposed to unpleasant odors, decaying substances, and the like (Rozin & Fallon, 1987; Schnall, Haidt, Clore, & Jordan, 2008). These real-world simulations can be quite effective, but great care must be taken to consider ethical and human subjects issues.

In most psychophysiological studies, emotional stimuli are relatively representational (e.g., viewing a picture of a gun pointed at the camera versus having an actual gun pointed at you) or vicarious (i.e., viewing someone else in an emotion-eliciting situation versus being in that situation yourself). Thus, films (Gross & Levenson, 1995) and static visual images (Lang, Greenwald, & Bradley, 1988) are commonly used to produce fear (e.g., Baldaro et al., 1996; Fredrickson & Levenson, 1998; Kreibig, Wilhelm, Roth, & Gross, 2007), disgust (e.g., Gross, 1998; Kring & Gordon, 1998; Meissner, Muth, & Herbert, 2011; Rohrmann & Hopp, 2008), sadness (e.g., Gross, Fredrickson, & Levenson, 1994; Kunzmann & Grühn, 2005; Seider, Shiota, Whalen, & Levenson, 2011), and happiness (e.g., Averill, 1969; Gruber, Johnson, Oveis, & Keltner, 2008; Johnson, Waugh, & Fredrickson, 2010; Klorman, Weissberg, & Wiesenfeld, 1977; Oveis et al., 2009).

Other approaches for eliciting discrete emotions have included the use of musical excerpts (e.g., Khalfa, Roy, Rainville, Dalla Bella, & Peretz, 2008; Krumhansl, 1997), relived emotional memories (e.g., Ekman, Levenson, & Friesen, 1983; Schwartz, Weinberger, & Singer, 1981; Tsai, Chentsova-Dutton, Freire-Bebeau, & Przymus, 2002), having participants make emotional facial expressions (e.g., Ekman et al., 1983; Levenson, Ekman, & Friesen, 1990; McCaul, Holmes, & Solomon, 1982; Soussignan, 2002), and showing participants images of other people making emotional facial expressions (Dimberg, 1982).

Positive emotions. Until relatively recently, psychophysiological studies in the discrete emotions tradition have been far more concerned with negative emotions than positive emotions. This bias reflects both theory (positive emotions are not thought to be associated with either "fight" or "flight" behaviors) and history (early studies focused on the sympathetic branch of the ANS, which is not dramatically activated by positive emotions; Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Ekman et al., 1983). Moreover, when positive emotions were studied, they were often referred to using the single term "happiness." As a result, studies that examined physiological responses to emotionally disparate elicitors such as slapstick films (likely to produce "amusement"), cute baby animals (likely to produce "affection" or nurturant "love"), and nature scenes (likely to produce "calm" or "contentment") were all said to be studying happiness and thus their results were lumped together.

As emotion researchers became more interested in positive emotions (Friedman, Brown, Tugade, Shiota, & Kirby, 2014), they identified particular positive emotions that may be associated with different types of behavioral activation (e.g., awe, compassion, enthusiasm, nurturant love) and, thus, potentially with different patterns of attendant peripheral nervous system activity (Shiota et al., 2014; Shiota, Neufeld, Yeung, Moser, & Perea, 2011). For example, in a recent study (Stellar, Cohen, Oveis, & Keltner, 2015), respiratory sinus arrhythmia was found to increase during one positive emotion (compassion) but not during two others (pride and inspiration). There clearly is a need for more research examining ANS activity associated with positive emotions.

Dimensional Emotions Tradition

Valence-arousal. The dimensions of valence and arousal emerged in the early work on semantic meaning (Osgood, Suci, & Tannenbaum, 1957). Cross-cultural work indicated that these dimensions show considerable consistency across cultures (Osgood, 1964). Applied to emotions, the two dimensions are typically viewed as orthogonal, forming a circumplex (Russell, 1980) with four quadrants (i.e., high arousal positive, low arousal positive, high arousal negative, low arousal negative). In the dimensional tradition, an emotional occurrence is not defined by a particular label (e.g., anger), but by its location in dimensional space (e.g., highly negative and highly aroused).

To study psychophysiological responding associated with valence and arousal, researchers have often used photographs from the International Affective Picture System (IAPS; Lang et al., 1988). The IAPS consists of a standardized, well-validated set of photographs that have been pre-rated in terms of valence and arousal. For example, low arousal negative photos may portray pollution and people crying, while high arousal negative images may depict death and mutilated bodies. Low arousal positive photos may depict scenes of nature and families, and high arousal positive photos may depict scenes of adventure or erotic activities. Neutral photos generally consist of household items, such as bowls or utensils (Lang, Bradley, & Cuthbert, 1999). In the realm of emotion, a great deal of the research using the IAPS pictures has utilized the startle eye blink modulation (SEM) paradigm (Lang, Bradley, & Cuthbert, 1990; Vrana, Spence, & Lang, 1988).

In SEM studies, participants typically view IAPS pictures that vary in valence and arousal and hear brief, moderately loud noises that elicit a reflexive eye blink. Using surface electrodes, electromyographic (EMG) activity from muscles that circle the eyes (orbicularis oculi) is quantified to measure the amplitude of the eye blink (Blumenthal et al., 2005). A common finding in this literature is that negatively valenced images increase the amplitude of the eye blink while positively valenced images decrease it (Vrana et al., 1988). In another variant of this paradigm, emotional state is not directly manipulated and the startle eye blink magnitude is used as a probe to measure changes in the underlying affective state (Amodio, Harmon-Jones, & Devine, 2003).

SEM studies constitute a large proportion of the psychophysiological research on emotion and attention. Because they typically only include one somatic nervous system measure (eye blink magnitude), these studies are not informative about the ways that ANS activity maps on to emotion dimensions. However, there have been a few studies using dimensional stimuli that have measured their effects on ANS responding. In these studies, stimuli have included IAPS images, noises (e.g., cheering, bird chirps, sirens, ocean sounds), classical musical excerpts, and real-life scenarios (e.g., preparing and giving a speech that was evaluated by judges) that differed in valence and arousal (e.g., Bradley & Lang, 2000; Gomez & Danuser, 2004; Lang, Greenwald, Bradley, & Hamm, 1993; Vrana & Rollock, 2002). Results from these studies indicate that arousal/activation is associated with increases in electrodermal responses (Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang et al., 1993; Mauss & Robinson, 2009; Russell & Barrett, 1999). Valence, on the other hand, is more closely related to heart rate, with negative stimuli associated with heart rate deceleration and positive stimuli associated with heart rate acceleration (Lang et al., 1993; Palomba, Angrilli, & Mini, 1997; Winton, Putnam, & Krauss, 1984).

Approach-avoidance. This dimension is often viewed in terms of motivational systems, with individuals inclined to move toward (i.e., approach) stimuli relevant to positive, desirable goals and to move away from (i.e., avoid) stimuli relevant to negative, undesirable goals. Much of the research utilizing this dimensional approach has been focused on the central nervous system rather than peripheral nervous system activation. For example, a number of studies have used electrocortical and neuroimaging methods to identify neural regions associated with approach and avoidance behaviors (e.g., findings that left anterior activity is associated with approach behaviors and right anterior activity is associated with avoidance behaviors; Carver & Harmon-Jones, 2009; Davidson & Irwin, 1999).

Threat-challenge. A variant of the approach-avoidance dimensional model that has been used with measures of peripheral nervous system activation focuses on the dimension of threat-challenge (Tomaka, Blascovich, Kelsey, & Leitten, 1993). In this work, threat and challenge are viewed as motivational states that result from the individual's perception of situational demands. To the extent that individuals believe they have the resources to meet these demands, they will appraise the situation more as a "challenge" and move toward it. On the other hand, to the extent that they believe they do not have the resources to meet the demands, they will appraise the situation more as a "threat" and withdraw or move away from it. This model posits that different patterns of ANS activity (referred to as sympathetic-adrenomedullary responding) are associated with threat and challenge. Challenge is associated with a pattern of ANS responding that mobilizes the body by increasing heart rate, increasing cardiac output, decreasing left-ventricular ejection time, and decreasing total peripheral resistance. Threat is associated with activation of the pituitary–adrenocortical axis, which inhibits the sympathetic-adrenomedullary challenge response and produces greater total peripheral resistance (Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001; Blascovich & Tomaka, 1996; Tomaka et al., 1993).

SIGNALING CONSPECIFICS

In discussions of emotion signaling systems, facial expressions and vocalizations have reigned supreme (Ekman et al., 1972a; Scherer, Banse, Wallbott, & Goldbeck, 1991). Although undeniably important, this has led to an unfortunate under-appreciation of the role the ANS plays in producing visible changes in bodily appearance that provide valuable information about conspecifics' emotional state (Campos, Mumme, Kermoian, & Campos, 1994; Ekman, 1993; Keltner & Kring, 1998; Levenson, 2003). The ANS produces a wide array of appearance changes related to emotion that we (Levenson, 2003) have previously grouped into four general areas: (a) coloration; (b) moisture and secretions; (c) protrusions; and (d) appearance of eyes.

Coloration

ANS-mediated changes in tissue coloration provide important information about emotional states. Facial reddening (flushing of the facial derma) is often associated with anger or rage (Tomkins, 1984). This reddening is caused by hormonal and vasodilator responses that direct blood to facial tissues. Facial reddening also occurs in blushing, with the reddening often extending to the neck and torso (Leary, Britt, Cutlip, & Templeton, 1992). Blushing is associated with the self-conscious emotions of embarrassment, guilt, or shame (Castelfranchi & Poggi, 1990; Edelmann, 1987; Keltner & Anderson, 2000; Keltner & Buswell, 1997). Blanching, or facial pallor, is the opposite of facial reddening. It results when blood is directed away from the facial skin due to the vasoconstriction of the facial veins. Blanching is typically associated with fear (Levenson, 2003).

Research on facial coloration has usually employed laser Doppler flowmetry (Sarnik, Hofirek, & Sochor, 2007), which measures movement of blood cells, or photoplethysmography (Allen, 2007; Shearn, Bergman, Hill, Abel, & Hinds, 1990), which measures blood volume. Additionally, skin temperature can provide an index of the changes in blood flow that are responsible for changes in coloration (Drummond & Lance, 1987).

Moisture and Secretions

In functionalist views, sweating is seen as part of the body's "fight or flight" response, with sweat on the soles of the feet increasing the friction between the foot and ground, and sweat on the palms increasing tactile sensitivity (Adelman, Taylor, & Heglund, 1975; Smith, Cadoret, & St-Amour, 1997). Sweating in response to emotional stressors is typically studied by examining electrodermal activity (EDA) in areas of the body where eccrine sweat glands are concentrated (e.g., palmar surface of hands, soles of feet). Unlike other sweat glands that are primarily stimulated by increases in temperature, eccrine glands are particularly sensitive to psychological stimulation. Eccrine glands have small tubes with openings at the surface of the skin. As SNS activation increases, sweat rises in the tubes, eventually overflowing onto the surface of the skin. EDA activity is typically determined using Ohm's Law, which establishes the relationships among voltage, current, and resistance. For example, to assess skin conductance (the inverse of resistance), a small fixed voltage is applied between pairs of surface electrodes and the resultant current flow is measured (Boucsein et al., 2012; Fowles et al., 1981). EDA can also be measured using thermal imaging (Krzywicki, Berntson, & O'Kane, 2014) or by using ventilated sweat capsules to collect pooled sweat from larger extremities, torso, and back (Bain, Deren, & Jay, 2011; Machado-Moreira & Taylor, 2012; Morris, Cramer, Hodder, Havenith, & Jay, 2013).

Salivation also provides valuable information about emotional states. Increases in salivation are typically associated with disgust (Angyal, 1941; Levenson, 2003), whereas foaming at the mouth is associated with extreme anger (Lakoff & Kövecses, 1987). Conversely, dryness of the mouth is associated with fear and anxiety (Bergdahl & Bergdahl, 2000; Brown, 1970). Action of the salivary glands is primarily under the control of the parasympathetic nervous system (PNS; Brown, 1970; Proctor & Carpenter, 2007). Salivary flow can be measured using the passive drool method, which requires participants to drool into funnels placed over test tubes (Navazesh & Christensen, 1982; Navazesh & Kumar, 2008), or by using cotton swabs (i.e., salivettes) that absorb the saliva (Rohleder, Wolf, Maldonado, & Kirschbaum, 2006).

