CHAPTER TWO

Coherence of emotional response systems: Theory, measurement, and benefits

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Advances in Experimental Social Psychology, Volume 69
ISSN 0065-2601, https://doi.org/10.1016/bs.aesp.2023.11.002

Abstract

Emotions are core to the human experience, with questions about what they are going back millennia. Most psychological theorists agree that emotions involve responses in multiple systems (experience, behavior, and physiology). However, theorists disagree regarding how these responses relate to one another. Here, we propose an integrative view that predicts *some* coherence exists but that the degree of coherence and its benefits *vary* across types of coherence, people, emotions, and contexts. We begin by addressing the theoretical underpinnings of coherence, and how their implications for coherence can be integrated. Then, we outline methodological considerations for empirically testing the predictions of this integrative view. Next, we review research from the past two decades that speaks to—and generally supports—these predictions, and discuss its theoretical and well-being implications. We close by discussing directions for future research on coherence that will further advance this area of profound theoretical and practical importance.

Emotions are a central part of the human experience, and they feature prominently in philosophy, psychology, and popular discourse (Barrett, 2017a; Darwin, 1872; Nussbaum, 2001). Most theorists agree that emotions involve responses in three kinds of systems: how we *feel*, how we *behave*, and how our *bodies react* . However, we have much less clarity on how the responses in these three systems—experience, behavior, and physiology—relate to each other during emotional episodes. Are the responses in the three systems highly coordinated with each other (thus showing substantial coherence), or does each of the three systems operate independently (thus showing little coherence)? This question of *coherence* is a topic of considerable theoretical difference in the field.

One theoretical view (here referred to as the *latent view*) maintains that (1) during an emotion, multiple response systems become synchronized and show substantial coherence, and (2) greater coherence contributes to beneficial outcomes for the individual (e.g., Ekman, 1992; Levenson, 2003). The other view (here referred to as the *emergent view*) maintains that response systems usually do not cohere during emotions (e.g., Russell, 2003). Our understanding of coherence serves as a critical foundation for how we think about emotions, with important implications for understanding what emotions are, what functions they serve, and how we measure them.

In this review, we aim to clarify our understanding of coherence and propose an integration of the two views of coherence.[1] In Section 1, we begin by describing the latent and emergent views of emotion and their implications for coherence. We then propose how the two views can be reconciled and integrated based on recent theorizing and research, leading to a more comprehensive and nuanced understanding of coherence. In Section 2, we lay out the major conceptual and methodological foundations for how to study coherence. In Section 3, we summarize empirical evidence regarding coherence. In Section 4, we discuss important methodological, theoretical, and well-being implications of our review and analysis and, in Section 5, we discuss directions for future research.

1. Do emotion response systems cohere? Two divergent views and a reconciliation

What is an emotion? In modern psychology's answers to this question, many perspectives converge on the idea that emotions involve the whole organism, including experience, behavior, and physiology (see Kleinginna & Kleinginna, 1981; Lang, 1988; Mesquita et al., 2003; Scherer, 1984; Tomkins, 1962). The idea that emotions involve multiple response systems, or types of responses, cuts across different traditions in affective science, including biological-evolutionary, appraisal, and social-constructivist theories (Kleinginna & Kleinginna, 1981). The most commonly represented emotion response systems[2] in psychological science are experience, behavior, and peripheral physiology.[3] Experience refers to the qualia of having an emotion; what it feels like to be angry, sad, or happy, for instance (Coan, 2010; Russell, 2003). Behavior refers to overt behaviors, including facial (e.g., raising of the lips),

[1] Here, we use the term coherence to refer to emotion response system coherence. Different terms have been used for the phenomenon, including response component syndromes (Averill, 1980; Reisenzein, 2000a), organization of response tendencies (Lazarus, 1991; Levenson, 1994), coherence (Ekman, 1992; Mauss et al., 2005), organization of response components (Frijda et al., 1992; Scherer, 1984), concordance (Hollenstein & Lanteigne, 2014; Lang, 1988; Wilhelm & Roth, 2001), and synchrony (Danyluck & Page-Gould, 2019). We use coherence here as it is relatively value neutral and accommodates various types of organization and dynamics.

[2] We use the term *emotion response systems* to refer to the various responses that can occur during emotions. We note this does not imply that these responses are specific or unique to emotion; rather, they are involved in other psychological and behavioral responses as well (see Barrett, 2017b; Cunningham, Dunfield, & Stillman, 2013).

[3] We do not consider central nervous system activation a response system in this context, because the various emotional responses are instantiated and represented in it.

vocal (e.g., tone of voice), whole-body (e.g., pumping one's fists in the air and raising one's chin), and instrumental ones (e.g., striking someone; Fridlund et al., 1987; Keltner et al., 2019). Peripheral physiology refers to autonomic physiology (e.g., heart rate, blood pressure, or vagal tone), endocrine responses (e.g., cortisol), and somato-visceral responses (e.g., muscle tension, stomach churning; Levenson, 2003; Mendes, 2016).

While emotion theorists agree that emotions involve several response systems in some way, shape, or form, different theories diverge sharply in terms of how they assume different types of responses relate to one another. Theories can be aligned along a gradient of coherence they imply, that is, the degree to which responses are thought to become synchronized when a person is emotional. To illustrate this gradient of coherence, consider two people, Person A and Person B, who are both experiencing anger. Person A displays angry behaviors (e.g., a furrowed brow and a raised voice) and has physiological responses associated with anger (e.g., increased heart rate and blood pressure). In contrast, Person B displays behaviors not associated with anger (e.g., a friendly smile) and does not have physiological responses associated with anger (e.g., no change in heart rate or blood pressure). In this example, Person A shows more coherence (i.e., their experience, behavior, and physiology align) than Person B (i.e., their experience does not align with either their behavior or their physiology).

Table 1 provides examples of prominent theories of emotion and their implications for emotion response system coherence. The table is organized along the gradient of coherence, ordering theories from relatively more to relatively less coherence. The theories at the top of Table 1 assume greater coherence and can be subsumed under the umbrella of latent emotion theories, as proposed by Coan (2010). In contrast, the theories at the bottom of the table assume less or no coherence and can be subsumed under the umbrella of emergent emotion theories (see Coan, 2010). In the next sections, we outline how emotion theories in the latent and the emergent grouping conceptualize emotion coherence and its functions. Then, we propose an integration of these theories.

1.1 Latent theories of emotions and coherence

As summarized in the upper part of Table 1, several emotion theories suggest responses should cohere rather tightly with one another (Ekman, 1977; Ekman, 1992; Lazarus, 1991; Levenson, 1994, 2003; Scherer, 1984; Tomkins, 1962). These theories are similar in that they presume a causal (or latent) emotion mechanism that, once activated, coordinates multiple

Table 1 Major theories of emotions and their views on emotional response coherence, ordered by gradient of stronger versus weaker coherence.

View on coherence of response systems

James (1884, pp. 189–190)	"My thesis… is that the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion."
Watson (1924, p. 195)	"An emotion is a hereditary 'pattern-reaction' involving profound changes of the bodily mechanism as a whole, but particularly of the visceral and glandular systems."
Dolan (2002, p. 1191)	"Emotions are embodied and manifest in uniquely recognizable, and stereotyped, behavioral patterns of facial expression, comportment, and autonomic arousal."
Darwin (1872/1965, pp. 349–350)	"Actions of all kinds, if regularly accompanying any state of mind, are at once recognized as expressive. (...) That the chief expressive actions, exhibited by man and by lower animals, are now innate or inherited, –that is, have not been learnt by the individual, –is admitted by every one."
Bowlby (1969, p. 104)	"Emotions are phases of an individual's intuitive appraisals either of his own organismic states and urges to act or of the succession of environmental situations in which he finds himself."
Tooby and Cosmides (2008, pp. 117–118)	"An emotion is a superordinate program whose function is to direct the activities and interactions of the subprograms governing perception; attention; (…) physiological reactions (such as heart rate, endocrine function, immune function) (…) behavioral decision rules; motor systems; communication processes; energy level and effort allocation; affective coloration of events and stimuli; … and so on. (...) Each emotion entrains various other adaptive programs—deactivating some, activating others, and adjusting the modifiable parameters of still others—so that the whole system operates in a particularly harmonious and efficacious way when the individual is confronting certain kinds of triggering conditions or situations."

(*continued*)

Table 1 Major theories of emotions and their views on emotional response coherence, ordered by gradient of stronger versus weaker coherence. (*cont'd*)

View on coherence of response systems

Ekman (1977, p. 59)	"Emotion refers to the process whereby an elicitor is appraised automatically or in an extended fashion, an affect programme may or may not be set off, organized responses may occur, albeit more or less managed by attempts to control emotional behavior."
Levenson (1999, p. 481)	"Physiologically, emotions rapidly organize the responses of disparate biological systems including facial expression, somatic muscular tonus, voice tone, autonomic nervous system activity, and endocrine activity to produce a bodily milieu that is optimal for effective response."
Lazarus (1975, p. 554)	"I define and analyze emotion as a complex disturbance that induces three main components: subjective affect, physiological changes related to species-specific forms of mobilization for adaptive action, and action impulses having both instrumental and expressive qualities."
Ellsworth et al. (1994, pp. 192–193)	"Usually the process of emotion (…) is initiated when one's attention is captured by some discrepancy or change. When this happens, one's state is different, physiologically and psychologically, from what it was before."
Gross (2015, p. 3)	"Emotions involve loosely coupled changes in the domains of subjective experience, behavior, and peripheral physiology."
Lang (1988, p. 177)	"The three data subsystems in emotion [verbal reports of experience, behavior, and visceral-somatic activation] are only loosely coupled, presenting a variable configuration within and between subjects and contexts."

Mesquita (2003, p. 872)	"Different emotion components do not automatically follow from each other. Each has its particular determinants, in addition to the occurrence of an emotionally charged event. The components tend to influence, but not fully determine, each other."
Coan (2010, p. 274)	"Emotions do not cause, but rather are caused by, the measured indicators of emotion, assuming no executive neural circuit or network, and requiring no covariation among indicators."
Russell (2003, p. 152)	"Each of the components listed can occur alone. Sometimes, pairs or larger groupings of components occur. Occasionally, the various events happen to co-occur in a pattern that fits the prototype. Because of dissociations among the components, a huge variety of combinations occur, which therefore vary in their resemblance to the prototype. There are many ways to resemble the prototype."

responses, thus yielding coherence (see Fig. 1 for a schematic depiction). However, they differ in the nature of the mechanism they postulate, falling roughly into three groups (see Barrett, 2017b): (a) basic emotion theories (e.g., Ekman, 1992; Keltner et al., 2019; Tracy & Randles, 2011), which invoke a biological-evolutionary mechanism, (b) appraisal theories, which invoke a cognitive mechanism (Ellsworth et al., 2003; Frijda, 1988; Lazarus, 1991; Roseman, 2011; Scherer, 1984), and (c) functionalist theories of emotion, which leave the exact mechanism unspecified (Anderson & Adolphs, 2014; Davis, 1992).

The latent view of emotion – and its implications for coherence – is illustrated by Coan (2010) with the example of a bear charging at a person in the wilderness (see also Bollen & Lennox, 1991; De Houwer, 2011, for a discussion of similar ideas). "The latent variable model argues that the charging bear activates "fear," which in turn activates the subjective, physiological, and behavioral sequelae of that fear" (p. 279). Given there is *one* central mechanism that causes *all* sequalae, we would expect relatively high levels of coherence during emotions according to these theories. We might make three additional predictions based on the latent view of emotions. First, we might expect that the more intensely the central mechanism is activated the greater coherence becomes; that is, coherence should increase with increasing emotional intensity. Second, given the system is driven by one central mechanism, we might expect coherence to operate in an all-or-none manner, such that coherence is absent or present across the whole organism, regardless of the particular response system involved (i.e., there should be experience-behavior, experience-physiology, and behavior-physiology coherence to equal amounts). Third, we

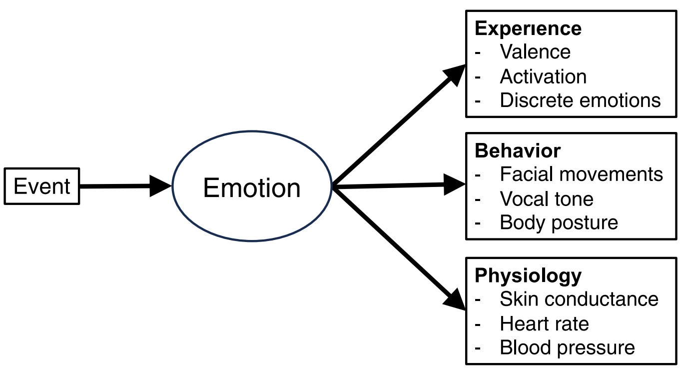

Fig. 1 Schematic of the latent view of emotions with examples for indicators of experience, behavior, and physiology. Arrows represent causal direction.

might expect coherence to be invariant, that is, not affected by the particular emotion, person, or context (cf. Davidson, 1992).

An important corollary of the idea that emotions involve coherent responses is that coherence is beneficial—that is, greater coherence is associated with benefits for the individual such as better functioning or greater well-being (Brown et al., 2020; Ekman, 1992; Lazarus, 1991; Levenson, 2003, 2014; Plutchik, 1980). The idea is that emotions coordinate responses across systems and impose coherence, thus allowing people to deal efficiently with important challenges and tasks. Levenson (2003) illustrated this idea in the context of the autonomic nervous system (ANS) responding in emotions: "Like a modern factory that subscribes to the "just in time" model of inventory control, the ANS 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" (Levenson, 2003, p. 350).

In the example above, our hypothetical Person A (high coherence) should be able to deal more effectively with the angering event than Person B (low coherence) because (a) they show anger in their face and gestures, thus communicating their experience of anger more directly and accurately to others, and (b) their physiology supports activation, allowing them to vigorously address the anger-eliciting event. Over time, repeated instances of coherent emotional responses and the accompanying effective addressing of challenges should accumulate to better functioning, social relationships, and well-being. We can thus think about coherence at the state level (instances with more coherent responses should be associated with greater benefits than instances with less coherent responses) or at the individual-differences level (people who tend to exhibit more coherent responses should experience greater benefits than people who tend to exhibit less coherent responses).

