

# The Tie That Binds? Coherence Among Emotion Experience, Behavior, and Physiology

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Emotion theories commonly postulate that emotions impose coherence across multiple response systems. However, empirical support for this coherence postulate is surprisingly limited. In the present study, the authors (a) examined the within-individual associations among experiential, facial behavioral, and peripheral physiological responses during emotional responding and (b) assessed whether emotion intensity moderates these associations. Experiential, behavioral, and physiological responses were measured second-by-second during a film that induced amusement and sadness. Results indicate that experience and behavior were highly associated but that physiological responses were only modestly associated with experience and behavior. Intensity of amusement experience was associated with greater coherence between behavior and physiological responding; intensity of sadness experience was not. These findings provide new evidence about response system coherence in emotions.

*Keywords:* emotion, coherence, emotion experience, facial behavior, physiological responses

For many theorists, a defining feature of emotion is *response coherence* (e.g., Ekman, 1972, 1992; Lazarus, 1991; Levenson, 1994; Scherer, 1984; Tomkins, 1962). This refers to the coordination, or association, of a person's experiential, behavioral, and physiological responses as the emotion unfolds over time. Despite the commonness of the response coherence postulate, empirical evidence bearing on this postulate is quite limited. Relatively few studies have tested this postulate, and the empirical work that has been conducted leaves crucial ambiguities about the extent to which response systems do in fact cohere. In this article, we first describe the emotion theories that advance the response coherence postulate. Next, we review the empirical literature and show that the evidence regarding response coherence is mixed. Finally, we describe factors that may have reduced prior estimates of response coherence and present a methodologically appropriate study de-

signed to assess the extent to which experiential, facial behavioral, and peripheral physiological response systems cohere during emotion.

## Response System Coherence in Emotion: Theoretical Expectations

From Darwin (1872/1965) onward, researchers interested in emotion have argued that emotions involve coordinated changes across experiential, behavioral, and physiological response systems (e.g., Dolan, 2002; Ekman, 1992; Izard, 1977; Lang, 1988; Lazarus, 1991; Levenson, 1994; Panksepp, 1994). As Tomkins (1962) put it, emotions are sets of organized responses that "are capable when activated of simultaneously capturing such widely distributed organs as the face, the heart, and the endocrines and imposing on them a specific pattern of correlated responses" (pp. 243–244). Most, but not all, of these theorists have taken a functional perspective, proposing that by imposing coherence across response systems, emotions facilitate the organism's response to environmental demands (e.g., Ekman, 1992; Lazarus, 1991; Levenson, 1994; Plutchik, 1980; Witherington, Campos, & Hertenstein, 2001). As Levenson (2003) illustrated this argument, emotions prepare the organism for

a set of diverse actions. . . . Like a modern factory that subscribes to the "just in time" model of inventory control, the ANS [autonomic nervous system] not only has to deliver sufficient quantities of all of the components needed to craft an appropriate response, but also has to deliver them at precisely the right time, and then quickly remove anything that is unused. (p. 351)

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Thus, many theorists assume that one central feature (and perhaps the *function*) of emotions is response coherence, variously labeled as response system coherence (Ekman, 1992), organization of response components (Frijda, Ortony, Sonnemans, & Clore, 1992; Scherer, 1984; Witherington et al., 2001), response component syndromes (Averill, 1980; Reisenzein, 2000), concordance (Nesse et al., 1985; Wilhelm & Roth, 2001), or organization of response tendencies (Lazarus, 1991; Levenson, 1994). The notion that response coherence is a core feature of emotion suggests two corollaries. First, response coherence should increase as the intensity of emotion increases (Davidson, 1992). Weak emotions may provoke little coordination of response systems, whereas strong emotions may provoke greater coordination. Second, different emotions should be associated with different patterns of experiential, behavioral, and physiological responding, tailored to meet the demands of different situations (e.g., Lazarus, 1991; Levenson, 1988). For instance, amusement might be associated with facial displays of amusement, increased somatic activity, and a commensurate pattern of increased cardiovascular and electrodermal responding (Lang, Greenwald, Bradley, & Hamm, 1993; Obrist, Webb, Sutterer, & Howard, 1970). By contrast, sadness might be associated with facial displays of sadness, decreased somatic activity, and a commensurate pattern of decreased cardiovascular and electrodermal responding (e.g., Fowles, 1980; Gray, 1994; Obrist et al., 1970).

#### Response System Coherence in Emotion: Empirical Findings

In contrast to the theoretically assumed coherence of response systems, empirical findings have been mixed. Psychophysicists have long emphasized the weak correlations among experiential and physiological response systems (e.g., Hodgson & Rachman, 1974; Mandler, Mandler, Kremen, & Sholiton, 1961; Stemmler, 1992; Weinstein, Averill, Opton, & Lazarus, 1968) and even among various measures within the physiological response system (e.g., Davidson, 1978; Lacey, 1967; Lazarus, Speisman, & Mordkoff, 1963). More recent studies have similarly found relatively modest correlations among experiential, behavioral, and physiological measures in the context of specific emotional states such as fear (Bradley & Lang, 2000; Hubert & de Jong-Meyer, 1990; Lang, 1988; Rachman, 1978). In general, links between emotion experience and facial behavior have been strongest and more consistent across contexts (Ekman, Davidson, & Friesen, 1990; Ekman, Friesen, & Ancoli, 1980; Rosenberg & Ekman, 1994), but again, by no means have they been perfect (e.g., Edelmann & Zajonc, 1989; Blumberg & Izard, 1991; Bonanno & Keltner, 2004; Reisenzein, 2000; Ruch, 1995; for a review, see Fridlund, Ekman, & Oster, 1987). Even with subtle EMG measures of facial behavior, correlations between indicators of facial behavior and emotion experience are only low to moderate (e.g., Brown & Schwarz, 1980; Cacioppo, Martzke, Petty, & Tassinary, 1988; Lang et al., 1993).

Still more disconcerting for the coherence view, some studies have found no relationships at all (e.g., Edelmann & Baker, 2002; Fernández-Dols, Sanchez, Carrera, & Ruiz-Belda, 1997; Fridlund, 1991; Jacobs, Manstead, & Fischer, 2001; Mauss, Wilhelm, & Gross, 2004) or even negative associations among response systems (e.g., Buck, 1977; Lacey, 1967; Lang, 1988). Other studies

have pointed to inconsistencies in correlations across situations and individuals (e.g., Casey, 1993; Chovil, 1991; Gross, John, & Richards, 2000; Lazarus, Opton, & Tomita, 1966) and across studies. For example, correlations between funniness ratings and facial expressions of exhilaration, while generally positive, ranged from  $-.30$  to nearly  $1.0$  across 25 different studies (cf. Ruch, 1995). Thus, as Russell (2003) recently concluded, "coherence remains to be demonstrated" (p. 166).

In light of these findings, there has been a growing trend to view response systems as "loosely coupled" (Lang, 1988, p. 177) or "weakly probabilistically" associated (Reisenzein, 2000, p. 1; see also Bradley & Lang, 2000; Cacioppo, Berntson, & Klein, 1992). Further qualifications have emerged, such as the possibility that even these weaker associations might occur only during relatively intense prototypical emotional episodes (Russell, 2003; Scherer, 1984). Just how substantial is response coherence in emotion? Although no one would expect perfect associations across response systems during all emotions and in all contexts, it is not clear whether there is any evidence for reliable associations across response systems during emotional responding or that the strength of the coherence increases with the intensity of the emotion.

#### Methodological Considerations

How are we to make sense of the mixed findings regarding emotion response coherence? One possibility is that contemporary emotion theorists are simply wrong when they postulate coherence across experiential, behavioral, and physiological response systems during emotional episodes. Another possibility, however, is that the methods used in prior studies may have made it difficult to detect associations among response systems that were actually present. In the following sections, we consider four such methodological factors.

#### *Emotion Type and Intensity*

One factor that could contribute to the variability in coherence estimates is the type and intensity of emotion induced. For example, surprise or anxiety might show less coherence between experiential and physiological responses than do other emotions because surprise and anxiety have a more pronounced cognitive element (e.g., Mauss et al., 2004; Reisenzein, 2000) than do other emotions (e.g., fear). It is also important to consider how intensely the target emotion is being elicited in a particular context. The target emotion likely has to be sufficiently intense to find coherence among response systems (cf. Davidson, 1992; Rosenberg & Ekman, 1994; Tassinary & Cacioppo, 1992). Thus, prior low estimates of coherence may have been due to the fact that the wrong type of, or only weak, emotional responses were induced.