Crying and tearing are typically associated with sadness, although in some cases crying can accompany the experience of joy (Bindra, 1972; Miceli & Castelfranchi, 2003; Vingerhoets, Cornelius, Van Heck, & Becht, 2000). The lacrimal glands located in the upper outer portion of the eye orbit control the production of tears, largely under

PNS control. Crying has been associated with increased autonomic and somatic activation (Gross et al., 1994). Crying is typically measured using self-report questionnaires assessing the frequency of crying and proneness to cry (Laan, Van Assen, & Vingerhoets, 2012; Vingerhoets et al., 2000). A few studies have employed observational measures of crying or direct assessment of lacrimal flow (Delp & Sackeim, 1987; Gross et al., 1994).

Although sexual arousal is not considered to be an emotion per se by many emotion theorists, it clearly has strong connections with emotional states. Female genital lubrication is associated with sexual excitement, functioning to create a more favorable environment for sexual activities and having important signal value for potential sexual partners (Masters, 1959; Salonia et al., 2010). Female genital arousal can be measured using a photoplethysmograph that is built into a tampon-shaped device (Sintchak & Geer, 1975).

Protrusions

Piloerection and genital erection both provide valuable information for conspecifics. Piloerection, or the visible erection of hair on the body, was documented in animals and humans by Darwin (1936). It results from muscle contractions at the base of the hair follicle that are activated by the SNS (Benedek & Kaernbach, 2011; Benedek, Wilfling, Lukas-Wolfbauer, Katzur, & Kaernbach, 2010). Although typically thought of as a thermoregulatory response to cold, piloerection has gained increased interest as an indicator of psychological states including fear, anger, awe, surprise, and enjoyment (Keltner & Haidt, 2003; Maruskin, Thrash, & Elliot, 2012; Panksepp, 1995). Piloerection can be measured using an optical recording device in a tube attached to the skin that is sensitive to small elevations at the skin surface (Benedek et al., 2010).

Genital erection results from vasodilation. In males vasodilation under the control of the PNS causes blood to fill the corpora cavernosa of the penis during sexual arousal (Andersson & Wagner, 1995). Penile erection was originally measured using a cuff device to detect changes in penile volume (Freund, 1991; Freund, Sedlacek, & Knob, 1965), but now is more typically measured using mercury-in-rubber strain gages applied to the penis to detect changes in penile circumference (Kuban, Barbaree, & Blanchard, 1999).

Appearance of Eyes

Pupil size is controlled by the joint action of SNS and PNS fibers. Changes in pupil diameter typically occur in response to changing light conditions but also occur in response to emotional arousal and psychological states such as exertion or mental effort (Beatty, 1982; Bradley, Miccoli, Escrig, & Lang, 2008; Hess & Polt, 1964; Kahneman & Beatty, 1966; Partala, Jokiniemi, & Surakka, 2000). Pupil dilation has been associated with sadness and fear (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006; Harrison, Wilson, & Critchley, 2007), whereas pupil constriction has been associated with anger (Boucher & Ekman, 1975). Pupil size is typically measured using eye-tracking systems that use reflected light to determine changes in pupil dilation (Duchowski, 2007).

PROVIDING INTEROCEPTIVE INFORMATION

Interoception refers to the perception of one's internal bodily states. In a number of theories of emotion, this information is critical for constructing subjective emotional experience (James, 1884; Levenson, 2003) and in motivating environmental appraisals (Schachter & Singer, 1962). People commonly report perceiving differentiated bodily feelings for various emotions (e.g., heart pounding in fear, lump in the throat in sadness, stomach churning in disgust, ready to explode in anger; Roseman, Wiest, & Swartz, 1994). Large survey studies have found considerable cross-national consistency in the relations between particular sensations and particular emotions (Scherer & Wallbott, 1994). Nonetheless, there is considerable debate over whether individuals can in fact perceive physiological information accurately from the body (Pennebaker, 1982). Moreover, this is likely an area in which important individual differences exist (Khalsa, Rudrauf, Sandesara, Olshansky, & Tranel, 2009; Mandler, Mandler, & Uviller, 1958).

Anatomical data suggest a plausible neural pathway that subserves the perception of differentiated physiological information from the body. In humans, an afferent pathway conveys continuous feedback on the physiological condition of the body, relaying that information for representation in the anterior portion of the insular cortex (Craig, 2002, 2009). Evidence from neuroimaging studies suggests that interoception and emotional experience share the same functional neural architecture within the insular cortex. The regions of the anterior insular cortex that are active during interoception are also active during emotional experience (Zaki, Davis, & Ochsner, 2012). Importantly, the degree of activity within these regions correlates with the intensity of participants' emotional experience, further solidifying the link between interoception and subjective emotional experience (Zaki et al., 2012).

Other data suggest that distinct regions within the insular cortex subserve concurrent interoceptive and affective processing roles, with the insula relaying and integrating information from diverse neural systems (Simmons et al., 2013). Some researchers have argued that instead of simply relaying information from the body, interoceptive experience may instead reflect limbic predictions about the expected state of the body (Barrett & Simmons, 2015).

Measuring Individual Differences in Interoceptive Processing

A number of methods have been used to measure individual differences in interoceptive sensitivity, with most focusing on sensitivity to information from the cardiovascular system. Examples include tasks where individuals count their heartbeats (Schandry, 1981) and those where individuals indicate whether a series of tones match their heart rate (Katkin, 1985). These methods are vulnerable to confounds such as a lack of control over the amount of access individuals have to peripheral pulse information (e.g., individuals can increase sensitivity to the peripheral pulse by placing their elbow or wrist on a hard surface). Further, the ability of individuals to discriminate heart rate often hovers around chance level. Nonetheless, heartbeat detection tasks have shown some predictive validity, with strong visceral perception being associated with heightened subjective experience of emotions (Wiens, Mezzacappa, & Katkin, 2000) and greater emotional intelligence (Schneider, Lyons, & Williams, 2005).

More invasive measures of interoceptive awareness have also been utilized, such as bolus infusions of isoproterenol, a non-selective beta adrenergic agonist that increases heart rate. In one such study, infusions were delivered sequentially through intravenous catheters and participants were asked to rate changes in heart rate (Khalsa et al., 2009). Unfortunately, such invasive measures are impractical for most research settings.

Because the experience of interoceptive sensations is continuous, newer methodologies that capture ongoing, moment-to-moment changes in perceived body states seem promising. Our laboratory has utilized emotion-eliciting stimuli to induce deviations in physiological arousal, and measured the synchrony (or coherence) between physiological systems and subjective emotional experience over time. Using this method, we found that individuals with heightened levels of physiological awareness training (i.e., Vipassana meditators) had higher levels of synchrony between their emotional ratings and physiology compared to individuals with somatic body awareness training (i.e., dancers) and individuals without either kind of training (Sze, Gyurak, Yuan, & Levenson, 2010). These findings provide indirect support for the usefulness of measuring the synchrony between physiology and subjective emotional experience when assessing interoceptive sensitivity. Importantly, emotion regulation strategies such as expressive suppression have been found to reduce the synchrony between emotional ratings and physiology (Dan-Glauser & Gross, 2013) and thus must be considered when assessing interoceptive sensitivity in this way.

Although there is some evidence that interoceptive sensitivity shows consistency across physiological systems (Herbert, Muth, Pollatos, & Herbert, 2012), the question remains as to which systems are most useful in studies of emotion. The primary measure in almost all studies of interoceptive sensitivity to date has been heart rate, which has the advantage of being easy to measure on a continuous basis. However, other peripheral nervous system responses that produce more powerful physical sensations and thus are more likely to be incorporated into subjective emotion experience could prove to be even more useful (e.g., measures of cardiac contractility, respiration, gastric activity, muscle tightening).

Interoception and Empathy

Our bodies can mirror changes in the physiological states of others through emotional contagion; these mirrored physiological responses provide valuable information about others' emotional state (Preston & De Waal, 2002). This notion is consistent with early empirical evidence that individuals whose peripheral physiology most closely mirrored that of another person were most accurate in rating that person's level of negative emotion over time (Levenson & Ruef, 1992). A number of lines of evidence underscore the importance of autonomic activity in recognizing the emotions of others. These include findings that: (a) greater interoceptive awareness is linked to greater empathy (Fukushima, Terasawa, & Umeda, 2011); (b) attending to interoceptive cues preceding an empathy task enhances neural activity in emotion-related neural regions when individuals empathize (Ernst, Northoff, Böker, Seifritz, & Grimm, 2013); (c) individuals suffering from pure autonomic failure, a form of dysautonomia, do poorly on questionnaire measures of emotional empathy (Chauhan, Mathias, & Critchley, 2008); and (d) a patient with "two hearts," one endogenous and one artificial (a small mechanical pump), each producing different patterns of visceral information, had social cognitive deficits including deficits in empathy (Couto et al., 2013).

REDUCING AROUSAL

Although historically the peripheral nervous system's role in preparing the body for action has been emphasized (e.g., support for fighting and fleeing), it also plays a critical role in reducing arousal. This can take a number of forms including: (a) restoring equilibrium after bouts of high-level arousal; (b) supporting low arousal bodily activities (e.g., resting and digesting); and (c) supporting social functioning (e.g., sexual activity, affiliation). The importance of these arousal-reducing functions is often underappreciated in psychophysiological theories. In our view, an organism that cannot deactivate by calming, soothing, and preserving resources when needed is at least as vulnerable in the long term as an organism that cannot activate by increasing arousal and expending resources when needed.

The ANS plays a critical role in these deactivating processes. For many organs, dual innervation by fibers from the SNS and PNS provides exquisite control over both activation and deactivation. A classic example is seen in the control of heart rate, one of the important ways that the outflow of blood to the body is regulated. SNS fibers increase the firing rate of pacemaker cells in the sino-atrial node of the heart with an attendant speeding of heart rate. PNS fibers have the opposite effect, decreasing the firing rate of pacemaker cells with an attendant slowing of heart rate. Although heart rate can be altered by both SNS and PNS influences, the PNS has been the primary focus in psychophysiological studies of emotion related to reducing arousal.

Restoring Equilibrium

The notion that positive emotions provide an "antidote" for the effects of negative emotions is part of our popular culture. For example, the lyrics written in the 1950s to Charlie Chaplin's classic song "Smile" suggest that you "smile though your heart is aching" and "smile through your fear and sorrow." A similar idea is seen in emotion theories that view positive emotions as effective coping strategies for dealing with stress and distress (e.g., Lazarus, Kanner, & Folkman, 1980; Tomkins, 1962). Expanding on this notion, we proposed that certain positive emotions have the capacity to "undo" the autonomic arousal produced by negative emotions and restore autonomic quiescence (Levenson, 1988). This notion was supported in a series of studies that found that the duration of ANS arousal produced by negative emotions (e.g., fear, sadness) was reduced significantly when positive emotions (e.g., contentment, amusement) were introduced experimentally or occurred spontaneously (Fredrickson, 2000; Fredrickson & Levenson, 1998; Tugade & Fredrickson, 2004). This undoing effect was also found in the realm of spontaneous emotional arousal. During discussions by married couples of a problem in their relationship, moments when levels of ANS arousal declined sharply were associated with a shift toward more positive emotional behaviors compared to moments where these declines did not occur (Yuan, McCarthy, Holley, & Levenson, 2010).

Low Arousal Bodily Activities

The PNS has been characterized as a "rest and digest" or "feed and breed" system (Herlihy, 2013; McCorry, 2007). With regard to "rest," PNS functioning has been linked with better sleep quality (Werner et al., 2015), which is thought to promote better long-term emotional outcomes (Walker & Harvey, 2010). With regard to "digest," the PNS increases salivary secretions to facilitate the swallowing of food and increases gastric motility and secretions to process and absorb nutrients (Quigley, 2004). Disruptions in the gastric system are often accompanied by negative emotions, which may help explain links between PNS activity and gastric symptoms (e.g., dyspepsia; Haug et al., 1994).

Supporting Social Functioning

The polyvagal theory (Porges, 2001) posits that the activation of the vagus nerve – a primary pathway of the PNS – is a critical part of a neural circuit that facilitates social interaction and flexible responses in social situations (e.g., Porges, 2007). Given its efferent connections to the heart and other visceral organs important in emotion and communication (e.g., soft palate, pharynx, larynx, facial muscles, etc.), the vagus nerve is anatomically well situated to play a central role in the experience and expression of emotion in social contexts. This idea draws empirical support from studies demonstrating a link between measures that reflect vagal activation (e.g., respiratory sinus arrhythmia) and measures of social engagement, prosociality, compassion, and flexibility (Butler, Wilhelm, & Gross, 2006; Hopp et al., 2013; Kogan et al., 2014; Muhtadie, Koslov, Akinola, & Mendes, 2014; Stellar et al., 2015).