The idea that coherence is beneficial stems from the theoretical background that emotions have evolved because they serve particular functions (Darwin, 1872). Specifically, evolutionary-biological theories argue that emotions have evolved in part because they impose coherence across response systems, which helps people respond quickly and effectively to important challenges in their ancestral environments and thus survive, reproduce, and thrive (Ekman, 1992; Keltner et al., 2019; Levenson, 2014; Plutchik, 1980; Tooby & Cosmides, 2008). For example, Tooby and Cosmides (2008, p. 117) write: "Thus each emotion evolved to deal with a particular, evolutionarily recurrent situation type. The design features of the emotion program, when the emotion is activated, presume the presence of an ancestrally structured situation type (regardless of the actual structure of the modern world)."

Overall, then, latent theories predict that coherence across response systems should be substantial, and that coherence is generally beneficial. However, on closer view, these theories allow for nuance, and this simple conclusion might require some qualifications. For one, a response system that is inflexible and invariant at all levels would not be very useful (Davidson, 1992; Scherer, 1984; Tooby & Cosmides, 2008). Indeed, looking more closely at Fig. 1 we see that each response system consists of multiple subsystems, such as facial movements, vocal tone, and body posture for the behavioral response system. Clearly, these three subsystems differ in their responsiveness, and we would not expect them to all be perfectly coherent in all emotions and all circumstances. This suggests nuance, to which we will return after contrasting latent theories with emergent theories of emotions.

1.2 Emergent theories of emotions and coherence

On the other end of the spectrum, as shown in the lower part of Table 1, several emotion theories lead to the prediction that responses do not or only minimally cohere during emotional episodes. At their core, these theories differ from the latent theories in denying the existence of a "central" or "latent" emotion mechanism that gives rise to coherent responses. Rather, as illustrated in Fig. 2, they view emotions as emerging, or being constructed

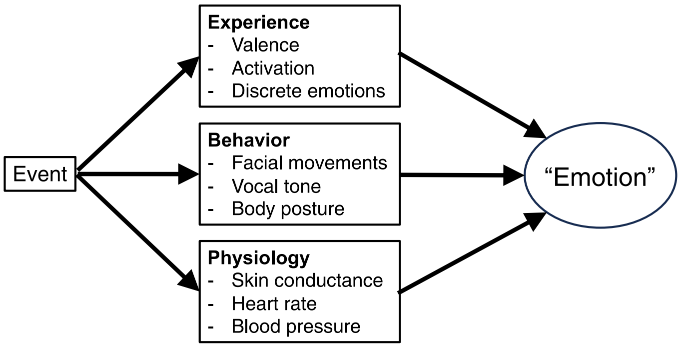

Fig. 2 Schematic of the emergent view of emotions with examples for indicators of experience, behavior, and physiology. Arrows represent causal direction. Emotion is in quotes to indicate that it emerges in people's perception when multiple indicators are perceived to resemble an emotion.

from, multiple responses that do not inherently or necessarily cohere (Boiger & Mesquita, 2012; Lindquist, 2013; Mesquita et al., 2003; Russell, 2003), which is why they are sometimes referred to as emergent theories (Coan, 2010). Usually, but not necessarily, these theories fall in the category of social-constructivist theories (cf. Crivelli & Fridlund, 2019).

For example, someone who is angry might physically assault the other person, yell at a bystander, stew in silence, try to escape a confrontation, or smile in a conciliatory way (Barrett et al., 2019). In each case, the person would still be angry, but we would not expect coherence given these quite different patterns of behavior. Conversely, similar configurations of facial movements can express instances of more than one emotion category. A smile can mean someone feels happy, nervous, angry, or not emotional at all but is only polite, depending on the person or the situation. It is possible that responses, *when they cohere*, are more likely to be labeled as an emotion but this is because they correspond to lay beliefs about emotions, not because the emotion inherently involves coherence: "Prototypical emotional episodes are coherent packages, not because they stem from one mechanism, but because they are just those cases selected by an observer on the basis of their resemblance to a coherent package: the folk concept" (Russell, 2003, p. 152).

Going back to the example of the charging bear, Coan (2010) illustrates the emergent view (pp. 179–180):

> *In the emergent variable model, no fear circuit is necessary. The bear charges, the brain perceives a number of unique problems that require solving, and the problem-solving ensues: First, and possibly foremost, the bear must be avoided, and avoidance-based behavioral action plans are formed. Second, the body must become physiologically prepared for quick and vigorous action, and ANS [autonomic nervous system] arousal meets that need. Third, elements of the experience must, by virtue of their life-threatening intensity, be tagged as highly salient in memory, resulting in amygdala activity. Finally, the ensemble of activity is experienced in consciousness (possibly at a later time) as a state of fear. If this pattern of responding resembles the classic fear prototype, the emergent variable model suggests it is elements of the situation, not a latent executive affect program in the brain, that determine their coactivation. One might fear bears and see one in the zoo, causing the brain to create a subjective experience that one might call fear, as well as salience tagging by the amygdala, but relatively little or no ANS arousal or avoidance behavior. The emergent variable model suggests this would simply be because the situation does not call for those problems to be solved, whereas latent variable models must posit some continuum of fear-circuit activity that would be, one presumes, on something like "low alert" at the zoo, and "high alert" in the wilderness.*

What do emergent theories say about possible benefits of coherence? On the whole, they do not expect coherence to be beneficial, because if emotions generally do not involve coherence, it makes less sense to assume coherence serves a function. Overall, then, emergent theories predict little or no coherence and few if any benefits of coherence. However, as we discuss next, on closer view these theories also allow for nuance.

1.3 Integration: Implications of the latent and emergent views for coherence

At an initial glance, the two types of emotion theories lead to starkly different predictions: The latent view predicts substantial, all-or-none, and invariant coherence that is generally beneficial, whereas the emergent view predicts no or minimal coherence and no benefits. At second glance, however, qualifications to both kinds of emotion theories allow us to reconcile their implications for coherence and its benefits.

Starting with latent views, they do not necessarily predict that responses *perfectly* and *always* cohere. In other words, they do not necessarily presume an all-or-none, invariant principle, such that one mechanism (or central organizing module) coordinates all aspects of emotion to the same degree, equally in all people, and across all situations. After all, such an inflexible organization makes little sense from a biological-evolutionary perspective (Davidson, 1992; Tooby & Cosmides, 2008). For example, in discussing coherence between behavior and physiological responses, Ekman (1992) indicates several qualifications (Ekman, 1992, pp. 184–185, Ekman's emphasis): "I propose that when we examine individuals who have not chronically or at the moment tried to inhibit their feelings or expression, we will find that there is *some* coherence, some systematic relationship (…) during emotional events (…). I am positing that the autonomic responses and expressive changes are not, by nature, disconnected, although there will be large individual differences, some constitutional and some based on social learning." We see that once we go beyond the simple core of the latent view, it does not necessarily presume an all-or-none principle but rather that coherence is imperfect and varies across people and contexts.

Conversely, emergent views do not necessarily predict that responses are *always* and *completely* unrelated (see Mesquita et al., 2003). Rather, they allow for coherence to emerge under certain circumstances. First, certain environmental challenges ("events" in Fig. 2) may pull for and give rise to coherent responses (see De Houwer, 2011). To the extent that key challenges humans often encounter are patterned to evoke coherent responses, we can imagine that the emotions that *emerge* in these contexts would involve coherent responses. Take Coan's (2010) example of encountering a bear in the zoo as opposed to wilderness. A person might not feel full-blown fear but feel nervous when seeing that the fence to the bear enclosure is a bit flimsy, which might lead them to prepare to flee—with slightly elevated heart rate—should it become necessary.

More generally, our environments are not random but instead patterned in ways that can engender coherence. For example, situations in which we feel fear tend to cluster with situations in which we alert conspecifics to danger and also prepare to flee or freeze (rather than other behaviors). In other words, environments with recurrent challenges might lead to probabilistic coherence, in general and on average, because they pull for and give rise to coherent responses. Thus, researchers should find coherence as a function of the environment, not as a function of a central mechanism within the person. In this way, recurring environmental challenges might call for coordinated responses, and we can expect *emergent coherence*.

A second way in which emergent views allow for coherence is that they often assume *core affective dimensions*—that is, basic, biologically meaningful dimensions that may organize responses in a coherent matter (Barrett & Bliss-Moreau, 2009; Davidson, 1992; Lindquist, 2013; Panksepp, 2007). For example, we might find coherence along the "core affect" dimensions of valence or activation. Given that emotions vary systematically along these dimensions (e.g., fear is negative in valence and highly activating; Cowen & Keltner, 2021; Lang et al., 1993), this would then lead to coherence during emotions. For example, encountering a bear might not lead to fear per se but to a negative, highly-activating state involving coherent responses in experience, behavior, and physiology.

To sum up, qualifications to both latent and emergent views of emotion lead to converging predictions regarding coherence, which form the basis of an integrated view of coherence. First, on average we should not expect coherence to be completely absent or to be perfect. This idea is expressed in views of coherence that fall in the middle of the spectrum in Table 1. For example, several theorists have referred to emotions as involving "loosely coupled" response systems (Gross, 2015; Lang, 1988).

Second, we should expect differences across types of coherence depending on the response system (and within response system depending on the indicator) involved; some domains (e.g., those that share more features and that are psychologically more similar) should cohere more tightly than other domains (e.g., those that share fewer features and that are psychologically more dissimilar; Bradley et al., 2000; Lang, 1988). For example, we could expect experience and behavior to cohere more tightly than experience and physiology because the first two of these response systems are relatively more deliberative than most physiological responses (e.g., Evers et al. (2014)). Another way in which behavior and physiology differ is in terms of their visibility and, thus, also vary in their signal value to others, again implying coherence involving behavior would differ from coherence involving physiology.

Third, we should expect variation in coherence across people and contexts depending on the extent to which emotions are influenced by factors extraneous to the emotion. Certain types of emotion regulation, certain sociodemographic and individual differences, and certain situations might lead to variation in coherence to the extent that they modify select response systems. For example, display rules or expressive suppression might alter behavior but not experience (Ekman & Friesen, 1969; Gross & John, 2003; Gross et al., 2000), thus lowering experience-behavior coherence. As another example, "individual response stereotypy" (Lacey, 1967), or, individual differences in response profiles across different physiological subsystems (e.g., cardiovascular, electrodermal, respiratory, neuromuscular), could lead to lower experience-physiology coherence.

What does an integration of the two views say about functions of coherence? Even if we are agnostic about whether emotions are responses to latent causal mechanisms or emerge from properties of the environment, there are plausible reasons to think that coherence has benefits for people. For example, social-functional accounts argue that emotions serve the important functions of creating and maintaining social connection, influencing others, getting help from others, and coordinating interactions (Frijda et al., 1994; Keltner & Haidt, 1999; Niedenthal & Brauer, 2012). They build on the idea that emotions are private as well as social (e.g., Crivelli & Fridlund, 2019; Fenigstein et al., 1975; Zerwas et al., 2021). While emotions are private in that others do not have direct access to a person's internal emotional experiences, they are also social in that others can view, interpret, and respond to a person's emotional *displays*.

Emotions serve these crucial social functions better when they are successfully and accurately communicated to others, and greater coherence between experience and behavior constitutes successful communication. Thus socio-functional accounts—consistent with either latent or emergent views—lead to the prediction that coherence should carry benefits. As described by Barrett (2006, p. 49): "Many cultures may have similar basic-level emotion concepts, not because these categories have some biological priority, but because these concepts are optimal tools for communicating in the kind of social environment that humans typically occupy (living in large groups with complicated relational rules)."

Thus, coherence might have benefits, whether it arises as a response to a latent causal mechanism or to the structure of the environment. However, in this view, the benefits—just like coherence itself—are not an all-or-none consequence of coherence. When we see emotion coherence as flexible, variable, and embedded in particular contexts, it should have benefits as a function of particular constellations of coherence and context. For example, communication of emotion through experience-behavior coherence but not through experience-physiology coherence should have benefits in social contexts, and it should have these benefits via social pathways.

Thus, qualifications to the 'pure' latent and the 'pure' emergent view both lead to the prediction of some coherence some of the time. In the qualified latent view, coherence is a core postulate, with some (but not perfect) coherence being a necessary outcome of latent theories of emotion. For the qualified emergent view, coherence is a possible, even likely, outcome—but not a necessary one, and if it emerges, it is caused by structure in the environment (to which humans have adapted), rather than by an internal process located in the person. While coherence is a theoretical given in the latent case, and an empirical possibility in the emergent case, both views lead to the conclusion that we should find some coherence. Conversely, if we find coherence this does not *necessarily* imply that emotions have a causal, central mechanism. Although most theories that favor coherence have come from the biological-evolutionary, latent view and those who are skeptical of coherence have come from the social-constructivist, emergent view, this mapping is not necessary.

In conclusion, we have proposed how the two major views of coherence can be reconciled with one another. The resulting integrated view of coherence is agnostic regarding the existence of a central causal mechanism. It predicts (a) response systems to cohere but only loosely so, (b) variation in coherence depending on the response system involved, (c) substantial individual and situational variation in coherence, and (d) some types of coherence to engender some benefits in some contexts. These ideas have crucial implications for understanding what emotions are, what functions they might serve, and how we can measure them. Before we turn to the empirical evidence regarding coherence, we discuss methodological considerations for how it can be studied.

2. Methodological considerations: How can emotion response system coherence be studied?

The investigation of coherence is fraught with conceptual and methodological issues (see Bonanno & Keltner, 2004; Butler et al., 2014; Hollenstein & Lanteigne, 2014; Levenson & Gottman, 1983; Levenson, 2014; Rosenberg & Ekman, 1994). These issues have obscured insights into coherence and its implications for affective science. Therefore, we next consider key methodological considerations both in designing new studies of coherence and in interpreting the results of existing studies.

In Table 2, we give an overview of these issues, each formulated as a question paired with a proposed answer that represents what we consider the currently best research practice. To help researchers in this area, we go into detail in the following section. Readers less interested in the full detail may want to review the questions and proposed answers in Table 2 and then proceed to the empirical review in Section 3.

2.1 Should coherence be measured with between-person or within-person approaches?

A first, fundamental consideration is whether coherence is conceptualized and measured at the *between-person* or the *within-person* level (Cacioppo et al., 1992; Levenson, 2014; Reisenzein et al., 2013). The between-person approach to measuring coherence is illustrated in Fig. 3, Panel A. For example, researchers have studied whether a person who experiences more emotion *relative to other people* also exhibits a greater behavioral response, again *relative to other people*. The alternative approach is to measure the strength of association between different response systems *within* a person and across time. This is illustrated in Fig. 3, Panel B. For example, a researcher might test whether a person shows greater behavioral responding in time periods when they experience greater emotion experience, relative to time periods when the same person experiences lower levels of emotion. Panel A of Fig. 4 shows relatively higher within-person coherence between two responses, whereas Panel B of Fig. 4 shows relatively lower within-person coherence.