#### *Measures of Emotional Responding*

A second factor that might influence the variability in coherence estimates is which measures are assessed and how well they are matched to the emotion under investigation. For example, a study assessing smiles in winners of Olympic gold medals reached the conclusion that there was low association between feelings of happiness and smiling (Fernández-Dols & Ruiz-Belda, 1995). However, the experience of happiness was not directly assessed in

this study (rather, a different group of athletes was asked to remember their emotion experience in similar situations), evoking the criticism that perhaps other emotions such as awe or sadness were actually felt when winning a gold medal (Bonanno & Keltner, 2004). Likewise, some studies investigating the emotion of happiness have found surprisingly low correlations between feelings of happiness and laughter (e.g., Bonanno & Keltner, 2004). Laughter may reflect amusement or relief from a negative emotion rather than happiness and thus might not be an appropriate index of happiness. These examples illustrate that failure to sample all three response systems—experiential, behavioral, and physiological—and failure to select one's measures of emotional responding carefully within response systems limit the conclusions that can be drawn from a study.

#### *Temporal Resolution and Timing*

A third factor that might affect indices of coherence among response systems consists of the timing of measures and their temporal resolution. Especially when measuring emotion experience, researchers have often relied on *retrospective* and *aggregated* ratings because it has been difficult to assess emotional experience online and moment-by-moment without impeding emotion induction (e.g., Gottman & Levenson, 1985; Rosenberg & Ekman, 1994). Assessing experience after the emotional event might lead to measurement error due to processes such as memory biases or defensive mechanisms (e.g., Feldman-Barrett, 1997; Kahneman, 2000; Rosenberg & Ekman, 1994). Increases in measurement error in any one of the response systems involved would likely cloud assessment of associations among response systems (Kettunen, Ravaja, & Keltikangas-Järvinen, 2000; Stemmler, 1992). Likewise, aggregating measures across mixed emotional contexts and longer time periods could obscure relationships among individual measures (e.g., Levenson, 1988). Finally, prior studies have sometimes neglected to take into account varying lags among measures of emotional responding. This also might artificially decrease indices of coherence because it might lead one to miss responses outside the window under investigation, especially if the responses involved are short-lived (e.g., Kettunen et al., 2000).

#### *Between- Versus Within-Individual Designs*

A fourth methodological factor that might explain some of the variability in the correlations found in prior studies is whether coherence has been measured at the *between-individual* or the *within-individual* level. In the between-individual approach, an individual who reports greater emotion experience than do other individuals would also be expected to exhibit greater behavioral and physiological responses. The alternative approach is to investigate within-individual correlations among different response systems across time. In this approach, we would expect greater physiological and behavioral responding in time periods when an individual self-reports greater emotion relative to time periods when the same individual self-reports less emotion. As several researchers have noted, the within-participant design is often more sensitive to detecting coherence than is the between-participants design because it minimizes sources of between-individual variance (e.g., Lazarus et al., 1963; Pennebaker, 1982; Reisenzein,

2000; Rosenberg & Ekman, 1994; Ruch, 1995). In addition, it has been noted that, conceptually, between-individual analyses might be irrelevant to the question of how tightly responses are associated (e.g., Buck, 1980; Cacioppo, Uchino, et al., 1992; Lacey, 1967; Stemmler, 1992). Indices of within-individual associations more closely denote response system coherence as implied by the theories of emotion outlined above, namely, that responses in one response system are associated with responses in other response systems across time.

#### The Present Study: Testing the Response Coherence Postulate

The present study was designed to (a) examine the extent to which response systems cohere during emotional responding within individuals and (b) test whether intensity of emotional responding is associated with response coherence between individuals. We addressed the four methodological considerations reviewed previously by (a) eliciting emotions that are well suited for detecting coherence at moderate-to-high intensity levels, (b) using a broad range of carefully selected measures, (c) measuring emotional response systems with appropriate timing and temporal resolution, and (d) using a within-individuals approach rather than a between-individuals approach.

1. We used a well-validated film known to induce moderate-to-high levels of amusement and sadness. We targeted amusement and sadness to sample positive and negative emotions that recruit behavioral as well as physiological responses. Amusement, rather than happiness, was chosen because amusement more clearly allows predictions for which facial behaviors to expect (e.g., Bonanno & Keltner, 2004). Furthermore, amusement and sadness can be ethically and reliably induced using films (Gross & Levenson, 1995), a feature crucial to the present design because films allow for standardization of moment-by-moment emotional context across participants. Because coherence cannot be assessed without a range of emotional responses (lack of variability across time would constrain correlations), a film was selected that would induce dynamic changes in emotional states over a 5-min period, ranging from neutral to more intense emotional states. The fact that different individuals respond to this film with different degrees of intensity (in combination with our large sample size) meant that we were able to assess varying levels of emotional intensity across participants. This permitted us to test the prediction that coherence among response systems is greater during more intense emotional responding relative to less intense emotional responding.

2. We sampled experiential, behavioral, as well as physiological response systems. Facial expressions of amusement and sadness were assessed by two judges, who independently rated moment-by-moment intensity of facial indices of amusement (smiling, laughter) and sadness (frowning, lowered lips, crying). Because no single measure can adequately represent the peripheral physiological system (e.g., Lacey, 1967), measures of cardiovascular, electrodermal, and somatic activity were acquired.

3. We addressed issues of time resolution and timing by assessing self-reported emotional experience online and moment by moment, using a variant of the rating dial method introduced and validated by Levenson and Gottman (1983; see also Gottman & Levenson, 1985). This method gave us near-continuous (200 Hz) data for the three major emotion systems (experience, behavior,

physiology). Compared with the more traditional method of obtaining retrospective whole-task emotion ratings at a single point in time, this method ensured that measures of all three response systems were matched with respect to temporal resolution (i.e., all data were averaged over 1-s measurement periods; henceforth, we refer to these ratings as “continuous”). Moreover, it minimized measurement error due to memory biases or aggregation across mixed emotional periods. Having time-series data of this nature also enabled us to take into account varying lags among systems by using cross-correlations.

4. We used a within-individual design by assessing responses to a film continuously across time. As noted previously, this design is better suited to assess coherence than is a between-individuals design (e.g., Ruch, 1995).

### The Present Study: What Is Not Being Tested

The investigation of response system coherence is fraught with conceptual and methodological difficulties, all of which necessitate the clearest possible statement of our aims. Our goal in this study was to establish whether coherence among three response systems exists at all during two carefully chosen emotional states. We did this by addressing a number of methodological issues that had made it difficult in the past to reach any clear conclusion.

Before presenting our study, we believe it may be helpful to note four corollaries of the coherence postulate that are not addressed in the present study. First, whereas the postulate of coherence is motivated in large part by a functionalist perspective (namely, that coherence is adaptive; e.g., Levenson, 1994), the present study does not directly test the adaptiveness of coherence. Rather, it tests one crucial empirical prediction of the functionalist view (namely, that some measure of coherence exists).

Second, the present study does not address whether coherence is a feature of emotional states only. Clearly, other states such as startle or physical activity might involve response system coherence as well. However, the existence or nonexistence of coherence during such states does not diminish the importance of establishing coherence during emotions.

Third, the present study does not address whether any coherence observed is a function of the emotional state of the individual or of the situation that is used to elicit that emotional state (i.e., the act of film viewing; e.g., Stemmler, 1992). The coherence views outlined above predict that the same pattern of coherence should be observed no matter how an emotion is evoked. Given our focus on determining whether there was any evidence for response coherence during emotional states, we considered two different emotions in this study (amusement and sadness) but only one context (film viewing).

Fourth, the present study is not concerned with the question of response specificity. Our design allows us to assess differences in within-individual response coherence between two emotional states (labeled “different patterns of response coherence” in our study); it does not allow us to assess the extent to which discrete emotions (e.g., anger, fear, sadness, happiness) evoke specific patterns of autonomic or behavioral responses between individuals (e.g., “response specificity” in Levenson, 1988; Levenson, Ekman, & Friesen, 1990). This limitation follows from the fact that, as Davidson (1994) and Levenson (1988) have argued, a meaningful test of response specificity would include two or more negative

emotions and a neutral comparison condition, with each state being elicited in multiple ways.

### Hypotheses

*Hypothesis 1:* As predicted by the coherence postulate, we expected positive correlations among amusement experience, amusement facial behavior, and peripheral physiological responses (indicative of cardiovascular, electrodermal, and somatic activation). We also expected positive correlations between sadness experience and sadness facial behavior, but we expected both to correlate negatively with physiological responding (indicative of cardiovascular, electrodermal, and somatic deactivation).

