Biological Psychology 98 (2014) 82–94

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Is there consistency and specificity of autonomic changes during emotional episodes? Guidance from the Conceptual Act Theory and psychophysiology

Karen S. Quigley[a,b,*], Lisa Feldman Barrett[a,c]

[a] Northeastern University, Department of Psychology, 125 NI, Boston, MA 02115, United States
[b] Edith Nourse Rogers (Bedford) Memorial VA Hospital, 200 Springs Road, Bedford, MA 01730, United States
[c] Massachusetts General Hospital, Harvard Medical School, 149 13th St., Charlestown, MA 02129, United States

ARTICLE INFO

Article history:
Received 2 September 2013
Accepted 17 December 2013
Available online 2 January 2014

Keywords:
Autonomic nervous system
Emotion
Psychological construction
Situational response specificity
Individual response specificity
Psychophysiology

ABSTRACT

The consistency and specificity of autonomic nervous system (ANS) responses during emotional episodes remains a topic of debate with relevance for emotional concordance. We present a recent model of how mental states are constructed, the Conceptual Act Theory (CAT), and then review findings from existing meta-analyses and a qualitative review along with studies using pattern classification of multivariate ANS patterns to determine if there is across-study evidence for consistency and specificity of ANS responses during emotional episodes. We conclude that there is thus far minimal evidence for ANS response consistency and specificity across studies. We then review the current understanding of the functional and anatomical features of ANS including its efferent and afferent connections with the central nervous system, which suggests the need to reformulate how we conceptualize ANS response consistency and specificity. We conclude by showing how this reformulation is consistent with the CAT, and how the model suggests when we would and would not expect to see consistency and specificity in ANS responses, and concordance more generally, during emotional episodes.

> "Were we to go through the whole list of emotions which have been named by men, and study their organic manifestations, we should but ring the changes on the elements which these three typical cases involve. . . . We should, moreover, find that our descriptions had no absolute truth; that they only applied to the average man; that every one of us, almost, has some personal idiosyncrasy of expression, laughing or sobbing differently from his neighbor, or reddening or growing pale where others do not." (James, 1890, pp. 447–448)

> "The fact is that there are changeable expressions of grief. . . and the shrunken, cold, and pale condition which Lange describes so well is more characteristic of a severe settled sorrow than of an acute mental pain. Properly we have two distinct emotions here, both prompted by the same object, it is true, but affecting different persons, or the same person at different times, and feeling (italics in the original) quite differently whilst they last, as anyone's consciousness will testify. (James, 1890, p. 444)

> "Surely there is no definite affection of 'anger' in an 'entitative' sense" (James, 1894/1994, p. 206)

Even before William James made popular the idea that peripheral physiological changes were a crucial feature of emotional states, scholars and poets had often remarked that feelings were inextricably entwined with bodily states. These ideas have been a part of the Western cultural or folk psychology since the time of Plato (for a more recent history, see Gendron & Barrett, 2009) and provide a compelling narrative that has stymied repeated attempts to develop a non-entitative model of emotion. What has been relatively ignored by the folk psychological view, but highlighted by the quotes from William James above, is the importance of *individual* and *situational* differences even in the physiological manifestations of emotional and affective experiences. All modern emotion theoretical views posit a role for variation in bodily responses during emotions, but the nature of that variability remains debated. At one end of the continuum, adaptationist ("basic" emotion) theories and some appraisal theories propose that instances of the same emotion category either share a pattern of bodily changes

---

[*] Corresponding author at: Department of Psychology, 125 NI, Northeastern University, Boston, MA 02115, United States. Tel.: +1 617 373 3794; fax: +1 617 373 8714.
E-mail addresses: k.quigley@neu.edu, karen.quigley@va.gov (K.S. Quigley).

0301-0511/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.biopsycho.2013.12.013

in common (so variability is error) or there is systematic variation around a modal bodily response (Ekman & Cordaro, 2011; Panksepp, 1998; Roseman, 2011; Tracy & Randles, 2011). At the other end of the continuum, psychological construction theories propose that each emotion category is populated with a set of variable instances, where the variation is meaningfully tied to the situation (Barrett et al., in press; Barrett & Bliss-Moreau, 2009). Views of emotional concordance across physiological, cognitive and behavioral emotional response patterns vary across these theoretical frameworks (Gendron & Barrett, 2009; Gross & Barrett, 2011). Although responses in multiple physiological measurement channels might be coordinated within an instance (e.g., a heart rate increase coupled with a systolic blood pressure increase), we consider here whether this coordinated physiological response pattern is consistent across instances within the same emotion category, and whether it is specific to that category. A similar comparative review of the literature could instead consider concordance among physiological, cognitive and behavioral emotional response patterns. We have focused here, however, on studies assessing concordance between physiological response patterns and the subjective labels used to define emotion categories. Specifically, we will consider the strength of the evidentiary base for concluding (or not) that there is sufficient consistency and specificity of autonomic changes during specific emotional episodes. Here we will take as strong evidence of consistency when induction of a specific emotion category instance results in a directionally consistent change in an outcome measure such as blood pressure, or in a pattern of measures, across multiple studies. We will take as strong evidence of specificity when a given emotion induction results in a consistent outcome that is also distinct from that evoked by another discrete emotion (i.e., both consistent and unique). Considering both space limitations and the goals of this Special Issue, we will focus on the consistency and specificity of autonomic nervous system (ANS) responses during emotional and affective states, and then discuss how ANS consistency and specificity relates to emotional response concordance more generally.

We begin by providing a brief outline (with section headings) of a recent theoretical approach, the Conceptual Act Theory (CAT), that takes variation and individual differences in ANS responses as phenomena to be explained by an emotion theory (*Conceptual Act Theory: When should we expect consistency and specificity?*). Using this new framework, we propose it might be possible to see consistency and specificity under certain circumstances, not because the physiological change is driven by a basic biological program as suggested by some basic emotion theories, but as a result of situated or embodied concepts that will be particularly likely to be activated in specific contexts or situations. This theory, guided by current understanding of both central and peripheral neuroscience, provides a theoretical framework for proposing hypotheses about when we would expect to see greater consistency and specificity of ANS responses in emotional episodes, and when we should see less. We then briefly review prior cross-study assessments (three meta-analyses and a qualitative review) of the ANS correlates of emotion (*Review of prior cross-study assessments of ANS consistency and specificity).* We next review studies that have used a multivariate modeling approach to look for consistent and/or specific physiological response patterning for different emotion or affective states (*Multivariate assessments of ANS consistency and specificity*). We then provide an overview of some psychophysiological principles that must be considered in future studies designed to assess consistent and specific ANS effects of emotion inductions (*ANS and CNS system features: Impact on consistency and specificity*). In the closing section (*Conceptual Act Theory: Hypotheses on Individual variation, contextual variation and temporal variation*), we return to the CAT, and suggest how it can be applied to understanding emotional response concordance in the context of individual, contextual and temporal variations in emotion responses.

1. The Conceptual Act Theory (CAT): When should we expect ANS consistency and specificity?

Psychological construction approaches to emotion explicitly account for and predict the variability in autonomic nervous system (ANS) responses during instances of the same emotion category (rather than explaining them as error or as systematic variation around a modal pattern). Psychological construction relies on the kind of population thinking that is popular in scientific accounts of the biological world where categories (such as species) have fuzzy boundaries. Emotions are not physical (morphological) types, but are cognitive categories that contain a variety of unique instances. The Conceptual Act Theory (CAT; Barrett, 2006, 2011a,b, 2013; Barrett & Satpute, 2013; Barrett, Wilson-Mendenhall, & Barsalou, in press; Lindquist & Barrett, 2012) is an example of this approach, where mental states like emotions are constructed moment to moment using basic processes (or ingredients) that integrate and make sense of sensory information from the world and from the body using stored representations from the past. In this model, instances within an emotion category vary in their physiological nature, because individual emotional episodes are tailored to the requirements of the immediate situation. Changes in peripheral physiological state (including the ANS, but also endocrine, immune, metabolic, proprioceptive, kinesthetic and other peripheral changes, which we will collectively refer to as the somatovisceral state), are combined with sensory information transduced via exteroceptive sense organs and with stored conceptual representations (organized as category knowledge) to instantiate a current mental state, thereby producing a “situated conceptualization” (Barsalou, 2005, 2009). This situated conceptualization is a prediction of how a person should prepare to act during a given emotion in a given context. The hypothesis is that situation-specific, embodied conceptual knowledge is applied to initial affective predictions (Barrett & Bar, 2009) during the act of categorization (Barrett, 2006). These affective predictions both impact a person’s expectations of what is to come, and also can shift the person’s somatovisceral state such that subsequent afferent traffic from the periphery is changed. Because of the brain’s heterarchical arrangement, afferent feedback from the periphery quickly leads to new predictions, and further updating of the situated conceptualization. Situated conceptualizing is instantaneous, ongoing, obligatory, and automatic, meaning that a person will rarely have a sense of agency, effort or control in constructing an emotion. It rarely happens because of a deliberate, conscious goal to figure something out. It is via the process of conceptualizing or the conceptual act, that physiological changes acquire functions (i.e., meaning) that they do not have on their own (i.e., without conceptualization). Thus physiological changes play a role in the conceptual act; they are like a biasing function, with particular physiological changes more likely to be conceptualized as one emotion or another depending on both the nature of the physiological change and the specific situated conceptualization used. The situated conceptualization is the process by which concordance across physiological, cognitive and behavioral action occurs in a given instance, although the pattern is not necessarily the same for each instance of a single emotion category. Thus, a pattern of concordant emotional responses will occur when a particular situated conceptualization is generated, and a similar pattern will be generated when a very similar situated conceptualization is generated in the future, although a given emotion category can be represented as a variety of different situated conceptualizations, depending on the demands of the situation.

We hypothesize that any conceptual act is embodied, because prior experience, in the form of category knowledge, comes "on-line" with the activation of sensory and motor neurons, and *reaches down* to influence bodily changes and/or their representation and sensory processing. Conceptual acts are also self-perpetuating, such that experiences created today *reach forward* to shape the trajectory of future experiences. In this way, all mental states are embodied *conceptualizations* of internal bodily sensations and incoming sensory input. Thus, the act of seeing, or feeling, or thinking is at once a perception, a cognition, and an emotion. These conceptualizations are *situated* in that they use highly context-dependent representations that are tailored to the immediate situation. Thus, variation in patterns of somatovisceral responses occur across situated conceptualizations for a given emotion category for three reasons: (1) different actions are called for in different situations in which an emotion episode is constructed; (2) the somatovisceral features of an episode can change after the initial affective prediction is modified by its conceptualization; and (3) conceptual knowledge within a category is, itself, a population of multiple unique instances. The conceptualization of somatovisceral and other sensory changes does not happen in a step-like fashion, but is simultaneously occurring with ongoing somatovisceral efferent changes. Therefore, variation is hypothesized to occur both within and between instances of the same emotion category.