Both approaches yield interesting insights and at first glance, they might appear to give similar kinds of information. However, as several researchers have noted, between-person approaches might not be well-suited for measuring coherence, for three key reasons (Levenson, 2014; Mauss et al., 2005; Reisenzein, 2000a; Ruch, 1995). First, between-person approaches

Table 2 Overview of methodological questions in research on coherence, with proposed answers.

Methodological question	Answer with key reasons
2.1 Should coherence be measured with between-person or within-person approaches?	Within-person measures are better suited to measure coherence, for methodological and conceptual reasons. Among within-person measures, cross-correlations provide several advantages, including robustness to non-stationarity and accounting for varying lags.
2.2 Should coherence be measured with systemwide or pairwise approaches?	Pairwise approaches are preferred because they provide greater nuance and flexibility.
2.3 What experimental and research-design factors need to be considered?	Coherence can be studied in a number of contexts, driven by the particular questions asked. Laboratory experiments are often well-suited because they allow high control over the emotional context and comparison conditions.
2.3.1 In what emotional contexts should we measure coherence?	Emotional film clips are optimal for measuring coherence, because they induce a wide range of intense and dynamically changing emotions in a standardized way. However, other emotion inductions can be well suited, as long as they induce intense, prolonged, and variable emotion.
2.3.2 What comparisons are informative?	• Compare coherence to 0, to effect size metrics, or to random pairings: This tells us whether coherence is present according to different criteria. • Compare coherence during emotions to coherence during neutral states: This tells us whether coherence is specific to emotion. • Compare coherence during emotions to coherence during other affective states: This tells us whether coherence is specific to emotion. • Compare coherence during more intense to coherence during less intense emotions: This tells us whether coherence increases with emotion intensity. • Compare coherence during different ways of inducing emotions: This tells us whether coherence is specific to particular ways of inducing emotions versus the emotion itself. • Compare coherence in different contexts (e.g., social versus non-social): This tells us how context-dependent coherence is.

(*continued*)

Table 2 Overview of methodological questions in research on coherence, with proposed answers. (*cont'd*)

Methodological question	Answer with key reasons
2.4 Which response systems should we measure and how should we measure them?	In general, more is better: More systems, more indicators within each system, and more frequent assessment to capture dynamic changes in emotion. All measures should be obtained concurrently with one another and while a person is emotional.
2.4.1 Experience	Rating dial approaches are optimally suited to capture ongoing experience (e.g., intensity of valence, arousal, or discrete emotions).
2.4.2 Behavior	Different questions require different behaviors to be captured, and we should go beyond coding only facial movements to also capture other behaviors such as vocal and whole-body aspects.
2.4.3 Physiology	Different questions require different physiological responses from different organs (e.g., cardiovascular, electrodermal, respiratory) to be captured; some indicators are purer reflections of underlying ANS patterns (e.g., pre-ejection period for sympathetic activation, high-frequency heart rate variability for parasympathetic activation), but their temporal resolution is lower than e.g., heart rate or skin conductance.
2.5 Practical steps: How do we get from time series to coherence indices?	In the final steps, we consider what temporal resolution of measures to choose, how to deal with lags among measures, and how to select an index of coherence. A 1-second resolution and a lag window of +/− 10 s are recommended, and the maximum cross-correlation is the best indicator of coherence.

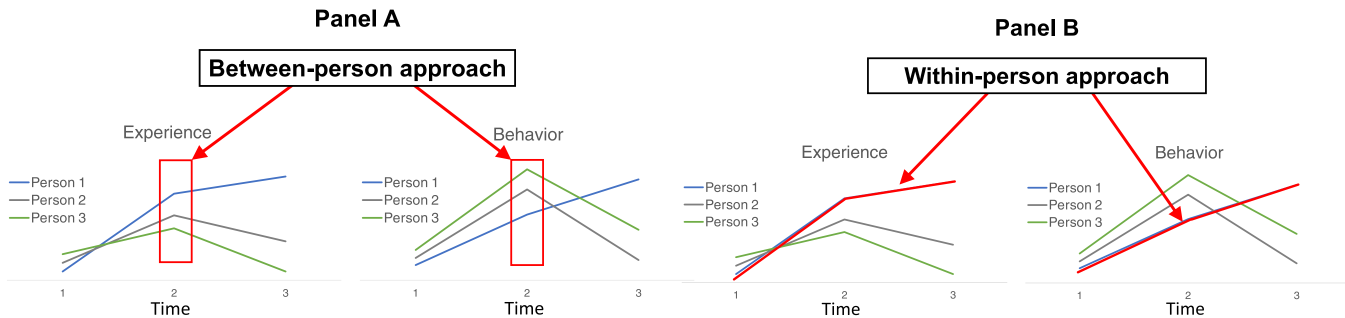

Fig. 3 An illustration of the between-person approach (Panel A, left) and the within-person approach (Panel B, right) to coherence. Although the same data are presented in Panels A and B, taking the between-person approach (Panel A) we would find lower coherence, because at Timepoint 2 Person 1 is the highest in experience but the lowest in behavior. Taking the within-person approach (Panel B) we would find higher coherence on average because Person 1 increases in experience and behavior across the three time points and Persons 2 and 3 show a consistent increase-decrease pattern in both experience and behavior. *Note*. The red line in Panel B illustrates the within-person approach for Person 1.

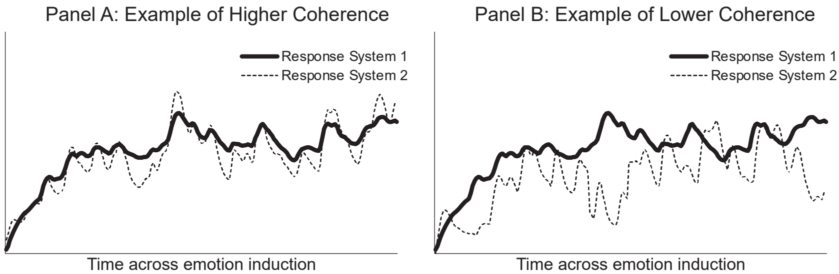

Fig. 4 Examples of higher coherence (Panel A, left) and lower coherence (Panel B, right) using the within-person approach. *Note.* Solid versus dotted lines indicate two different response systems (e.g., experience, behavior) over time during an emotion induction. The panel on the left indicates higher coherence, because the two response systems are more tightly linked across time; the panel on the right indicates lower coherence, because the two response systems are not as tightly linked across time.

are subject to between-person variance and confounds, which might obscure true coherence. Second, between-person approaches rely either on a single point in time or on averages over longer periods of time. When looking at Fig. 3, we can see that if we look at only one time point or averages across the three time points, we would lose important information about changes across time, and points of coherence versus dissociation would be missed (Kahneman, 2000). Third, between-person approaches essentially require participants to rate their experiences relative to other people or to other events, which might be difficult to do. Methodologically, thus, between-person approaches might not be optimal for capturing coherence.

The within-person approach is methodologically better suited to measure coherence, for three reasons. First, it avoids between-person variance and confounds. Second, it allows for more precise capturing (and a closer matching) of dynamic and fast changes in the response systems, as illustrated in Fig. 4. For example, a person whose emotion experience and behavioral expression align at the beginning and end of a stressful speech, when anxiety is highest, but less so during the middle of the speech, when anxiety is lower, would show greater within-person coherence because this approach tracks dynamic changes rather than averaging across the whole period. Honoring the time course of emotions unfolding in time, as within-person approaches do, allows us to capture coherence more completely. Such ratings might also be easier to complete because they provide participants with proximal and direct comparison points. Third, the within-person approach provides coherence measures for each individual person and thus allows one to model individual differences in coherence. As discussed above, the integrative coherence view predicts that people should systematically vary in the strength of coherence, and within-person approaches can test these ideas.

Indeed, research that has taken the between-person approach has been inconsistent. For example, using this approach in different kinds of emotion inductions researchers have found *experience-behavior* coherence ranging from small and negative (e.g., Johnson et al., 2010) to large and positive (e.g., Ruch, 1997) with many estimates falling in between (e.g., Gross et al., 2000; Herring et al., 2011; Lang et al., 1993; Mauss et al., 2004; Mehu et al., 2007; see, for a review, Reisenzein et al., 2013). Studies of *experience-physiology* coherence with this approach have similarly typically resulted in weak or nonexistent effects (Grossman et al., 2001; Hodgson & Rachman, 1974; Mandler et al., 1961; Mauss et al., 2003, 2004; Stemmler et al., 2001; see, for a review, Cacioppo et al., 2000).

In addition to methodological considerations, there are conceptual reasons to favor within-person approaches. Within-person associations more closely denote coherence as conceptualized by the theories of emotion outlined above, namely that emotions involve coherence of responses *relative to non-emotional states*. This phenomenon happens within a person and across different points in time (Cacioppo et al., 1992; Reisenzein et al., 2013; Stemmler, 1992). As has been shown by several researchers, between-person associations do not necessarily reflect within-person processes (Fisher et al., 2018; Molenaar & Campbell, 2009). Fig. 3 illustrates this idea for the case of coherence: We can see that the between-person approach depicted in Panel A would yield lower coherence while the within-person approach to the same data depicted in Panel B would yield higher coherence.

In sum, for methodological and conceptual reasons, within-person approaches are better suited for measuring coherence than between-person ones.

2.2 Should coherence be measured with pairwise approaches or for all three systems at once?

The second question to address is whether to measure coherence holistically and across more than two systems with multivariate approaches or on a pairwise basis. In other words, do we characterize coherence across experience, behavior, and physiology at once or separately for the three pairings of experience-behavior, experience-physiology, and behavior-physiology? Several multivariate approaches exist that measure within-person coherence for more than two variables. For example, researchers have used a network approach to characterize emotional coherence across 15 variables at once (Hsieh et al., 2011) and

Multidimensional Recurrence Quantification Analysis to quantify coherence in multivariate time-series data (Wallot et al., 2016).

While these approaches give insight into overall within-person coherence and its properties, they are not optimally suited to tease apart different types of coherence (e.g., experience-physiology versus experience-behavior). This is an important limitation, in that the integrative coherence view predicts that coherence is not an all-or-none process with uniform functions but rather that (a) different types of coherence differ from one another and (b) their functions vary depending on the response systems involved (Cacioppo et al., 1999; Evers et al. (2014); Keltner & Haidt, 1999; Levenson, 1999; Mauss et al., 2005; Rachman, 1978). So, for example, we can imagine that a person has high experience-physiology coherence but low experience-behavior coherence, and that experience-physiology coherence has different functions from experience-behavior coherence. Pairwise measures have the advantage that they allow us to study these different types of coherence.

In terms of pairwise measures, several approaches are possible. Many researchers have used cross-correlations (e.g., Brown et al., 2020; Butler et al., 2014; Dan-Glauser & Gross, 2013; Mauss et al., 2005; Saito et al., 2023; Sze et al., 2010). These correlations are computed between two time series at varying lags (e.g., Time Series 1 correlated with Time Series 2 at lag 0, 1, 2, and 3 s). Accounting for lags is important because some emotional responses react more slowly than others (for example, blood pressure reacts more slowly than facial behavior). If researchers did not account for lags, true but lagged coherence would be obscured. In addition, cross-correlations can handle time series data that are expected to be non-stationary, with mean and variance varying over time as people's emotional responses become more or less intense. Lastly, cross-correlations capture between-variable associations that occur due to shared mean, slope, variance, oscillations, or momentary fluctuations, and thus encompass a wide range of potential shared dynamics (Butler et al., 2014).

A related approach has used random-order presentation of short emotional film clips and averaging of responses to each film to calculate a within-subject nonparametric correlation index for each pair of variables (Rattel et al., 2020). This analytic approach is preferred when data cannot be collected with a high enough temporal resolution such as in this case, where experience ratings were obtained at the end of each film.

In sum, it is important for conceptual reasons to measure pairwise coherence, and, while multiple approaches are feasible, cross-correlations provide an overall accurate and productive approach for doing so.

2.3 What experimental and research-design factors need to be considered?

A third methodological set of considerations is in what experimental contexts to measure coherence as well as, just as important, what comparison conditions to include.

2.3.1 In what emotional contexts should we measure coherence?

Most basically, measuring coherence during emotions requires that an emotional state has been induced. The induced emotion has to be sufficiently intense in order to find coherence among response systems (see Davidson, 1992; Levenson, 2014; Rosenberg & Ekman, 1994). This requires, at minimum, that participants have a 'real' emotional experience rather than the recognition that a stimulus represents an emotion. A related consideration is about the type of emotion induced. For example, surprise might show less coherence involving physiological responses than other emotions because surprise has a more pronounced cognitive element (e.g., Reisenzein et al., 2000b) than other emotions (e.g., fear). Similarly, contentment might show less coherence involving behavior than other emotions because contentment does not have a salient behavioral signature compared to other emotions (e.g., amusement). In addition, to measure *within-person* coherence of emotional responses, an emotion induction needs to last long enough to observe *changes* in responses that can covary across response systems. Further, it should ideally involve a range of intensities or emotional states because lack of variability across time would constrain correlations.

Several approaches can be used to induce such states, including emotional film clips, emotional recall, script-driven imagery, multiple emotional pictures, virtual-reality paradigms, music, and specific tasks that elicit emotions, such as the Trier Social Stress Task (Coan & Allen, 2007). Each has advantages and disadvantages. On balance, emotional film clips present several advantages when it comes to examining coherence (Fernández-Aguilar et al., 2019; Gross & Levenson, 1995; Rottenberg et al., 2007). First, libraries of validated film clips are available that reliably and ethically induce moderate to high levels of a range of emotions, including amusement, joy, contentment, affection, awe, pride, sadness, anxiety, and disgust (Samson et al., 2016). Film clips can be used in laboratory and non-laboratory contexts that allow researchers to measure multiple emotional response systems. Because films naturally unfold over time, they also allow for standardization of moment-by-moment emotional context across participants. Films uniquely allow for dynamic changes in emotional states over time, ranging from neutral to more intense emotional states, as their narrative unfolds, even within the span of a few minutes.

An interesting novel approach has examined spontaneous emotional episodes during a four-week period in daily life using ecological momentary assessment, including experience sampling and psychophysiological measurement (Van Doren et al., 2021). Although the lack of experimental control has some disadvantages, this kind of approach complements laboratory approaches by testing generalizability to ecologically valid contexts (Hofmann & Grigoryan, 2023).