*Hypothesis 2:* We expected the intensity of emotion to be associated with greater response system coherence. Specifically, we expected the intensity of amusement and sadness experience to be positively correlated across participants with the magnitude of correlations among facial behavioral and peripheral physiological measures. We expected the intensity of amusement and sadness facial behavior to be positively correlated with the magnitude of correlations among experiential and peripheral physiological measures.

### Method

#### Overview

Participants watched the same 5-min film—which consisted of an amusing scene, a sad scene, and a second amusing scene—three times in a row. During each film viewing, participants either simply watched the film or were asked to rate continuously either their sadness or their amusement experience using a rating dial as they watched the film (see Figure 1). During the first film viewing, expressive behavior was videotaped. After the first film viewing, participants provided retrospective whole-film ratings of amusement and sadness experience. Throughout the session, cardiovascular activation, skin conductance level, and somatic activity were assessed. To obtain indices of coherence, cross-correlations were calculated among second-by-second experience ratings (from Film Viewings 1, 2, or 3, depending on when a given participant first continuously rated sadness and amusement), facial behavior (from Film Viewing 1), and peripheral physiological responding (from Film Viewing 1) for each participant.

#### Participants

Participants were 60 female undergraduates enrolled in introductory psychology courses. Participants' mean age was 19.1 years ( $SD = 1.7$ ). The ethnic composition of the sample was mixed: 7% African American, 40% Asian American, 22% Caucasian American, and 32% Latino American. Written informed consent was obtained after the procedures had been fully explained. One participant was later excluded because of technical difficulties. This left 59 participants. Participants received course credit.

#### Procedure

On arrival, the participant was seated in a comfortable chair in a well-lit 3 m × 6 m room. The experimenter informed her that “We are interested in learning more about emotion” and that her reactions would be videotaped. After physiological sensors (see below for list of physiological measures) were attached, participants viewed two short films as part of another study. Films viewed were a fear-evoking film (showing a man balancing on the ledge of a high rise) followed by one of four films: a pleasant film (waves breaking), an amusing film (a puppy playing), a neutral film (a screensaver showing colored sticks piling up), or a sad film

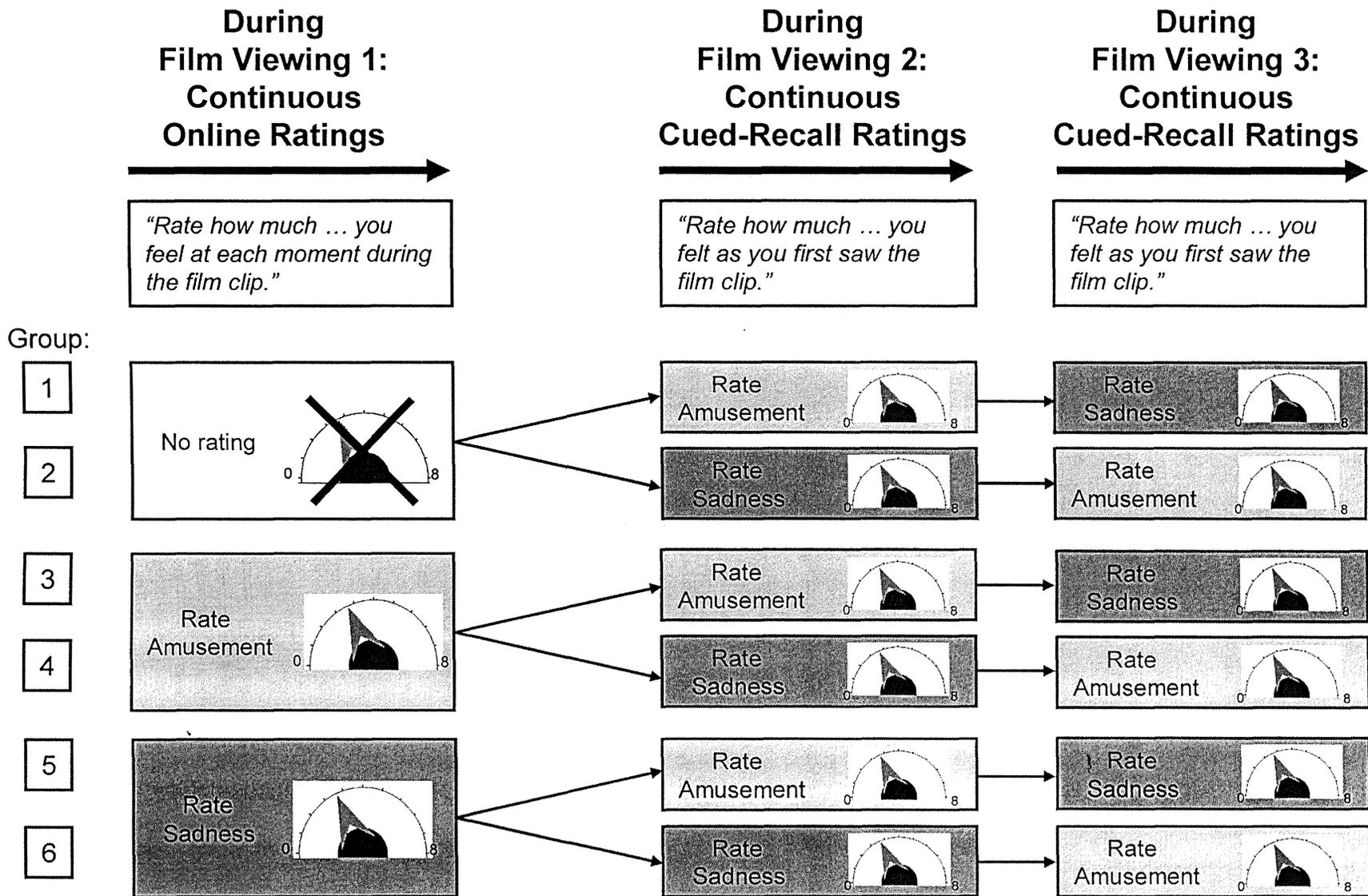


Figure 1. Participants viewed the same film three times in a row under one of six instructional orders, as shown in this schematic of the study design.

(a boy crying over his father's death). The present study began as participants listened to a 2-min piece of classical music to create a comparable affective state in all participants that was independent of the affective state evoked by prior films and prior events of the day. Participants were then asked to clear their mind of all thoughts, memories, and feelings while focusing for 1 min on a blank screen with an X. To ensure the effectiveness of this procedure, participants then rated their current amusement and sadness experience on 9-point Likert scales ranging from 0 (*none*) to 8 (*extremely*). Two one-way analyses of variance (ANOVAs) with prior film order as the independent variable and emotion experience as the dependent variable confirmed that groups were comparable with respect to amusement and sadness experience ( $ps > .61$ ).

Participants were told that they were going to watch the same film three times in a row (Film Viewings 1–3). This 5-min film consisted of an amusing scene (an antic scene with a dog), a sad scene (a woman crying at the death of her daughter), and a second amusing scene (a humorous interaction between women). These three scenes were drawn from the same film (*Steel Magnolias*) and together formed a coherent narrative unit. During each of the three viewings of the film, participants were asked to just watch (no rating), to rate continuously their sadness experience, or to rate continuously their amusement experience (see Figure 1). Continuous ratings of emotional experience were obtained using a rating dial similar to that used by Levenson and Gottman (1983; see also Gottman & Levenson, 1985). The dial allows participants to move a pointer along a 180° scale, with the legends "none" at 0° and "most in my life" at 180°. Participants were asked to adjust the dial position as often as necessary so that it always reflected the amount of a particular emotion (sadness or amusement) they felt. The dial was attached to a potentiometer in a voltage-dividing circuit that was monitored by a computer to enable determination of the dial position at a sample rate of 200 Hz.

To counterbalance rating orders, we randomly assigned participants to one of six groups ( $n = 10$  per group; see Figure 1). During Film Viewing 1, Groups 1 and 2 just watched the film, without rating their emotion experience; Groups 3–6 provided continuous ratings online ("Rate how much . . . you feel at each moment"). During Film Viewings 2 and 3, all participants provided continuous ratings with cued recall ("Rate how much . . . you felt as you first saw the film clip"). Immediately after the first film viewing, participants provided whole-film ratings of amusement and sadness experience ("Rate the greatest amount of each emotion you felt at any time during the film clip"). After each film viewing, participants rested for 1 min while focusing on an X on a blank screen. After the procedure, participants were thanked and debriefed. For example, a participant in Group 1 watched the film a first time without continuous online ratings, then provided whole-film ratings of amusement and sadness experience, then watched the film a second time while continuously rating amusement using cued recall, then watched it a third time while continuously rating sadness using cued recall.