METHODOLOGICAL ISSUES

At first glance, conducting a psychophysiological study of emotion should be extremely simple. You merely recruit some undergraduates, hook them up to a finger pulse device, show them pictures of guns being pointed at them, and measure changes in heart rate. If heart rate increases, you can count this as evidence for the proposition that heart rate increase is part of the ANS "signature" for fear. Moreover, in future studies, whenever you notice that a subject's heart rate increases, you can use that as prima facie evidence that this person is in fact afraid. What could be simpler?

This seeming simplicity, of course, is completely illusory. In their discussion of psychophysiological inference, Cacioppo and Tassinary (1990, p. 28) note: "There is little to be gained … by simply generating an increasingly lengthy list of 'correlates' between psychological and physiological variables." Underlying their position is the realization that links between psychological and physiological states are rarely one-to-one, but rather are more likely to be one-to-many, many-to-one, or, most likely, many-to-many. Thus, in our imaginary study, fear is likely linked with a number of physiological responses in addition to increased heart rate, and increased heart rate is likely to be linked with a number of emotional, attentional, psychological, and non-psychological states in addition to fear. Moreover, in our imaginary study we neglected to establish whether our picture of the pointed gun in fact produced fear, another emotion, some blend of emotions, or no emotion in each of our subjects. And we do not know from the description provided whether the ANS data were obtained at a reasonable time and reduced in a reasonable way to capture the period of time in which the ANS was actually responding in the service of the emotion we hoped to elicit. Finally, we do not know if reasonable non-emotional baselines were established against which emotional responses could be measured (Levenson, 1983). These baselines help control for individual differences among subjects in resting physiological levels and changes in these levels that occur over time in studies that use within-subject designs (e.g., the typical practice of exposing individual subjects to multiple emotion-eliciting trials).

In our view, psychophysiological studies of emotion are anything but simple, and they require great care and serious commitment if results are going to be meaningful and informative. This is not meant to be offputting or discouraging. At this juncture, many of the major methodological issues that have plagued this research area are well known and addressable. In the following sections, we consider some of the most important of these issues (see also Chapter 27, this volume).

Selecting Stimuli

Many laboratory stimuli produce different emotions across individuals and produce blends or sequences of different emotions within individuals. Associating physiological correlates to particular emotions will only be meaningful if the physiological information is obtained when subjects are actually in the throes of those emotions (see section on verification below). Emotion elicitation is a key challenge for studies in both the discrete and dimensional traditions. Studies depend on the experimenter being able to create conditions under which participants will experience the target emotional states of interest at a particular point in time. Because many studies are concerned with differences among discrete emotions or dimensions, there is the additional challenge of keeping elicitation conditions for different emotional states as comparable as possible. If this challenge is not met, emotion type can easily become confounded with elicitation method (Stemmler, 1989).

As an example of this issue, consider a study interested in comparing ANS responding in disgust versus amusement (or avoidance versus approach). For disgust (or avoidance), the film is silent and consists of the camera slowly scanning a plate of horribly rotting food. For amusement (or approach), the film has a sound track and consists of a comedy monologue that requires the subject to keep track of a fairly complicated set of social relationships and events. If ANS differences are found (or CNS differences in studies measuring brain activity), are they related to the emotions, the differences in sensory information, the different kinds and amounts of cognitive processing required, or something else?

Stimulus selection challenges also derive from the fact that some elicitors are not very effective in producing some emotions. For example, short films can be very effective for producing disgust, amusement, and sadness, but not for producing anger (Gross & Levenson, 1995). Musical excerpts can be effective for producing sadness, amusement, and pride, but not disgust (Juslin & Laukka, 2004). Thus, the set of emotions under study can constrain the choices of stimulus type and vice versa.

Finally, some kinds of emotional stimuli may produce emotions that are simply too weak and ambiguous to activate physiological responses reliably. This can be particularly problematic in contexts where weak stimuli are used for other reasons (e.g., fMRI studies that measure peripheral nervous system activity but also must limit movement to comply with the demands of signal processing in the scanner environment). Recognizing the emotional content in a stimulus (e.g., recognizing that a smiling face is happy and that a frowning face is sad) is not likely to have the same impact on peripheral nervous system responding as being fully in the throes of happiness or sadness.

Verifying Emotional Elicitation

Even the most carefully validated emotion-eliciting stimulus will likely produce different emotional responses in different subjects. Thus, even with the quite powerful disgust film described above, there will be subjects who respond with disgust, others who respond with disgust followed by amusement, others who show anticipatory fear, and yet others who become enraged at being exposed to such unpleasant material. Lumping the physiological data from all of these subjects into the same “disgust” bin makes little sense.

Self-report ratings of emotions experienced in response to emotional stimuli are useful in the verification process. The ratings should assess both targeted and non-targeted emotions on a multi-point intensity scale to determine whether targeted emotions are present and most prominent. In some studies we have obtained continuous ratings of the targeted emotion using a rating dial (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005; Ruef & Levenson, 2007), which also reveals temporal information such as onset and offset times.

Measures of facial behavior can also be valuable in verifying emotional states and in establishing temporal characteristics of emotional responses. Video recordings of subjects can be coded by raters without formal training (i.e., the “cultural informants” approach) or by trained coders using well-established coding schemes. Some of the available coding systems that reflect different theories and methodological considerations include: (a) anatomically based coding of facial movements (e.g., Facial Action Coding System; Ekman & Friesen, 1978), (b) coding for discrete emotions (e.g., Emotional Expressive Behavior System; Gross & Levenson, 1993), (c) coding for dimensions (e.g., Facial Expression Coding System; Kring & Sloan, 2007), and (d) coding for emotional behaviors in interpersonal interactions (e.g., Specific Affect Coding System; Coan & Gottman, 2007). In addition, electromyography from muscles that lower the eyebrows (corrugator) and those that raise the lip corners (zygomatic major) can be useful in providing dimensional information on valence and timing. Automated systems for analyzing facial behavior continue to be refined (e.g., Cohn & De la Torre, 2015) and may become increasingly useful in future studies.

Finally, even when using previously validated stimuli, it is important to obtain new data confirming that these work with the populations under study. For example, we have found that films depicting medical procedures that are quite effective in eliciting disgust in younger participants are not as effective with older individuals, who may view medical procedures in quite different ways (Kunzmann, Kupperbusch, & Levenson, 2005). Similarly, there may be important differences between individuals from different cultures (Levenson, Soto, & Pole, 2007; Soto, Levenson, & Ebling, 2005; Soto et al., 2012).

SELECTING PHYSIOLOGICAL MEASURES

Historically, heart rate has been the most common measure used in psychophysiological studies of emotion (Kreibig, 2010; Mauss & Robinson, 2009). The popularity of heart rate reflects its relative ease, inexpensiveness, and reliability. Heart rate can readily be assessed using surface electrodes to detect the electrocardiogram or photoplethysmography to detect surges of blood in the periphery (Jennings et al., 1981). In addition, quite robust computer algorithms are available to automate the computation of heart rate from digitized data. On the other hand, heart rate clearly exemplifies the one-to-many issue in psychophysiological inference, having been linked with a host of different physiological and psychological states, including arousal and valence (Bradley & Lang, 2000; Lang et al., 1993; Vrana & Rollock, 2002), attentional processing (Libby, Lacey, & Lacey, 1973), sympathy and distress (Eisenberg et al., 1988), and somatic demand (Obrist, Webb, Sutterer, & Howard, 1970).

Heart rate is influenced by both the SNS and PNS and thus is sensitive to a variety of ANS influences. Contemporary psychophysiological studies of emotion have become increasingly concerned with separately estimating SNS and PNS effects. This interest reflects theoretical advances in our understanding of the structure of the PNS and its role in emotion (Porges, 2001). These more recent studies have begun to move away from an exclusive focus on negative, high arousal emotions (which often involve high levels of SNS action) toward an increasing interest in self-conscious emotions (e.g., embarrassment, pride), positive emotions, and low arousal affective states (which often involve PNS action). For researchers interested in linking emotion with activation by particular branches of the ANS, heart rate by itself is not informative.

Assessing SNS influences. SNS activity in emotion is often indexed using measures of cardiac pre-ejection period and electrodermal activity. At one time, power in low frequency bands derived from spectral analysis of heart rate variability was also proposed as an index of SNS influences on the heart (Akselrod et al., 1981), but this now appears to reflect PNS influences as well (Houle & Billman, 1999; Reyes del Paso, Langewitz, Mulder, Roon, & Duschek, 2013) .

Pre-ejection period. Pre-ejection period (PEP) is a relatively pure measure of SNS influence on the heart (Newlin & Levenson, 1979; see also Chapter 9, this volume). PEP reflects cardiac contractility, which is primarily controlled by beta-adrenergic influences and the neurotransmitter norepinephrine. PEP is calculated as the time between ventricular depolarization (typically measured as the Q-point on the electrocardiogram) and the opening of the aortic valve that marks the beginning of the flow of blood out of the left ventricle. The opening of the aortic valve was originally measured using the phonocardiogram to detect the related heart sound (Newlin & Levenson, 1979), but now is typically measured as the B-point on the $\Delta z/\Delta t$ signal derived from impedance cardiography. Shorter PEP times indicate greater left-ventricular contractile force, which is a highly effective way for the heart to increase its output of oxygenated blood in times of high metabolic need.

PEP has been linked to a number of emotional states including negative approach-oriented emotions like anger (Sinha, Lovallo, & Parsons, 1992; Herrald & Tomaka, 2002), but also positive emotions and reward (Brenner, Beauchaine, & Sylvers, 2005). Shortened PEP has also been observed in avoidance-oriented emotions like fear and anxiety, although perhaps to a lesser extent than in approach-oriented emotions (Mendes, Major, McCoy, & Blascovich, 2008).

Measuring PEP is relatively resource- and expertise-intensive. Subtle variations among individuals in the shape and dynamics of the impedance cardiography signal and the vulnerability of the signal to movement artifacts can create difficult challenges (Sherwood et al., 1990). As a result, signal detection algorithms are quite complex, often resorting to estimating rather than actually measuring critical signal features (Lozano et al., 2007) and requiring the averaging of multiple waveforms to increase signal-to-noise ratios (with attendant loss of temporal resolution). Laboratories contemplating measuring PEP should plan on devoting a significant period of time to mastering electrode placement and becoming familiar with signal idiosyncrasies. This effort is definitely worthwhile; in addition to PEP, impedance cardiography can provide a number of other extremely valuable measures of cardiovascular activity (e.g., stroke volume and cardiac output), as well as respiration.

Electrodermal activity. Electrodermal activity (EDA) has a long history in psychophysiological research on emotion (Boucsein et al., 2012; Landis, 1930). EDA is typically used to measure the activity of the eccrine sweat glands, which are innervated by the SNS. Importantly, unlike other organ systems that are innervated by the SNS, the neurotransmitter for the sweat glands is acetylcholine rather than norepinephrine. Reflecting this unique neurochemistry, EDA has demonstrated dissociations from other sympathetic indicators, and thus may not be useful as a sole indicator of SNS functioning (Kreibig, Schaefer, & Brosch, 2010).

EDA is one of the most common measures used in the broader psychophysiological literature (Cacioppo & Tassinary, 1990) and is also commonly used in emotion research (Kreibig, 2010). Although skin potential can be measured directly (Fowles et al., 1981), it is more typically measured indirectly (e.g., applying a small constant voltage to a pair of surface electrodes and measuring the resultant current flow). Measured in this way, EDA does not involve the amplification of small electrical signals from the body, and thus it is much less vulnerable to noise and movement artifacts than most other psychophysiological signals (Fowles et al., 1981). One caveat is that EDA, because of its cholinergic neurochemistry, is profoundly affected by cholinergic medications (e.g., antihistamines, tricyclic antidepressants, bronchodilators, dementia medications, barbiturates, muscle relaxants). Because so many drugs have these effects, it is important to control for medications in studies of EDA. This is especially important in studies using older participants and clinical populations, where complex drug histories will be common. Studies that do not control for these medications when comparing EDA between young and old participants or between patients (psychiatric or medical) and normal controls are likely to confound medication effects with the group differences of interest (similar precautions should be taken for medications that affect other aspects of ANS responding, such as beta-blockers and alpha-blockers in studies using cardiovascular measures).