2.3.2 What comparisons are informative?

In addition to the context itself in which we measure coherence, we must ask about what we compare the context to. These comparison conditions are just as important as the target context in determining what we can learn about coherence. Several comparisons are interesting. First, we need to think about our criterion for establishing whether a particular cross-correlation indicates coherence. Imagine we find a cross-correlation of .22. How do we decide whether this means there is coherence? A first approach is to conduct a null-hypothesis significance test to compare .22 to 0, testing whether coherence is greater than chance. To gain more nuanced information, and to deal with short-falls of null-hypothesis significance testing, we can consider effect sizes, which in this example would indicate we have a medium effect size (Funder & Ozer, 2020), indicating some coherence. Last, and more stringently, we could compare the cross-correlation we obtain to a cross-correlation of random pairs of signals (across random pairs of participants rather than within the same participant). This comparison tells us whether within-person coherence is greater than coherence that is driven by the stimulus context.

Second, to establish whether coherence characterizes specifically emotional versus neutral states, we could compare coherence during emotional states to coherence during neutral states. This of course raises the difficulty of establishing and inducing a truly neutral state. Ultimately, it may be impossible to induce a truly neutral state that is neither unpleasant (e.g., boring) nor pleasant (e.g., amusing, interesting); thus, states that are less emotional may represent the best comparison condition, as we consider in the next point.

Third, examining gradations within emotional states and to test the idea that coherence becomes stronger the more intense an emotion is, we could compare coherence during more intense emotions to coherence during less intense emotions. Fourth, to test whether coherence specifically characterizes emotional states, we could compare coherence during emotions to coherence during other motivational and physiological states, such as hunger, fatigue, or cognitive effort (see Clore et al., 1987). Fifth, to test whether coherence is a feature of the way in which we induced the emotion versus the emotion itself (see Stemmler, 1992), we could induce the same emotion in different ways (e.g., recall and film clips). Last, to examine boundary conditions and functions of coherence, we could compare various contexts. For example, ideas about the communicative function of experience-behavior coherence could be tested by comparing coherence in the presence of other people to coherence when alone. Or ideas about the active coping function of experience-physiology coherence could be tested by comparing coherence during active coping (e.g., when a threat can be avoided) to conditions when active coping is not possible (e.g., when a threat cannot be avoided).

In sum, coherence is best measured in intense, standardized emotion inductions that involve varied emotion intensity levels. To allow for nuanced insights regarding the when and how of coherence, research on coherence should include several different emotional states or states that allow for interesting, conceptually motivated comparisons (e.g., emotional to non-emotional states, more emotional to less emotional states, social to non-social contexts).

2.4 Which response systems should we measure and how can we measure them?

Given the coherence postulate is concerned with coherence among emotional responses, we need to measure multiple emotional responses during our emotion inductions. The fourth set of methodological considerations concerns which ones and how we can best measure them. At the most basic level, we should measure as many systems as possible, as precisely as possible, and as validly as possible, as guided by our hypotheses.

In addition, three principles emerge from the fact that emotions are dynamic and fast-changing states (Kuppens & Verduyn, 2017). First, to capture emotional responses *during* emotional states, measures should be obtained *online*—that is, while a person is in the emotional state, rather than afterwards when responses have faded away. Second, to account for the fact that emotional states change dynamically and quickly, measures should be obtained with a high sampling rate, *moment-by-moment*. And third, to match measures across response systems, different measures should be assessed *concurrently* (rather than at different times). Thus, as a general guide, more is better: We should, if feasible, assess as many systems as possible, with as many indicators within each system as possible, and do so as frequently and simultaneously as possible.

Next, we review how to measure emotion response systems focusing on systems that are most relevant to research on coherence, namely experience, behavior, and autonomic physiology. We focus our discussion on measurement questions that are most pertinent to research on coherence because other reviews provide more general guidance (Bradley et al., 2000; Coan & Allen, 2007; Ekman & Friesen, 1978; Mauss & Robinson, 2009; Mendes & Beer, 2009; Mendes, 2016). A consideration that cuts across response systems is how well measures are matched to one another and the emotion under investigation. Failure to sample all three response systems—experiential, behavioral, and physiological—well and failure to select one's measures of emotional responding carefully within response systems limit the conclusions that can be drawn from a study.

2.4.1 Experience

When measuring emotion experience, researchers have often relied on *retrospective* (rather than *online*) ratings and on *aggregated* (rather than *moment-by-moment*) ratings. For example, one could ask participants: "How much amusement did you feel during the 3-min emotional film clip you just watched?" Such retrospective ratings make sense for many research questions. However, assessing experience ratings *after* the emotional event, even if it is right after the event, might lead to measurement error due to processes such as memory biases or defensive mechanisms (Barrett, 1997; Kahneman, 2000; Rosenberg & Ekman, 1994), which could cloud assessment of coherence. In addition, as discussed above, ideally measures are sampled during the emotion, concurrently with one another, and with a high time resolution.

One way to address these issues is to assess emotional experience *moment-by-moment* using a rating dial method introduced and validated by Levenson and Gottman (1983); see also (Gottman & Levenson, 1985; Ruef & Levenson, 2007). In this method, participants use a dial or a slider to indicate each moment how much of a particular emotion they experience. Compared to the more traditional method of obtaining retrospective whole-task emotion ratings at a single point in time, this method ensures that emotion experience can be measured during the emotion induction, concurrently with other measures (e.g., physiology, behavior) and with a high sampling rate. Moreover, it minimizes measurement error due to memory biases or aggregation across mixed emotional periods.

This method has two potential downsides. First, participants can only provide one rating at a time (e.g., how pleasant do you feel right now?). This concern can be mitigated in three ways. If film clips are used to induce emotion, participants can view clips multiple times, providing a different rating each time (see Mauss et al., 2005). Two-dimensional grids or multiple sliders like on a multi-channel audio mixer (allowing participants to rate multiple dimensions such as valence and arousal at the same time) can be used as well (Russell et al., 1989). Last, the rating dial approach can be supplemented with retrospective ratings of multiple emotions to have the best of both worlds.

A second concern is that using a rating dial might disrupt the very emotional process one is attempting to study. This concern can be mitigated in two ways. First, a brief practice period before using the dial has been shown to be effective for allowing participants to use the dial without too much mental effort. We confirmed this by comparing physiological and behavioral indices of emotion of participants who used a dial to participants who did not use a dial. On both indices, we found no or weak group differences, indicating that emotional reactivity is not or only weakly affected by using the dial (Mauss et al., 2005). Another way to address this concern is to employ cued-recall video (Gottman & Levenson, 1985; Rosenberg & Ekman, 1994). In this approach, participants are videotaped while they give a stressful speech or have an emotionally evocative interaction, tasks that do not allow them to concurrently use the rating dial. They can then watch the videotape while they rate their experience during the task using a rating dial.

2.4.2 Behavior

Measures of behavioral emotional responses can include those focused on the face, the voice, or the whole body. For each of these channels, we can obtain 'naïve' cultural informants' global impressions, trained coders' global ratings or more specific muscle movements (e.g., the Facial Action Coding System, FACS) (Ekman & Friesen, 1978), automated algorithms (Girard et al., 2015; Martinez, 2017), electromyography (EMG; e.g. of the corrugator supercilii muscle responsible for furrowed brows; see Bradley et al., 2000; Cacioppo et al., 2000; Mauss & Robinson, 2009), or head magnetomyography (Barchiesi et al., 2020). Unless automated or physiological measures such as EMG are used, challenges similar to those for experience are faced when we want to obtain moment-by-moment measures. In these cases, rating-dial approaches similar to the self-reports discussed for experience can be used, except that the coders rate the behaviors they observe moment by moment using a rating dial (Mauss et al., 2005, 2011).

Two concerns with assessing behavior are particular to the study of coherence, both of which have to do with researchers' unchallenged assumptions about emotional responses. One such concern is indicated by the term "expression," which indicates that some facial movements are assumed to be *expressions* of particular inner emotional states (Barrett et al., 2019; Crivelli & Fridlund, 2019). This assumption can lead us astray as illustrated by a study that investigated the emotion of joy and found surprisingly low correlations between feelings of joy on the one hand and laughter on the other hand (laughter: $r = .14$; smiles: $r = .24$; $n = 31$; Bonanno & Keltner, 2004). Yet, laughter may reflect joy but also amusement, embarrassment, or relief from a negative emotion, and thus might not be the most appropriate behavioral index of joy. Thus, in choosing behavioral measures, we need to think carefully about what each measure might mean and question our assumptions.

Second, the vast majority of research on coherence has focused on facial movements versus the voice or body movements (Hertenstein et al., 2006; Matsumoto et al., 2008; Mauss & Robinson, 2009). This might again have to do with Western ideas about how emotions are expressed, or with pragmatics of what we can measure relatively easily. Yet, this focus might have obscured coherence, especially for emotions that are primarily expressed in vocal patterns (e.g., sadness) or bodily movements (e.g., pride) (Keltner et al., 2019; Tracy & Robins, 2004).

2.4.3 Physiology

The most commonly used measures of physiological responses in research on coherence are autonomic nervous system (ANS) responses. Far less research has involved other types of physiological responses such as central nervous system (CNS) or endocrine responses. This is because CNS responses can be seen to instantiate emotions (rather than representing a response system). Endocrine responses generally are slower (e.g., salivary cortisol has about at least a 5–minute lag; Kirschbaum et al., 1993), and thus are not studied to capture faster dynamics of emotional responses. Yet other responses are very difficult to measure (e.g., the sensation of "knots" in one's stomach). Lastly, the ANS is intuitively highly relevant to questions of coherence as physiological responses are *felt* to covary with emotional experiences (James, 1884).

The ANS is a general-purpose system responsible for modulating peripheral functions (Öhman et al., 2000). It consists of sympathetic and parasympathetic branches, which are generally but not always associated with organismic activation and relaxation (including digestive and restorative functions), respectively. Physiological signals are typically recorded continuously at high sampling rates (e.g., 1000 Hz for electrodermal activity and

ECG), and can thus be analyzed with a relatively high effective resolution (e.g., 10 Hz for skin conductance level and 1 Hz for heart rate).[4] Thus, they are ideally suited for moment-by-moment coherence analyses. The most commonly assessed indices of ANS activation are based on electrodermal (i.e., sweat gland) or cardiovascular (i.e., blood circulatory system) responses. Electrodermal responding is typically quantified in terms of skin conductance level (SCL) or short-duration skin conductance responses (SCRs). Cardiovascular measures include heart rate (HR), blood pressure (BP), total peripheral resistance (TPR), cardiac output (CO), pre-ejection period (PEP), finger pulse time and amplitude (FPT and FPA), and heart rate variability (HRV) (Cacioppo et al., 2000; Kreibig, 2010; Levenson, 2003, 2014; Mauss & Robinson, 2009; Mendes & Beer, 2009; Mendes, 2016). Each of these measures varies in terms of whether it primarily reflects sympathetic activity, parasympathetic activity, or both. For example, SCL and PEP predominantly reflect sympathetic activity, HR and BP reflect a combination of sympathetic and parasympathetic activity, and HRV related to respiratory cycle (high-frequency HRV) has been linked to parasympathetic activity (Berntson et al., 1997, 2007; Mendes & Beer, 2009; Mendes, 2016).

Given there are so many different measures with different features, one question faced by researchers is whether to use individual measures such as heart rate versus composites such as cardiovascular activation (e.g., a composite of heart rate, finger pulse transit time, finger pulse amplitude, and mean arterial pressure). There are two competing considerations. On the one hand, the more fully we capture a system, the more comprehensive and reliable a measure may be. On the other hand, there is response fractionation (e.g., Lacey, 1967) whereby measures of different autonomic subsystems (e.g., cardiovascular, electrodermal) may move in different directions. This means that if we use a composite, this might obscure evidence for coherence that we would find for individual measures. Thus, on balance it appears that individual measures might have an advantage over composites.

[4] An important point to consider for coherence analysis is that the effective temporal resolution of some measures is reduced due to physiological and computational constraints. While SCL can be computed for every millisecond (although all meaningful information is probably captured with a sample rate of 10 Hz), HR provides an updated value with each heartbeat about every second, and PEP typically requires an averaging over several seconds to overcome noise in the impedance cardiography signal. Further, high-frequency HRV only provides an updated measure with each respiratory cycle about every 3–5 s. Variables with low effective resolution might be upsampled using cubic spline interpolation to allow for coherence analysis with the other variables.

In addition, whenever possible, we should obtain multiple ANS measures to capture multiple ANS subsystems. For example, one could sample heart rate (indexing general psychophysiological arousal, driven by sympathetic and parasympathetic activity), skin conductance level and pre-ejection period (indexing electrodermal and cardiac sympathetic activity, respectively), and high-frequency heart rate variability (indexing parasympathetic activity).

Next, we turn to how we get from time series of individual responses (e.g., a continuous three-minute recording of positive experience along with corrugator supercilii activity and heart rate) to pairwise indices of coherence using cross-correlations.

2.5 Practical steps: how do we get from time series to coherence indices?

In this last section on methodological considerations, we give practical, step-by-step guidance on the steps required once time-series data have been obtained for multiple emotional responses. How do we get from these time series to pairwise indices of coherence? As discussed above, cross-correlations present an appropriate way of doing so, and so we use them to illustrate the remaining steps. The steps involved in using cross-correlations to measure coherence are outlined in Fig. 5. In Step 1, time series are obtained for each measure and for each participant. In Step 2, cross-correlations are calculated for each pair of measures and for each participant. In Step 3, one cross-

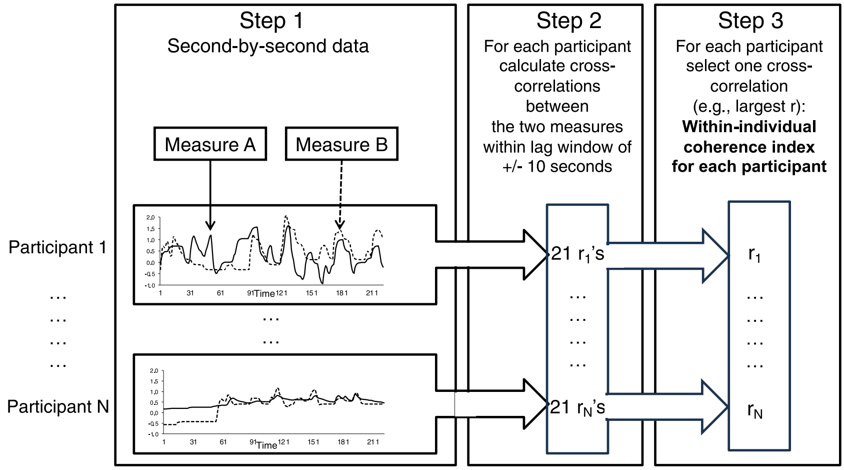

Fig. 5 Steps to Calculate Coherence Using Cross-Correlations. *Note.* The solid line indicates Measure A (for example, emotional experience) and the dashed line indicates Measure B (for example, a physiological response). The ellipses (…) indicate that the same procedures are conducted for each participant in a dataset.

correlation is selected as the index of a person's coherence for two measures. These can then be averaged to obtain estimates of coherence across people.