This design permitted us to estimate effects of providing continuous ratings on emotional responding (by comparing Groups 1 and 2 with Groups 3–6) as well as the validity of continuous ratings (by comparing continuous with whole-film ratings and by comparing online with cued-recall ratings of a target emotion: amusement for Groups 3 and 4 and sadness for Groups 5 and 6).

## Measures

**Continuous ratings of amusement and sadness experience.** For the first film viewing, participants in Groups 3–6 (see Figure 1) were instructed to use the rating dial to rate continuously either their amusement experience (Groups 3 and 4) or their sadness experience (Groups 5 and 6) online as they watched the film ("Rate how much . . . you feel at each moment"). For the second and third film viewings, participants were instructed to rate continuously with cued recall either amusement or sadness as they had experienced it during the first film viewing ("Rate how much . . . you felt

as you first saw the film clip"). The output of the rating dial yielded near-continuous data (200 Hz).

**Whole-film ratings of amusement and sadness experience.** After the first film viewing, participants rated the extent to which they felt amusement and sadness (as well as a number of other distractor items) during the whole film-viewing period ("Rate the greatest amount of each emotion you felt at any time during the film clip") on a 9-point scale ranging from 0 (*none*) to 8 (*the most in my life*). This assessment was designed to enable us to validate our continuous experience assessment approach.

**Continuous ratings of amusement and sadness behavior.** Working with the video recordings made during the first film viewing, two coders independently rated facial expressions of amusement and sadness using the same rating dial used by participants to rate their emotional experience. Coders used a global cultural informant approach (Gross & Levenson, 1995), rating overall amusement and sadness intensity by using a coding system that is informed by microanalytic analyses of expressive behavior (Ekman & Friesen, 1978). The rating dial that the coders used was anchored at 0° with neutral (no sign of emotion) and at 180° with strong laughter for amusement and strong sadness expression/crying for sadness. The rating dial output was sampled at 200 Hz. Coders were unaware of hypotheses and stimuli. They were instructed to adjust the dial position so that it always reflected the amount of a particular emotion (sadness or amusement) that participants showed. Ratings were done independently, and each judge continuously rated each participant's amusement and sadness facial behavior (the order of amusement and sadness ratings was counterbalanced). The two judges' ratings were then averaged to create one continuous amusement and one continuous sadness rating for each participant. Average interrater reliabilities were satisfactory, with Cronbach's alphas of .84 ( $SD = .13$ ) and .80 ( $SD = .80$ ) for amusement behavior and for sadness behavior, respectively ( $ps < .001$ ).

**Continuous measures of peripheral physiology.** During the experimental session, physiological measures were monitored using a 12-channel Grass Model 7 polygraph. Six measures were obtained, representing cardiovascular, electrodermal, and somatic activation. Heart rate was derived from interbeat intervals, which were assessed by placing Beckman miniature electrodes in a bipolar configuration on the participant's chest and calculating the interval (in ms) between successive R-waves. Finger pulse amplitude was assessed using a UFI plethysmograph transducer attached to the tip of the participant's second finger. Finger pulse transit time was indexed by the time (in ms) elapsed between the closest previous R-wave and the upstroke of the peripheral pulse at the finger. Blood volume in the ear was measured with a UFI plethysmograph transducer attached to the participant's right ear lobe, and ear pulse transit time (EPTT) was indexed by the time (in ms) elapsed between the closest previous R-wave and the upstroke of the peripheral pulse at the ear. Skin conductance level (SCL) was derived from a signal using a constant-voltage device to pass 0.5 V between Beckman electrodes (using an electrolyte of sodium chloride in Unibase) attached to the palmar surface of the middle phalanges of the first and second fingers of the nondominant hand. Somatic activity was measured by an electromechanical transducer attached to the platform under the participant's chair. This device generates an electrical signal proportional to the participant's overall body movement in any direction. Custom software was used to compute second-by-second averages. All data were then smoothed using a 3-s moving average. This method reduces random variation in time series and thus facilitates the detection of common variance among measures in cross-correlations (Kettunen et al., 2000).

To assess the theoretically important construct of cardiovascular activation and to reduce the number of measures, we standardized heart rate, finger pulse transit time (reversed), finger pulse amplitude (reversed), and EPTT (reversed) within individuals and then averaged to form a composite (Gross & Levenson, 1997). Greater numbers on this composite indicate greater cardiovascular activation. Cronbach's alpha for the theoretically derived cardiovascular composite was adequate (.47). Despite its modest internal consistency, we used this composite because we believe it repre-

sents the appropriate level of specificity to test our hypotheses regarding coherence and because the individual measures taken separately yield a very similar pattern of results but dramatically increase the complexity of the data presentation.

### Data Analysis: Assessment of Methods

Before testing our core hypotheses, we tested the effectiveness of the emotion-inducing film and the validity and appropriateness of our continuous experience ratings. To assess the effectiveness of the film at inducing emotions, we examined the across-participants averages of experiential, behavioral, and physiological responding across the 5-min film-viewing period. Peak and range of affective responding across time were considered. To assess the validity of continuous online and cued-recall ratings of emotion experience, we correlated maxima from continuous ratings with the whole-film experience ratings obtained immediately after the first viewing of the film. To further test the validity of continuous cued-recall ratings, we computed within-participant correlations of online and cued-recall experience ratings for those 39 participants who had provided both types of ratings (Groups 3–6). For each emotion, half of the cued-recall ratings were completed during the second film viewing and half were completed during the third film viewing, depending on the group.

To assess whether performing continuous online ratings during the film viewing altered emotional responding relative to just watching the film, we calculated average emotion experience (based on whole-film ratings), facial behavior, and physiological activation for the first film viewing separately for the 39 participants who provided continuous online ratings of emotion experience (Groups 3–6) and for the 20 participants who did not provide continuous online ratings of emotion experience (Groups 1–2). Using *t* tests for independent groups, we then compared the two groups' averages.

### Data Analysis: Hypothesis Testing

We tested Hypothesis 1 (coherence among emotion response systems) by calculating for each pair of measures for each participant the maximum cross-correlation within lags from  $-10$  s to  $10$  s. The time window of  $-10$  to  $+10$  was chosen because theoretical considerations lead us to expect meaningful time lags among measures that are not greater than  $10$  s in either direction (e.g., Gratton, 2000; Kettunen, Ravaja, Näätänen, Keskivaara, & Keltikangas-Järvinen, 1998; Levenson, 1988). Each of these cross-correlations indexes the extent to which two measures covary across time within a given individual, while taking into account lags between measures. To obtain an average cross-correlation for each pair of measures, we performed a Fisher's *Z* transformation on each participant's cross-correlations, averaged the *Z*-transformed cross-correlations across participants, and transformed average cross-correlations back into *r*s. Thus, these average cross-correlations index the average extent to which two measures covary across time within individuals. Statistical significance of the average cross-correlations was assessed by calculating one-sample *t* tests to compare them to 0.<sup>1</sup>

To control for measurement error, we also calculated disattenuated cross-correlations for each participant with the formula  $R_{xy} = r_{xy}/\sqrt{r_{xx} * r_{yy}}$ , where  $R_{xy}$  = disattenuated cross-correlation,  $r_{xy}$  = observed cross-correlation,  $r_{xx}$  = reliability of *x*, and  $r_{yy}$  = reliability of *y* (Muchinsky, 1996). Reliability of continuous ratings was estimated using the correlations between online and cued-recall ratings. Reliability of continuous behavioral measures was estimated using Cronbach's alpha of continuous behavior ratings provided by the two coders. Because there were no estimates available for the peripheral physiological measures (one would not expect physiological responding during the second film viewing to be equal to that of the first film viewing), we used 1 as the reliability. Choosing this high estimate was conservative in that it worked against finding higher disattenuated correlations. Because these methods only allow us to estimate, rather than actually determine, measurement error, we interpret the disattenuated correlations reported here as an upper limit of coherence rather than true coherence.