EDA is often viewed as reflecting ANS activation and preparation for action, corresponding to the arousal dimension of emotion (Kreibig, 2010). EDA has also assumed a prominent role in the influential "somatic marker" model of emotion (Bechara, Damasio, Tranel, & Damasio, 1997). In this model EDA is viewed as a nonconscious signal that reflects prior emotional experiences, and helps guide people toward making more advantageous future decisions (e.g., whether or not to engage in risky choices).

Assessing PNS influences. In psychophysiological studies of emotion, PNS activity has been most often assessed using measures of cardiac vagal control and, more rarely, by measures of stomach activity.

Cardiac vagal control. Acting via the vagus nerve, the PNS plays an important role in the regulation of heart rate by reducing heart rate at rest (in fact, cardiac pacemaker cells would produce resting heart rates of about 100 bpm if not restrained by vagal action). Vagal influences also produce the respiratory sinus arrhythmia (RSA), which is the periodic slowing of heart rate during expiration and speeding of heart rate during inspiration (Berntson, Cacioppo, & Quigley, 1993b). A number of different methods have been used to estimate cardiac vagal control (Allen, Chambers, & Towers, 2007; Berntson et al., 1997). Some of these methods are based on beat-to-beat variability in heart rate alone, others weight variability based on the typical frequency spectrum of respiration (activity in the band of approximately 0.12–0.4Hz is typically used), and yet others actually measure respiration and use it in their calculations of vagal activity (Grossman, Karemaker, & Wieling, 1991). In reviewing this literature, the argument for measuring respiration seems quite compelling to us. Moreover, it seems prudent in studies using RSA to control for the influence of heart rate and respiration rate, as well as other confounding factors such as age, body mass, and medication.

Measures of cardiac vagal tone have been linked to a wide range of constructs including physiological regulation (e.g., Eisenberg et al., 1995), autonomic flexibility (e.g., Kok & Fredrickson, 2010), positive emotionality (e.g., Gruber et al., 2008), emotion regulation ability (e.g., Diamond, Hicks, & Otter-Henderson, 2011), social engagement (e.g., Hopp et al., 2013), and social sensitivity (e.g., Muhtadie et al., 2014). Given this striking conceptual heterogeneity (i.e., the one-to-many problem), coupled with the use of many different measures and the intermixing of paradigms that assess cardiac vagal tone at rest with those that assess changes in vagal tone in response to experimental stimuli, it is not surprising that links with emotional phenomena are inconsistent. Thus, for example, there are reports of positive associations (e.g., Oveis et al., 2009), negative associations (e.g., Rottenberg, Wilhelm, Gross, & Gotlib, 2002), and no associations (e.g., Bosch et al., 2012) between RSA and positive emotion measures.

Stomach activity. It is important to remember that the vagus nerve is not the only nerve in the PNS and that the vagus innervates many organs other than the heart. Among these other organs, the stomach seems particularly relevant to emotion both as a source of physical sensations (e.g., "butterflies," "churning") and the links these sensations have with emotions such as fear and disgust. Electrical activity from the stomach (electrogastrogram; EGG) can be measured using surface electrodes applied to the abdomen and is typically quantified in terms of activity in particular frequency bands (Stern, Koch, Stewart, & Vasey, 1987). PNS activation is thought to be associated with well-defined activity at frequencies of three cycles per minute (normogastria). Other frequency bands of interest include bradygastria (one to two cycles per minute) and tachygastria (four cycles per minute or greater).

EGG has not been widely used in studies of emotion and existing studies have tended to have very small subject samples. However, associations have been found between EGG responses and disgust reactions (Harrison, Gray, Gianaros, & Critchley, 2010; Shenhav & Mendes, 2014), and arousal to emotional stimuli (Vianna, Weinstock, Elliott, Summers, & Tranel, 2006). One challenge when using EGG in emotion research is the slow periodicity of the signal. Long recording periods (e.g., 30 minutes; Yin & Chen, 2013) may be required to obtain stable estimates of power in the frequency bands of interest. This creates additional challenges in the selection of emotional stimuli and the design of experiments. Nonetheless, measures of gastric activity have great potential to help illuminate the role of the PNS in emotion.

Dealing with Multiple Measures

Including multiple physiological measures is increasingly common in studies of emotion. This creates significant challenges for data reduction and analysis (including the need to control for Type I error). In this section, we will briefly review some of the ways that multiple measures can be handled (see also, Chapter 29 on "Biosignal Processing" in this *Handbook*).

Data from each measure are typically averaged for the period of emotion elicitation. For comparison, a non-emotional baseline period located close in time is also averaged (see discussion of uses for these baselines in the section on "Methodological Issues" in this chapter). The number of variables can be reduced empirically using factor analytic techniques (e.g., principal component analysis) or on an *a priori* basis reflecting theory or prior research. As an example of the latter, researchers interested in the threat-challenge dimension typically analyze four specific physiological measures: heart rate, cardiac output, pre-ejection period, and total peripheral resistance, and characterize results in terms of their similarity to the prototypical responses thought to represent threat and challenge (Blascovich, Mendes, Hunter, & Salomon, 1999).

SNS and PNS responses can also be used to characterize patterns of response. "Autonomic balance" reflects the view that SNS and PNS influences are reciprocal (i.e., as the influence of one increases, the influence of the other decreases; Eppinger & Hess, 1915). In contemporary models, the SNS and PNS are viewed as orthogonal dimensions; thus, responding can be situated anywhere in a two-dimensional "autonomic space" (Berntson, Cacciopo, & Quigley, 1993a).

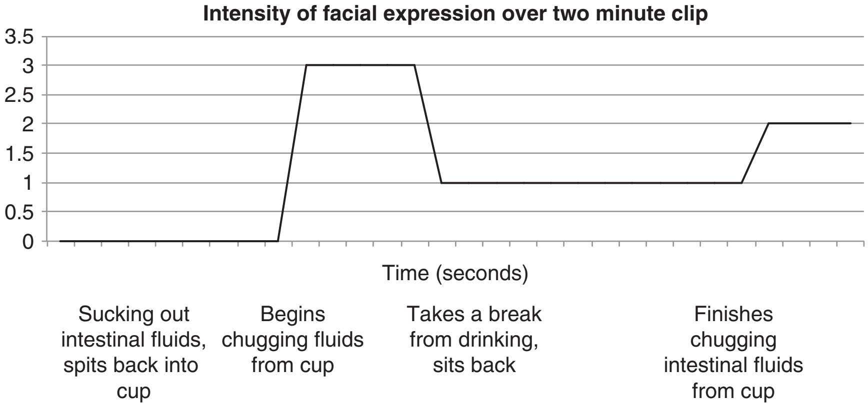

Figure 20.2 Intensity of disgust facial expressions during two-minute film clip.

Another approach to studying patterns in physiology is to examine coherence, or the coordination between emotion response systems over time. Coherence can be examined within the ANS (e.g., heart rate and electrodermal activity) or between the ANS and other emotion systems (e.g., facial expression, subjective emotional experience). Functionalist and evolutionary theories posit that emotions increase coherence within and across physiological systems to facilitate effective responses to environmental demands (Levenson, 1994, 1999). Thus, in response to a predator, fear might organize cardiovascular and electrodermal responses within the ANS to support fleeing, and align those responses with facial expression, vocalization, and subjective experience to facilitate alerting conspecifics. Although most theoretical accounts of emotional coherence envision organization within individuals over time, almost all existing studies have utilized between-subjects designs (e.g., determining whether individuals who have relatively large physiological responses to a given stimulus also have relatively large facial expressive responses) with inconsistent results. However, the few existing within-subject studies have found evidence that some kinds of coherence can be quite sizable during emotion (e.g., correlations between subjective emotional experience and facial expression over time, $r = 0.74$, and between facial expression and skin conductance over time, $r = -0.52$; Mauss et al., 2005).

Timing of Physiological Measurement

Emotions are brief and pulsatile, often occurring in a wavelike form in which each onset–offset cycle lasts for a matter of seconds (Ekman, 1984). Because of these temporal characteristics, great care needs to be taken to ensure that psychophysiological measures are obtained during the time period when the emotion is actually occurring. Researchers need to consider the impact of their stimuli (e.g., is the emotion likely to occur repeatedly throughout presentation, at a particular moment during the presentation, or after the presentation has ended?) when conducting data reduction and analyses (see also, Chapter 29 on "Biosignal Processing" and Chapter 27 on "Methodology" in this *Handbook*). Figure 20.2 illustrates the dynamic complexity of a research participant's emotional response (as indicated by disgust-related facial behaviors) to a disgust-eliciting film that depicts a person drinking fluid from cow intestines. As the visual information in the film changes, the disgust facial behavior waxes and wanes. Researchers need to consider these dynamics in deciding when and how to measure ANS response and determine whether it makes sense to average responses over the entire stimulus presentation, identify a thematic “hot spot” and extract psychological data around that point, or make extraction decisions for each individual subject based on some non-ANS criterion (e.g., facial expression or continuous report of subjective emotional experience). A related timing issue arises when participants have a secondary emotional response. For example, young subjects who watch disgust-eliciting movies often show a disgust facial display followed by a display of laughter and amusement. If the focus of a particular trial is on the emotion of disgust, it will be important to measure physiology prior to the onset of the secondary emotional response.

BUILDING A LABORATORY FOR PSYCHOPHYSIOLOGICAL STUDIES OF EMOTION

Building a laboratory that is suitable for psychophysiological studies of emotion requires thought and planning regarding presenting emotional stimuli, measuring emotional responses, and synchronizing data sources.

Presenting Emotional Stimuli

At one time, presenting visual and auditory stimuli (e.g., acoustic startle) required specialized stand-alone equipment. However, with modern technologies, almost all stimuli can be presented in digital form, which allows for precise software editing and presentation via standard media player and experiment management software (e.g., E-Prime). In most laboratories, a dedicated laptop or desktop computer will be used for stimulus presentation, with its outputs routed to video monitors and speakers/headphones. For stimulus preparation, an internal or external video capture device is useful for digitizing older media (DVDs, videocassettes). Although lower resolutions (e.g., 720 × 480 dpi) may prove adequate for many uses, we recommend a system that is capable of at least 1080p (1920 × 1080 dpi) video resolution and 48 MHz (96 MHz if acoustic analyses are going to be conducted).

Measuring Emotional Responses

For psychophysiological studies of emotion, a great deal of thought needs to go into the measures that will be obtained. These decisions will be guided in part by theoretical orientation (see above), likely paradigms, and practical considerations (e.g., costs).

Physiology. Psychophysiology was once the province of do-it-yourself technologists, with researchers mixing electrode pastes, building bioamplifiers, and writing data reduction algorithms. Now there are a number of sources for high quality electronics; shareware, open-source, and commercial software; and turnkey hardware–software systems that can be configured to order. This ready availability makes it quite tempting to set up a laboratory that “does everything,” assuming sufficient funds are available. In thinking about psychophysiological data collection and processing, it is wise to consider that there is a learning curve associated with each measure. Simply stated, it takes considerable time and practice to get to the point where high quality signals can be obtained reliably and good decisions can be made regarding the editing, reduction, analysis, and interpretation of each physiological measure (see also Chapter 29, this volume).

Consistent with the discussion of measure selection earlier in this chapter, new laboratories will want to obtain measures that have been used historically in emotion research as well as the new measures that are currently popular. The “classic” measures will include heart rate/interbeat interval, electrodermal activity (probably skin conductance), and respiration (including respiration rate and respiration depth). Heart rate and electrodermal activity are typically obtained using surface electrodes and specialized bioamplifiers. Respiration can be measured using belts with stretch sensors that are wrapped around the chest, thermal sensors that are affixed to the nose that respond to temperature differences between inspired and expired air, or mouthpiece devices that respond to the actual flow of air.

Because of the intimate relationships between cardiovascular and somatic responses (Obrist et al., 1970), a measure of somatic activity is extremely useful for understanding the sources of cardiovascular activation and detecting movement artifacts. Activity from particular muscles can be monitored via electromyography, but for this purpose a measure of overall activity is likely to be most useful. This can be obtained using movement sensitive platforms or by having subjects wear actigraph devices.