The variation observed within an emotion category is inherent to the way that category knowledge is learned and applied during emotion construction. Initially, when encoding a category instance of emotion, say anger, for example, we hypothesize that the brain captures the elements of the setting in which the anger occurs (i.e., other agents and objects), internal sensory (i.e., somatovisceral) cues from the body, as well as actions or instructions from others (e.g., in the form of rules) and words (e.g., the phonological form for "anger" or "angry"). Over time, these situated conceptualizations create a heterogeneous population of information that is available to represent new instances of the category "anger". Later, when the brain utilizes existing conceptual knowledge to construct an instance of emotion, it samples from the population of different but related situated conceptualizations associated with relevant concepts to create a new situated conceptualization, which integrates current sensory input and retrieved conceptual knowledge. From this perspective, conceptual processing is akin to scene perception because the brain creates a conceptual state using multimodal information about entire situations. For example, when another driver cuts off you off in traffic, you might shout as you slam on the brakes, or gesture to the other driver. When your child picks up a sharp knife, you might take it from her, or calmly ask her to put it down. When you hear a news report about a bombing or hurricane, you might turn up the radio or turn it off. When a colleague criticizes you in front of a group, you might sit very still and even nod your head and smile, or you might look away. During these instances, your blood pressure might go up, or down, or stay the same–whatever best allows you to prepare for the situated action. Sometimes you will feel your heart beating in your chest, and other times you will not. Your hands might become clammy or they might stay dry. Sometimes your eyes will widen, other times your brow will furrow, or you may even smile. What you feel and do depends upon the situated conceptualization.[1]

In the CAT, unlike in some adaptationist emotion views (e.g., Ekman & Cordaro, 2011; Panksepp, 1998; Roseman, 2011; Tracy & Randles, 2011), there is no physical response that is inherited or hardwired in the brain for any specific emotion category. Rather, due to shared cultural concepts and specific personal histories, distinct configurations of somatovisceral changes occur in particular contexts. The CAT predicts that there will be ANS variation across instances within an emotion category and similarities in instances across categories. The model predicts, for example, that an individual will be most likely to activate a specific embodied, situated instance of a particular emotion when a particular pattern of ANS changes (and the broader somatovisceral pattern) co-occurs within a distinctive and frequently encountered context. For example, if you commute alone by car every day in a big city, you may feel anger at a driver who cuts you off, and the emotional response may occur relatively frequently and be relatively similar in this commonly encountered and distinctive context. The response may even become habitual due to the enhanced accessibility of the situated conceptualization. Distinctive, commonly encountered contexts like this are more likely to result in a specific pattern of physiological, cognitive and behavioral responses. When the context changes (your child is in the car with you, or the other driver's actions were life-threatening, not merely annoying), you instead access a different situated conceptualization. Even a physiological or behavioral pattern that is relatively specific and consistent in a particular context for a given individual can be much less so for another individual in the same context, depending on the prior learning history. Similarly, groups of people who share more similar conceptual systems for specific emotion categories also will be more likely to have similar (i.e., consistent and specific) ANS response patterns. This will result in what appears as situational response specificity, or situation-specific autonomic response patterning (Engel, 1960; Engel & Moos, 1967), but this will only occur under some circumstances, not all. For example, we predict that for many Americans, a large increase in TPR and a modest increase in heart rate in the context of having an important goal blocked is especially likely to lead to activating one among several possible situated conceptualizations of "anger." For those from a different cultural or subcultural group with different life histories and cultural norms, we predict that there will be a different (although possibly overlapping) set of typical situated conceptualizations from which those individuals will draw when they experience a goal being blocked, depending on the behavior that they are most likely to execute. Repeated exposure to somatovisceral and situational co-occurrences in early life or particular genetic propensities also can produce what can appear as consistency and specificity within an individual for a particular situated emotional instance and pattern of ANS activation. We now turn to a review of the literature on ANS consistency and specificity as an exemplar of possible concordance between a subjective emotion category or situated conceptualization, and physiological emotional responses.

1.1. *Review of prior cross-study assessments of ANS consistency and specificity*

To date, there have been three meta-analyses and one qualitative review of the ANS changes during emotional episodes. The earliest meta-analysis of this literature first appeared in Cacioppo et al. (1997; 16 studies), and was updated in Cacioppo, Berntson, Larsen, Poehlmann, and Ito (2000; 21 studies). In the later meta-analysis, Cacioppo and colleagues assessed specificity for 20 ANS-related variables across five discrete emotions (anger, fear, disgust, sadness and happiness). Detailed data on ANS response consistency (mostly clearly assessed by determining whether a response to one discrete emotion differs from a control emotion or baseline) were only reported in the smaller 1997 meta-analysis which showed that anger differed from a control condition on heart rate (HR), diastolic blood pressure (DBP), and systolic blood pressure (SBP); fear differed from control on HR, SBP, the number

---

[1] Empirical testing of the CAT requires new statistical methods and experimental designs which are still being developed. For statistical methodologies and the philosophy underlying emergent phenomena as proposed in the CAT, see (Barrett, 2000, 2011a; Coan, 2010).

Table 1
Meta-analytic/qualitative review summaries for specificity outcomes.

	Anger	Fear	Happiness	Sadness	Disgust
Cacioppo et al. (2000)	>↑ in HR rel. to disgust and happy; <↑ in HR rel. to fear	>↑ in HR rel. to anger, disgust, happy and sad	<↑ in HR rel. to anger	>↑ in HR rel. to disgust	<↑ in HR rel. to anger, fear and sad; HR not diff. from control
	>↑ in DBP rel. to fear, happy, and sad	<↑ in DBP rel. to anger	<↑ in DBP rel. to anger and sad	<↑ in DBP rel. to anger; >↑ in DBP rel. to happy	
	>NNSCRs rel. to fear	>NNSCRs rel. to sad		<NNSCRs rel. to fear	
		<↑SCL rel. to sad	<↑SCL rel. to disgust	>↑SCL rel. to fear	>↑SCL rel. to happy
	>↑ TPR and finger PVA and <↑ in CO and SV rel. to fear	<↑ TPR and finger PVA and >↑ in CO and SV rel. to anger			
	>↑ in face temp rel. to fear	<↑ in face temp rel. to anger			
Stemmler (2004)[a]	>↑ in DBP rel. to fear	<↑ in DBP rel. to anger			
	>↑ in TPR rel. to fear	<↑ in TPR rel. to anger			
	<↑ in CO rel. to fear	>↑ in CO rel. to anger			
	>↑ in facial temp rel. to fear	<↑ in facial temp rel. to anger			
	<↑ in resp. rate rel. to fear[b]	>↑ in resp. rate rel. to anger[b]			
Kreibig (2010)[c]	↑ in HR	↓ in HR (IT)	↑ in HR	↓ in HR (NC)	↓ in HR (MT)
		↑ in HR		↓ in HR (NC)	↓ in HR (MT)
				↑ in HR (CR)	↓ in HR (MT)
	↓ in HRV	↓ in HRV	↓ in HRV	↓ in HRV (NC)	↑ in HRV (CT)
	↑ NNSCR	↑ NNSCR	↑ NNSCR	↓NNSCR(NC)	↑ NNSCR (CT and MT)
	↑ in SCL	↓ in SCL (IT)		↓ in SCL (NC)	↑ in SCL (CT and MT)
		↑ in SCL		↓ in SCL (NC)	
	↑ in TPR	↓ in TPR		↑ in TPR (ANT)	↑ in TPR (CT)
	↓ in FPTT	↓ in FPTT	↑ in FPTT		
		↓ in EPTT	↑ in EPTT		
	↓ in face temp	↓ in face temp	↑ in face temp	↓ in face temp (CR and NC)	
		↓ in Expir. Time	↓ in Expir. Time		↑ in Expir. Time (CT)
				↑ in Tidal Volume (NC)	↓ in Tidal Volume (CT)

Notes. Variables are usually reported as change from a neutral control or from baseline. >↑ = greater increase; <↑ = smaller increase; ># = greater number; <# = fewer. We report here on the most commonly reported ANS measures for clarity.

[a] Stemmler (2004) compared only anger and fear; and for this meta-analysis we report only those effect sizes in which the weighted mean effect size was significant.

[b] In Stemmler, 2004, respiration rate was the only outcome measure for which the heterogeneity in effect sizes across studies was NOT significant.

[c] The Kreibig review did not compare specific emotions to one another, but rather proposed a modal ANS response pattern for each emotion. Thus, we can distinguish here only emotions for which the physiological responses across two emotions had a modally different direction of change (see Kreibig's Table 2); we included here only cases where the modal response direction was observed in a minimum of 3 studies. For heart rate (HR), multiple rows are shown to distinguish responses that differentiated emotion subforms (per Kreibig), and comparisons are made within a row. Emotion subforms are indicated by the codes in parentheses as follows: for fear, (IT) = imminent threat vs. typical fear (no abbreviation); for sadness, (CR) = crying or (NC) = non-crying or (ANT) = anticipatory; for disgust, = (CT) = contamination or (MT) = mutilation.

Physiological abbreviations used in the table: CO = cardiac output; DBP = diastolic blood pressure; EPTT = ear pulse transit time; Expir. Time = respiratory expiration time; facial temp = facial temperature; finger PVA = finger pulse volume amplitude; FPTT = finger pulse transit time; HR = heart rate; HRV = heart rate (or heart period) variability; NNSCR = number of non-specific skin conductance responses; SCL = skin conductance level; SV = stroke volume; TPR = total peripheral resistance.

of non-specific skin conductance responses (NNSCRs), skin conductance level (SCL), and face temperature; sadness differed from control on HR, DBP, SBP, NNSCRs, and finger pulse volume amplitude (finger PVA), and happiness differed from control on DBP, SBP, NNSCRs and SCL. ANS responses did not differentiate disgust from control. From the 2000 meta-analysis, there were only a small number of physiological dependent variables for which there was specificity for one versus another emotion induction. Notably, they observed greater increases in diastolic blood pressure in anger relative to fear, happiness, and sadness (for details, see Table 1 above). Further, across multiple variables, anger and fear were most reliably distinguished, differing on HR, DBP, NNSCRs, total peripheral resistance (TPR), finger PVA, cardiac output (CO), stroke volume (SV) and face temperature. The authors also noted high heterogeneity across their meta-analytic findings raising concern about the reliability of the findings across studies perhaps due to features of particular studies, inductions or samples. The authors concluded by suggesting that despite a reasonable number of studies for some physiological variables, there was relatively little emotion specificity across studies and emotions and that more studies were needed to provide definitive results (Cacioppo et al., 2000). Further, the authors conducted a moderated meta-analysis suggesting greater specificity for positive and negative emotion states, although the potential differential effects of arousal across these negative and positive emotions was not addressed, and happiness was the only positive emotion comparison available. Further, the authors acknowledged that the meta-analysis was limited by the small literature available, and by having effect size estimates only for univariate, not multivariate patterns.