To gain an overall index of coherence for amusement and sadness, we calculated averages across the seven Fisher's *Z*-transformed absolute *r*s (disregarding direction) among amusement experience, amusement behavior, and physiological responding and the seven Fisher's *Z*-transformed absolute *r*s (disregarding direction) among sadness experience, sadness behavior, and physiological responding. The averages were then transformed back into *r*s. Following Cohen's (1988) criteria, we interpreted correlations of 0.1–0.3 as small, 0.3–0.5 as moderate, and 0.5 and greater as large effect sizes.

We tested Hypothesis 2 (intensity of emotion moderates response coherence) by calculating between-participants correlations among indices of response system coherence (based on results testing Hypothesis 1) and maxima from continuous ratings of amusement and sadness experience and facial behavior. For example, to examine whether intensity of amusement experience is associated with coherence between amusement behavior and cardiovascular activation, we correlated maximum experience ratings of amusement with cross-correlations between amusement behavior and cardiovascular activation across all participants. To gain an overall index of the extent to which intensity of amusement experience, sadness experience, amusement facial behavior, and sadness facial behavior are associated with coherence, we calculated averages across the six Fisher's *z*'-transformed *r*s for amusement experience, sadness experience, amusement facial behavior, and sadness facial behavior.<sup>2</sup> Emotion intensity was not varied using measures of physiological activation because, for our physiological measures, it is not clear what would constitute greater emotional intensity (e.g., lesser cardiovascular responding could constitute greater sadness intensity but less amusement intensity).

## Results

### Assessment of Methods

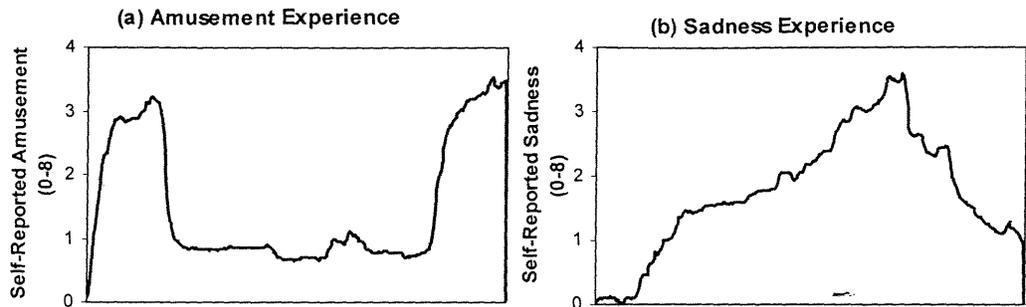
Before testing our two main hypotheses, we addressed four questions concerning the effectiveness of the film stimulus and the validity of the continuous experience ratings.

*Did the film induce adequate emotion levels and variability in emotional responding?* Figure 2 shows across-participants averages of amusement experience (0–8 scale), amusement facial behavior (0–8 scale), sadness experience (0–8 scale), sadness facial behavior (0–8 scale), cardiovascular responding (*Z* scores), SCL ( $\mu$ Siemens), and somatic activity (*Z* scores) across the 5-min

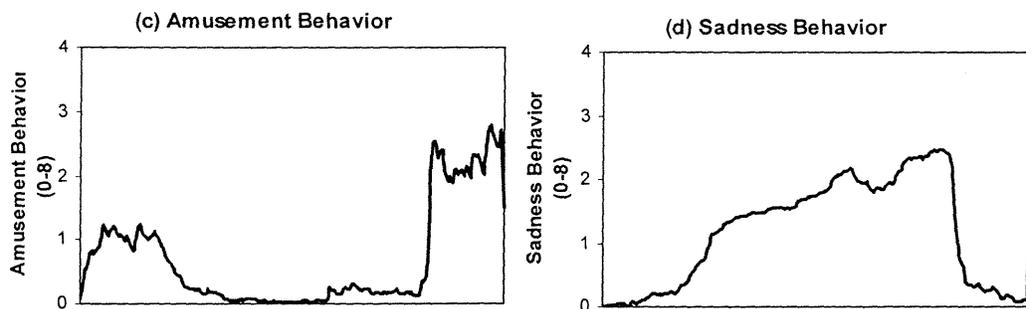
<sup>1</sup> There are a number of ways to assess coherence using time series methods (e.g., autoregression, ARIMA). However, cross-correlations were judged to be the optimal technique for the present study for two reasons. First, time-series techniques require stationarity of the data. The present data were *not* stationary, as assessed by the Kwiatkowski–Phillips–Schmidt–Shin test of stationarity (Kwiatkowski, Phillips, Schmidt, & Shin, 1992). Second, the data could not be rendered stationary (e.g., by employing first differences) because one of the primary goals of the study, and the primary basis for coherence put forth by emotion theories, was precisely to induce a range of emotional experiences across time—that is, *nonstationarity*. Given this, cross-correlations were the optimal time-series technique, because as they are used in the present paper (to capture individual differences in bivariate association over time, treating all participants' data alike) they are least affected by nonstationarity of the data.

<sup>2</sup> Note that all scores are standardized within participants. This rules out the alternative explanation that the magnitude of correlations is attributable to variability of emotional responding.

## Experience



## Behavior



## Physiology

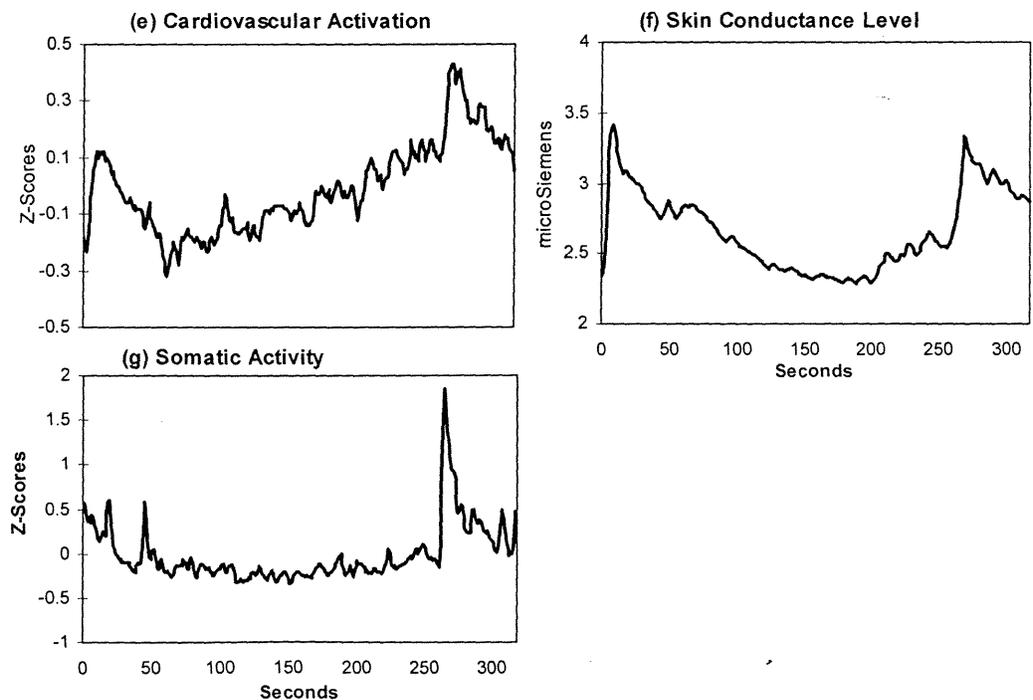


Figure 2. Panels (a) through (g): average continuous plots for (a) amusement experience, (b) sadness experience, (c) amusement behavior, (d) sadness behavior, (e) cardiovascular activation, (f) skin conductance level, and (g) somatic activity. Lines represent 3-s moving averages, averaged across all 59 participants. Behavior ratings and physiological responding correspond to the first film viewing; experience ratings correspond to the first (for Groups 4–6) or the second (for Groups 1 and 2) film viewing (depending on when the emotion in question was first rated; see Figure 1 for groups).

film-viewing period.<sup>3</sup> These data clearly show that the film was effective in inducing moderate-to-high peak experiential, behavioral, and physiological responses (indicating that the film induced moderately intense emotional responses) as well as a wide range of responses across time (indicating that the film provides a good context for assessing dynamic changes of emotional responding across time). Of course, individual curves deviate from the group response patterns, and their peaks are attenuated by the averaging. Thus, the group averages present a conservative picture of the within-individual variance in emotional responding. It is important to note that as Figure 2 shows across-individuals averages, the graphs do not bear on the within-individual correlations testing our hypotheses.