Given the current interest in measuring SNS and PNS influences on physiological responding, impedance cardiography has become very common in psychophysiology laboratories. The impedance signal is acquired with surface electrodes (spot or band electrodes) and specialized bioamplifiers. Measures of PNS influence based on RSA will require decisions to be made about directly measuring respiration. If this is done using belts with stretch sensors, great care and skill will be required in getting clean respiration signals and in dealing with inevitable movement artifacts.

In earlier sections of this chapter we noted the importance of gastric measures and measures that are sensitive to the appearance changes caused by ANS activity during emotion (e.g., blushing, blanching, salivation, piloerection). For electrogastography, we cited some helpful references. In addition, specialized bioamplifiers exist that are appropriate for dealing with the very low frequency gastric signals. For the appearance changes, we also cited helpful references, but here you will likely be on the “bleeding” edge of technology development and may need to work closely with engineering staff at your university or at the commercial equipment companies.

In traditional psychophysiology laboratories, subjects are tethered to bioamplifying equipment by wires. Considerable advances have been made in developing wireless technologies. As always there are tradeoffs in reliability and costs, but wireless equipment is definitely worth considering if your laboratory will be engaged in research where there is a need for subjects to be less encumbered and to be able to move about more freely.

Behavior. Although behavior can be observed and rated "live," there are many advantages to obtaining video recordings (e.g., recoding at a later date with different coding systems). Advances in video camera technology have made high quality, high resolution, low light sensitive cameras much more affordable and smaller in size. An important initial decision is whether you want to have a multiple camera setup (e.g., for devoting a camera to each of the two people engaged in an interaction). If multiple cameras are used, then an additional video-mixing device will be required to combine multiple camera images into a single image (e.g., having side-by-side head and torso images of interaction partners). Camera placement and concealment are important issues to consider when designing the laboratory. Finally, it is extremely useful to be able to control camera position (pan and tilt) and lens characteristics (zoom in particular, but also iris size and focus) remotely. In a typical laboratory that has separate rooms for subjects and experimenters/equipment, these remote controls will allow video adjustments to be made during experimental sessions without having to interrupt the session by entering the subject room.

Audio recordings will be of the highest quality when microphones are placed closest to the source. Clip-on lavaliere microphones (directional or cardioid type) are very useful for this purpose. For paradigms where subjects will be moving, wireless microphones should be considered. It is also useful to have one or more room microphones (omnidirectional type) to pick up additional sounds (e.g., communications with experimenters when they are in the room). An audio mixer is needed to combine the microphone signals along with any other audio information of interest (e.g., audio from experimental stimuli) into the final recording. Modern video capture devices typically allow for recording two audio channels. If additional processing of speech is planned (e.g., acoustic analysis of fundamental frequency) in studies of dyads and small groups, each person should be recorded on a separate audio channel. This may require an additional audio capture device that allows for recording multiple digital audio channels (e.g., external devices that record eight channels of audio simultaneously via USB or firewire interfaces are widely available and reasonably priced).

Subjective experience. Subjective emotional experience will often be obtained by having subjects rate discrete emotions and/or emotion dimensions following experimental trials using verbal response, paper and pencil, or keyboard/button/tablet devices (Mauss & Robinson, 2009; Scherer, 2005). For studies requiring continuous emotion ratings, rating dial devices can be used (Ruef & Levenson, 2007).

Synchronizing Data Sources

Synchronizing emotional responses from subjects (physiological, behavioral, and subjective experience) and matching them with timing information from the experiment (e.g., stimulus presentation) and information from other apparatus (e.g., eye-tracking equipment) will be a major consideration in laboratory design. The basic principle of synchronization is to apply a common timing metric to all data sources. In the simplest form of synchronization, all devices start recording at the same time and/or some signal is recorded to indicate the start of each trial (e.g., a sound burst on an audio track, a square wave pulse on a polygraph channel, a light flash on a video image). From that common start time, data that occur later in trials can be matched in terms of elapsed time. More sophisticated and powerful methods record continuous timing information throughout experiments (e.g., recording machine readable SMPTE time code and visible elapsed time information on video frames).

Developing a viable synchronization system is one of the most challenging parts of building a laboratory for psychophysiological studies of emotion. For this reason, consultation with local experts and hardware/software companies should be initiated early in the planning process. In thinking about the future, a synchronization system that enables adding new measures and equipment is most desirable.

PSYCHOPHYSIOLOGICAL RESEARCH ON EMOTION: THE FUTURE

Handbook chapters inevitably end up spending a great deal of time focusing on the past and present. In the case of psychophysiological research on emotion, both past and present are incredibly rich, bristling with interesting ideas, lively debates, clever and courageous studies, and the inexorable march of improving methodology. Despite this, surprisingly few issues in this area of research can be considered "settled." Major ideas about the structure and function of emotion, the ways that emotions are involved in shaping our social lives, the bases of individual differences in emotional characteristics, the interplay between cognition and emotion, and the role that emotions play in our physical and mental health continue to be debated. Importantly, these are all areas that cry out for more and better research.

In the realm of psychophysiological research in emotion, better research doesn't "just happen," but requires serious commitment and effort on the part of investigators. Considering the current status of this research area and its potential for continuing to develop and grow in the future, we can offer a few simple do's and don't's that we hope will be helpful:

- **Inspect all signals.** Garbage in/garbage out is the great enemy of psychophysiological research. It is critically important to know your measures and to check the quality of your signals continuously. This is the only way you can be confident that the averages and other summary statistics you are analyzing are based on valid physiological signals and not on artifacts and noise.
- **Trust but verify.** Psychophysiological research on emotion requires knowing what emotional state your participants are in at the time of measurement and using that information to inform data analyses. To loosely paraphrase Socrates: the unverified emotion is not worth studying.
- **Know your algorithms.** Programmers are human, software bugs are everywhere, and all computer programs represent compromises and approximations. Make sure you understand what the wizard is doing behind the curtain of fancy GUIs and inside the black box of data acquisition and data reduction programs (see also chapter "Methodology" in this *Handbook*). Even better, with all the current emphasis on "coding," it may be time for another generation of psychophysiologists to learn how to craft (or at least modify) their own software.
- **Don't look for love (and other emotions) in all the wrong places.** Physiological measures that are convenient, easy, and historically common may not be the best choices to test thorny issues in emotion. For example, a few new studies examining ANS measures that create appearance changes (e.g., blushing) and prominent physical sensations (e.g., stomach activity) in emotion may be much more informative about ANS specificity than 100 more studies that only measure heart rate and skin conductance.
- **Embrace your inner agnostic.** Psychophysiological methodologies can generate rich data that are critical for testing emotion theories. Experiments should be designed so that the data can both support and not support your favorite theory. Even better, strive to run studies that could prove you to be completely wrong (e.g., Platt, 1964).

In writing this chapter, it is our hope that psychophysiologists will *not* see basic research issues concerning the nature of emotion (e.g., specificity, coherence, interoceptive processing, organization of emotions and appraisals, universality) either as being "asked and answered" or as "hopelessly fraught with insoluble problems." Rather, we hope that a new generation of psychophysiologists will be inspired to pursue these issues using fresh insights, new methodologies, sound research designs, the unbounded energy of youth (and other ages), and at least a modicum of theoretical agnosticism. If this happens, we expect that future handbook chapters on the psychophysiology of emotion will be filled with new and exciting discoveries, fewer "either–or" debates that cry out for data that are unavailable, and a much deeper understanding about the nature of emotion and the critical roles emotions play in influencing the most important qualities of human life.

REFERENCES

Adelman, S., Taylor, C. R., & Heglund, N. C. (1975). Sweating on paws and palms: what is its function? *American Journal of Physiology*, 229: 1400–1402.

Akselrod, S., Gordon, D., Ubel, F. A., Shannon, D. C., Berger, A. C., & Cohen, R.J. (1981). Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science*, 213: 220–222.

Allen, J. (2007). Photoplethysmography and its application in clinical physiological measurement. *Physiological Measurement*, 28: R1–R39.

Allen, J. J., Chambers, A. S., & Towers, D. N. (2007). The many metrics of cardiac chronotropy: a pragmatic primer and a brief comparison of metrics. *Biological Psychology*, 74: 243–262.

Amodio, D. M., Harmon-Jones, E., & Devine, P. G. (2003). Individual differences in the activation and control of affective race bias as assessed by startle eyeblink response and self-report. *Journal of Personality and Social Psychology*, 84: 738–753.

Andersson, K.-E. & Wagner, G. (1995). Physiology of penile erection. *Physiological Reviews*, 75: 191–236.

Angyal, A. (1941). Disgust and related aversions. *Journal of Abnormal and Social Psychology*, 36: 393–412.

Arnold, M. B. (1960). *Emotion and Personality*. New York: Columbia University Press.

Averill, J. R. (1969). Autonomic response patterns during sadness and mirth. *Psychophysiology*, 5: 399–414.

Ax, A. F. (1953). The physiological differentiation between fear and anger in humans. *Psychosomatic Medicine*, 15: 433–442.

Bain, A. R., Deren, T. M., & Jay, O. (2011). Describing individual variation in local sweating during exercise in a temperate environment. *European Journal of Applied Physiology*, 111: 1599–1607.

Baldaro, B., Battacchi, M. W., Codispoti, M., Tuozzi, G., Trombini, G., Bolazni, R., & Palomba, D. (1996). Modifications of electrogastrographic activity during the viewing of brief film sequences. *Perceptual and Motor Skills*, 82: 1243–1250.

Barrett, L. F. (2006). Are emotions natural kinds? *Perspectives on Psychological Science*, 1: 28–58.

Barrett, L. F. (2009). The future of psychology: connecting mind to brain. *Perspectives on Psychological Science*, 4: 326–339.

Barrett, L. F. & Simmons, W. K. (2015). Interoceptive predictions in the brain. *Nature Reviews Neuroscience*, 16: 419–429.

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin*, 91: 276–292.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, 275: 1293–1294.

Benedek, M. & Kaernbach, C. (2011). Physiological correlates and emotional specificity of human piloerection. *Biological Psychology*, 86: 320–329.

Benedek, M., Wilfling, B., Lukas-Wolfbauer, R., Katzur, B. H., & Kaernbach, C. (2010). Objective and continuous measurement of piloerection. *Psychophysiology*, 47: 989–993.

Bergdahl, M. & Bergdahl, J. (2000). Low unstimulated salivary flow and subjective oral dryness: association with medication, anxiety, depression, and stress. *Journal of Dental Research*, 79: 1652–1658.

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., Stone, P. H., & van Der Molen, M. W. (1997). Heart rate variability: origins, methods, and interpretive caveats. *Psychophysiology*, 34: 623–648.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993a). Cardiac psychophysiology and autonomic space in humans: empirical perspectives and conceptual implications. *Psychological Bulletin*, 114: 296–322.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993b). Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*, 30: 183–196.

Berntson, G. G., Norman, G. J., Bechara, A., Bruss, J., Tranel, D., & Cacioppo, J. T. (2011). The insula and evaluative processes. *Psychological Science*, 22: 80–86.

Bindra, D. (1972). Weeping: a problem of many facets. *Bulletin of the British Psychological Society*, 25: 281–284.

Blascovich, J., Mendes, W. B., Hunter, S. B., Lickel, B., & Kowai-Bell, N. (2001). Perceiver threat in social interactions with stigmatized others. *Journal of Personality and Social Psychology*, 80: 253–267.

Blascovich, J., Mendes, W. B., Hunter, S. B., & Salomon, K. (1999). Social facilitation as challenge and threat. *Journal of Personality and Social Psychology*, 77: 68–77.

Blascovich, J. & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. In M. Zanna (ed.), *Advances in Experimental Social Psychology, vol. 28* (pp. 1–51). New York: Academic Press.

Blumenthal, T. D., Cuthbert, B. N., Filion, D. L., Hackley, S., Lipp, O. V., & van Boxtel, A. (2005). Committee report. Guidelines for human startle eyeblink electromyographic studies. *Psychophysiology*, 42: 1–15.

Bosch, N. M., Riese, H., Reijneveld, S. A., Bakker, M. P., Verhulst, F. C., Ormel, J., & Oldehinkel, A. J. (2012). Timing matters: long term effects of adversities from prenatal period up to adolescence on adolescents' cortisol stress response. *The TRAILS study*. *Psychoneuroendocrinology*, 37: 1439–1447.