Several years later, Stemmler (2004) assessed consistency and specificity in a meta-analysis of 15 studies (8 of which also appeared in the Cacioppo et al., 2000 meta-analysis) that focused specifically on whether physiological patterns were distinguishable during instances of anger and fear (both high arousal negative emotions for which there was data from a relatively large number of studies). This meta-analysis examined consistency across 11 autonomic variables by comparing both fear and anger inductions to control conditions. Stemmler (2004) reported that instances of fear differed from a control condition on 9 of 11 autonomic variables, failing to find significant effect sizes only for skin conductance level and facial temperature. Similarly, instances of anger differed from a control condition on 10 of 11 autonomic variables. There was, however significant heterogeneity in most of these analyses, suggesting that study moderators were impacting the effect sizes. There were too few studies to assess some moderators, but moderators of the mean effect size were analyzed when at least 10 studies were available, thereby limiting the analyses to measures of DBP, SBP, and HR and induction, between vs. within, and type of control (rest vs. neutral; see Stemmler, 2004, Tables 2.5, 2.6 and 2.7 for details). Moderator analyses suggested that even holding induction type constant or whether the design was between or within-subjects, heterogeneity of the consistency effects continued to be significant across inductions and particularly in within-subjects designs. What cannot be discerned from these data is whether the heterogeneity of the effects derived from directionally inconsistent findings across studies and large variance (such that the mean of the distribution is not an accurate estimate of the distribution), or if there were a few outlier studies. The author's claims for consistency should be assessed in the context of the moderator analyses, and would have been facilitated by being able to examine the distributions of the effect sizes across studies. Despite the heterogeneity, the weighted mean effect sizes suggest that anger and fear inductions generally produced consistent univariate physiological effects relative to a control condition (baseline or a context control).

Stemmler's (2004) analysis provided more modest evidence for autonomic specificity during fear and anger (i.e., a direct comparison of fear versus anger). Five autonomic response variables distinguished fear from anger–diastolic blood pressure (DBP), total peripheral resistance (TPR), cardiac output (CO), facial temperature, and respiration rate (see details in our Table 1), and the weighted mean effect sizes were modest (about .20 for all 5 variables). Like Cacioppo et al. (2000), greater increases in DBP, TPR and facial temperature and smaller increases in CO were observed during anger than during fear. However, a substantial overlap in the studies (>50% of the Stemmler studies also in the Cacioppo et al. (2000) analysis) likely contributed to these similarities. The one variable to significantly differentiate fear and anger and that did not have a heterogeneous effect size was respiratory rate (Stemmler, 2004, Table 2.4) which increased more during fear than anger. Results in the moderator analyses were inconsistent, with the greatest consistency appearing for DBP across three different moderator analyses (see Stemmler (2004), Table 2.5). Thus, there are not simple differences across inductions or experimental designs that can explain all of the heterogeneity. Given the importance of the emotion induction and design moderators in the specificity of the responses observed, Stemmler (2004) concluded the discussion of his meta-analytic results by discussing the importance of non-specific features of physiological responses and the role of the context. His assertion that "Conceivably, a particular context may render an emotional response unspecific that in a different context is specific (p. 61)" is wholly consistent with a situated conceptualization viewpoint. What has not been widely appreciated however, is that "context" goes beyond features of an experiment such as whether the induction is a "real-life" or imagery-based induction. What the CAT suggests is that the entire situated conceptualization matters, and this can differ even with two inductions both conducted using imagery.

Lench, Flores, & Bench (2011) recently conducted a meta-analysis that examined among other variables, physiological outcomes in 109 emotion induction studies. Crucial for our discussion, however, the physiological variables were handled in the meta-analysis in a way that does not permit claims about physiological specificity or consistency. First, effect sizes from studies with physiological outcomes were not reported for each of the physiological variables. Rather, the effect size for each physiological outcome was determined, then combined into an overall physiological effect size for each study, and the overall physiological outcome effect size was reported for each pair of emotion induction categories (e.g., anger vs. anxiety) across studies (see Lench et al., 2011, Table 3). By reporting the physiological outcomes in this way, we cannot assess any potential patterns in the physiological measures. Second, effect sizes for certain variables were not analyzed because they were deemed redundant. For example, the authors noted that no effect size for respiratory sinus arrhythmia (RSA) was calculated when both heart rate and respiration rate were reported. RSA is not, however, a simple mathematical transformation of heart rate or respiration rate, but rather an estimate of the variability in the timing of a sequence of heart beats partly due to changes in respiration. Thus, RSA was incorrectly excluded because it is not mathematically redundant with either heart rate or respiration rate. The authors did not report which other variables were considered redundant and thus not included. Taken together, this meta-analysis does not provide sufficiently detailed physiological outcome effect sizes to assess consistency or specificity of ANS responses during emotion instances (for additional discussion of this meta-analysis, see Lindquist, Siegel, Quigley, & Barrett, 2013).

Finally, Kreibig (2010) compiled a large qualitative review of 134 studies for 35 ANS measures (see Kreibig, 2010, Table 2) that summarized the physiological responses during 16 different emotions. However, this review did not use meta-analysis methodology for combining data across studies. Rather, Kreibig (2010) reported an unweighted "modal" response across papers defined as seeing the same response direction in the majority of papers and where at least 3 papers showed the "model" response. There was, however, no adjustment for study sample size or other quality indicators, and no quantitative definition of "modal" response direction was given (e.g., what difference for a given emotion induction category was considered within error, and thus tabulated as "no change"?). To permit some comparisons of the patterns proposed in the Kreibig (2010) review with the meta-analyses of Cacioppo et al. (2000) and Stemmler (2004), Table 1 depicts only the directionally distinct responses (i.e., increase, decrease, no change) from Kreibig (2010) Table 2 for papers where the same directionally distinct response was observed in a minimum of 3 studies. Thus, we are limited to assessing consistency with the other meta-analyses for cases where the direction of ANS response was qualitatively different. The Kreibig (2010) qualitative review revealed some potential issues not apparent in the meta-analyses. First, with more studies and inductions to consider, Kreibig suggested considering the possibility that there is more than one type of anger, or what Kreibig called different "subforms" of emotions like anger, sadness or disgust. For example, she proposed both a contamination-related disgust and a mutilation-related disgust. Note that this terminology is a departure from the basic emotions approach, and raises the theoretical question of whether these proposed subforms are considered new basic emotions or instead contextually-based variations on ANS patterns of the basic "form". Second, although in some cases a "modal" pattern could be discerned, there was still considerable cross-study variability. The extent of this variability was difficult to assess due to a lack of quantitative comparisons and the fact that there was no consideration of study quality or sample size. Third, this review did not emphasize comparisons between emotions, which means that this review could not definitively answer whether there is a unique and specific ANS response pattern for each emotion. Most crucially though, there are relatively few points of commonality (see our Table 1 for comparisons) across this qualitative review, and the Cacioppo et al. (2000) and Stemmler (2004) meta-analyses. Some differences would be expected. First, the meta-analyses did not distinguish subforms of some emotions as did Kreibig (2010). Second, cardiac impedance, heart rate variability, or respiratory-based measures were relatively uncommon and not included in earlier studies. Even for common measures like heart rate, skin conductance level, number of non-specific skin conductance responses, or diastolic or systolic blood pressure, however, there are few similarities. We could discern two cases of potential similarity across these reviews: (1) an increase in TPR during anger relative to fear and (2) an increase in the number of non-specific skin conductance (EDA) responses during fear relative to non-crying sadness. Even here there are some inconsistencies. Although all three reviews revealed an increase in TPR during anger relative to fear, the meta-analyses revealed a smaller increase in TPR during fear, whereas Kreibig observed a decrease in

TPR during fear. Further, Kreibig also observed an increase in TPR during both anticipatory sadness and contamination-type disgust. These data suggest that increases in TPR per se are not specific to anger, although lack of specificity with single variables does not preclude a possible specific multivariate pattern. In the case of the increases in non-specific EDA responses during fear relative to non-crying sadness, this finding was noted in Cacioppo et al. (2000) and Kreibig (2010), but not Stemmler (2004). Further, Kreibig also observed an increased number of non-specific EDA responses in anger, again suggesting that the univariate response is not specific. Thus, even for these two possible instances of univariate similarity, multivariate assessments will be required to address the issue of specificity. As a result of her review, Kreibig proposed modal ANS response patterns for each emotion. Despite our concerns about the methods used to qualitatively summarize the literature and the inconsistencies of this review with the meta-analytic findings, Kreibig's proposed patterns can provide testable hypotheses for future efforts to determine whether there are reliable, ANS patterns of response during emotion inductions.

Given the variability in the literature reviewed thus far, it is not possible to conclude that there are replicable, emotion-specific physiological changes across four reviews of the psychophysiological emotion literature. The best characterization of these findings is that the ANS responses during instances of the most commonly assessed emotion categories (i.e., anger, fear, happiness, sadness and disgust) were highly heterogeneous across studies. As is clear from Table 1, however, the evidence for consistency (i.e., that an emotion induction consistently produces a physiological response relative to a control condition) is stronger than that for specificity, echoing Lench et al.'s (2011) observation, but the high heterogeneity tempers this conclusion. Consistent evidence that ANS responses are significantly different from neutral inductions or baseline, however, arises in part, from the fact that an emotion or affect induction that does not produce a significant physiological change from baseline (or relative to a neutral induction) will be viewed as ineffective, and thereafter, less likely to be used. Further, none of the reviews from which we could assess consistency or specificity considered the file drawer problem, namely, how many studies were run, but not reported? Although it may seem minor, including unreported studies is considered one of the most critical features of meta-analyses (Ellis, 2010). A related file drawer concern for meta-analyses of physiological data is the possibility that some study authors may report only those physiological outcomes that resulted in significant changes, potentially contributing to a file drawer problem that will be difficult to quantify. To address this issue, authors need to report all physiological measures recorded in future studies, even those that were non-significant.

1.2. *Multivariate assessments of ANS consistency and specificity*

As noted by the review authors and others, current meta-analysis tools only permits separately assessing individual ANS variables, limiting the ability to understand multivariate patterns which will be critical for addressing consistency and specificity (e.g., Christie & Friedman, 2004; Harrison, Kreibig, & Critchley, 2013; Kragel & Labar, in press; Mauss & Robinson, 2009; Nyklicek, Thayer, & van Doornen, 1997; Stemmler, 2003). Recently, a number of multivariate pattern classification studies have been completed that attempt to address whether multivariate ANS patterns are consistent and specific. The univariate data suggest limited consistency for a small number of emotions (potentially anger vs. fear), but has not (and likely cannot) demonstrate specificity. Existing multivariate pattern classification efforts have instead shown specificity, but have not shown consistent multivariate patterns across studies or in the one multi-induction study using pattern classification, not provided strong evidence of consistency.