*Are continuous ratings of emotion experience valid?* Average correlations between maximal online ratings and whole-film ratings of emotion experience were .51 for amusement ( $p < .001$ ;  $n = 18$ ; Groups 3–4) and .82 for sadness ( $p < .001$ ;  $n = 16$ ; Groups 5–6), indicating that continuous online ratings converge with whole-film ratings. The magnitude of these correlations is what one would expect for correlations between moment-based and memory-based affective ratings (Feldman-Barrett, 1997; Kahneman, 2000). Correlations between maximal cued-recall ratings and whole-film ratings were .67 for amusement ( $p < .001$ ;  $n = 33$ ; Groups 1, 2, 5, and 6) and .62 for sadness ( $p < .001$ ;  $n = 35$ ; Groups 1, 2, 3, and 4), indicating that continuous cued-recall ratings converge with whole-film ratings of emotional experience.<sup>4</sup>

*Are cued-recall ratings of emotional experience valid?* For the participants who provided continuous online as well as continuous cued-recall ratings of amusement (Groups 3 and 4), online ratings correlated .80 with cued-recall ratings of amusement ( $p < .001$ ;  $n = 19$ ). For the participants who provided continuous online as well as continuous cued-recall ratings of sadness (Groups 5 and 6), online ratings correlated, on average, .73 with cued-recall ratings of sadness ( $p < .001$ ;  $n = 16$ ). These results indicate that participants' cued-recall ratings of emotional experience were valid with respect to online ratings and provide strong support for our use of cued-recall ratings as an index of continuous experience.

*Does continuous online rating alter emotional responding?* Table 1 shows average emotion experience, facial behavior, and physiological activation during the first film viewing for the 39 participants who provided online ratings of emotion experience (Groups 3–6) and for the 20 participants who did not provide online ratings of emotion experience (Groups 1 and 2). *T* tests for independent groups indicated that participants who rated their emotion experience online did not differ from participants who did not provide such ratings in terms of emotion experience, facial behavior, or peripheral physiological responding.<sup>5</sup> Because these analyses test the null hypothesis that the groups did not significantly differ from each other, the last column in Table 1 provides effect sizes. Overall, effect sizes are small to moderate, suggesting that nonsignificance of the *t* tests is not just a function of moderate cell sizes. Whereas effect sizes for amusement behavior, cardiovascular responding, and somatic activity might be cause for concern (Cohen's *d*s = .54, .45, and .40, respectively), even these group differences were below statistical significance ( $ps = .07, .13, .18$ ). Moreover, small group differences in average or peak responding would not plausibly affect results testing our hypotheses. Overall, then, it appears that continuous online rating does not substantially alter emotional responding.

### Coherence Among Response Systems

In the following sections, we test Hypothesis 1 (response coherence) by presenting average Pearson correlations for amusement experience ratings, amusement facial behavior, and peripheral physiological responding (Table 2, rows 1–3) and sadness experience ratings, sadness facial behavior, and peripheral physiological responding (Table 2, rows 4–6). We test Hypothesis 2 (intensity moderates response coherence) by presenting average Pearson correlations for amusement experience and coherence (Table 3, rows 2–6), sadness experience and coherence (Table 3, rows 8–12), amusement facial behavior and coherence (Table 3, rows 14–18), and sadness facial behavior and coherence (Table 3, rows 20–24). In view of the evidence that both online and cued-recall ratings of emotion experience are valid, as well as evidence that online ratings do not alter emotional responding, results for coherence among response systems are presented for all 59 participants, irrespective of whether they provided continuous ratings of emotion experience online or with cued recall.

*Testing Hypothesis 1: Coherence among responses for amusement and sadness.* Consistent with Hypothesis 1, Table 2 (rows 1–3) shows that amusement experience ratings were positively correlated with amusement facial behavior ( $r = .73$ ). Amusement experience and facial behavior were positively correlated with SCL, cardiovascular activation, and somatic activity ( $r$ s ranged from .22 to .51). Variance explained ranged from 5% for experience and cardiovascular responding (small effect size) to 53% for experience and behavior (large effect size). Disattenuated correlations were considerably greater than correlations not corrected for measurement error (the disattenuated  $r$  between experience and facial behavior correlation was .87; all other disattenuated  $r$ s ranged from .25 to .89). Secondary analyses using  $r$  to  $Z$  transformations revealed that the experience–behavior correlation was significantly greater than all other correlations (all  $ps < .06$ ).

Partially consistent with Hypothesis 1, Table 2 (rows 4–6) shows that sadness experience ratings were positively correlated with sadness facial behavior ( $r = .74$ ). Sadness experience and sadness facial behavior were negatively correlated with SCL and were not correlated with cardiovascular activation ( $r$ s ranged from

<sup>3</sup> Note that cell sizes vary slightly because of the exclusion of artifactual data. For experience data, we excluded participants who did not comply with instructions (e.g., not moving the rating dial for more than half of the film-viewing period), resulting in the loss of 4 participants' amusement ratings and 5 participants' sadness ratings). For skin conductance level, we excluded 3 participants. In addition, 1 participant was completely excluded because of equipment failure.

<sup>4</sup> It is also noteworthy in this context that amusement and sadness experience are not simply mirror images. To ensure that there are two separate emotional dimensions, as opposed to merely one pleasant–unpleasant dimension, we correlated amusement and sadness self-reports and behavior for each participant. Average correlations are  $-.72$  ( $n = 52$ ) for amusement and sadness self-reports and  $-.63$  ( $n = 58$ ) for amusement and sadness behavior. Thus, correlations between amusement and sadness are quite high, but they suggest that amusement and sadness may be separate.

<sup>5</sup> *T* tests for maxima (as opposed to averages) from continuous measures of physiological activation also indicate that there were no significant differences between participants who provided online ratings and those who did not.

Table 1  
Average Emotion Experience, Behavior, and Physiological Responses for the First Film Viewing for Participants Who Provided Online Ratings Versus Participants Who Did Not

Measure	First film viewing				$r^a$	$p$	Cohen's $d$
	Participants provide online ratings ( $n = 39$ )		Participants just watch ( $n = 20$ )				
	$M$	$SEM$	$M$	$SEM$			
Experience							
Whole-film ratings of							
Maximum amusement (0–8)	5.2	.40	4.8	.30	0.9	.36	.26
Maximum sadness (0–8)	5.0	.40	5.1	.30	0.2	.85	.06
Facial behavior							
Maximum ratings of							
Amusement behavior (0–8)	5.5	.30	4.6	.30	1.9	.07	.54
Sadness behavior (0–8)	4.2	.20	3.9	.30	0.8	.42	.21
Physiology							
Average cardiovascular activation ( $z$ scores) <sup>b</sup>	0.08	.09	–0.16	.13	1.5	.13	.45
Average SCL ( $\mu$ Siemens)	2.88	.26	2.59	.39	0.6	.53	.18
Average somatic activity (A–D units)	0.21	.01	0.18	.01	1.3	.18	.40

Note. SCL = skin conductance level.

<sup>a</sup> From  $t$  test for independent groups. <sup>b</sup> Composite of heart rate, reverse-scored finger pulse amplitude, reverse-scored finger pulse transit time, and reverse-scored ear pulse transit time.

–.52 to .00). Sadness experience was not correlated with somatic activation ( $r = -.07$ ), while sadness facial behavior was negatively correlated with somatic activity ( $r = -.19$ ). Variance explained ranged from 0% for experience and cardiovascular responding to 55% for experience and facial behavior (large effect size). Disattenuated correlations were considerably greater than correlations not corrected for measurement error (the disattenuated  $r$  between experience and behavior was .97; all other disattenuated  $r$ s ranged from –.58 to .00). Secondary analyses using  $r$  to  $Z$  transformations revealed that the experience–behavior correlation was significantly greater than all other correlations (all  $p$ s < .06).

*Testing Hypothesis 2: Association between emotion intensity and response coherence.* Consistent with Hypothesis 2, Table 3 shows that two measures of amusement intensity (amusement experience, rows 2–6; amusement facial behavior, rows 8–12) were moderately associated with coherence among response systems. The greater the amusement experience, the greater was coherence among measures of amusement facial behavior and peripheral physiological responding (average  $r$ s = .38,  $p$  < .01). Likewise, the greater the amusement facial behavior, the greater was the coherence among amusement experience and peripheral physiological responding (average  $r$ s = .32,  $p$  < .05). All correlations among intensity of amusement experience and behavior, on the one hand, and coherence indices, on the other hand, were positive and mostly significant ( $r$ s ranged from .21 to .48). Thus, more intense amusement experience and facial behavior were associated with greater coherence among response systems.