Boucher, J. D. & Ekman, P. (1975). Facial areas and emotional information. *Journal of Communication*, 25: 21–29.

Boucsein, W., Fowles, D., Grimnes, S., Ben-Shakhar, G., Roth, W., Dawson, M., & Filion, D. (2012). Society for Psychophysiological Research Ad Hoc Committee on Electrodermal Measures: publication recommendations for electrodermal measurements. *Psychophysiology*, 49: 1017–1034.

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation: defensive and appetitive reactions in picture processing. *Emotion*, 1: 276–298.

Bradley, M. M. & Lang, P. J. (2000). Affective reactions to acoustic stimuli. *Psychophysiology*, 37: 204–215.

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology*, 45: 602–607.

Brenner, S. L., Beauchaine, T. P., & Sylvers, P. D. (2005). A comparison of psychophysiological and self-report measures of BAS and BIS activation. *Psychophysiology*, 42: 108–115.

Brown, C. C. (1970). The parotid puzzle: a review of the literature on human salivation and its applications to psychophysiology. *Psychophysiology*, 7: 66–85.

Butler, E. A., Wilhelm, F. H., & Gross, J. J. (2006). Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. *Psychophysiology*, 43: 612–622.

Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., & Ito, T. A. (2000). *The Psychophysiology of Emotion*. New York: Guilford Press.

Cacioppo, J. T. & Tassinary, L. G. (1990). Inferring psychological significance from physiological signals. *American Psychologist*, 45: 16–28.

Campos, J. J., Mumme, D. L., Kermoian, R., & Campos, R. G. (1994). A functionalist perspective on the nature of emotion. *Monographs of the Society for Research in Child Development*, 59: 284–303.

Cannon, W. B. (1932). *The Wisdom of the Body*. New York: W. W. Norton.

Carver, C. S. & Harmon-Jones, E. (2009). Anger is an approach-related affect: evidence and implications. *Psychological Bulletin*, 135: 183–204.

Castelfranchi, C. & Poggi, I. (1990). Blushing as a discourse: was Darwin wrong? In W. R. Crozier (ed.), *Shyness and Embarrassment: Perspectives from Social Psychology* (pp. 230–251). Cambridge University Press.

Chauhan, B., Mathias, C. J., & Critchley, H. D. (2008). Autonomic contributions to empathy: evidence from patients with primary autonomic failure. *Autonomic Neuroscience*, 140: 96–100.

Coan, J. A. & Allen, J. J. B. (eds.) (2007). *Handbook of Emotion Elicitation and Assessment*. Oxford University Press.

Coan, J. A. & Gottman, J. M. (2007). The specific affect coding system (SPAFF). In J. A. Coan & J. J. B. Allen (eds.), *Handbook of Emotion Elicitation and Assessment* (pp. 267–285). Oxford University Press.

Cohn, J. F. & De la Torre, F. (2015). Automated face analysis for affective computing. In R. A. Calvo, S. K. D'Mello, J. Gratch, & A. Kappas (eds.), *The Oxford Handbook of Affective Computing* (pp. 131–150). Oxford University Press.

Couto, B., Salles, A., Sedeño, L., Peradejordi, M., Barttfeld, P., Canales-Johnson, A., . . . & Ibanez, A. (2013). The man who feels two hearts: the different pathways of interoception. *Social Cognitive and Affective Neuroscience*, 9: 1253–1260.

Craig, A. D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Nature Reviews Neuroscience*, 3: 655–666.

Craig, A. D. (2009). How do you feel – now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, 10: 59–70.

Craig, W. (1918). Appetites and aversions as constituents of instincts. *Biological Bulletin*, 34: 91–107.

D'Andrade, R. & Egan, M. (1974). The colors of emotion. *American Ethnologist*, 1: 49–63.

Dan-Glauser, E. S. & Gross, J. J. (2013). Emotion regulation and emotion coherence: evidence for strategy-specific effects. *Emotion*, 13: 832–842.

Darwin, C. (1936). *The Origin of Species by Means of Natural Selection: Or the Preservation of Favored Races in the Struggle for Life and The Descent of Man and Selection in Relation to Sex*. New York: Modern Library.

Davidson, R. J. & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences*, 3: 11–21.

Delp, M. J. & Sackeim, H. A. (1987). Effects of mood on lacrimal flow: sex differences and asymmetry. *Psychophysiology*, 24: 550–556.

Diamond, L. M., Hicks, A. M., & Otter-Henderson, K. D. (2011). Individual differences in vagal regulation moderate associations between daily affect and daily couple interactions. *Personality and Social Psychology Bulletin*, 37: 731–744.

Dimberg, U. (1982). Facial reactions to facial expressions. *Psychophysiology*, 19: 643–647.

Drummond, P. D. & Lance, J. W. (1987). Facial flushing and sweating mediated by the sympathetic nervous system. *Brain*, 110: 793–803.

Duchowski, A. (2007). *Eye Tracking Methodology: Theory and Practice*: London: Springer Verlag.

Eckart, J. A., Sturm, V. E., Miller, B. L., & Levenson, R. W. (2012). Diminished disgust reactivity in behavioral variant frontotemporal dementia. *Neuropsychologia*, 50: 786–790.

Edelmann, R. J. (1987). *The Psychology of Embarrassment*. Oxford: John Wiley.

Eisenberg, N., Fabes, R. A., Murphy, B., Maszk, P., Smith, M., & Karbon, M. (1995). The role of emotionality and regulation in children's social functioning: a longitudinal study. *Child Development*, 66: 1360–1384.

Eisenberg, N., Schaller, M., Fabes, R. A., Bustamante, D., Mathy, R. M., Shell, R., & Rhodes, K. (1988). Differentiation of personal distress and sympathy in children and adults. *Developmental Psychology*, 24: 766–775.

Ekman, P. (1984). Expression and the nature of emotion. In K. R. Scherer & P. Ekman (eds.), *Approaches to Emotion* (pp. 319–343). Hillsdale, NJ: Lawrence Erlbaum Associates.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist*, 48: 384–392.

Ekman, P. (1994). Strong evidence for universals in facial expressions: a reply to Russell's mistaken critique. *Psychological Bulletin*, 115: 268–287.

Ekman, P. & Friesen, W. V. (1978). *Facial Action Coding System*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., Friesen, W. V., & Ellsworth, P. (1972a). *Emotion in the Human Face*. New York: Pergamon Press.

Ekman, P., Friesen, W. V., & Ellsworth, P. (1972b). What are the similarities and differences in facial behavior across cultures? In P. Ekman, W. V. Friesen, & P. Ellsworth (eds.), *Emotion in the Human Face* (pp. 128–146). New York: Pergamon Press.

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*, 221: 1208–1210.

Ekman, P., Sorenson, E. R., & Friesen, W. V. (1969). Pan cultural elements in facial displays of emotion. *Science*, 164: 86–88.

Elliot, A. J. & Covington, M. V. (2001). Approach and avoidance motivation. *Educational Psychology Review*, 13: 73–92.

Eppinger, H. & Hess, L. (1915). VAGOTONIA: a clinical study. *Journal of Nervous and Mental Disease*, 42: 112–119.

Ernst, J., Northoff, G., Böker, H., Seifritz, E., & Grimm, S. (2013). Interoceptive awareness enhances neural activity during empathy. *Human Brain Mapping*, 34: 1615–1624.

Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W. W., Lykken, D. T., & Venables, P. H. (1981). Committee report. Publication recommendations for electrodermal measurements. *Psychophysiology*, 18: 232–239.

Fredrickson, B. L. (2000). Cultivating positive emotions to optimize health and well-being. *Prevention & Treatment*, 3: article 0001a.

Fredrickson, B. L. & Levenson, R. W. (1998). Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. *Cognition & Emotion*, 12: 191–220.

Freund, K. (1991). Reflections on the development of the phallometric method of assessing erotic preferences. *Annals of Sex Research*, 4: 221–228.

Freund, K., Sedlacek, F., & Knob, K. (1965). A simple transducer for mechanical plethysmography of the male genital. *Journal of the Experimental Analysis of Behavior*, 8: 169–170.

Friedman, H. L., Brown, N. J. L., Tugade, M. M., Shiota, M. N., & Kirby, L. D. (2014). *The State of Contemporary Positive Emotions Research*. Washington, DC: American Psychological Association.

Friesen, W. V. (1972). *Cultural differences in facial expressions in a social situation: an experimental test of the concept of display rules*. Dissertation, University of California, San Francisco.

Fukushima, H., Terasawa, Y., & Umeda, S. (2011). Association between interoception and empathy: evidence from heartbeat-evoked brain potential. *International Journal of Psychophysiology*, 79: 259–265.

Gendron, M., Roberson, D., van der Vyver, J. M., & Barrett, L.F. (2014). Perceptions of emotion from facial expressions are not culturally universal: evidence from a remote culture. *Emotion*, 14: 251–262.

Gomez, P. & Danuser, B. (2004). Affective and physiological responses to environmental noises and music. *International Journal of Psychophysiology*, 53: 91–103.

Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, 74: 224–237.

Gross, J. J., Fredrickson, B. L., & Levenson, R. W. (1994). The psychophysiology of crying. *Psychophysiology*, 31: 460–468.

Gross, J. J. & Levenson, R. W. (1993). Emotional suppression: physiology, self-report, and expressive behavior. *Journal of Personality and Social Psychology*, 64: 970-986.

Gross, J.J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition & Emotion*, 9: 87–108.

Grossman, P., Karemaker, J., & Wieling, W. (1991). Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythmia: the need for respiratory control. *Psychophysiology*, 28: 201–216.

Gruber, J., Johnson, S. L., Oveis, C., & Keltner, D. (2008). Risk for mania and positive emotional responding: too much of a good thing? *Emotion*, 8: 23–33.

Harrison, N. A., Gray, M. A., Gianaros, P. J., & Critchley, H. D. (2010). The embodiment of emotional feelings in the brain. *Journal of Neuroscience*, 30: 12878–12884.

Harrison, N. A., Singer, T., Rotshtein, P., Dolan, R. J., & Critchley, H. D. (2006). Pupillary contagion: central mechanisms engaged in sadness processing. *Social Cognitive and Affective Neuroscience*, 1: 5–17.

Harrison, N. A., Wilson, C. E., & Critchley, H. D. (2007). Processing of observed pupil size modulates perception of sadness and predicts empathy. *Emotion*, 7: 724–729.

Haug, T. T., Svebak, S., Hausken, T., Wilhelmsen, I., Berstad, A., & Ursin, H. (1994). Low vagal activity as mediating mechanism for the relationship between personality factors and gastric symptoms in functional dyspepsia. *Psychosomatic Medicine*, 56: 181–186.

Herbert, B. M., Muth, E. R., Pollatos, O., & Herbert, C. (2012). Interoception across modalities: on the relationship between cardiac awareness and the sensitivity for gastric functions. *PLoS One*, 7: e36646.

Herlihy, B. (2013). *The Human Body in Health and Illness*. St. Louis, MO: Elsevier.

Herrald, M. M. & Tomaka, J. (2002). Patterns of emotion-specific appraisal, coping, and cardiovascular reactivity during an ongoing emotional episode. *Journal of Personality and Social Psychology*, 83: 434–450.

Hess, E. H. & Polt, J. M. (1964). Pupil size in relation to mental activity during simple problem-solving. *Science*, 143: 1190–1192.

Hopp, H., Shallcross, A. J., Ford, B. Q., Troy, A. S., Wilhelm, F. H., & Mauss, I. B. (2013). High cardiac vagal control protects against future depressive symptoms under conditions of high social support. *Biological Psychology*, 93: 143–149.

Houle, M. S. & Billman, G. E. (1999). Low-frequency component of the heart rate variability spectrum: a poor marker of sympathetic activity. *American Journal of Physiology*, 276: H215–H223.

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

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

Jennings, J. R., Berg, W. K., Hutcheson, J. S., Obrist, P., Porges, S., & Turpin, G. (1981). Committee report. Publication guidelines for heart rate studies in man. *Psychophysiology*, 18: 226–231.

Johnson, K. J., Waugh, C. E., & Fredrickson, B. L. (2010). Smile to see the forest: facially expressed positive emotions broaden cognition. *Cognition & Emotion*, 24: 299–321.