The first decision point concerns Step 1: How frequently should we sample each signal, that is, what should the temporal resolution of the time series be? Given emotions can, in principle, change frequently and dynamically, this is an important question. Several studies on within-person coherence assume that the "best" timing resolution for each response system is second-by-second (vs. every 2 s, 5 s, etc.). This assumption is understandable because theories of emotion often suggest that emotional episodes are brief, typically lasting only one to ten seconds (Ekman, 1992; Levenson, 1994, 2003). Yet, although second-by-second ratings might be appropriate for measuring changes in more immediate responses (i.e., emotion experience), it is possible that this level of granularity does not add information when we examine coherence with less immediate responses (i.e., physiology).

A recent study (Zerwas et al., 2023) empirically tested this assumption. It did so by obtaining four coherence indices for a 5-minute film clip: Experience—behavior, experience—inter-beat interval (inversely related to heart rate), experience—skin conductance level, and experience—heart rate variability. Each coherence index was obtained for measures sampled with a resolution of 1, 2, 5, 10, and 15 s Table 3 shows the resulting coherence indices as well as whether they differ from indices obtained for the 1-second resolution.

Table 3 Coherence estimates using different temporal resolutions.

Type of coherence (sample size)	Timing resolution				
	1-s	**2-s**	**5-s**	**10-s**	**15-s**
Experience-behavior (100)	0.47	0.47	0.47	**0.40**	0.40
Experience-physiology					
Experience-inter-beat interval (115)	−0.05	−0.06	−0.06	−0.08	−0.09
Experience-skin conductance level (104)	0.40	0.39	0.41	0.42	**0.45**
Experience-heart rate variability (117)	−0.04	−0.05	−0.05	**−0.08**	−0.04

Note. Bolded values indicate the estimate for that temporal resolution is significantly different from the estimate for the standard 1-second temporal resolution. Sample sizes are denoted in parentheses. Heart rate variability in the high-frequency band (0.15–0.50 Hz) as a measure of parasympathetic activity was estimated up to 1-second resolution using complex demodulation (Wilhelm et al., 2005).

For experience-behavior, the 10-second resolution was significantly lower in coherence than the 1-second resolution. We see comparable levels of coherence for the 1-, 2-, and 5-second resolutions, but the 10-second resolution seems too coarse to capture the full extent of coherence. For coherence involving the three physiology measures, the different resolutions did not differ much from one another. For experience—skin conductance level, the 15-second resolution coherence was significantly higher than the 1-second resolution, and for experience—heart rate variability, the 10-second resolution coherence was significantly higher than the 1-second resolution. Thus, not much information is lost for coherence estimates when going from a 1-second to a 10- or 15-second resolution. Coherence estimates even appear to become somewhat higher, which may reflect that these physiological measures respond more slowly or that averaging across time can make physiology measures more reliable. Despite these minor differences between different resolutions, it did not appear that meaningful information is gained or lost by adjusting the temporal resolution. On the whole, the 1-second resolution appears to be the best approach, given (a) there was not strong evidence to utilize another timing resolution, (b) it allows researchers to be consistent across different indices of coherence, (c) it provides the most nuanced information, and (d) it is consistent with previous research. We note that many researchers recommend using a 3-s moving average to smooth the signal, given that sharp changes from one second to the next are typically noise rather than signal.

The next decision concerns Step 2, calculating lagged correlations for pairs of responses (Dan-Glauser & Gross, 2013; Mauss et al., 2005, 2011; Sze et al., 2010). Lags account for the possibility that emotion response systems do not instantaneously cohere. For example, emotional behavior might most strongly cohere with emotional experience with a lag of a few seconds because it follows experience in time. For cross-correlations, we need to decide what window of lags we consider looking for coherence. Existing work typically utilizes a -10 to $+10$-second lag window (i.e., one signal leads and trails the other signal up to 10 s), because it maps onto theory about the duration of emotional episodes typically lasting 1–10 s (Ekman, 1992; Levenson, 1994, 2003) and accounts for the slower response time of some physiological measures such as peripheral temperature or skin conductance (Bach et al., 2010). Other work has relied on a more data-driven approach, which involves investigating whether there is evidence of semi-regular oscillations in any of the response systems, and if so with what period; choosing a lag-window that is equal to the period of the semi-regular oscillations reduces the risk of confounds due to oscillatory processes (Butler et al., 2014).

Given the heavy reliance on theory and the use of inconsistent approaches in choosing a lag window, Zerwas et al. (2023) empirically compared coherence estimates obtained considering 1-, 2-, 5-, 10-, and 15-second lag windows, using the same time-series data as results in Table 4, with a temporal resolution of 1 s Table 4 shows the coherence indices for each lag window as well as whether they differ from indices obtained for the 10-second lag window. We used this window as the criterion as it has been the most frequently used.

Some of the narrow lag windows for experience—behavior and for experience—skin conductance level significantly reduced coherence compared to the 10-second lag window. For experience—inter-beat interval and experience—heart rate variability, none of the lag windows differed significantly from the 10-second lag window. In sum, the standard 10-second lag window appears to be a good choice, at least for the commonly used measures examined by Zerwas et al. (2023).

Last, we must decide in Step 3 which correlation to use as our index of coherence because cross-correlations computed at different lag times result in *multiple* coherence estimates for each person and because we do not know the true lag between different response systems. For example, using a lag window of -10 to $+10$ s, for each pair of measures we get 21 correlations, one correlation for each lag. Which one should we select? We have five options. For each participant, we could use (a) the average of the 21 correlations, (b) the most positive of the 21 correlations, (c) the most negative of the 21 correlations, (d) the largest (in absolute terms) of the 21 correlations, neglecting

Table 4 Coherence estimates using different lag windows.

Type of coherence (sample size)	**Lag window**				
	10-s	**1-s**	**2-s**	**5-s**	**15-s**
Experience-behavior (100)	0.47	**0.41**	**0.43**	0.45	**0.48**
Experience-physiology					
Experience-inter-beat interval (115)	−0.05	−0.06	−0.06	−0.06	−0.04
Experience-skin conductance level (104)	0.40	**0.37**	**0.37**	**0.38**	**0.42**
Experience-heart rate variability (117)	−0.04	−0.03	−0.04	−0.04	−0.05

Note. Bolded values indicate the estimate for that lag window is significantly different from the estimate for the standard 10-s lag window. Sample sizes are denoted in parentheses.

its sign for subsequent statistical analyses (i.e., using its absolute value), or (e) the largest (in absolute terms) of the 21 correlations, retaining its sign for subsequent statistical analyses. In the latter four cases, the logic is that the largest value indicates a signal. Using the average (Option a) is not optimal because it obscures coherence, especially of swift emotional responses. Using the most positive or the most negative correlation (Options b and c) is generally not indicated, in our opinion, because it assumes a priori that two responses are associated in a particular direction. Using the absolute value (Option d) has the advantage that it is agnostic about direction of associations (for example, amusement could be associated with greater or lower heart rate). However, it only provides information about how strongly two measures are associated with one another, not whether two measures are positively or negatively associated with one another. In cases where information about directionality is of interest, Option e provides the most information about the nature of coherence while making the fewest assumptions. For example, it allows researchers to distinguish in-phase (signals move in the same direction) from anti-phase (signals move in opposite directions) responses (Chen et al., 2021). We note generally the cross-correlation approach is ideographic in that each pair of measures and each person can be based on a different lag.

In sum, when constructing coherence indices from cross-correlations, the currently best approach is to use a resolution of 1 s for time series, a lag window of − 10 to + 10 s for cross-correlations, and to use the largest cross-correlation for each pairing as the person's coherence indicator (Options d or e).

3. What do we know about coherence among response systems and the benefits of coherence?

What does empirical research tell us about the nature and functions of emotion coherence? As we described above (and as summarized in Table 2), the most relevant and informative studies are those that (a) used within-person measures of coherence, (b) measured coherence during dynamic stimuli such as film clips, (c) present pairwise coherence measures, and (d) used a second-by-second temporal resolution for these measures. In addition, we required a sample size of at least 50, typically allowing detection of medium effect sizes with 80% statistical power (Funder & Ozer, 2020). We found nine studies that fulfilled these methodological criteria and measured experience-behavior coherence or experience-physiology coherence or both. These studies are all summarized in Table 5 below. For the third

Table 5 Studies that used methods optimal for examining emotion coherence: within-person approaches, dynamic stimuli, continuous measures of emotion responses, and accounting for lags.

Study	Sample	Context	Response Systems Measured	Index of Coherence and Lag Window	Results
Mauss et al., 2005	59 US students 100% female *M*age = 19 7% Af-Am 40% As-Am 22% Eu-Am 32% L-Am	**One** film clip with 3 scenes (amusing, sad, amusing)	**Experience:** Rating dial (neutral to amusement and neutral to sadness) **Behavior:** Trained coders, rating dial (neutral to amusement and neutral to sadness) **Physiology:** Cardio composite (HR, FPTT (R), FPA (R), and EPTT (R)) and SCL	Highest cross-correlation, retaining sign +/− 10 *s* lag	**Experience-behavior coherence**: E-Amuse—B-Amuse: .73** (*SD*: .38, range: NA) E-Sad—B-Sad: .74** (*SD*: .38, range: NA) **Average** experience-behavior coherence: .74 (*SD*: .38) **Experience-physiology coherence:** E-Amuse—P-Cardio: .22** (*SD*: .38, range: NA) E-Amuse—P-SCL: .51** (*SD*: .38, range: NA) E-Sad—P-Cardio: .00 (*SD*: .46, range: NA) E-Sad—P-SCL: -.39** (*SD*: .61, range: NA) **Average** experience-physiology coherence: .29 (*SD*: .46) **Group/Individual differences:** Emotion intensity: People showing greater coherence had more intense E and B for amusement (but not for sadness) Ethnicity: No differences **Associations with well-being:** NA

(*continued*)

Table 5 Studies that used methods optimal for examining emotion coherence: within-person approaches, dynamic stimuli, continuous measures of emotion responses, and accounting for lags. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence and Lag Window	Results
Sze et al., 2010	63 US adults 63% female 37% male *M*age = 28 2% Af-Am 13% As-Am 78% Eu-Am 3%, L-Am 5% Other	**Four** film clips (amusing, disgusting, sad, and disturbing scenes)	**Experience:** Rating dial (negative to positive) **Behavior:** NA **Physiology:** IBI	Absolute value of the highest cross-correlation +/− 10 *s* lag	**Experience-behavior coherence:** NA **Experience-physiology coherence:** Average across all films and groups: E-Valence—P-IBI: .33^{x} (*SD*: .16, range = NA) **Group/Individual differences:** Body awareness training: E-Valence—P-IBI in Meditators > Dancers > Controls **Associations with well-being:** NA
Mauss et al., 2011	125 US students 47% female 53% male *M*age = 21 2% Af-Am 30% As-Am 43% Eu-Am 9% L-Am 11% Multiple ethnic backgrounds 5% Other or missing	**One** of three possible amusing film clips	**Experience:** Rating dial (neutral to amusement) **Behavior:** Trained coders, rating dial (neutral to amusement) **Physiology:** NA	Highest cross-correlation, retaining sign +/− 10 *s* lag	**Experience-behavior coherence:** E-Amuse—B-Amuse: .68** (*SD*: .34, range: -.36 to .92) **Experience-physiology coherence:** NA **Group/Individual differences:** Gender: No differences Ethnicity: No differences **Associations with well-being:** Depressive symptoms 6 months later: *r*: -.25** (change: -.18*) Satisfaction with life 6 months later: *r*: .22** (change: .23**)

Butler et al., 2014	186 US students 100% female *M*age = 20 3% Af-Am 36%, As-Am 44% Eu-Am 4% L-Am 13% other	**One** discussion of a negative film clip with stranger	**Experience:** Rating dial (negative to positive) **Behavior:** Trained coders, rating dial (separate ratings for neutral to positive and neutral to negative) **Physiology:** IBI, SCL, and MAP	Most positive cross-correlation: E-Valence—B-Pos, |E-Valence|—P-SCL, |E-Valence|—P-MAP Most negative cross-correlation: E-Valence—B-Neg, |E-Valence|—P-IBI +/− 6 *s* for IBI +/− 10 *s* for all other variables	**Experience-behavior coherence:** Average across conditions: E-Valence—B-Pos: .12[X] (*SD*: .10, range: NA)E-Valence—B-Neg: -.13[X] (*SD*: .15, range: NA) **Average** experience-behavior coherence: .13 (*SD*: .13) **Experience-physiology coherence:** Average across all conditions: E-Valence—P-IBI: -.08[X] (*SD*: .14, range: NA) E-Valence—P-SCL: .07[X] (*SD*: .19, range: NA) E-Valence—P-MAP: .13[X] (*SD*: .16, range: NA) **Average** experience-physiology coherence: .09 (*SD*: .16) **Group/Individual differences:** Condition (instructed suppression, instructed reappraisal, and control): E-Valence—P-IBI, E-Valence—B-Pos, and E-Valence—B-Neg in control > instructed suppression E-Valence—B-Neg in control > instructed reappraisal and E-Valence—B-Pos in control < instructed reappraisal **Associations with well-being:** NA

(*continued*)

Table 5 Studies that used methods optimal for examining emotion coherence: within-person approaches, dynamic stimuli, continuous measures of emotion responses, and accounting for lags. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence and Lag Window	Results
Lohani et al., 2018	60 younger and 60 older US adults 64% female 36% male *M*age (younger)=20 *M*age(older) =71 No ethnicity reported	**One** sad film clip	**Experience:** Rating dial (no sadness to extreme sadness) **Behavior:** Facial EMG (corrugator) **Physiology:** IBI	Absolute value of the highest cross-correlation +/− 10 *s* lag	**Experience-behavior coherence:** E-Sad—B-Corr: .43** (*SD*: 0.21, range: NA) **Experience-physiology coherence:** E-Sad—P-IBI: .43** (*SD*: 16, range: NA) **Group/Individual differences:** Age: E-Sad—P-IBI in older > younger Condition (instructed suppression, instructed acceptance, control): No differences Max intensity of experience: No effect **Associations with well-being:** NA
Brown et al., 2020	63 US adults 63% female 37% male *M*age = 28 2% Af-Am 13% As-Am 78% Eu-Am 3%, L-Am 5% Other	**Four** film clips (amusing, disgusting, sad, and disturbing scenes)	**Experience:** Rating dial (negative to positive) **Behavior:** NA **Physiology:** Composite (IBI (R), SCL, EPTT (R), FPTT (R), FPA (R), SBP, DBP, MAP)	Absolute value of the highest cross-correlation +/− 10 *s* lag	**Experience-behavior coherence:** NA **Experience-physiology coherence:** E-Valence—P-Composite: .37** (SD: .11, range: .17 to .60) **Group/Individual differences:** NA **Associations with well-being:** Cross-sectional well-being composite: β = .30*