Contrary to Hypothesis 2, however, Table 3 (rows 14–18 and 20–24) shows that sadness experience and facial behavior were not associated with coherence among response systems. The average correlations for sadness experience and coherence between sadness facial behavior and peripheral physiological responding were .16 ( $p$  > .05); the average correlations for sadness facial behavior and coherence between sadness experience and peripheral physiological responding were .19 ( $p$  > .05). In fact, the only significant correlations ( $r$  between sadness experience and sadness facial behavior–SCL coherence = .28,  $p$  < .05, and  $r$  between sadness facial behavior and sadness experience–somatic activity coherence = .40,  $p$  < .01) were in the direction opposite to prediction. Recall that the sign of the correlations between sadness facial behavior and SCL as well as between sadness experience and somatic activity were negative; thus, a positive correlation between sadness experience and sadness facial behavior–SCL coherence and between sadness facial behavior and sadness experience–somatic activity coherence means that greater sadness intensity is associated with lower coherence. Overall, these findings indicate that intensity of sadness experience and sadness facial behavior generally were not associated with coherence among response systems.<sup>6</sup>

<sup>6</sup> Using whole-film ratings to vary intensity of emotion experience and emotion behavior yields comparable results to using maxima from continuous ratings.

Table 2  
*Testing Hypothesis 1: Average Maximum Cross-Correlations (and Disattenuated Average Maximum Cross-Correlations) at Lags of +/- 10 s for Amusement (Rows 1–3) and Sadness (Rows 4–6)*

Row	Measure	Amusement facial behavior	Cardio	SCL	Somatic activity
1	Amusement experience	.73*** (.89***) <sup>a</sup> SEM = .05	.22*** (.25***) SEM = .05	.51*** (.57***) SEM = .05	.28*** (.31***) SEM = .04
2	Amusement facial behavior	—	.34*** (.37***) SEM = .05	.47*** (.51***) SEM = .07	.39*** (.43***) SEM = .04
3	Average absolute <i>r</i> for amusement				.39 (.52)
Row	Measure	Sadness facial behavior	Cardio	SCL	Somatic activity
4	Sadness experience	.74*** (.97***) <sup>a</sup> SEM = .05	.00 (.00) SEM = .06	-.39*** (-.53***) SEM = .08	-.07 (-.10) SEM = .04
5	Sadness facial behavior	—	-.05 (-.06) SEM = .05	-.52*** (-.58***) SEM = .07	-.19*** (-.21***) SEM = .03
6	Average absolute <i>r</i> for sadness				.36 (.53)

*Note.* Each average cross-correlation presented is based on 59 within-individual cross-correlations. Cardio = cardiovascular activation (composite of heart rate, reverse-scored finger pulse transit time, reverse-scored finger pulse amplitude, and reverse-scored ear pulse transit time). SCL = skin conductance level. Significance tests were one-sample *t* tests comparing values to 0;  $n = 56-59$ , depending on missing values. Coherence among cardio, SCL, and somatic activity was assessed by calculating correlations for each pair of measures for each participant and then averaging across the within-individual correlations. As predicted by the theory of somatovisceral coupling (e.g., Obrist et al., 1970), these measures were, on average, positively correlated ( $r = .31, p < .001$ , for cardio-SCL;  $r = .42, p < .001$ , for cardio-somatic activity;  $r = .38, p < .001$ , for SCL-somatic activity).

<sup>a</sup> Experience-behavior correlations are statistically significantly greater than all other correlations (all  $p < .06$ ).

\*\*\*  $p < .001$ .

## Discussion

Many contemporary theories of emotion postulate that emotions involve coordinated changes across multiple response systems. For some theorists, this response coherence is one of the main features of emotions, as it is thought to organize an organism's response to environmental challenges (e.g., Ekman, 1972, 1992; Levenson, 1994, 2003). However, despite the centrality of the coherence postulate to many emotion theories, it has yet to garner convincing empirical support.

In the present study, we found moderate-to-high response coherence for amusement (average Pearson  $r_s = .39$ ) and for sadness (average Pearson  $r_s = .36$ ). As indicated by the disattenuated correlations (average  $r_s$  for amusement = .52; average  $r_s$  for sadness = .53), "true" coherence, controlling for measurement error in measures of experience and behavior, is probably even greater. Amusement experience and facial behavior were positively related (i.e., significantly positively correlated) to one another and to SCL, cardiovascular activation, and somatic activity. Sadness experience and facial behavior were positively related to one another but negatively related to SCL and somatic activity and not related to cardiovascular activation. Intensity of amusement was associated with the extent to which behavioral and peripheral physiological response systems cohere, suggesting that emotion response coherence increases with greater levels of amusement; intensity of sadness, however, was not associated with the extent to which behavioral and peripheral physiological response systems cohere, suggesting that emotion response coherence does not increase with greater levels of sadness.

### Methodological Implications

One of the major response components of emotion is the experiential component, and yet researchers have been unsure of how

to best assess emotion experience without disrupting the emotion in the process (Schooler & Schreiber, 2004). One finding of note is that our online rating method (which also has the advantage of providing continuous measurement of emotional experience) may be a suitable alternative to previous retrospective measures for accurately assessing emotion experience. First, our analyses suggest that participants who provided continuous ratings evidenced, on average, comparable experiential, behavioral, and physiological responding relative to participants who did not provide such ratings. Thus, the cognitive (and any motor) load added by the continuous ratings does not interfere with "natural" affective responding. Second, our findings reveal that continuous cued-recall ratings were comparable to continuous online ratings. Thus, several continuous self-report ratings can be acquired serially for the same emotion-eliciting stimulus, providing crucial information about multiple discrete emotions. Together, these findings suggest that continuous ratings are a valuable method for validly and accurately measuring emotion experience across time. In future research, the study of response system coherence as well as the study of other questions (e.g., time course of experiential relative to behavioral and physiological responding; factors affecting how emotional events are remembered) might benefit from this method.

### Implications for Emotion Theory

The present results are broadly consistent with accounts that postulate response system coherence during emotional episodes. As such, they provide evidence for one of the central tenets of a large number of emotion theories (e.g., Ekman, 1992; Frijda et al., 1992; Lazarus, 1991; Levenson, 1994; Scherer, 1984; Tomkins, 1962), namely, that emotion response systems, including subjective experience, facial behavior, and peripheral physiological responding, are associated during emotional episodes. This finding

Table 3  
*Testing Hypothesis 2: Correlations Between Coherence for Pairs of Measures and Amusement Experience, Sadness Experience, Amusement Facial Behavior, and Sadness Facial Behavior*

Row	Pairs of measures	<i>r</i>
1	Amusement experience	
2	Amusement facial behavior-Cardio	.48
3	Amusement facial behavior-SCL	.21
4	Amusement facial behavior-Act	.41**
5	Cardio-SCL	.35**
6	Cardio-Act	.31*
7	Sadness experience	
8	Sadness facial behavior-Cardio	.03
9	Sadness facial behavior-SCL	.28*
10	Sadness facial behavior-Act	.08
11	Cardio-SCL	.21
12	Cardio-Act	.24
13	Amusement facial behavior	
14	Amusement experience-Cardio	.23
15	Amusement experience-SCL	.31*
16	Amusement experience-Act	.29*
17	Cardio-SCL	.27*
18	Cardio-Act	.54*
19	Sadness facial behavior	
20	Sadness experience-Cardio	.16
21	Sadness experience-SCL	.18
22	Sadness experience-Act	.40**
23	Cardio-SCL	.03
24	Cardio-Act	.23

*Note.* Column 3 lists correlations (Pearson *r*s;  $n = 56-59$ , depending on missing values) between indices of coherence for pairs of measures (maximum cross-correlations among measures based on results testing Hypothesis 1) and maxima from continuous ratings of amusement (Rows 2-6), sadness experience (Rows 8-12), amusement facial behavior (Rows 14-18), and sadness facial behavior (Rows 20-24). For example, .48 denotes the extent to which amusement experience correlates across participants with the coherence between amusement facial behavior and cardiovascular responding. Using whole-film ratings of amusement and sadness experience instead of maxima from continuous ratings produced a similar pattern of results. Using maxima from amusement and sadness behavior instead of maxima from ratings of amusement and sadness experience to predict coherence among other measures also produced a similar pattern of results. Cardio = cardiovascular activation (composite of heart rate, reverse-scored finger pulse amplitude, reverse-scored finger pulse transit time, and reverse-scored ear pulse transit time); SCL = skin conductance level; Act = somatic activity.