In one of the earliest pattern classification studies, Nyklicek et al. (1997) categorized self-report and physiological responses during happy, sad, serene or agitated music and to a white noise control condition. The authors used a multivariate discriminant function pattern classification approach to reveal three discriminant functions. Specifically, happy, sad, serene and agitated were correctly classified in 57.7, 44.9, 42.3 and 41.0% of the cases (chance = 25%; overall hit rate = 46.5%). The largest discriminant function accounted for 62.5% of the explained variance and distinguished emotions that varied in subjective arousal. The ANS variables that loaded most on this arousal function were respiratory variables (respiratory rate, expiratory time, inspiratory time), heart period, and RSA. Later work indicated a potential alternative explanation for these respiratory and RSA findings, namely, music tempo can entrain rhythmic physiological patterns (like respiration and the respiration-related variable, RSA) because some individuals begin to breathe in rhythm to the music (e.g., Etzel, Johnsen, Dickerson, Tranel, & Adolphs, 2006; Haas, Distenfeld, & Axen, 1986) especially when longer, and more strongly rhythmic musical excerpts are used (cf. Khalfa, Roy, Rainville, Dalla Bella, & Peretz, 2008 with short musical excerpts). If rhythmic entrainment can account for the most discriminating feature of the multivariate patterns in this study, then it is not clear that an affective or emotional explanation is needed. A second discriminant function, accounting for 27.5% of the explained variance, was not easily explained and was not considered further. A third discriminant function, accounting for 10% of the explained variance distinguished emotions that varied in valence. ANS variables that loaded most on this valence function were heart period, left ventricular ejection time (LVET), and DBP. Again, the possibility that tempo entrainment could be a powerful source of variance in these results has to be considered (even for heart period and LVET).

Following on Nyklicek et al. (1997), but using evocative films rather than music, and a similar discriminant function pattern classification approach, Christie and Friedman (2004) again revealed three primary discriminant functions that distinguished patterns of ANS responses elicited by one film clip each for amusement, anger, contentment, fear, and sad discrete emotion instances. Neutral and disgust films were classified above chance (17.6% and 20.6% correct classification, respectively; chance = 14.3%), but also were misclassified as contentment and anger, respectively (see Christie & Friedman, Table 1), and thus these emotions were not included in the discriminant function analyses. Amusement was correctly classified in 32.4% of cases, anger in 38.2%, contentment in 61.8%, fear in 52.9%, and sad in 38.2%. In addition, two cases had particularly high error rates, namely neutral was incorrectly classified as contentment 38.2% of the time, and sadness was incorrectly classified as contentment 32.4% of the time. The largest discriminant function accounted for 58.3% of the variance and distinguished emotions that that varied in subjective arousal. This interpretation was bolstered by large factor loadings for mean skin conductance level (over the entire film period) that were positively related to activation, and mean successive differences in beat to beat heart period (MSD; an estimate of overall heart period variability) that were negatively related to arousal. Both of these outcomes would be expected for films that resulted in sympathetic activation and/or parasympathetic withdrawal responses with increased subjective arousal. Again, however, the possibility that tempo entrainment could be a powerful source of variance in these results has to be considered. In the future, these effects can be mitigated by using less rhythmic music, and using music that does not have strong rhythmicities at frequencies that are common in the natural variations of the heartbeat (e.g., centered around 0.1 Hz or in the respiratory frequency range of 0.12–0.4 Hz). A second discriminant function, accounting for 26.4% of the explained variance, was not interpretable and was not considered further. A third discriminant function, accounting for 14.4% of the explained variance, distinguished emotions that varied along an approach-avoidance dimension.[2] ANS variables that loaded most on this approach–withdrawal function were heart period, skin conductance level, mean arterial pressure (MAP) and DBP. Thus, although both Nyklicek et al. (1997) and Christie and Friedman (2004) both derived two primary (interpretable) discriminant functions, the interpretation of the first function as reflecting arousal, was the same for both studies, whereas the third function was interpreted as related to valence by Nyklicek et al. (1997) but related to approach-avoidance by Christie and Friedman (2004). Only a few similarities in ANS response pattern were observed, namely, in a heart rate variability measure related to arousal (RSA in Nyklicek et al., 1997; MSD in Christie & Friedman, 2004). Nyklicek et al. (1997) did not measure skin conductance, the other arousal-related measure in Christie and Friedman (2004) and Christie and Friedman (2004) did not measure respiratory variables as in Nyklicek et al. (1997). DBP was associated with the third discriminant function in both studies, although the interpretation of this function differed across the studies. Finally, heart period, measured in both studies, loaded highly on the arousal function in Nyklicek et al. (1997), but loaded highly on the third discriminant function in Christie and Friedman (2004). All told, the most consistent finding was that heart rate variability was associated with the arousal function.[3]

In a third multivariate study, Rainville, Bechara, Naqvi, and Damasio (2006) assessed ANS specificity during well-remembered and intense recollection/relived imagery for experiences of anger, fear, happiness, and sadness using cardiorespiratory variables (i.e., respiration, heart period, and heart period variability). The investigators used an exploratory principal components analysis to extract five factors (accounting for 34%, 21%, 17%, 11% and 8% of the variance, respectively) followed by a series of stepwise discriminant analyses to categorize the recorded ANS patterns into one of the four emotion categories. Factor 4 did not discriminate among the four emotion instances and was not used in the subsequent discriminant analysis. Anger was correctly classified in 61.5% of cases, fear in 72.7%, happiness in 63.6%, and sadness in 64.3% of cases.[4] Variables that loaded most heavily on Factor 1 were short-term heart rate variability measures including the peak-valley RSA, for Factor 2 were mean respiratory rate, median respiratory amplitude and peak-valley RSA, for Factor 3 were two variables related to heart period, and for Factor 5 were the standard deviation of respiratory rate and the standard deviation of respiratory amplitude. Thus, there was little comparability of the factor structure here with that reported by Nyklicek et al. (1997), or Christie and Friedman (2004). Here, for example, happy and sad experiences were differentiated by respiratory variables, although not the same variables as in the prior work. Given the considerable differences in the physiological variables chosen across studies, and the different emotions and inductions assessed, it is not possible to discern consistent cross-study ANS patterns that appear to distinguish emotion categories.

A critical limitation of the preceding multivariate studies is that although they assessed multivariate patterns across categories of emotion inductions (anger, sad, etc.), a single induction type cannot be used to assess whether the *same* emotion category, induced in a different way, produces the *same* multivariate pattern. Demonstrating consistency across two different inductions of the same emotion category would strengthen the inference that a multivariate ANS pattern was not idiosyncratic to a particular induction procedure, and instead more likely due to one versus another emotion. As we will see, however, two recent studies each assessed more than one induction type across a large number of emotion instances (Kragel & Labar, in press; Stephens, Christie, & Friedman, 2010), and still the issue of consistency cannot be settled.[5]

Stephens et al. (2010) used music and film clips designed to elicit two inductions each of amusement, anger, contentment, fear, sadness, surprise and a neutral (control) emotional state[6] and measured the electrocardiogram (e.g., heart period, RSA), impedance cardiogram (pre-ejection period or PEP, LVET, stroke volume, cardiac output, total peripheral resistance), vascular measures (SBP, DBP, MAP), respiration (respiratory rate, inspiratory time, expiratory time), and skin conductance level over the final 60 s of each clip. Stephens et al. (2010) used pattern classification analysis followed by cluster analysis to categorize ANS patterns for each emotion category. Using the ANS response data for music and film inductions, respectively, amusement was correctly classified in 32.7 and 46.9% of cases, anger in 49.0 and 28.6%, contentment in 36.7 and 51.0%, fear in 32.7 and 22.4%, neutral 44.9 and 38.8%, sadness 34.7 and 34.7%, and surprise in 32.7 and 59.2% of cases (chance = 14.3%). Only univariate physiological data, aggregated across the two inductions were reported, thus making it impossible to discern the multivariate ANS patterns associated with each emotion state. From the depicted univariate data (Stephens et al., 2010, Fig. 1), the mean change scores for most of the dependent variables do not differentiate between emotion categories at the univariate level. Exceptions include: (1) heart period (IBI in their Fig. 1), which lengthened less in contentment and sadness than for other emotion instances, (2) respiratory rate, which decreased in surprise relative to other emotions, and (3) skin conductance level, which was below the baseline level for contentment and sadness, but increased for amusement, fear and neutral instances. These findings show little concordance with the findings in the earlier univariate studies, or with the multivariate studies just reviewed.

In a similar vein, Kragel & LaBar (in press) used a pattern classification approach, here a support vector machine algorithm, with a randomly chosen half of the participants' data used to train the algorithm, and half to test it (with this process repeated 100 times). These investigators used both music and film inductions (most of them identical to those of Nyklicek et al., 1997, and Christie & Friedman, 2004, respectively) of fear, anger, sadness, surprise, contentment, amusement, and a neutral condition within-participants (two clips for each of the seven emotion conditions), and recorded cardiac, respiratory, heart rate variability and gastrointestinal ANS measures.[7] ANS pattern classifiers exceeded chance levels (overall accuracy 58.0%; chance = 14.3%; hit rates for correctly predicting each of the seven emotion instances about 20–25% from Kragel &

---

[2] A fourth, uninterpretable dimension accounted for <1% of the variance.

[3] We also note that both of these studies found that discriminant functions were better able to predict emotion categories using self-reports than ANS outcomes. The meta-analysis of Lench et al. (2011) similarly reported better discriminability of emotion categories from self-reports than from broad physiological outcomes.

[4] Some participants completed more than one emotion induction, but data were treated as between subjects comparisons. Moreover, data on correct classification rates for each emotion were calculated for only 13/15 anger, 11/15 fear, 11/15 happiness and 14/17 sadness inductions. It is not clear why data on the remaining 13 inductions (2 anger, 4 fear, 4 happiness and 3 sadness) were not included in the discriminant analysis.

[5] Other prior studies used similar approaches to distinguish between just two emotions and a neutral condition (Kolodyazhniy, Kreibig, Gross, Roth, & Wilhelm, 2011; Kreibig, Wilhelm, Roth, & Gross, 2007; Sinha, 1996) or to distinguish between a small number of laboratory-induced stressor states (Allen, Boquet, & Shelley, 1991).

[6] Stephens et al. (2010) used primarily music and film clips from Nyklicek et al. (1997) and Christie and Friedman (2004).

[7] Several of the ANS variables used in Kragel & Labar (in press) reflect phenomena that change on a relatively slow time scale, including normogastria at a typical 3 cycles/min, and both low (0.04–0.15 cycles/s) and very low (0–0.04 cycles/s) frequency heart period variability. For these variables, the short epochs used (i.e., 124 seconds) are likely to result in low reliability estimates since the number of cycles sampled will be few.