Zerwas et al., 2023	160 US adults 100% female *M*age = 47 6% Af-Am 23% As-m 62% Eu-Am 2% ME-Am 4% L-Am 1% N-Am 3% Other	**One** film clip with 3 scenes (amusing, sad, amusing); **One** stressful speech task	**Experience:** Rating dial (negative to positive) **Behavior:** Trained coders, rating dial (negative to positive) **Physiology:** IBI, SCL, and HRV	Highest cross-correlation, retaining sign +/− 10 *s* lag	**Experience-behavior coherence**: Film clip: E-Valence—B-Valence: .49* (*SD*: .46, range: -.72 to .92) Speech task: E-Valence—B-Valence: .17* (*SD*: .40, range: -.67 to .84) **Average** experience-behavior coherence: .34 (*SD*: .43) **Experience-physiology coherence:** Film clip: E-Valence—P-IBI: -.06 (*SD*: .40, range: -.80 to .70) E-Valence—P-SCL: .41* (*SD*: .51, range: -82. to .95) E-Valence—P-HRV: -.05 (*SD*: .27, range: -.56 to .70) Speech task: E-Valence—P-IBI: -.12* (*SD*: .55, range: -94. to .93) E-Valence—P-SCL: -.01 (*SD*: .61, range: -.95 to .99) E-Valence—P-HRV: -.04 (*SD*: .36, range: -.68 to .75) **Average** experience-physiology coherence: .12 (*SD*: .45) **Group/Individual differences:** NA **Associations with well-being:** Psychological well-being 6 months later: Film clip: E-Valence—B: *r*: .27*, E-Valence—P-IBI: *r:* -.02, E-Valence—P-SCL: *r*: .06, E-Valence—P-HRV: *r*: .07 Speech task: E-Valence—B: *r:* -.05 m E-Valence—P-IBI: *r*: .08, E-Valence—P-SCL: *r*: -.11, E-Valence—P-HRV: *r*: .05

(*continued*)

Table 5 Studies that used methods optimal for examining emotion coherence: within-person approaches, dynamic stimuli, continuous measures of emotion responses, and accounting for lags. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence and Lag Window	Results
Constantinou et al., 2023	79 Cypriot students 85% female 15% male *M*age = 20 No ethnicity reported	**Six** film clips (2 positive, 2 negative, and 2 neutral)	**Experience:** Rating dial (very unpleasant to very pleasant) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** HR and SCL	Most positive cross-correlation: E-Valence—P-SCL, E-Valence—B-Zyg Absolute cross-correlation: E-Valence—P-HR Most negative cross-correlation: E-Valence—B-Corr +/− 6 *s* for HR+/− 10 *s* for all other variables	**Experience-behavior coherence:** Neutral: E-Valence—B-Corr: -.10^{X} (*SD*: .26, range: NA) E-Valence—B-Zyg: .11^{X} (*SD*: .18, range: NA) Negative: E-Valence—B-Corr: -.47^{X} (*SD*: .34, range: NA) E-Valence—B-Zyg: .16^{X} (*SD*: .26, range: NA) Positive: E-Valence—B-Corr: -.24^{X} (*SD*: .34, range: NA) E-Valence—B-Zyg: .30^{X} (*SD*: .26, range: NA) **Average** experience-behavior coherence: .30 (*SD*: .27) **Experience-physiology coherence:** Neutral: E-Valence—P-HR: .30^{X} (*SD*: .18, range: NA) E-Valence—P-SCL: -.04^{X} (*SD*: .26, range: NA) Negative: E-Valence—P-HR: .27^{X} (*SD*: .09, range: NA) E-Valence—P-SCL: -.11^{X} (*SD*: .34, range: NA) Positive: E-Valence—P-HR: .32^{X} (*SD*: .18, range: NA) E-Valence—P-SCL: -.07^{X} (*SD*: .34, range: NA) **Average** experience-physiology coherence: .20 (*SD*: .24) **Group/Individual differences:** NA **Associations with well-being:** NA

Saito et al., 2023 (Part 1)	26 older and 30 younger Japanese adults 52% female 48% male *M*age(older) =73 *M*age (younger)=23 No ethnicity reported	**Five** film clips (anger, sadness, neutral, contentment, and amusement)	**Experience:** Rating dial, valence and arousal (negative to positive and not aroused to highly aroused) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** SCL and fingertip temperature	Highest cross-correlation, retaining sign +/− 10 *s* lag	**Experience-behavior coherence:** E-Valence—B-Corr: Anger: -.33^{X} (*SD*: .25, range: NA) Sadness: -.07^{X} (*SD*: .25, range: NA) Neutral: -.06^{X} (*SD*: .16, range: NA) Contentment: -.02^{X} (*SD*: .20, range: NA) Amusement: -.08^{X} (*SD*: .16, range: NA) E-Valence—B-Zyg: Anger: .02^{X} (*SD*: .20, range: NA) Sadness: -.01^{X} (*SD*: .18, range: NA) Neutral: .03^{X} (*SD*: .15, range: NA) Contentment: -.01^{X} (*SD*: .18, range: NA) Amusement: .10^{X} (*SD*: .13, range: NA) **Average** experience-behavior coherence: **Experience-physiology coherence:** E-Arousal—P-SCL: Anger: -.07^{X} (*SD*: .42, range: NA) Sadness: -.08^{X} (*SD*: .40, range: NA) Neutral: .14^{X} (*SD*: .42, range: NA) Contentment: .20^{X} (*SD*: .33, range: NA) Amusement: <.001^{X} (*SD*: .30, range: NA) E-Arousal—P-Temp Anger: -.10^{X} (*SD*: .41, range: NA) Sadness: .25^{X} (*SD*: .36, range: NA) Neutral: -.04^{X} (*SD*: .39, range: NA) Contentment: -.07^{X} (*SD*: .32, range: NA) Amusement: -.11^{X} (*SD*: .29, range: NA) **Group/Individual differences:** Age and emotion: E-Valence—B-Corr in younger adults > older adults for anger. Positive E-Arousal—P-SCL for older adults and negative E-Arousal—P-SCL for younger adults for anger. Positive E-Arousal—P-Temp for older adults and negative E-Arousal—P-Temp for younger adults for contentment **Associations with well-being:** NA

(*continued*)

Table 5 Studies that used methods optimal for examining emotion coherence: within-person approaches, dynamic stimuli, continuous measures of emotion responses, and accounting for lags. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence and Lag Window	Results
Saito et al., 2023 (Part 2)	Same as above	Same as above	Same as above	Absolute value of the highest cross-correlation +/− 10 *s* lag	**Experience-behavior coherence:** E-Valence—B-Corr: Anger: .47^{X} (*SD*: .17, range: NA) Sadness: .37^{X} (*SD*: .14, range: NA) Neutral: .30^{X} (*SD*: .11, range: NA) Contentment: .35^{X} (*SD*: .11, range: NA) Amusement: .26^{X} (*SD*: .09, range: NA) E-Valence—B-Zyg: Anger: .32^{X} (*SD*: .12, range: NA) Sadness: .29^{X} (*SD*: .10, range: NA) Neutral: .25^{X} (*SD*: .10, range: NA) Contentment: .31^{X} (*SD*: .11, range: NA) Amusement: .08^{X} (*SD*: .08, range: NA) **Average** experience-behavior coherence: .30 (*SD*: .12) **Experience-physiology coherence:** E-Arousal—P-SCL: Anger: .62^{X} (*SD*: .16, range: NA) Sadness: .58^{X} (*SD*: .16, range: NA) Neutral: .60^{X} (*SD*: .16, range: NA) Contentment: .51^{X} (*SD*: .17, range: NA) Amusement: .44^{X} (*SD*: .16, range: NA) E-Arousal—P-Temp: Anger: .61^{X} (*SD*: .15, range: NA) Sadness: .58^{X} (*SD*: .16, range: NA)

			Neutral: .55^{X} (*SD*: .17, range: NA) Contentment: .47^{X} (*SD*: .16, range: NA) Amusement: .44^{X} (*SD*: .15, range: NA) **Average** experience-physiology coherence: .53 (*SD*: .16) **Group/Individual differences:** E-Valence—B-Corr in younger adults > older adults for anger **Associations with well-being:** NA

Note. Af-Am = African-American. As-Am = Asian-American. Eu-Am = European-American. L-Am = Latinx-Am. ME-Am = Middle Eastern-American. N-Am = Native-American. E = Experience. B = Behavior. P = Physiology. |E| = absolute value of the experience rating. HR = heart rate. FPTT = finger pulse transit time. FPA = finger pulse amplitude. EPTT = ear pulse transit time. SCR = non-specific skin-conductance response rate, SCL = skin conductance level. EMG = electromyography. IBI = inter-beat interval. MAP = mean arterial pressure. SBP = systolic blood pressure. DBP = diastolic blood pressure. (R) = reverse scored. Brown et al. and Sze et al. used the same participants. * = $p < .05$. ** = $p < .01$. ^{X} = no significance test. In some cases, SD was calculated using standard error and sample size. **Average** experience-behavior coherence and **average** experience-physiology coherence were computed by taking the absolute values of coherence indices for emotional contexts (i.e., excluding neutral contexts), Fisher transforming them, averaging within a study across emotion inductions and measures, and then reverse Fisher transforming the averages.

pairwise comparison, behavior-physiology coherence, we did not find enough studies to justify meaningful conclusions, and we have therefore omitted them from this review.

The demographic characteristic of the 9 core studies in Table 5 are summarized in the second column. One noticeable feature are the sample sizes: they are small by current standards, with a mean of 101, ranging from 56 to 186 participants. These generally small sample sizes are not surprising: they reflect the high effort, time commitment, and expertise required for collecting and analyzing the data *for each person* in these lab studies: intensive time-series sampling of multiple response channels involved in measuring experience, behavior, and physiology second-by-second during laboratory emotion inductions, as well as detailed behavior coding and complex data management. We note the included sample sizes provide sufficient statistical power for analyses involving within-subjects effects (i.e., changes in coherence at within-subjects level, the effects of main interest here).

Most of these studies (7 of 9) were conducted in the US, with the two remaining studies conducted in Japan and Cyprus. In the four US samples for which ethnicity was reported, the ethnic groups were primarily European-American (47%) and Asian American (30%), with much smaller numbers of Latinx American (12%) and African American (3.5%); the two non-US studies add Japanese nationals and Greek-speaking Cypriots. Most studies included both women and men. Notably, the studies in Table 5 are also diverse in terms of participants' age, ranging from young to older adults.

With regard to substantive characteristics, the nine studies are diverse in terms of the emotional context in which they assessed coherence. Most used film clips lasting several minutes to induce a wide range of emotions, including positive emotions like amusement and contentment, as well as negative emotions like sadness, disgust, and anger. One study (Butler et al., 2014) examined coherence in emotional reactions during a discussion between strangers about an upsetting film clip they had watched.

The studies are also diverse in the way emotional reactions were measured. To measure *emotion experience*, all studies used rating dials second-by-second. However, some studies captured the intensity of discrete emotions such as amusement and sadness (e.g., from none to a lot) whereas others captured the dimensions of valence (e.g., very unpleasant to very pleasant) or arousal (e.g., degree of activation). To measure *behavior*, most studies either trained coders who used rating dials to rate behavior second-by-second (e.g., degree of sadness on the face) or obtained facial EMG (e.g., recording activation over the zygomaticus major muscle). To measure *physiological* responding, studies included cardiovascular and electrodermal responses that index sympathetic, parasympathetic, and mixed ANS responses, such as skin conductance, heart rate variability, and heart rate. One important difference is that studies reported results for either individual indices (i.e., leading to several separate coherence estimates) or composites of physiological indices. Section 2.3 gives more background on the various measures used.

Finally, we found some differences between studies in the way coherence indices were computed. Although all nine studies used cross-correlations taking account of potential lags, some selected the highest correlation while retaining the sign, some selected the absolute value of the highest correlation, and some selected the most positive or the most negative correlation (see Section 2.5 for more detail on the different coherence indices). In sum, the studies represent diverse samples, emotions, contexts, and approaches to studying coherence. This means that we have to be aware of considerable heterogeneity across studies when we try to draw conclusions about general trends that emerge across these diverse studies.

In addition to these methodologically optimal nine studies, we wanted to consider a second group of studies that do not fit all the criteria but can help provide a broader evidence base regarding particular questions that are not addressed in many studies in Table 5. Those questions include, for example, potential group differences in coherence (e.g., between women and men) and the potential benefits of coherence for mental health and well-being. This second set of studies is shown in Table 6. These studies are of high quality and also used within-participant approaches to capture coherence but fall short of the optimal approach to quantifying coherence in one or more ways (e.g., they disregard lags among measures or they average responding across film clips). While these studies provide important insights, we weigh them less heavily in our analysis. Of the many available studies, we selected those that were methodologically sound, involved large samples, and provide a diverse range of emotion inductions and measures of emotion responses.

3.1 How pronounced is response system coherence during emotions?

The first question we asked of the studies summarized in Table 5 is whether their results show evidence for coherence in emotions. At the broadest level, we reviewed the *Results* column in Table 5 and aggregated the coherence indices across studies. The results are clear: the evidence is

Table 6 Examples of studies that examined within-person coherence using other approaches.