Juslin, P. N. & Laukka, P. (2004). Expression, perception, and induction of musical emotions: a review and a questionnaire study of everyday listening. *Journal of New Music Research*, 33: 217–238.

Kahneman, D. & Beatty, J. (1966). Pupil diameter and load on memory. *Science*, 154: 1583–1585.

Katkin, E. S. (1985). Blood, sweat, and tears: individual differences in autonomic self-perception. *Psychophysiology*, 22: 125–137.

Keltner, D. & Anderson, C. (2000). Saving face for Darwin: the functions and uses of embarrassment. *Current Directions in Psychological Science*, 9: 187–192.

Keltner, D. & Buswell, B. N. (1997). Embarrassment: its distinct form and appeasement functions. *Psychological Bulletin*, 122: 250–270.

Keltner, D. & Haidt, J. (2003). Approaching awe, a moral, spiritual, and aesthetic emotion. *Cognition & Emotion*, 17: 297–314.

Keltner, D. & Kring, A. M. (1998). Emotion, social function, and psychopathology. *Review of General Psychology*, 2: 320–342.

Khalfa, S., Roy, M., Rainville, P., Dalla Bella, S., & Peretz, I. (2008). Role of tempo entrainment in psychophysiological differentiation of happy and sad music? *International Journal of Psychophysiology*, 68: 17–26.

Khalsa, S., Rudrauf, D., Sandesara, C., Olshansky, B., & Tranel, D. (2009). Bolus isoproterenol infusions provide a reliable method for assessing interoceptive awareness. *International Journal of Psychophysiology*, 72: 34–45.

Klorman, R., Weissberg, R. P., & Wiesenfeld, A. R. (1977). Individual differences in fear and autonomic reactions to affective stimulation. *Psychophysiology*, 14: 45–51.

Kogan, A., Oveis, C., Carr, E. W., Gruber, J., Mauss, I. B., Shallcross, A., … & Cheng, C. (2014). Vagal activity is quadratically related to prosocial traits, prosocial emotions, and observer perceptions of prosociality. *Journal of Personality and Social Psychology*, 107: 1051–1063.

Kok, B. E. & Fredrickson, B. L. (2010). Upward spirals of the heart: autonomic flexibility, as indexed by vagal tone, reciprocally and prospectively predicts positive emotions and social connectedness. *Biological Psychology*, 85: 432–436.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: a review. *Biological Psychology*, 84: 394–421.

Kreibig, S. D., Schaefer, G., & Brosch, T. (2010). Psychophysiological response patterning in emotion: implications for affective computing. In K. R. Scherer, T. Baenziger, & E. Roesch (eds.), *Blueprint for Affective Computing: A Sourcebook* (pp. 105–130). Oxford University Press.

Kreibig, S. D., Wilhelm, F. H., Roth, W. T., & Gross, J. J. (2007). Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films. *Psychophysiology*, 44: 787–806.

Kring, A. M. & Gordon, A. H. (1998). Sex differences in emotion: expression, experience, and physiology. *Journal of Personality and Social Psychology*, 74: 686–703.

Kring, A. M. & Sloan, D. M. (2007). The Facial Expression Coding System (FACES): development, validation, and utility. *Psychological Assessment*, 19: 210–224.

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology*, 51: 336–352.

Krzywicki, A. T., Berntson, G. G., & O'Kane, B. L. (2014). A non-contact technique for measuring eccrine sweat gland activity using passive thermal imaging. *International Journal of Psychophysiology*, 94: 25–34.

Kuban, M., Barbaree, H. E., & Blanchard, R. (1999). A comparison of volume and circumference phallometry: response magnitude and method agreement. *Archives of Sexual Behavior*, 28: 345–359.

Kunzmann, U. & Grühn, D. (2005). Age differences in emotional reactivity: the sample case of sadness. *Psychology and Aging*, 20: 47–59.

Kunzmann, U., Kupperbusch, C. S., & Levenson, R. W. (2005). Behavioral inhibition and amplification during emotional arousal: a comparison of two age groups. *Psychology and Aging*, 20: 144–158.

Laan, A. J., Van Assen, M. A., & Vingerhoets, A. J. (2012). Individual differences in adult crying: the role of attachment styles. *Social Behavior and Personality*, 40: 453–471.

Lakoff, G. & Kövecses, Z. (1987). The cognitive model of anger inherent in American English. In D. Holland & N. Quinn (eds.), *Cultural Models in Language & Thought* (pp. 195–221). Cambridge University Press.

Landis, C. (1930). Psychology and the psychogalvanic reflex. *Psychological Review*, 37: 381–398.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review*, 97: 377–395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *International Affective Picture System (IAPS): Technical Manual and Affective Ratings*. Gainesville, FL: Center for Research in Psychophysiology, University of Florida.

Lang, P. J., Greenwald, M. K., & Bradley, M. M. (1988). *The International Affective Picture System (IAPS) Standardization Procedure and Initial Group Results for Affective Judgments*. Gainesville, FL: Center for the Study of Emotion and Attention, University of Florida.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: affective, facial, visceral, and behavioral reactions. *Psychophysiology*, 30: 261–273.

Lazarus, R. S., Kanner, A. D., & Folkman, S. (1980). Emotions: a cognitive-phenomenological analysis. In R. Plutchik & H. Kellerman (eds.), *Theories of Emotion* (pp. 189–217). New York: Academic Press.

Lazarus, R. S., Opton, E., Tomita, M., & Kodama, M. (1966). A cross-cultural study of stress-reaction patterns in Japan. *Journal of Personality and Social Psychology*, 4: 622–633.

Leary, M. R., Britt, T. W., Cutlip, W. D., & Templeton, J. L. (1992). Social blushing. *Psychological Bulletin*, 112: 446–460.

Levenson, R. W. (1983). Personality research and psychophysiology: general considerations. *Journal of Research in Personality*, 17: 1–21.

Levenson, R. W. (1988). Emotion and the autonomic nervous system: a prospectus for research on autonomic specificity. In H. L. Wanger (ed.), *Social Psychophysiology and Emotion: Theory and Clinical Applications* (pp. 17–42). Oxford: John Wiley.

Levenson, R. W. (1992). Autonomic nervous system differences among emotions. *Psychological Science*, 3: 23–27.

Levenson, R. W. (1994). Human emotion: a functional view. In P. Ekman & R. J. Davidson (eds.), *The Nature of Emotion: Fundamental Questions* (pp. 123–126). Oxford University Press.

Levenson, R. W. (1999). The intrapersonal functions of emotion. *Cognition & Emotion*, 13: 481–504.

Levenson, R. W. (2003). Blood, sweat, and fears: the autonomic architecture of emotion. *Annals of the New York Academy of Sciences*, 1000: 348–366.

Levenson, R. W. (2014). The autonomic nervous system and emotion. *Emotion Review*, 6: 100–112.

Levenson, R. W., Ekman, P., & Friesen, W. V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology*, 27: 363–384.

Levenson, R. W. & Ruef, A. M. (1992). Empathy: a physiological substrate. *Journal of Personality and Social Psychology*, 63: 234–246.

Levenson, R. W., Soto, J., & Pole, N. (2007). Emotion, biology, and culture. In S. Kitayama & D. Cohen (eds.), *Handbook of Cultural Psychology* (pp. 780–796). New York: Guilford Press.

Libby, W. L., Lacey, B. C., & Lacey, J. I. (1973). Pupillary and cardiac activity during visual attention. *Psychophysiology*, 10: 270–294.

Lozano, D. L., Norman, G., Knox, D., Wood, B. L., Miller, B. D., Emery, C. F., & Berntson, G. G. (2007). Where to B in dZ/dt. *Psychophysiology*, 44: 113–119.

Machado-Moreira, C. A. & Taylor, N. A. (2012). Psychological sweating from glabrous and nonglabrous skin surfaces under thermoneutral conditions. *Psychophysiology*, 49: 369–374.

Mandler, G., Mandler, J. M., & Uviller, E. T. (1958). Autonomic feedback: the perception of autonomic activity. *Journal of Abnormal and Social Psychology*, 56: 367–373.

Maruskin, L. A., Thrash, T. M., & Elliot, A. J. (2012). The chills as a psychological construct: content universe, factor structure, affective composition, elicitors, trait antecedents, and consequences. *Journal of Personality and Social Psychology*, 103: 135–157.

Masters, W. H. (1959). The sexual response cycle of the human female: vaginal lubrication. *Annals of the New York Academy of Sciences*, 83: 301–317.

Matsumoto, D. & Willingham, B. (2006). The thrill of victory and the agony of defeat: spontaneous expressions of medal winners of the 2004 Athens Olympic Games. *Journal of Personality and Social Psychology*, 91: 568–581.

Mauss, I. B., Cook, C. L., & Gross, J. J. (2007). Automatic emotion regulation during anger provocation. *Journal of Experimental Social Psychology*, 43: 698–711.

Mauss, I. B., Levenson, R. W., McCarter, L., Wilhelm, F. H., & Gross, J. J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion*, 5: 175–190.

Mauss, I. B. & Robinson, M. D. (2009). Measures of emotion: a review. *Cognition & Emotion*, 23: 209–237.

McCaul, K. D., Holmes, D. S., & Solomon, S. (1982). Voluntary expressive changes and emotion. *Journal of Personality and Social Psychology*, 42: 145–152.

McCorry, L. K. (2007). Physiology of the autonomic nervous system. *American Journal of Pharmaceutical Education*, 71: 1–11.

Meissner, K., Muth, E. R., & Herbert, B. M. (2011). Bradygastric activity of the stomach predicts disgust sensitivity and perceived disgust intensity. *Biological Psychology*, 86: 9–16.

Mendes, W. B., Major, B., McCoy, S., & Blascovich, J. (2008). How attributional ambiguity shapes physiological and emotional responses to social rejection and acceptance. *Journal of Personality and Social Psychology*, 94: 278–291.

Mesquita, B., Barrett, L. F., & Smith, E. R. (2010). The context principle. In B. Mesquita, L. F. Barrett, & E. R. Smith (eds.), *The Mind in Context* (pp. 1–24). New York: Guilford Press.

Miceli, M. & Castelfranchi, C. (2003). Crying: discussing its basic reasons and uses. *New Ideas in Psychology*, 21: 247–273.

Morris, N. B., Cramer, M. N., Hodder, S. G., Havenith, G., & Jay, O. (2013). A comparison between the technical absorbent and ventilated capsule methods for measuring local sweat rate. *Journal of Applied Physiology*, 114: 816–823.

Muhtadie, L., Koslov, K., Akinola, M., & Mendes, W. B. (2014). Vagal flexibility: a physiological predictor of social sensitivity. *Journal of Personality and Social Psychology*, 109: 106–120.

Navazesh, M. & Christensen, C. (1982). A comparison of whole mouth resting and stimulated salivary measurement procedures. *Journal of Dental Research*, 61: 1158–1162.

Navazesh, M. & Kumar, S. (2008). Measuring salivary flow: challenges and opportunities. *Journal of the American Dental Association*, 139: 35S–40S.

Newlin, D. B. & Levenson, R. W. (1979). Pre-ejection period: measuring beta-adrenergic influences upon the heart. *Psychophysiology*, 16: 546–553.

Obrist, P. A., Webb, R. A., Sutterer, J. R., & Howard, J. L. (1970). The cardiac-somatic relationship: some reformulations. *Psychophysiology*, 6: 569–587.

Osgood, C. E. (1964). Sematic differential technique in the comparative study of cultures. *American Anthropologist*, 66: 171–200.

Osgood, C. E. G., Suci, G. J., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana: University of Illinois Press.

Oveis, C., Cohen, A. B., Gruber, J., Shiota, M. N., Haidt, J., & Keltner, D. (2009). Resting respiratory sinus arrhythmia is associated with tonic positive emotionality. *Emotion*, 9: 265–270.

Palomba, D., Angrilli, A., & Mini, A. (1997). Visual evoked potentials, heart rate responses and memory to emotional pictorial stimuli. *International Journal of Psychophysiology*, 27: 55–67.

Panksepp, J. (1995). The emotional sources of "chills" induced by music. *Music Perception*, 13: 171–207.

Panksepp, J. (1998). *Affective Neuroscience: The Foundations of Human and Animal Emotions*. Oxford University Press.

Panksepp, J. (2000). Emotions as natural kinds within the mammalian brain. In M. Lewis & J. M. Haviland-Jones (eds.), *Handbook of Emotions* (pp. 137–156). New York: Guilford Press.