LaBar's, in press, Fig. 3). Again, however, the power of using multiple inductions was not fully brought to bear on the classification process. Rather than determining the physiologically-based classifier on one induction and assessing its goodness of fit to the other induction (or using one replicate to train the algorithm and the other to test it), all data from each participant were used either for training ($N = 10$) or testing ($N = 10$). Thus, inductions were never pitted directly against one another. Although the authors report that "post-hoc tests comparing the accuracy of classification on instances of film versus music induction did not reveal a significant difference ($z = 0.89$, $p = .374$), indicating that emotion specific patterns did not vary significantly as a function of induction method," this logic is flawed because the classifiers were not determined separately for the two inductions. This test reveals only that agreement with predefined emotion categories was not different across the induction instances. Moreover, several design choices, namely, a small sample ($N = 20$) and relatively short inductions (approx. 124 sec each) together with no direct cross-induction assessment of ANS patterns suggests that these classifiers still require further testing, specifically across inductions, and in a new set of participants (i.e., a cross-validation sample).

Despite several ever-improving attempts at multivariate ANS pattern classification for discrete emotion categories, the question of whether there are consistent and specific multivariate ANS patterns remains unanswered. Moreover, none of the authors of these multivariate studies provided the equations for their discriminant functions, which would permit a specification of the multivariate ANS pattern and facilitate comparisons across studies.

Another multivariate technique, profile analysis, has also been used to examine whether there are consistent and specific multivariate emotion profiles (Stemmler, 1988, 1989, 2003; Stemmler, Aue, & Wacker, 2007; Stemmler, Heldmann, Pauls, & Scherer, 2001). Specifically, Stemmler and colleagues have used multistage discriminant analysis to identify profile levels (the average intensity of an autonomic change), profile scatter (differences in response magnitude across multiple ANS variables) and profile shape (the overall configuration or pattern of ANS changes). Advantages of this technique are that it can both determine statistical differences across all three profile features, and identify the multivariate patterns that have thus far usually remained unidentified in multivariate pattern classification studies. A disadvantage of the profiles strategy is that the graphical representations of the profiles (either depicted as standard scores for all ANS variables or as profile plots; (e.g., Stemmler, 2003) can be complex to interpret in the context of multiple emotions. As a result, this technique has been predominantly used in comparing a small number of emotion categories, most commonly anger vs. fear. For this pair of emotion concepts, Stemmler et al. (2007) reported a cross-study correlation of 0.53 between the effect sizes of the physiological profile responses to anger and fear in Stemmler et al. (2001, 2007) using different induction contexts across the two studies. These data suggest an important role for context since physiological response profiles in one study only accounted for 28% of the variance in the physiological response profiles of the other study despite being conducted within the same lab, and thereby minimizing methodological variance. Using these multivariate strategies, Stemmler and colleagues have rejected the claim of absolute ANS specificity for anger vs. fear (Stemmler, 1989; Stemmler et al., 2001, 2007), and it remains to be determined whether some more constrained specificity (e.g., specificity within contexts, but not necessarily across contexts as proposed by Stemmler, 1992) is still to be found. Multivariate approaches will likely be critical in this determination.

The meta-analytic and qualitative reviews, and the multivariate evidence described above reveal considerable variation in ANS responses for a given emotion category across studies (where ANS patterns can be discerned). Low concordance of ANS response patterns for a given emotion category across studies could arise, at least in part, from constraints inherent to ANS measures which can limit our inferences, and we now turn to describing several of these features.

1.3. ANS and CNS system features: Impact on consistency and specificity

It has been observed in many studies that there is greater variability in ANS response specificity across emotion categories than in self-reported experience during episodes of the same emotion category (when defined by experimenters' a priori classification of stimuli; Christie & Friedman, 2004; Kragel & Labar, in press; Lench et al., 2011; Nyklicek et al., 1997; Stephens et al., 2010). We outline three basic features of the ANS and CNS that will contribute to this greater variability and thus provide important boundary conditions on when it will be possible to see consistency and/or specificity of ANS responses for instances of an emotion category (e.g., like 'fear', 'anger' or 'happiness'). These include: (1) The Laws of Autonomic Constraint (Berntson, Cacioppo, & Quigley, 1991; Berntson, Cacioppo, & Quigley, 1993; Berntson, Cacioppo, Quigley, & Fabro, 1994), (2) the interplay of afferent and efferent ANS traffic to and from the CNS that modulates physiological and behavioral adaptations as emotions unfold over time, and (3) situational response specificity (SRS) and individual response specificity (IRS). SRS refers to the idea that specific situations (or experimental paradigms) tend to result in similar ANS responses across individuals, whereas IRS refers to the idea that individuals can have specific but idiographic patterns of ANS response to emotional episodes or other psychological events.

The Laws of Autonomic Constraint. The Laws of Autonomic Constraint (Berntson et al., 1991; Berntson, Cacioppo, & Quigley, 1993; Berntson, Cacioppo, Quigley, et al., 1994) describe limitations on how the viscera innervated by the ANS can alter the extent of possible consistency and specificity of ANS-mediated changes in organ response during emotion inductions. Some organs, like the heart, receive efferent ANS input from the CNS via both sympathetic and parasympathetic autonomic branches (Berntson et al., 1991, 1993; Brading, 1999; Loewy & Spyer, 1990). Although these two branches of the ANS commonly operate in a reciprocal "mode" (i.e., sympathetic activation is accompanied by parasympathetic withdrawal or vice versa), this is by no means the only mode possible. Uncoupled modes (i.e., activation in one branch increases or decreases in the absence of any change in activation of the other) or coactivational modes (activation in both branches increases or decreases simultaneously) are also possible, and these occur more commonly than is generally appreciated (Berntson et al., 1993; Paton, Nalivaiko, Boscan, & Pickering, 2006). One critical implication for our discussion here is that some variables, like heart period[8] that are commonly used to assess the specificity of the ANS responses during an emotion episode are multiply determined by both autonomic branches. As a result, heart period viewed in isolation can obscure systematic and meaningful variance in the changes in the two underlying autonomic inputs because different configurations of sympathetic and parasympathetic input can

---

[8] We use the term heart period here, rather than its inverse, heart rate, which is more commonly reported in the emotion literature because prior work revealed that the relationship between parasympathetic and sympathetic activation is more nearly linearly related to changes in heart period than in heart rate (Berntson et al., 1993; Quigley & Berntson, 1996). Thus, a one unit change in parasympathetic (or sympathetic) activation results in approximately a one unit change in heart period regardless of the basal heart period. The same is not true of heart rate changes which are affected by the baseline heart rate. We advise that especially when comparing groups with very different basal cardiac rates or for inductions that cause large changes in rate, that heart period be used.

lead to the same heart period change (Berntson et al., 1991). To address this issue, we advise investigators to include measures to estimate the sympathetic and parasympathetic contributions to a heart period change (Berntson, Cacioppo, Binkley et al., 1994; Berntson, Cacioppo, & Quigley, 1994). Moreover, two of the Laws of Autonomic Constraint, the Law of Reactive Lability and the Law of Directional Stability, demonstrate limitations that will impact the consistency of ANS responses to emotion inductions. For example, the Law of Reactive Lability was coined to describe the idea that different modes of control can produce a smaller or larger ANS response even with an equivalent increment or decrement in sympathetic or parasympathetic activation. For example, for an equivalent basal heart period, a reciprocal mode resulting from a one unit increase in sympathetic activation accompanied by a one unit decrease in parasympathetic activation will produce a larger heart period response than an uncoupled mode in which the same one unit increase in sympathetic activation occurs with no change in parasympathetic activity. In turn, this uncoupled response will be larger than that produced by a coactivational mode consisting of a one unit increase in sympathetic activation and a one unit increase in parasympathetic activation (which will cancel one another and produce no change in organ response). So, reactive lability is largest for reciprocal modes, and smallest for coactivational modes, all else being equal.

Another ANS feature, the Law of Directional Stability, describes how coactivation in particular, can produce directional instability in the cardiac response because the two branches produce opposing effects on the target organ. Depending upon the extent of activation in one branch versus the other, the response direction can differ. For cardiac responses like coactivation characterized by directional instability, across-study and across-individual effects of emotion episodes will be highly variable (i.e., less consistent and reliable) than cardiac patterns due to reciprocal activation where both branches are producing a similar effect on the organ response. Kreibig (2010), for example, suggested that coactivation might characterize the cardiac response to a contamination-related, disgust-eliciting stimulus, although this has not yet been shown across more than a couple of studies in which both sympathetic and parasympathetic effects were measured. A coactivational effect on the heart would be consistent, however, with Kreibig's (2010) qualitative review in which the modal cardiac response was either a heart rate increase (i.e., a heart period decrease) or no change in the cardiac response to stimuli evoking an instance of contamination-related disgust. We reinforce the aforementioned advice to measure parasympathetic and sympathetic changes that impact heart period because as these data make clear, the mode of ANS control is not determinable from heart period alone.

A final ANS feature, the Law of Dynamic Range, also illustrates how ANS responses can be constrained because there is a limit on the extent to which each ANS branch can impact organ output, termed the dynamic range. When heart period, for example, is near a physiological limit inherent to the operating characteristics of the ANS effects on the heart, there is a constraint on how much more heart period can change. For example, if parasympathetic activity is relatively low (i.e., near zero as would happen during intense exercise), then heart period will be relatively short (i.e., a fast heart rate), and further parasympathetic withdrawal will be minimized, thereby limiting additional parasympathetically-mediated shortening of heart period (although changes in sympathetic activation may still be able to further reduce the heart period). Thus, the current state of an individual's ANS-regulated physiological systems,[9] and the operating characteristics governing changes in activation of those systems, importantly determine what physiological changes can be observed. Physiological changes associated with emotion episodes will only be measurable and then replicable across studies if the current physiological context permits changes. The decreased heart period sometimes observed during a fear induction, for example, can be small or even non-existent if parasympathetic activation is already near its lower limit such that further parasympathetic withdrawal is not possible. Finally, emotion inductions must be potent enough to take precedence over other concurrent physiological needs. This latter point has been made by several authors (e.g., Harrison et al., 2013; Mauss & Robinson, 2009; Quigley, Lindquist, & Barrett, in press; Stemmler & Wacker, 2010), yet its implications have not sufficiently permeated the experimental methods of affective science. Laboratory paradigms remain frequently tepid, often due to ethical constraints, but likely unrepresentative of the full range of emotions (especially intense ones) as they occur in the real world outside the laboratory. For an excellent treatment of the need to study emotion both inside and outside the laboratory, see Wilhelm and Grossman (2010). Laboratory inductions are most likely to produce ANS responses of small to moderate effect sizes that can be masked by other ANS-mediated bodily changes (e.g., during exercise) or blunted by physiological system limits (e.g., the smaller additional increases in sympathetic activation that are possible in a standing person than one who is supine). For example, investigators can address this issue by determining, where possible, if observed responses could be constrained by occurring too near a boundary (see Berntson et al., 1993; Berntson, Uchino, & Cacioppo, 1994), which includes considering whether medications could be preventing an autonomically-mediated response, whether pathophysiological states are impacting the basal ANS state for some individuals, or whether developmental constraints could be limiting changes in ANS response.