Study	Sample	Context	Response Systems Measured	Index of Coherence	Results
Brown & Schwartz, 1980	60 US students and ex-students 50% female 50% male *M*age=NA No ethnicity reported	48 standardized imagery situations to evoke happiness, sadness, anger, and fear	**Experience:** Valence (abbreviated version of Differential Emotion Scale) **Behavior:** Facial EMG (zygomatic, corrugator, masseter, lateral frontalis) **Physiology:** NA	Within-individual correlation	**Experience-behavior coherence:** E-Happy—B-Zyg: $.19^{X}$ (*SD* and range: NA) E-Happy—B-Corr: $-.24^{X}$ (*SD* and range: NA) E-Happy—B-Mas: $.06^{X}$ (*SD* and range: NA) E-Happy—B-Lat: $-.08^{X}$ (*SD* and range: NA) E-Sad—B-Zyg: $-.12^{X}$ (*SD* and range: NA) E-Sad—B-Corr: $.24^{X}$ (*SD* and range: NA) E-Sad—B-Mas: $-.04^{X}$ (*SD* and range: NA) E-Sad—B-Lat: $.06^{X}$ (*SD* and range: NA) E-Anger—B-Zyg: $-.07^{X}$ (*SD* and range: NA) E-Anger—B-Corr: $.19^{X}$ (*SD* and range: NA) E-Anger—B-Mas: $.01^{X}$ (*SD* and range: NA) E-Anger—B-Lat: $.06^{X}$ (*SD* and range: NA) E-Fear—B-Zyg: $-.04^{X}$ (*SD* and range: NA) E-Fear—B-Corr: $.11^{X}$ (*SD* and range: NA) E-Fear—B-Mas: $-.01^{X}$ (*SD* and range: NA) E-Fear—B-Lat: $.06^{X}$ (*SD* and range: NA) **Experience-physiology coherence:** NA **Group/Individual differences:** NA **Associations with well-being:** NA

Lang et al., 1993	64 US students 50% female 50% male No ethnicity reported	42 pictures varied widely in content (including the neutral and mundane) and affective tone, from calm to arousing and pleasant to unpleasant	**Experience:** Valence and arousal (Self-Assessment Manikin) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** HR and SCR	Linear and quadratic correlation (reflect physiological reactions as a function of differences in pleasantness (or arousal) and are not responses to particular pictures	**Experience-behavior coherence:** E-Valence—B-Corr: -.90* (*SD* and range: NA) E-Arousal—B-Corr: .00 (*SD* and range: NA) E-Valence—B-Zyg: .57* (*SD* and range: NA) E-Arousal—B-Zyg: .47* (*SD* and range: NA) **Experience-physiology coherence:** E-Valence—P-HR: .76* (*SD* and range: NA) E-Arousal—P-HR: .48* (*SD* and range: NA) E-Valence—P-SCR: -.52* (*SD* and range: NA) E-Arousal—P-SCR: .81* (*SD* and range: NA) **Group/Individual differences:** Gender: E-Valence—B-Corr ~twice as many women (vs. men) showed significant coherence E-Arousal—P-SCR more than twice as many men (vs. women) showed significant coherence **Associations with well-being:** NA
Ruch, 1995	61 German students 100% female *M*age=23 No ethnicity reported	One of two permutations of a set of 35 black and white slides of jokes and cartoons	**Experience:** Funniness ratings **Behavior:** FACS behavior coding (AU12) **Physiology:** NA	Median value of product-moment correlations	**Experience-behavior coherence:** E-Funniness—B-AU12: $.71^{X}$ (*SD* and range: NA) **Experience-physiology coherence:** NA **Group/Individual differences:** NA **Associations with well-being:** NA

(*continued*)

Table 6 Examples of studies that examined within-person coherence using other approaches. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence	Results
Reisenzein, 2000b	35 German students 69% female 31% male *M*age=26 No ethnicity reported	Surprise induction; Computerized quiz (45 items) with questions and solutions	**Experience:** Self-report ratings of surprise at the quiz solutions **Behavior:** Behavior coding (brow raise, eye widening, mouth opening/jaw drop summed into an index of surprise ranging from 0 (no component shown) to 3 (all three components shown)) **Physiology:** NA	Intra-individual correlations among syndrome components for nonaggregated (raw) data	**Experience-behavior coherence:** E-Surprise—B-Surprise: .46** (*SD* and range: NA) **Experience-physiology coherence:** NA **Group/Individual differences:** Surprise intensity: No effect **Associations with well-being:** NA

Larsen et al., 2003	68 US students (subsamples ranged from 63-64 for different tasks) 100% female *M*age=20 3% Af-Am 15% As-Am 67% Eu-Am 7% L-Am	66 affective pictures, sounds, and words were chosen from standardized stimulus sets	**Experience:** Valence (Affect Matrix: pos-neg, so higher scores indicate positive valence) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** NA	Linear correlation (reflect EMG reactivity as a function of valence and are not responses to particular stimuli)	**Experience-behavior coherence:** Average across pictures, words, and sounds: E-Valence—B-Corr: -.85^{X} (*SD* and range: NA) E-Valence—B-Zyg: .50^{X} (*SD* and range: NA) **Experience-physiology coherence:** NA **Group/Individual differences:** NA **Associations with well-being:** NA
Hastings et al., 2009	215 US adolescents 49% female 51% male *M*age=13 16% Af-Am 70% Eu-Am 14% Other or mixed	Eight film clips eliciting fear, anger, sadness, and happiness	**Experience:** Valence (ratings of anxious, hostile, depressed, positive) **Behavior:** NA **Physiology:** HR	HLM: Relations between feelings and HR within each condition were modeled at Level 1, and reflected the unique relation between HR and that specific feeling in that condition, while controlling for	**Experience-behavior coherence:** NA **Experience-physiology coherence:** Only significant/trending effects were reported Fear Film clip E-Anxious—P-HR: *B*: 1.21** (*SE*: .42, range: NA) Anger Film clip E-Anxious—P-HR: *B*: .86 (*SE*: .48, range: NA) E-Depressed—P-HR: *B:* -1.31* (*SE*: .64, range: NA) Sad Film clip:

(continued)

Table 6 Examples of studies that examined within-person coherence using other approaches. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence	Results
				all other feeling–HR relations at baseline and in the four emotion conditions	E-Anxious—P-HR: *B*: 1.50** (*SE*: .52, range: NA) E-Depressed—P-HR: *B*: -1.74** (*SE*: .61, range: NA) **Group/Individual differences:** Externalizing and internalizing symptoms were related to some types of coherence. However, there are complex interactions involving emotional context, measured emotion, and gender **Associations with well-being:** NA
Dan-Glauser & Gross, 2013, Study 1	37 US students 100% female *M*age=20 5% Af-Am 35% As-Am 27% Eu-Am 5% L-Am 27% "other," "more than one race," or missing	25 neutral pictures under the unregulated instruction, 75 negative pictures (25 under each instruction), and 75 positive pictures (25 under each instruction)	**Experience:** Rating dial (negative to positive) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** Composite (HR, systolic and	Most positive cross-correlation +/− 8 *s*	**Experience-behavior coherence:** Average across all conditions: Negative pictures: E-Valence—B-Corr: $.43^{X}$ (*SD* and range: NA) Positive pictures: E-Valence—B-Zyg: $.40^{X}$ (*SD* and range: NA) **Experience-physiology coherence:** Average across all conditions: Negative pictures: E-Valence—P-Composite: $.53^{X}$ (*SD* and range: NA) Positive pictures: E-Valence—

			diastolic blood pressure, respiratory rate, respiratory amplitude (R), FPA (R), FPTT (R))		P-Composite: .54^{X} (*SD* and range: NA) **Group/Individual differences:** Condition (instructed behavior suppression, instructed physio suppression and control): General coherence in control > both instructed conditions **Associations with well-being:** NA
Dan-Glauser & Gross, 2013, Study 2	37 US students 100% female *M*age=20 8% Af-Am 32% As-Am 30% Eu-Am 8% L-Am 3% N-Am, 19% "other," "more than one race," or missing	25 neutral pictures under the unregulated instruction, 75 negative pictures (25 under each instruction), and 75 positive pictures (25 under each instruction)	**Experience:** Rating dial (negative to positive) **Behavior:** Facial EMG (corrugator and zygomatic) **Physiology:** Composite (HR, systolic and diastolic blood pressure, respiratory rate, respiratory amplitude (R), FPA (R), FPTT (R))	Most positive cross-correlation +/− 8 *s*	**Experience-behavior coherence:** Average across all conditions: Negative pictures: E-Valence—B-Corr: .45^{X} (*SD* and range: NA) Positive pictures: E-Valence—B-Zyg: .24^{X} (*SD* and range: NA) **Experience-physiology coherence:** Average across all conditions: Negative pictures: E-Valence—P-Composite: .56^{X} (*SD* and range: NA) Positive pictures: E-Valence—P-Composite: .59^{X} (*SD* and range: NA) **Group/Individual differences:** Condition (instructed behavior and physio suppression, instructed acceptance and control): General coherence in control and instructed acceptance > instructed suppression General coherence in control = instructed acceptance **Associations with well-being:** NA

(*continued*)

Table 6 Examples of studies that examined within-person coherence using other approaches. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence	Results
Sommerfeldt et al., 2019	1,065 US adults 57% female 43% male *M*age=56 18% Af-Am < 1% As-Am 78% Eu-Am 1% N-Am 3% listed another option	Laboratory stress tasks: Stroop color-word task and Morgan and Turner Hewitt MATH task	**Experience:** Ratings of stress (not stressed at all to extremely stressed) **Behavior:** NA **Physiology:** HR	6 time points; Linear mixed-effects model (LMEM) to examine whether the (statistical) effect of one of the Level 1 variables (e.g., subjective stress) on the other Level 1 variable (e.g., heart rate) is moderated by the individual-differences variable	**Experience-behavior coherence:** NA **Experience-physiology coherence:** NA **Group/Individual differences:** Denial coping: b: -.07** **Associations with well-being:** Cross-sectional Depressive symptoms: b: -0.25** Trait anxiety: b: -0.21** Psychological well-being: b: 0.05*

Rattel et al., 2020	44 Austrian students 50% female 50% male *M*age=23.5 No ethnicity reported	15 film clips with five emotional states (threat-,loss-, achievement-, and recreation-related, and neutral)	**Experience:** Valence (very unpleasant to very pleasant) and arousal (very calm to very excited) **Behavior:** Facial EMG (corrugator and zygomaticus) **Physiology:** HR, SCR, SCL RR, PEP, RSA	Nonparametric-correlations (Spearman)	**Experience-behavior coherence:** Average across genders: E-Valence—B-Corr: .39^{X} (*SD* and range: NA) E-Valence—B-Zyg: -.15^{X} (*SD* and range: NA) E-Arousal—B-Corr: .20^{X} (*SD* and range: NA) E-Arousal—B-Zyg: .14^{X} (*SD* and range: NA) **Experience-physiology coherence:** Average across genders: E-Valence—P-HR: -.06^{X} (*SD* and range: NA) E-Valence—P-SCR: .22^{X} (*SD* and range: NA) E-Valence—P-SCL: .14^{X} (*SD* and range: NA) E-Valence—P-RR: .19^{X} (*SD* and range: NA) E-Valence—P-PEP: -.07^{X} (*SD* and range: NA) E-Valence—P-RSA: -.02^{X} (*SD* and range: NA) E-Arousal—P-HR: .11^{X} (*SD* and range: NA) E-Arousal—P-SCR: .57^{X} (*SD* and range: NA) E-Arousal—P-SCL: .37^{X} (*SD* and range: NA) E-Arousal—P-RR: .37^{X} (*SD* and range: NA) E-Arousal—P-PEP: -.19^{X} (*SD* and range: NA) E-Arousal—P-RSA: -.10^{X} (*SD* and range: NA) **Group/Individual differences:** Gender: Almost all coherence pairs in women > men **Associations with well-being:** NA

(*continued*)

Table 6 Examples of studies that examined within-person coherence using other approaches. (*cont'd*)

Study	Sample	Context	Response Systems Measured	Index of Coherence	Results
Petrova et al., 2021	279 US adults *M*age=62 53% female 47% male 98% Eu-Am	Trier Social Stress Test and expressive writing	**Experience:** Ratings on 6 triplets of negative emotions **Behavior:** NA **Physiology:** HR	Within-person slope of the relationship between heart rate and negative affect; only 3 time points for experience (pre Trier, post Trier, after expressive writing)	**Experience-behavior coherence:**NA **Experience-physiology coherence:** E-Negative—P-HR: *b:* 1.26^{X} (*SD*: 1.89, range: NA) **Group/Individual differences:** Negative affect: *r:* -.14* Trait mindfulness: *r.* .18** Describing facet of FFMQ: *r.* .25** Suppression: *r:* -.21** Reappraisal: *r.* .10* **Associations with well-being:** Satisfaction with life measured 1 year before coherence: *r.* .12**
Van Doren et al., 2021	25 US adults 68% female 32% male *M*age=32 8% As-Am 84% Eu-Am 8% L-Am	Ecological momentary assessment	**Experience:** Arousal (6 daily prompts of "How awake/active do you feel right now?" from not at all to extremely) **Behavior:** NA **Physiology:** HR and EDA	Bayesian multi-level models: Within-person estimate between HR/SCL and self-reported arousal	**Experience-behavior coherence:** NA **Experience-physiology coherence:** E-Arousal—P-HR: *b* = 0.23* (SE: .04, range = NA) E-Arousal—P-SCL: *b* = 0.68* (SE: .23, range = NA) **Group/Individual differences:** Negative emotionality: No effect Psychological well-being: No effect Gender: No differences

Note. Af-Am = African-American. As-Am = Asian-American. C/E-Am = Caucasian/European-American. L-Am = Latinx-Am. ME-Am = Middle Eastern-American. N-Am = Native-American. E = Experience. B = Behavior. P = Physiology. |E| = absolute value of the experience rating. HR = heart rate. FPTT = finger pulse transit time. FPA = finger pulse amplitude. EPTT = ear pulse transit time. SCR = non-specific skin-conductance response rate, SCL = skin conductance level. EMG = electromyography. IBI = inter-beat interval. MAP = mean arterial pressure. SBP = systolic blood pressure. DBP = diastolic blood pressure. (R) = reverse scored. * = $p < .05$. ** = $p < .01$. ^{X} = no significance test. In some cases, SD was calculated using standard error and sample size.

consistent with the idea that experience-behavior and experience-physiology coherence exist. Specifically, all of the six significance tests reported for experience-behavior coherence were significantly different from 0. Of the 12 significance tests reported for experience-physiology coherence, seven (58%) were significantly different from 0.