\*  $p < .05$ . \*\*  $p < .01$ .

provides some support for functionalist accounts, which have relied on the claim that emotions serve to impose response coherence on emotion response systems (Ekman, 1992; Lazarus, 1991; Levenson, 1994; Plutchik, 1980; Tooby & Cosmides, 1990). Whereas the present results do not directly speak to the functionality of coherence (i.e., what coherence does for the organism), they at least provide strong evidence, essential to the functionalist perspective, that some measure of coherence exists in affective responding.

Also noteworthy is the type of response systems for which we find coherence (i.e., coherence involving socially less visible systems such as heart rate or SCL) and the relative strength of association among different response systems (i.e., experience-behavior coherence is greater than experience-physiology or

behavior-physiology coherence). These findings speak to the factors shaping response coherence. Some theories have conceptualized coherence as an evolutionarily evolved adaptive pattern with primarily biological functions (e.g., Ekman, 1992; Levenson, 1994), whereas others have conceptualized coherence as socially evolved with primarily social functions (e.g., Barrett & Campos, 1987; Cacioppo, Uchino, et al., 1992). The present results lend some support for each account. On the one hand, we find coherence in a relatively nonsocial context (film viewing by oneself) involving measures that are not highly visible socially (e.g., heart rate or SCL). This indicates that there might be a biologically evolved pattern present that is played out in response to a set of stimuli, without the presence of other individuals or socially instrumental action. On the other hand, our results are at least partially consistent with accounts that emphasize the social functions of coherence (e.g., Keltner & Haidt, 2001). As Cacioppo, Uchino, et al. (1992) noted, "externalized processes such as vocalizations, facial expressions, and overt actions are more obviously subject to forces of socialization and instrumental conditioning than are the internalized processes of visceral, humoral, and immunological responses" (p. 110). The fact that correlations between experience and behavior are greater than those between experience and physiological responding supports the view that response coherence is shaped by socialization.

#### *Boundary Conditions of Response Coherence*

Thus far, we have emphasized the extent to which response systems cohered in the context of film viewing. It is also important to note, however, that we did not obtain perfect correlations and thus might be able to identify some boundary conditions of response coherence. What factors might explain these less-than-perfect correlations? One possibility is that, on average, coherence truly might not be perfect. Indeed, there was considerable interindividual variance in degree of coherence among response systems, suggesting that response systems can be dissociated for some individuals. Exploring the boundary conditions of response system coherence provides insight into the nature and function of emotions.

One factor determining the degree of coherence might be the particular emotion. We considered the emotions of sadness and amusement at only moderate-to-high intensity levels. More prototypical emotions (e.g., fear) at greater intensities might produce even greater estimates of response coherence than those produced in the present context. A second factor that may prove important in understanding the boundary conditions of response system coherence is individual differences in emotion expressivity and emotion regulation (e.g., Ekman, 1992; Gross & John, 1997; Gross et al., 2000). It seems likely that there are a number of individual differences that would moderate response coherence. One example is regulation of facial expression of emotion, leading to varying degrees of experience-behavior association (Gross & John, 2003). Likewise, there might be individual differences in physiological reactivity or awareness of emotional responding, leading to varying degrees of experience-physiology or experience-behavior association (e.g., Brosschot & Janssen, 1998; Cacioppo, Uchino, et al., 1992; Porterfield et al., 1988).

One puzzling question is why intensity of amusement experience is associated with the coherence of behavioral and physio-

logical response systems whereas intensity of sadness experience is not. This result casts doubt on the unqualified conclusion that greater emotional intensity equals greater response system coherence. Rather, it seems to hold for amusement only. Whereas these findings must be replicated, they converge with findings from studies of emotion suppression, which show that when behaviorally suppressing positive emotions, participants self-report experiencing less positive emotions. However, when behaviorally suppressing negative emotions, self-reports of negative emotions are not lessened (Gross & John, 2003; Gross & Levenson, 1997). One possibility is that sadness, unlike fear or anger, is not associated with highly organizing fight and flight behavioral tendencies and hence involves less tightly organized emotional responses. Another interpretation of such findings is that the intensity of negative emotions is less associated with coherence than is experience of positive emotions because the expression of negative emotions has to be controlled more often in social interactions (i.e., dissociated from other responses).

#### *Limitations and Directions for Future Research*

In this study, we continuously sampled experiential, behavioral, and peripheral physiological response systems as participants' amusement and sadness responses unfolded over time. This type of study presents a number of methodological and conceptual challenges. Although we believe the present study constitutes an important first step, we also acknowledge that it has a number of limitations. In the following section, we discuss four limitations and related future research directions.

A first limitation is our focus on just two emotions—amusement and sadness—in a passive film-viewing context at moderate-to-high intensity levels. As delineated in the introduction, this focus was necessary for optimal testing of our hypotheses but limits the conclusions that can be drawn with respect to the function and the specificity of the coherence observed. Whereas the film-viewing context in a laboratory setting is well suited to an initial controlled examination of response coherence, it will be important in future research to examine the association among response systems in different contexts (e.g., contrasting coherence in nonemotional states such as startle or physical activity with coherence in emotional states; contrasting coherence in nonsocial situations with coherence in social situations; e.g., Jacobs et al., 2001). Further, constraints on subject time and energy precluded our use of a design that included either a “neutral” control condition (i.e., a film not inducing much emotion) or multiple levels of peak intensity within individuals. Although our relatively large sample size allowed us to compare coherence at different levels of emotion intensity between individuals (Hypothesis 2), in future research it will be important to vary emotional intensity within individuals. Last, it will also be important in future studies to investigate other emotions such as fear, anger, happiness, or pride to assess how our findings generalize to other emotions. Sampling a range of emotions as well as nonemotional states in multiple contexts and at several intensities will permit stronger inferences about the function and the specificity of response system coherence.

A second limitation is our use of female college students only. We focused on young women because we sought to reduce between-participants variance and because female participants typically show more variable expressive behavior (Buck, Miller, &

Caul, 1974; Gross & John, 1998). Moreover, although we included participants from different ethnic backgrounds, and secondary analyses did not reveal an effect of ethnicity on coherence, we did not formally test effects of ethnicity. Gender, age, and ethnicity might moderate the extent to which individuals tend to express feelings, are aware of their emotions, or react physiologically (e.g., Gross et al., 1997; Matsumoto & Kuppertsbusch, 2001; Pennebaker, Gonder-Frederick, Stewart, Elfman, & Skelton, 1982; Tsai, Chentsova-Dutton, Freire-Bebeau, & Przymus, 2002), suggesting that, in future studies, influences of sociocultural group membership on response system coherence should be tested.

A third limitation is our focus on a core set of peripheral physiological measures. In future work, it will be important to also examine central correlates of response coherence. If response coherence exists, there might be brain systems, “convergence zones” (Damasio, 1989, p. 127), that generate coherence by integrating and organizing multiple responses (e.g., Davidson, 1992; Hagemann, Waldstein, & Thayer, 2003; Lane & Schwartz, 1990). Recent research indeed is consistent with the existence of such hierarchically organized brain systems involving cortical and subcortical areas (e.g., Critchley, Corfield, Chandler, Mathias, & Dolan, 2000; Critchley, Elliot, Mathias, & Dolan, 2000; Saper, 2002). Clearly, however, research is just at the beginning of identifying brain systems that could represent or generate response coherence in emotions, and much more research is needed.

Finally, in future research it will be important to assess the consequences that varying degrees of coherence have for individuals' functioning. The assertion that the coherence we observed is characteristic of adaptive emotional responding implies that lower coherence might be maladaptive. Dissociation of response systems might be a mechanism underlying the harmful effects of certain types of emotion regulation such as suppression (e.g., Butler et al., 2003; Gross & John, 2003; Mauss & Gross, 2004). Whereas the present study did not allow us to test the consequences of varying levels of coherence on outcome measures such as physiological responding or well-being, the methods we developed will allow such assessments in the future.

#### *Concluding Comment*

Are emotions the tie that binds together multiple response systems? We set out to test this question using methods tailored to detect response system coherence. Our findings indeed suggest that, under these conditions, experience, facial behavior, and peripheral physiology are significantly associated. This finding provides crucial support for the coherence hypothesis and for theories that presuppose it. However, our findings indicate that coherence is not absolute, suggesting that emotion theories need to accommodate varying degrees of response system coherence. Future research needs to clarify the function, the specificity, and the boundary conditions of response system coherence, the neural mechanisms underlying response system coherence, and the consequences of varying degrees of response coherence.

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