Thus far, we have considered how the Laws of Autonomic Constraint impact ANS-mediated responses. However, there is also notable regional and organ specificity of ANS responses that also impact the extent of possible ANS specificity and consistency. Historically, regional specificity was well documented for parasympathetic effects on the visceral organs, but is now understood to also characterize sympathetic efferent effects on the viscera. This contrasts with a traditional, but incorrect view of the sympathetic nervous system as activating in a unitary or "mass" fashion across all systems of the body (Janig, 2003; Morrison, 2001). Thus, situated stimuli that lead a person to prepare to run can increase blood flow to the lower limbs, but not necessarily to the arms (e.g., Anderson, Wallin, & Mark, 1987), reflecting ANS changes that are exquisitely tuned to overall organism needs. This regional specificity means that we should expect to see variability in the autonomic changes observed with emotion inductions as the body coordinates multiple physiological changes required to best meet current needs. Further, the state of the body prior to the onset of an emotional episode will play a role in the ANS response that is observed during the emotional episode. Because of the operating features described by the Laws of Autonomic Constraint, and the regional specificity of ANS responses that will vary with current physiological needs, there will be practical limits on the extent of possible consistency and specificity of ANS changes during emotional episodes across people and across situations.

Efferent and afferent ANS communication with the CNS. Another operating feature of the nervous system that can create response variability even for emotional episodes from the same emotion category stems from the constant interplay of efferent and afferent neural traffic between the ANS and CNS (see Harrison et al., 2013; Kleckner and Quigley, in press), and how this ongoing afferent and efferent traffic impacts ANS responses during emotion episodes as they unfold over time. The neural networks in which this

---

[9] Because of our focus on the ANS, we leave aside the complementary, interacting, and critically important roles of other physiological regulatory systems like the endocrine and immune systems.

central-going (i.e., afferent) and peripheral-going (i.e., efferent) neural traffic flows occur have been described as having a *heterarchical arrangement* (Berntson, Cacioppo, & Sarter, 2003; Berntson, Sarter, & Cacioppo, 2003). A heterarchical arrangement implies that neural traffic does not have to flow in a stepwise fashion through anatomically nearby networks, but can also flow to and from both nearby and more distant networks, including directly from the forebrain to the hindbrain (i.e., without the need to pass through intermediary networks). In this way, afferents quickly convey information across multiple anatomically distributed networks in the CNS to provide sensory and somatovisceral information about the periphery. Similarly, efferents arising from forebrain networks can directly modify networks across the neuraxis, including direct impact on hindbrain motor or physiological pattern generators or reflexes that support behavioral adaptations like fight and flight. Autonomic efferent signals are generated via CNS circuitry that includes brain regions spanning the neuraxis from cortical networks involving the orbitofrontal cortex and insula to medullary areas like the nucleus tractus solitarius and hypothalamus which receive afferent inputs from peripheral organs, the dorsal motor nucleus of the vagus and nucleus ambiguus which contain the parasympathetic efferent cell bodies, and the ventrolateral medulla which contains the sympathetic efferent cell bodies. Critically, these widely divergent neuroanatomical loci are highly interconnected (Craig, 2002, 2009; Critchley, 2005; Critchley & Harrison, 2013; Harrison et al., 2013; Loewy & Spyer, 1990). A well-known example of direct cortical influence over a hindbrain reflex occurs when psychological stressors dampen the gain of the baroreceptor-heart rate reflex (Steptoe & Sawada, 1989). Under non-stressful conditions, blood pressure increases are sensed by baroreceptors in the aorta and large arteries, and cause reduced heart rate and vasodilation. The reduced heart rate and vasodilation buffer the increase in blood pressure and help return blood pressure to its basal level. However, under distress, the gain or relationship between a given change in blood pressure and the extent of heart rate reduction is blunted. This permits both blood pressure and heart rate to increase simultaneously in support of increased cardiac output that may be needed to support large muscle action. This modulation of a basic physiological reflex illustrates the potency of the heterarchical arrangement of the CNS, and the constant interplay of both afferent and efferent changes in the ANS that permit constant readjustment of the peripheral milieu and of CNS activity. The interplay of afferent and efferent effects is also inherent in the aforementioned data showing that musical tempos can entrain peripheral physiological systems via respiratory changes (Etzel et al., 2006; Haas, Omura, Constable, & Canli, 2007). Respiratory entrainment provides a peripheral physiological mechanism that can impact the physiological change that occurs when music is used to induce an emotional episode. Since both efferent and afferent ANS influences co-occur and together unfold over time during an emotional episode, both must be considered in understanding the ANS changes that occur during emotional episodes (Harrison et al., 2013; Kleckner & Quigley, in press).

Situational response specificity and individual response specificity. Any emotion-specific ANS patterns also will be limited by *situational response specificity* (SRS) and *individual response specificity* (IRS) which describe variation in autonomic responses as a function of either the situation or the individual, respectively. These characteristics of psychophysiological responses were described by early psychophysiologists (Davis, 1957; Engel, 1960; Engel & Bickford, 1961; Engel & Moos, 1967; Lacey, 1967; Lacey & Lacey, 1958) who emphasized that there are two major sources of variation that can lead to similar ANS responses during emotion episodes (or other psychological events; for a brief review of the early history of these concepts, see Friedman, 2010). These constructs are often assessed in different types of studies, with those taking a nomothetic approach assessing SRS, and those taking an idiographic approach assessing IRS. However, these sources of variance in ANS responses are both operating to varying degrees when people experience an instance of an emotion. Psychology has a strong history of using the nomothetic approach, given that a major goal of psychology has been to determine generalizable "laws" of human behaviors, thoughts and feelings. Stemmler (1989), Stemmler et al. (2001) and Stemmler & Wacker (2010) have conducted several notable studies demonstrating the importance of context (i.e., differences across emotion inductions) in ANS patterns, and demonstrated that the situational context can impact the extent of IRS (Marwitz & Stemmler, 1998; Stemmler & Wacker, 2010). Often, however, investigators have been less attentive to the variance attributable to the individual, instead treating this variance as "noise" in nomothetically-oriented analyses. Some of the inconsistency observed in ANS patterns during emotion inductions stems from this idiographic variation, which can be observed both in how evocative the inducing stimuli are for a person and the person's ANS responsivity. Inconsistencies due to IRS are not frequently modeled or accounted for in nomothetically-oriented studies, and in the future they should be, because they are an important source of variation that will appear to reduce any observed specificity and consistency of ANS patterns during emotion inductions. We now return to the CAT theoretical framework and consider how variation across the individual, context and time (and the interaction of the individual within a context) is central to understanding concordance of emotional responses during emotional experience. Using the CAT framework, we will describe how the consistency and specificity of ANS responses during emotional episodes can be affected by these different sources of variation.

2. Conceptual Act Theory: hypotheses on individual variation, contextual variation and temporal variation

The CAT proposes novel hypotheses about ANS consistency and specificity, and demonstrates the need to explicitly model variation in ANS responses during emotional instances that occur (1) across individuals, (2) across contexts, and (3) as an emotional experience unfolds across time.

Individual variation. First, we hypothesize that ANS specificity for a given emotion category will be greatest for individuals who have a more similar population of situated conceptualizations from which they draw when constructing an emotional state in a given situation or induction context. If the prediction for a situated action is the same across instances of the same emotion category, then the ANS pattern also will be more similar. Furthermore, when a situation calls for one of only a relatively constrained number of possible actions, then the ANS pattern of response should be more similar than in situations that permit a greater variety of possible actions. ANS responses also can differ across two people, even when the situated action is constrained, because each person draws from a different population of situated instances for a given emotion category. To test these hypotheses, scientists must sample not only individuals but also contexts in which emotions arise (a point we address in the next subsection). A growing number of studies are designed explicitly to capture heterogeneity within emotion categories both within individuals and across cultures (Ceulemans, Kuppens, & Van Mechelen, 2012; Hortensius, Schutter, & Harmon-Jones, 2012; Kuppens, Van Mechelen, & Rijmen, 2008; Kuppens, Van Mechelen, Smits, De Boeck, & Ceulemans, 2007; Nezlek & Kuppens, 2008; Stemmler et al., 2007; Stemmler et al., 2001; Wilson-Mendenhall et al., in press; Wilson-Mendenhall, Barrett, Simmons, & Barsalou, 2011). Importantly, scientists cannot define a person's emotional response by the type of stimulus delivered, rather the person's conceptualization of the stimulus is what matters, and this should be measured. Also, knowing more about the conceptual structure, accessibility, and extent of variability of an individual's population of situated emotion concepts could also provide empirical leverage for understanding individual differences in ANS patterning. In what situations do two people tend to draw upon similar situated concepts, and in what situations is their population of situated conceptualizations likely to be different? And what are the consequences for ANS patterning during emotion instances for a person who has a large and varied population of situated concepts from which to construct an emotional experience versus for a person with a smaller or more constrained population of situated concepts? Very similar kinds of questions can be posed when considering behavioral and cognitive response patterns as well. Our hypothesis is that the population of situated conceptualizations on which a person draws in a given situation will contribute to the extent of response concordance across cognitive and behavioral response domains as well.

Contextual variation. The CAT also emphasizes the need to assess ANS response patterns during emotion instances across individuals nested within multiple contexts. Only then can we assess the extent of variation due to IRS and SRS (for a related approach to understanding the role of context in ANS responses, see Marwitz & Stemmler, 1998; Stemmler, 1992; Stemmler et al., 2001; Stemmler & Wacker, 2010).[10] Within the CAT, the more culturally normative the emotion induction used in the lab, and the more culturally homogeneous the sample, the more likely it is that similar patterns of both peripheral physiological response and emotion self-reports will be seen across individuals (i.e., stronger SRS). Conversely, this model also suggests that greater variation across individuals (i.e., weaker SRS and stronger IRS) will be found when the emotion inductions are less culturally (or subculturally) normative, when situations are unfamiliar, or when inductions activate a complex blend of emotion concepts because of the greater variety of concepts that could be activated. Even in these cases, however, there may be homogenous subgroups with similar responses, such as groups of individuals who because of a similar personal or cultural history, tend to draw on similar situated concepts especially under constrained circumstances like the psychological laboratory. For example, those living in Boston, Massachusetts who were recently exposed to the distressing sights and sounds of the Boston Marathon bombings and barrage of local media coverage are more likely to activate a situated fear concept when seeing a picture of marathon runners than those with minimal exposure, at least until the tendency to co-activate "marathon" and "fear" as part of a new situated concept becomes weakened by subsequent nonthreatening information about marathons and runners. In this way, new situated concepts arise and weaken as a result of newly learned contextual information, producing an ever-changing population of situated instances from which people can draw when constructing new emotional experiences. Effects of context in altering concepts over time will likewise affect concordance of cognitive and behavioral features of emotional response patterns.