Partala, T., Jokiniemi, M., & Surakka, V. (2000). Pupillary responses to emotionally provocative stimuli. In *Proceedings of the 2000 Symposium on Eye Tracking Research & Applications* (pp. 123–129). New York: ACM.

Pauls, C. A. & Stemmler, G. (2003). Repressive and defensive coping during fear and anger. *Emotion*, 3: 284–302.

Pennebaker, J. W. (1982). *The Psychology of Physical Symptoms*. New York: Springer-Verlag.

Platt, J. R. (1964). Strong inference. *Science*, 146: 347–353.

Porges, S. W. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*, 42: 123–146.

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, 74: 116–143.

Preston, S. D. & De Waal, F. B. M. (2002). Empathy: its ultimate and proximate bases. *Behavioral and Brain Sciences*, 25: 1–72.

Prkachin, K. M., Mills, D. E., Zwaal, C., & Husted, J. (2001). Comparison of hemodynamic responses to social and nonsocial stress: evaluation of an anger interview. *Psychophysiology*, 38: 879–885.

Proctor, G. B. & Carpenter, G. H. (2007). Regulation of salivary gland function by autonomic nerves. *Autonomic Neuroscience*, 133: 3–18.

Quigley, K. S. (2004). Parasympathetic nervous system. In W. E. Craighead & C. B. Nemeroff (eds.), *Concise Corsini Encyclopedia of Psychology and Behavioral Science*, 3rd edn. New York: John Wiley.

Reyes del Paso, G. A., Langewitz, W., Mulder, L. J., Roon, A., & Duschek, S. (2013). The utility of low frequency heart rate variability as an index of sympathetic cardiac tone: a review with emphasis on a reanalysis of previous studies. *Psychophysiology*, 50: 477–487.

Rohleder, N., Wolf, J. M., Maldonado, E. F., & Kirschbaum, C. (2006). The psychosocial stress-induced increase in salivary alpha-amylase is independent of saliva flow rate. *Psychophysiology*, 43: 645–652.

Rohrmann, S. & Hopp, H. (2008). Cardiovascular indicators of disgust. *International Journal of Psychophysiology*, 68: 201–208.

Roseman, I. J., Wiest, C., & Swartz, T. S. (1994). Phenomenology, behaviors, and goals differentiate discrete emotions. *Journal of Personality and Social Psychology*, 67: 206–221.

Rottenberg, J., Wilhelm, F. H., Gross, J. J., & Gotlib, I. H. (2002). Respiratory sinus arrhythmia as a predictor of outcome in major depressive disorder. *Journal of Affective Disorders*, 71: 265–272.

Rozin, P. & Fallon, A. E. (1987). A perspective on disgust. *Psychological Review*, 94: 23–41.

Ruef, A. M. & Levenson, R. W. (2007). Continuous measurement of emotion: the affect rating dial. In J. A. Coan & J. J. B. Allen (eds.), *Handbook of Emotion Elicitation and Assessment* (pp. 286–297). Oxford University Press.

Russell, J. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, 39: 1161–1178.

Russell, J. A. (1994). Is there universal recognition of emotion from facial expressions? A review of the cross-cultural studies. *Psychology Bulletin*, 115: 102–141.

Russell, J. A. & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. *Journal of Personality and Social Psychology*, 76: 805–819.

Salonia, A., Giraldi, A., Chivers, M. L., Georgiadis, J. R., Levin, R., Maravilla, K. R., & McCarthy, M. M. (2010). Physiology of women's sexual function: basic knowledge and new findings. *Journal of Sexual Medicine*, 7: 2637–2660.

Sarnik, S., Hofirek, I., & Sochor, O. (2007). Laser doppler fluxmetry. *Biomedical Papers*, 151: 143–146.

Sauter, D. A., Eisner, F., Ekman, P., & Scott, S. K. (2010). Cross-cultural recognition of basic emotions through nonverbal emotional vocalizations. *Proceedings of the National Academy of Sciences of the USA*, 107: 2408–2412.

Schachter, S. & Singer, J. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review*, 69: 379–399.

Schandry, R. (1981). Heart beat perception and emotional experience. *Psychophysiology*, 18: 483–488.

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information*, 44: 695–729.

Scherer, K. R., Banse, R., Wallbott, H. G., & Goldbeck, T. (1991). Vocal cues in emotion encoding and decoding. *Motivation & Emotion*, 15: 123–148.

Scherer, K. R. & Wallbott, H. G. (1994). Evidence for universality and cultural variation of differential emotion response patterning. *Journal of Personality and Social Psychology*, 66: 310–328.

Schnall, S., Haidt, J., Clore, G. L., & Jordan, A. H. (2008). Disgust as embodied moral judgment. *Personality and Social Psychology Bulletin*, 34: 1096–1109.

Schneider, T. R., Lyons, J. B., & Williams, M. (2005). Emotional intelligence and autonomic self-perception: emotional abilities are related to visceral acuity. *Personality and Individual Differences*, 39: 853–861.

Schwartz, G. E., Weinberger, D. A., & Singer, J.A. (1981). Cardiovascular differentiation of happiness, sadness, anger, and fear following imagery and exercise. *Psychosomatic Medicine*, 43: 343–364.

Seider, B. H., Shiota, M. N., Whalen, P., & Levenson, R. W. (2011). Greater sadness reactivity in late life. *Social Cognitive and Affective Neuroscience*, 6: 186–194.

Shearn, D., Bergman, E., Hill, K., Abel, A., & Hinds, L. (1990). Facial coloration and temperature responses in blushing. *Psychophysiology*, 27: 687–693.

Shenhav, A. & Mendes, W. B. (2014). Aiming for the stomach and hitting the heart: dissociable triggers and sources for disgust reactions. *Emotion*, 14: 301–310.

Sherwood, A., Allen, M. T., Fahrenberg, J., Kelsey, R. M., Lovallo, W. R., & van Doornen, L. J. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology*, 27: 1–23.

Shiota, M. N., Neufeld, S. L., Danvers, A. F., Osborne, E. A., Sng, O., & Yee, C. I. (2014). Positive emotion differentiation: a functional approach. *Social and Personality Psychology Compass*, 8: 104–117.

Shiota, M. N., Neufeld, S. L., Yeung, W. H., Moser, S. E., & Perea, E. F. (2011). Feeling good: autonomic nervous system responding in five positive emotions. *Emotion*, 11: 1368–1378.

Simmons, W. K., Avery, J. A., Barcalow, J. C., Bodurka, J., Drevets, W. C., & Bellgowan, P. (2013). Keeping the body in mind: insula functional organization and functional connectivity integrate interoceptive, exteroceptive, and emotional awareness. *Human Brain Mapping*, 34: 2944–2958.

Sinha, R., Lovallo, W. R., & Parsons, O. A. (1992). Cardiovascular differentiation of emotions. *Psychosomatic Medicine*, 54: 422–435.

Sintchak, G. & Geer, J. H. (1975). A vaginal plethysmograph system. *Psychophysiology*, 12: 113–115.

Smith, A., Cadoret, G., & St-Amour, D. (1997). Scopolamine increases prehensile force during object manipulation by reducing palmar sweating and decreasing skin friction. *Experimental Brain Research*, 114: 578–583.

Soto, J. A., Levenson, R. W., & Ebling, R. (2005). Cultures of moderation and expression: emotional experience, behavior, and physiology in Chinese Americans and Mexican Americans. *Emotion*, 5: 154–165.

Soto, J. A., Roberts, N. A., Pole, N., Levenson, R. W., Burleson, M. H., King, A. R., & Breland-Noble, A. (2012). Elevated baseline anxiety among African Americans in laboratory research settings. *Journal of Psychophysiology*, 26: 105–115.

Soussignan, R. (2002). Duchenne smile, emotional experience, and autonomic reactivity: a test of the facial feedback hypothesis. *Emotion*, 2: 52–74.

Stellar, J. E., Cohen, A., Oveis, C., & Keltner, D. (2015). Affective and physiological responses to the suffering of others: compassion and vagal activity. *Journal of Personality and Social Psychology*, 108: 572–585.

Stemmler, G. (1989). The autonomic differentiation of emotions revisited: convergent and discriminant validation. *Psychophysiology*, 26: 617–632.

Stemmler, G., Heldmann, M., Pauls, C. A., & Scherer, T. (2001). Constraints for emotion specificity in fear and anger: the context counts. *Psychophysiology*, 38: 275–291.

Stern, R. M., Koch, K. L., Stewart, W. R., & Vasey, M. W. (1987). Electrogastrography: current issues in validation and methodology. *Psychophysiology*, 24: 55–64.

Sternbach, R. A. (1962). Assessing differential autonomic patterns in emotions. *Journal of Psychosomatic Research*, 6: 87–91.

Sze, J. A., Gyurak, A., Yuan, J. W., & Levenson, R. W. (2010). Coherence between emotional experience and physiology: does body awareness training have an impact? *Emotion*, 10: 803–814.

Tomaka, J., Blascovich, J., Kelsey, R. M., & Leitten, C. L. (1993). Subjective, physiological, and behavioral effects of threat and challenge appraisal. *Journal of Personality and Social Psychology*, 65: 248–260.

Tomkins, S. S. (1962). *Affect, Imagery, Consciousness, vol. 1: The Positive Affects*. New York: Springer.

Tomkins, S. S. (1984). Affect theory. In T. Scherer & P. Ekman (eds.), *Approaches to Emotion* (pp. 353–395). Cambridge University Press.

Tooby, J. & Cosmides, L. (1990). The past explains the present: emotional adaptations and the structure of ancestral environments. *Ethology and Sociobiology*, 11: 375–424.

Tracy, J. L. & Matsumoto, D. (2008). The spontaneous expression of pride and shame: evidence for biologically innate nonverbal displays. *Proceedings of the National Academy of Sciences of the USA*, 105: 11655–11660.

Tsai, J. L., Chentsova-Dutton, Y., Freire-Bebeau, L., & Przymus, D. E. (2002). Emotional expression and physiology in European Americans and Hmong Americans. *Emotion*, 2: 380–397.

Tugade, M. M. & Fredrickson, B. L. (2004). Resilient individuals use positive emotions to bounce back from negative emotional experiences. *Journal of Personality and Social Psychology*, 86: 320–333.

Vianna, E. P., Weinstock, J., Elliott, D., Summers, R., & Tranel, D. (2006). Increased feelings with increased body signals. *Social Cognitive and Affective Neuroscience*, 1: 37–48.

Vingerhoets, A. J., Cornelius, R. R., Van Heck, G. L., & Becht, M. C. (2000). Adult crying: a model and review of the literature. *Review of General Psychology*, 4: 354–377.

Vrana, S. R. & Rollock, D. (2002). The role of ethnicity, gender, emotional content, and contextual differences in physiological, expressive, and self-reported emotional responses to imagery. *Cognition & Emotion*, 16: 165–192.

Vrana, S. R., Spence, E. L., & Lang, P. J. (1988). The startle probe response: a new measure of emotion? *Journal of Abnormal Psychology*, 97: 487–491.

Walker, M.P., &Harvey, A.G. (2010). Obligate symbiosis: Sleep and affect. *Sleep medicine reviews*, 14: 215-217.

Werner, G. G., Ford, B. Q., Mauss, I. B., Schabus, M., Blechert, J., & Wilhelm, F. H. (2015). High cardiac vagal control is related to better subjective and objective sleep quality. *Biological Psychology*, 106: 79–85.

Wiens, S., Mezzacappa, E. S., & Katkin, E. S. (2000). Heartbeat detection and the experience of emotions. *Cognition & Emotion*, 14: 417–427.

Winton, W. M., Putnam, L. E., & Krauss, R. M. (1984). Facial and autonomic manifestations of the dimensional structure of emotion. *Journal of Experimental Social Psychology*, 20: 195–216.

Yin, J. & Chen, J. D. (2013). Electrogastrography: methodology, validation and applications. *Journal of Neurogastroenterology and Motility*, 19: 5–17.

Yuan, J. W., McCarthy, M., Holley, S. R., & Levenson, R. W. (2010). Physiological down-regulation and positive emotion in marital interaction. *Emotion*, 10: 467–474.

Zaki, J., Davis, J. I., & Ochsner, K. N. (2012). Overlapping activity in anterior insula during interoception and emotional experience. *NeuroImage*, 62: 493–499.