Temporal variation as an emotional episode unfolds. A third hypothesis is that ANS changes during emotional episodes must be studied and understood as they unfold over time, because these responses will change as conceptualizations occur and change over time, and because both afferent and efferent ANS changes unfold over the course of an emotional episode. The previously described heterarchical organization of the nervous system provides a neural substrate for this critical feature of the CAT because heterarchical connections support frequent and obligatory predictions about what one expects to occur next (i.e., hypothesis generation; Bar, 2007, 2009; Bar et al., 2006; Barrett & Bar, 2009). Predictions based on coarse (gist-level) visual sensory information that quickly reaches the frontal cortex permits a person to respond faster and more adaptively to an ever-changing internal and external context. Barrett and Bar (2009) proposed that people make affective predictions, using internal sensory information. Early gist-level predictions about objects in visual consciousness are constructed when internal sensations occur that are associated with prior experience of a similar gist-level visual representation. These affective predictions are one type of conceptual act whereby human brains constitute an emotional mental state.

The ubiquity of these predictive processes using both internal and external contextual information complicates attempts to understand emotion in laboratory-based experiments. In many experimental designs, we typically assume a stimulus–response–output framework for our experiments as if each response to a new stimulus begins with the organism in some presumed stable "basal" internal state to which they return after each stimulus or that any change in "basal" state is unimportant variation. But, this assumption is likely wrong on at least two counts. First, if we think of the brain as a predictor, then over the course of any experiment (particularly one with many within-subjects conditions or emotion inductions), participants are building a mental model (i.e., generating hypotheses) about what is going to come. These predictions change the neural context in which each subsequent stimulus is processed. Second, generated hypotheses about what is to come can cause anticipatory shifts in somatovisceral state that mean that people do not start each emotional episode with the same internal state as when they began. To add further complexity, some inductions generate physiologically potent changes in mental state (e.g., rumination or mental fatigue), that can lengthen or shorten the effect of emotion inductions and impact the induced changes in physiological state. For example, consider the prolonged increase in "basal" systolic and diastolic blood pressure responses for at least 10 min following a harassing mental arithmetic task and an avoidance of shock task (Glynn, Christenfeld, & Gerin, 2002). A person's starting point, in terms of their current internal and external context when a stimulus is encountered, is also important in determining which among several possible concepts is activated. Thus, regardless of the duration of a baseline period, one basal state may not be equivalent to another one. Techniques like the vanilla baseline (Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992) in which a bland, easy task (e.g., counting colored squares) is used to "standardize" the mental state of participants in a psychophysiological experiment are helpful for minimizing rumination that can occur after emotional stimuli. This procedure, however, does not address the issue that sentient participants create a mental model that updates over time in the experiment when they encounter new stimuli and have new mental experiences. The mental context changes over time in the experiment (as it does in real life). Future empirical work will need to take into account these temporal dependencies that can influence how emotional experiences are constructed.

Finally, the CAT reminds emotion researchers that in interpreting experiments, it is important to resist the temptation to essentialize. Temptations are everywhere. As an analytic approach, scientists can use pattern classification techniques with psychophysiological or brain imaging data to attempt to find a multivariate pattern of variables that are repeatable across instances of a category, and to classify new instances of that category. The temptation, of course, it is to interpret these patterns

---

[10] Stemmler (1992) also notes that to demonstrate a form of absolute emotion specificity, one would need to show that the same emotion produces the same physiological response profile across two (or more) contexts. However, in his papers assessing ANS response specificity, there was no evidence of absolute specificity (Stemmler, 1989; Stemmler et al., 2001), consistent with both Stemmer's Component Model of Somatovisceral Response Organization and the CAT.

as the essence of each category. Yet, diagnosis is not explanation. A pattern represents features that are repeatable, and are diagnostic, but this does not mean that those features are sufficient for representing all that is meaningful and important about each and every instance of the emotion. For example, it would instead be consistent to hypothesize that an instance of an emotion category, such as anger, could be modeled as an N-dimensional pattern of physiological response, or a brain state (or a series of brain states) constituted by interactions between widely distributed networks. Further, some parts of this pattern will be repeatable across instances of the category, but these parts, in and of themselves, would be insufficient for understanding any given instance – that is, there may be some aspects to the interactions that are unique and important to understanding and explaining that instance. Such a modeling approach is consistent with a psychological construction assumption that all semantic categories, even those that are highly abstract and man-made categories (i.e., those without an essence) can have characteristic patterns of activation within the human brain (e.g., Naselaris, Prenger, Kay, Oliver, & Gallant, 2009).

3. Conclusions

As the quotes from William James (1890, 1894/1994) with which we began suggest, there is considerable variability in the ANS response during emotions that differentiate people and situations, and that can unfold differently over time across different instances of a given emotion category. We propose that the same is true of cognitive and behavioral emotional response patterns. The CAT framework considers this variation as a critically important aspect of emotional mental states that should be modeled in studies of potential consistent and specific ANS responses during emotion episodes. This framework requires that emotion scientists take seriously the importance of an individual's situated conceptualizations because they will influence any potential ANS consistency and specificity. Or more broadly, physiological, cognitive or behavioral concordance will only be apparent once we understand variation in these conceptualizations as they occur across individuals, context, and time.

Acknowledgement

This work was supported by a National Institutes of Health Director's Pioneer Award (DP1OD003312) to Lisa Feldman Barrett.

References

Allen, M. T., Boquet, A. J., & Shelley, K. S. (1991). Cluster analyses of cardiovascular responsivity to three laboratory stressors. *Psychosomatic Medicine*, *53*(3), 272–288.

Anderson, E. A., Wallin, B. G., & Mark, A. L. (1987). Dissociation of sympathetic nerve activity in arm and leg muscle during mental stress. *Hypertension*, *9*(Suppl. III), III114–III119.

Bar, M. (2007). The proactive brain: Using analogies and associations to generate predictions. *Trends in Cognitive Sciences*, *11*(7), 280–289.

Bar, M. (2009). The proactive brain: Memory for predictions. *Philosophical Transactions of the Royal Society: B*, *364*, 1235–1243.

Bar, M., Kassam, K. S., Ghuman, A. S., Boshyan, J., Schmid, A. M., Dale, A. M., & Halgren, E. (2006). Top-down facilitation of visual recognition. *Proceedings of the National Academy of Sciences*, *103*(2), 449–454.

Barrett, L. F. (2000). Modeling emotion as an emergent phenomenon: A causal indicator analysis. In *Paper presented at the Annual Meeting of the Society for Personality and Social Psychology* Nashville, TN, http://www.affective-science.org/publications.shtml

Barrett, L. F. (2006). Solving the emotion paradox: Categorization and the experience of emotion. *Personality and Social Psychology Review*, *10*(1), 20–46.

Barrett, L. F. (2011a). Bridging token identity theory and supervenience theory through psychological construction. *Psychological Inquiry*, *22*(2), 115–127.

Barrett, L. F. (2011b). Constructing emotion. *Psychological Topics*, *3*, 359–380.

Barrett, L. F. (2013). Psychological construction: The Darwinian approach to the science of emotion. *Emotion Review*, *5*(4), 1–11.

Barrett, L. F., & Bar, M. (2009). See it with feeling: Affective predictions during object perception. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1325–1334.

Barrett, L. F., & Bliss-Moreau, E. (2009). Variety is the spice of life: A psychological construction approach to understanding variability in emotion. *Cognition and Emotion*, *23*(7), 1284–1306.

Barrett, L. F., & Satpute, A. (2013). Large-scale brain networks in affective and social neroscience: Towards an integrative functional architecture of the brain. *Current Opinion in Neurobiology*, *23*, 361–372.

Barrett, L. F., Wilson-Mendenhall, C. D., & Barsalou, L. W. (in press). The Conceptual Act Theory: A roadmap. In L. F. Barrett & J. A. Russell (Eds.), *The psychological construction of emotion*. New York, NY: Guilford Press.

Barsalou, L. W. (2005). Situated conceptualization. In H. Cohen, & C. Lefebvre (Eds.), *Handbook of categorization in cognitive science* (pp. 619–650). New York, NY: Elsevier.

Barsalou, L. W. (2009). Simulation, situated conceptualization, and prediction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1281–1289.

Berntson, G. G., Cacioppo, J. T., Binkley, P. F., Uchino, B. N., Quigley, K. S., & Fieldstone, A. (1994). Autonomic cardiac control. III. Psychological stress and cardiac response in autonomic space as revealed by pharmacological blockades. *Psychophysiology*, *31*(6), 599–608.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1991). Autonomic determinism: The modes of autonomic control, the doctrine of autonomic space and the laws of autonomic constraint. *Psychological Review*, *98*(4), 459–487.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Cardiac psychophysiology and autonomic space in humans: Empirical perspectives and conceptual implications. *Psychological Bulletin*, *114*(2), 296–322.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1994). Autonomic cardiac control. I. Estimation and validation from pharmacological blockades. *Psychophysiology*, *31*(6), 572–585.

Berntson, G. G., Cacioppo, J. T., Quigley, K. S., & Fabro, V. T. (1994). Autonomic space and psychophysiological response. *Psychophysiology*, *31*(1), 44–61.

Berntson, G. G., Cacioppo, J. T., & Sarter, M. (2003). Bottom-up: Implications for neurobehavioral models of anxiety and autonomic regulation. In R. J. Davidson, K. S. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 1105–1116). New York, NY: Oxford University Press.

Berntson, G. G., Sarter, M., & Cacioppo, J. T. (2003). Ascending visceral regulation of cortical affective information processing. *European Journal of Neuroscience*, *18*(8), 2103–2109.

Berntson, G. G., Uchino, B. N., & Cacioppo, J. T. (1994). Origins of baseline variance and the law of initial values. *Psychophysiology*, *31*(2), 204–210.

Brading, A. (1999). *The autonomic nervous system and its effectors*. Oxford: Blackwell Science.

Cacioppo, J. T., Berntson, G. G., Klein, D. J., & Poehlmann, K. M. (1997). Psychophysiology of emotion across the life span. *Annual Review of Gerontology and Geriatrics*, *17*, 27–74.

Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., & Ito, T. A. (2000). The psychophysiology of emotion. In M. Lewis, & J. M. Haviland-Jones (Eds.), *The handbook of emotion* (2nd ed., pp. 173–191). New York: Guilford Press.

Ceulemans, E., Kuppens, P., & Van Mechelen, I. (2012). Capturing the structure of distinct types of individual differences in the situation-specific experience of emotions: The case of anger. *European Journal of Personality*, *26*(5), 484–495.

Christie, I. C., & Friedman, B. H. (2004). Autonomic specificity of discrete emotion and dimensions of affective space: A multivariate approach. *International Journal of Psychophysiology*, *51*(2), 143–153.

Coan, J. A. (2010). Emergent ghosts in the emotion machine. *Emotion Review*, *2*(3), 274–285.

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.

Critchley, H. D. (2005). Neural mechanisms of autonomic, affective, and cognitive integration. *The Journal of Comparative Neurology*, *493*, 154–166.

Critchley, H. D., & Harrison, N. A. (2013). Visceral influences on brain and behavior. *Neuron*, *77*(4), 624–638.

Davis, R. C. (1957). Response patterns. *Transactions of the New York Academy of Sciences*, *19*(8 Series II), 731–739.

Ekman, P., & Cordaro, D. (2011). What is meant by calling emotions basic. *Emotion Review*, *3*(4), 364–370.

Ellis, P. D. (2010). Minimizing bias in meta-analysis. In *The essential guide to effect sizes*. Cambridge, UK: Cambridge University Press.

Engel, B. T. (1960). Stimulus-response and individual-response specificity. *Archives of General Psychiatry*, *2*(3), 305–313.

Engel, B. T., & Bickford, A. F. (1961). Response specificity: Stimulus-response and individual-response specificity in essential hypertensives. *Archives of General Psychiatry*, *5*(5), 478–489.

Engel, B. T., & Moos, R. H. (1967). The generality of specificity. *Archives of General Psychiatry*, *16*(5), 574–581.

Etzel, J. A., Johnsen, E. L., Dickerson, J., Tranel, D., & Adolphs, R. (2006). Cardiovascular and respiratory responses during musical mood induction. *International Journal of Psychophysiology*, *61*(1), 57–69.

Friedman, B. H. (2010). Feelings and the body: The Jamesian perspective on autonomic specificity of emotion. *Biological Psychology*, *84*(3), 383–393.

Gendron, M., & Barrett, L. F. (2009). Reconstructing the past: A century of ideas about emotion in psychology. *Emotion Reviews*, *1*(4), 316–339.

Glynn, L. M., Christenfeld, N., & Gerin, W. (2002). The role of rumination in recovery from reactivity: Cardiovascular consequences of emotional states. *Psychosomatic Medicine*, *64*(5), 714–726.

Gross, J. J., & Barrett, L. F. (2011). Emotion generation and emotion regulation: One or two depends on your point of view. *Emotion Review*, *3*(1), 8–16.

Haas, B. W., Omura, K., Constable, R. T., & Canli, T. (2007). Emotional conflict and neuroticism: personality-dependent activation in the amygdala and subgenual anterior cingulate. *Behavioral Neuroscience*, *121*(2), 249–256.

Haas, F., Distenfeld, S., & Axen, K. (1986). Effects of perceived musical rhythm on respiratory pattern. *Journal of Applied Physiology*, *61*(3), 1185–1191.

Harrison, N. A., Kreibig, S. D., & Critchley, H. D. (2013). A two-way road: Efferent and afferent pathways of autonomic activity in emotion. In J. Armony, & P. Vuilleumier (Eds.), *The Cambridge handbook of human affective neuroscience* (pp. 82–106). New York: Cambridge University Press.

Hortensius, R., Schutter, D. J. L. G., & Harmon-Jones, E. (2012). When anger leads to aggression: Induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger–aggression relationship. *Social Cognitive and Affective Neuroscience*, *7*(3), 342–347.

James, W. (1890). *The principles of psychology Vol. 2*. New York: Henry Holt & Co.

James, W. (1894/1994). The physical basis of emotion. *Psychological Review*, *101*(2), 205–210.

Janig, W. (2003). The autonomic nervous system and its coordination by the brain. In R. J. Davidson, K. S. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 135–186). New York, NY: Oxford University Press.

Jennings, J. R., Kamarck, T., Stewart, C., Eddy, M., & Johnson, P. (1992). Alternate cardiovascular baseline assessment techniques: Vanilla or resting baseline. *Psychophysiology*, *29*(6), 742–750.

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*(1), 17–26.

Kleckner, I. R., & Quigley, K. S. (in press). An approach to mapping the neurophysiological state of the body to affective experience. In L. F. Barrett & J. A. Russell (Eds.), *The psychological construction of emotion*. New York, NY: Guilford Press.

Kolodyazhniy, V., Kreibig, S. D., Gross, J. J., Roth, W. T., & Wilhelm, F. H. (2011). An affective computing approach to physiological emotion specificity: Toward subject-independent and stimulus-independent classification of film-induced emotions. *Psychophysiology*, *48*(7), 908–922.

Kragel, P. A., & Labar, K. S. (2013). Multivariate pattern classification reveals autonomic and experiential representations of discrete emotions. *Emotion*, *13*(4), 681–690.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, *84*(3), 394–421.

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*(5), 787–806.

Kuppens, P., Van Mechelen, I., & Rijmen, F. (2008). Toward disentangling sources of individual differences in appraisal and anger. *Journal of Personality*, *76*(4), 969–1000.

Kuppens, P., Van Mechelen, I., Smits, D. J. M., De Boeck, P., & Ceulemans, E. (2007). Individual differences in patterns of appraisal and anger experience. *Cognition and Emotion*, *21*(4), 689–713.

Lacey, J. I. (1967). Somatic response patterning and stress: Some revisions of activation theory. In M. H. Appley, & R. Trumbull (Eds.), *Psychological stress: Issues in research* (pp. 14–37). New York: Appleton-Century-Crofts.

Lacey, J. I., & Lacey, B. C. (1958). Verification and extension of the principle of Autonomic Response-Stereotypy. *American Journal of Psychology*, *71*(1), 50–73.

Lench, H. C., Flores, S. A., & Bench, S. W. (2011). Discrete emotions predict changes in cognition, judgment, experience, behavior, and physiology: A meta-analysis of experimental emotion elicitations. *Psychological Bulletin*, *137*(5), 834–855.

Lindquist, K. A., & Barrett, L. F. (2012). A functional architecture of the human brain: emerging insights from the science of emotion. *Trends in Cognitive Sciences*, *16*(11), 533–540.

Lindquist, K. A., Siegel, E. H., Quigley, K. S., & Barrett, L. F. (2013). The hundred-year emotion war: are emotions natural kinds or psychological constructions? Comment on Lench, Flores, and Bench (2011). *Psychological Bulletin*, *139*(1), 255–263.

Loewy, A. D., & Spyer, K. M. (1990). *Central regulation of autonomic functions*. New York: Oxford University Press.

Marwitz, M., & Stemmler, G. (1998). On the status of individual response specificity. *Psychophysiology*, *35*(01), 1–15.

Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. *Cognition and Emotion*, *23*(2), 209–237.

Morrison, S. F. (2001). Differential control of sympathetic outflow. American Journal of Physiology: Regulatory. *Integrative and Comparative Physiology*, *281*, R683–R698.

Naselaris, T., Prenger, R. J., Kay, K. N., Oliver, M., & Gallant, J. L. (2009). Bayesian reconstruction of natural images from human brain activity. *Neuron*, *63*(6), 902–915.

Nezlek, J. B., & Kuppens, P. (2008). Regulating positive and negative emotions in daily life. *Journal of Personality*, *76*(3), 561–580.

Nyklicek, I., Thayer, J. F., & van Doornen, L. J. P. (1997). Cardiorespiratory differentiation of musically-induced emotions. *Journal of Psychophysiology*, *11*, 304–321.

Panksepp, J. (1998). The periconscious substrates of consciousness: Affective states and the evolutionary origins of the self. *Journal of Consciousness Studies*, *5*(5-6), 566–582.

Paton, J. F. R., Nalivaiko, E., Boscan, P., & Pickering, A. E. (2006). Reflexly evoked coactivation of cardiac vagal and sympathetic motor outflows: Observations and functional implications. *Clinical and Experimental Pharmacology and Physiology*, *33*, 1245–1250.

Quigley, K. S., & Berntson, G. G. (1996). Autonomic interactions and chronotropic control of the heart: Heart period versus heart rate. *Psychophysiology*, *33*(5), 605–611.

Quigley, K. S., Lindquist, K. A., & Barrett, L. F. 2014. (in press). Inducing and measuring emotion and affect: Tips, tricks, and secrets. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology*. New York: Cambridge University Press.

Rainville, P., Bechara, A., Naqvi, N. H., & Damasio, A. R. (2006). Basic emotions are associated with distinct patterns of cardiorespiratory activity. *International Journal of Psychophysiology*, *61*(1), 5–18.

Roseman, I. J. (2011). Emotional behaviors, emotivational goals, emotion strategies: Multiple levels of organization integrate variable and consistent responses. *Emotion Review*, *3*(4), 434–443.

Sinha, R. (1996). Multivariate response patterning of fear and anger. *Cognition & Emotion*, *10*(2), 173–198.

Stemmler, G. (1988). Effects of profile elevation, scatter, and shape on discriminant analysis results. *Educational and Psychological Measurement*, *48*(4), 853–871.

Stemmler, G. (1989). The autonomic differentiation of emotions revisited: Convergent and discriminant validation. *Psychophysiology*, *26*(6), 617–632.

Stemmler, G. (1992). The vagueness of specificity: Models of peripheral physiological emotion specificity in emotion theories and their experimental discriminability. *Journal of Psychophysiology*, *6*, 17–28.

Stemmler, G. (2003). Methodological considerations in the psychophysiological study of emotion. In R. J. Davison, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 225–255). New York, NY: Oxford Univeristy Press.

Stemmler, G. (2004). Physiological processes during emotion. In P. Philippot, & R. S. Feldman (Eds.), *The regulation of emotion* (pp. 33–70). Mahwah, NJ: Lawrence Erlbaum Associates.

Stemmler, G., Aue, T., & Wacker, J. (2007). Anger and fear: Separable effects of emotion and motivational direction on somatovisceral responses. *International Journal of Psychophysiology*, *66*(2), 141–153.

Stemmler, G., Heldmann, M., Pauls, C. A., & Scherer, T. (2001). Constraints for emotion specificity in fear and anger: The context counts. *Psychophysiology*, *38*(2), 275–291.

Stemmler, G., & Wacker, J. (2010). Personality, emotion and individual differences in physiological responses. *Biological Psychology*, *84*, 541–551.

Stephens, C. L., Christie, I. C., & Friedman, B. H. (2010). Autonomic specificity of basic emotions: evidence from pattern classification and cluster analysis. *Biological Psychology*, *84*(3), 463–473.

Steptoe, A., & Sawada, Y. (1989). Assessment of baroreflex function during mental stress and relaxation. *Psychophysiology*, *26*(2), 140–147.

Tracy, J. L., & Randles, D. (2011). Four models of basic emotions: A review of Ekman and Cordaro, Izard, Levenson, and Panksepp and Watt. *Emotion Review*, *3*(4), 397–405.

Wilhelm, F. H., & Grossman, P. (2010). Emotions beyond the laboratory: Theoretical fundaments, study design, and analytic strategies for advanced ambulatory assessment. *Biological Psychology*, *84*(3), 552–569.

Wilson-Mendenhall, C. D., Barrett, L. F., & Barsalou, L. W. (2013). Neural evidence that human emotions share core affective properties. *Psychological Science*, *24*(6), 947–956.

Wilson-Mendenhall, C. D., Barrett, L. F., Simmons, W. K., & Barsalou, L. W. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia*, *49*, 1105–1127.