Next, we estimated central tendency of effect sizes across studies. To do so, we had to reduce heterogeneity across studies. We achieved this by (a) converting all effect sizes to absolute effect sizes, (b) obtaining one effect size per coherence index per study by averaging across multiple indices of coherence within studies (across multiple emotion inductions or multiple measures; see "Results" column of Table 5), and (c) focusing on the seven studies that were conducted within US-American cultural contexts, leaving the two studies conducted in Japan and Cyprus separate. For the five US studies that reported *experience-behavior* coherence, the mean effect size was $r = .49$, and the range was $.13 < r < .74$. For the seven US studies that reported experience-physiology coherence, the mean effect size was $r = .28$, and the range was $.09 < r < .43$. These coefficients represent cross-method convergence correlations and are not corrected for the imperfect reliability of the two measures being correlated. In other words, they could not possibly reach the maximum correlation of 1.0. In fact, the correlations observed here are similar to those for cross-method correlations in other research areas (Funder & Ozer, 2020).[5]

How do these trends across the US studies compare with the two studies conducted outside the US? In the Cypriot study (Constantinou et al., 2023), average experience-behavior coherence was $r = .30$ and average experience-physiology coherence was $r = .20$ for the emotional film clips. In the Japanese study (Saito et al., 2023), average experience-behavior coherence was $r = .30$ and average experience-physiology coherence was $r = .53$ for the emotional film clips, when using the absolute coherence index.[6] The Cypriot study thus showed results comparable to the US studies. The Japanese study showed similar results in experience-behavior coherence but higher experience-physiology coherence compared to the other studies. This could be due to cultural differences or to

[5] For example, cross-method correlations for Big Five personality traits average about.50 (John et al., 2008) and convergence correlations between different informants (e.g., parents and teachers) in the psychopathology literature are often in the.30 range or lower (Achenbach et al., 1987).

[6] This study also reported coherence indices with the sign retained. These findings looked quite different, indicating that which index is chosen can make a difference for results.

the fact that experience of arousal was used in this study when measuring experience-physiology coherence (versus experience of valence or discrete emotions in the eight other studies). We come back to this distinction.

On the whole, based on these analyses, we can conclude there is on average moderate to strong experience-behavior coherence in the US, Cypriot, and Japanese samples, and moderate experience-physiology coherence in the US and Cypriot samples. Studies ranged widely in their effect sizes for both types of coherence, going from small to large effects (Funder & Ozer, 2020).

So far, we have addressed the question of whether response systems cohere by comparing coherence during emotion inductions to the null hypothesis of a zero correlation, and then we considered average effect sizes to capture the trends across studies. Other ways to address this question add greater specificity, such as comparing (a) coherence during emotional states to coherence during neutral states or (b) coherence during more intense emotional states to coherence during less intense states. Two studies compared emotional to neutral states (Constantinou et al., 2023; Saito et al., 2023). These studies indicate that coherence levels are on the whole similar for emotional and neutral states, with one exception: experience-behavior coherence for *neutral* film clips in Constantinou et al. (2023) was lower compared to positive and negative film clips.

Similar coherence for neutral versus emotional states could mean two things. First, it could mean coherence is not specific to emotions. However, it could also mean the neutral stimuli were not entirely neutral. Indeed, Figs. 1 and 2 in Saito et al. (2023) indicate the Japanese participants had rated the valence of the "Abstract Shapes" film clip (considered a neutral stimulus) about as negatively as the valence of the sad "The Champ" film clip (which shows a boy whose father has just died). Similarly, the Cypriot participants in Constantinou et al. (2023) rated the neutral clips just above the midpoint of the valence scale (5.8 on a 1–9 scale) but showed some elevation in arousal ratings (3.9 on a 1–9 scale). It is possible, for example, that the neutral film clips evoked aversive feelings of boredom. This observation speaks to the general difficulty of inducing truly neutral states.

Is there any evidence that coherence increases with increasing emotional intensity? Five studies addressed this possibility. Brown and colleagues (2020) compared one high-intensity emotional film clip to three low-intensity ones and found that experience-physiology coherence was significantly higher in the high-intensity condition. Another study approached the same question by comparing coherence based on the intensity with which participants experienced and expressed emotions (Mauss et al., 2005). They found that intensity of participants' amusement experience was associated with greater amusement behavior-physiology coherence and intensity of participants' sadness experience was associated with greater sadness behavior-physiology coherence (albeit with smaller effect sizes). Three additional studies did not find effects of emotion intensity on coherence (Lang et al., 1993; Lohani et al., 2018; Reisenzein, 2000a). Due to the correlational design, these associations need to be interpreted with caution because they are subject to confounds (e.g., a third variable could drive both emotion intensity and coherence). Nonetheless, on the whole, some findings are consistent with the idea that coherence becomes greater with increasing emotion intensity. However, only a few studies have addressed the question, there are several null findings, and the findings are at odds with those pointing to generally comparable levels of coherence for emotional versus neutral states.

What can we tell about the *directionality* of coherence? Of the studies that allow for directional conclusions (e.g., those that retained the sign of cross-correlations), we observe that positive emotion experience (e.g., amusement or positive valence) positively coheres with behavior indicative of greater positive emotional expressions (amusement behavior, positively valenced behavior, or zygomaticus activation), and vice versa for negative emotion experience (sadness behavior, negatively valenced behavior, or corrugator activation). Thus, there are clear and consistent associations between experience and behavior along the valence dimension.

In terms of physiological responses, findings are more complicated. There appears to be a valence and arousal (or possibly a discrete emotion) effect, such that positive emotion experience (amusement) is associated with greater cardiovascular activation or skin conductance level. In contrast, negative emotion experience (sadness) is generally not associated with cardiovascular responding or negatively associated with skin conductance level. These effects held when controlling for somatic activation (Mauss et al., 2005), which addresses the possibility that muscular activation during amusement (i.e., amusement behavior) may have driven the physiological activation.[7] These findings indicate some level of response fractionation within physiological systems: direction of associations depends on the

[7] It is interesting to consider what it means when somatic activity does not account for experience-physiology linkage. After all, somatic activity is linked to behaviors and to ANS responding and can be considered part of an emotional response (see Chen et al., 2022).

specific physiological subsystem (cardiovascular vs. electrodermal; Lacey, 1967). In another study (Hastings et al., 2009), anxiety was positively associated with heart rate whereas feelings of depression were negatively associated with heart rate. These findings indicate that different emotions (based on combinations of dimensions or based on discrete categories) are associated in different directions with individual physiological measures.

One possibility is that, when it comes to physiological responses, the arousal dimension of experience matters more than the valence dimension. Indeed, when the arousal dimension of experience is assessed (compared to the valence or discrete emotion), we observe higher experience-physiology coherence but lower experience-behavior coherence (Lang et al., 1993; Rattel et al., 2020). On the whole, this is in line with the idea that responses that share more features with one another (e.g., degree of reflectiveness versus automaticity; Evers et al. (2014); Lang et al., 1993) cohere more tightly with each other. In addition, in most cases where arousal experience was assessed we observe a positive direction of association, such that greater arousal experience is associated with greater cardiovascular or sympathetic activation – consistent with the view that sympathetic activation prepares the organism for action (Lang et al., 1993; Rattel et al., 2020; Saito et al., 2023; Van Doren et al., 2021).

3.2 Does response system coherence vary across types of coherence, emotions, contexts, and people?

The second set of questions we can ask is whether coherence varies depending on the type of coherence, the emotion, the context, or the person. At the broadest level, the studies in Table 5 show more consistent evidence as well as larger effect sizes for experience-behavior compared to experience-physiology coherence. For the five US studies that reported *experience-behavior* coherence, the mean effect size was $r = .49$, and the range was $.13 < r < .74$. For the seven US studies that reported experience-physiology coherence, the mean effect size was $r = .28$, and the range was $.09 < r < .43$. Across five studies that obtained both types of coherence indices,[8] experience-behavior coherence was greater than experience-physiology coherence in four cases (and equal in one case) as seen in the "Results" column in Table 5. We note this asymmetry—greater

[8] We do not include the study by Saito and colleagues in this count because experience-behavior coherence involved ratings of valence while experience-physiology coherence involved ratings of arousal. Thus, the two indices cannot be compared.

experience-behavior coherence compared to experience-physiology coherence—is found only when experience is assessed along the valence dimension or with discrete emotion experience but not with the arousal dimension. As described above, when we consider *arousal* experience, coherence between experience and physiology is greater. This finding, along with the fact that some studies involved single-item (rather than composite) indices of physiological responding (Mauss et al., 2005; Zerwas et al., 2023), speaks against the explanation that experience-physiology coherence is lower only because measures of physiological responding are less reliable.

Two studies compared coherence across different emotions, as indicated in the Results column in Table 5 (Saito et al., 2023; Zerwas et al., 2023). Saito et al. (2023) found some differences across different emotion inductions. However, it is difficult to come to firm conclusions based on these findings given the study had a relatively small sample size and a complex design involving four different coherence pairings, two kinds of coherence indices, and two age groups that yielded different results from one another. Zerwas et al. (2023) compared a film clip (that generally induces amusement and sadness) to a speech task (that generally induces anxiety). They found greater experience-behavior coherence and experience-skin conductance level coherence during the film clip than the speech. Yet, as we discuss next, these two conditions vary with regard to the larger context and not only in emotion. Two additional studies shown in Table 6 compared different emotional context (e.g., positive to negative, fear and sadness; Dan-Glauser & Gross, 2013; Hastings et al., 2009). They found generally similar levels of coherence across the emotions they studied. At this point, then, the evidence as to whether coherence differs by emotional state is weak and inconclusive.

In terms of the larger context, we were able to compare less social to more social conditions. Only one study examined coherence in a social context, a conversation between strangers (Butler et al., 2014), which we can compare to the other studies in which participants were alone (e.g., viewing films by themselves). Effect sizes in Butler and colleagues' (2014) study were smaller than in most other studies, especially when considering experience-behavior coherence. This discrepancy was also found when comparing it to the study by Constantinou and colleagues (2023) that used indices of coherence comparable to those used by Butler and colleagues (2014).

Another study compared a relatively more social context (a speech given by oneself but video-recorded) to a less social context (amusing and sad film clips viewed by oneself) within the same study (Zerwas et al., 2023). The argument here is that even though participants gave the speech alone without an audience physically present, an audience was implied because the speech was recorded, and participants were informed that a friend as well as a panel of judges would later view the recordings. The study found lower levels of experience-behavior coherence and experience-SCL coherence for the speech than the film viewing task. These differences could be due to differences in methodology or the simple fact that the tasks vary in terms of somatic movement and difficulty. However, these differences could also be due to the more social nature of the conversation and the speech task. Specifically, participants might regulate their emotions to adhere to social norms in social contexts, which would lead to lower coherence, particularly with behavior measures that are relatively easy to control.

In terms of variation across individuals, we can look at standard deviations and ranges of coherence indices across participants (see the Results column in Table 5) to capture two aspects of variation. Both indices point consistently to substantial individual differences: Across the five US studies, the mean standard deviation is.30 for experience-behavior coherence. Two studies reported ranges across participants. Overall, the lowest correlation was −.74 and the highest correlation was .92. Across the six US studies, the mean standard deviation is .25 for experience-physiology coherence. One study reported ranges across participants. Overall, the lowest correlation was −.95 and the highest correlation was .99. In sum, the standard deviations and the ranges of coherence indices consistently support substantial variation across people in experience-behavior coherence as well as in experience-physiology coherence.

What predicts this variation? A few studies examined whether people differ in coherence based on age, gender, or ethnicity (see the Results column in Table 5). For age, one study (Lohani et al., 2018) found that older adults in the US showed greater experience-physiology coherence than younger adults, with no age differences in experience-behavior results. A second study (Saito et al., 2023) found some age effects in the opposite direction; however, this study with Japanese participants had a smaller sample size, and age effects were found only in some emotional contexts (e.g., anger but not any of the other four emotions). Based on only these two studies, no clear picture emerges for age differences.

In terms of gender, studies have found either no effect (e.g., Mauss et al., 2011) or greater coherence in women than in men (e.g., Lang et al., 1993; Rattel et al., 2020). No study we are aware of found ethnicity differences in coherence but only two studies reported having tested for such effects (Mauss et al., 2005; Mauss et al., 2011). Mauss et al. (2005) compared all ethnic groups that were included (African American, European American, Asian American, and Latinx American), which likely led to inconclusive results given small sample sizes (the total sample size was 59 in the study). Mauss et al. (2011) is the most diagnostic test in that they compared specifically Asian/Asian American to European/European American groups on theoretical grounds (Tsai et al., 2002). Many studies did not report ethnicity, and those that do show that ethnicity is not well sampled in most studies (see Sample column in Tables 5 and 6). Thus results for ethnicity are inconclusive to date.

What psychological processes predict coherence? Several studies examined emotion regulation, with a focus on suppression and reappraisal (see Gross & John, 2003). In two studies, instructions to suppress emotional behaviors led to lower levels of experience-behavior as well as experience-physiology coherence compared to no instruction conditions (Butler et al., 2014; Dan-Glauser & Gross, 2013). Dan-Glauser and Gross (2013) also examined a condition in which participants were instructed to suppress their physiological responses and found it led to lower levels of experience-behavior as well as experience-physiology coherence compared to no-instruction conditions. Studies measuring individual differences in habitual suppression show a converging picture, with greater suppression predicting lower coherence (Brown et al., 2020; Petrova et al., 2021).

The picture for reappraisal is more complicated and less conclusive. In Butler and colleagues' (2014) study, instructions to use reappraisal led to lower levels of coherence between experience and negative behavior but higher levels of coherence between experience and positive behavior. One study found no significant relationship between habitual reappraisal and coherence (Brown et al., 2020) and one study found a small positive link (Petrova et al., 2021).

Other studies have examined aspects of mindfulness, including emotional acceptance and awareness (Baer et al., 2008; Brown et al., 2007; Ford et al., 2018). Instructions to accept emotions did not lead to differences in coherence compared to a no-regulation control condition (Dan-Glauser & Gross, 2013). In contrast, in terms of individual differences, Petrova and colleagues (2021) measured two facets of mindfulness, namely the tendency to describe and to be aware of one's emotions, and found that both were associated with greater experience-physiology coherence. Conversely, Sommerfeldt and colleagues (2019) measured use of denial as a coping strategy (which can be seen as the opposite of acceptance, in some ways) and found that less denial predicted higher experience-physiology coherence. Lastly, a study by Sze and colleagues (Sze et al., 2010) provides evidence on mindfulness as a predictor of coherence. They compared Vipassana meditators, dancers, and control participants with no meditation or dance expertise. They found a gradient of coherence along the lines of mindfulness expertise, with meditators showing the highest levels of coherence, followed by dancers, followed by controls.

3.3 Does response system coherence have benefits?

We found five studies that examined whether within-person coherence of response systems is associated with benefits such as well-being and mental health. One study examined experience and behavior during a positive emotion induction and found that coherence predicted a decrease in depressive symptoms and an increase in well-being six months later, even when controlling for levels of positive emotion reactivity (Mauss et al., 2011). Three studies examined experience-physiology coherence during laboratory stressors (Petrova et al., 2021; Sommerfeldt et al., 2019) or mixed emotion inductions (Brown et al., 2020), and found coherence was associated cross-sectionally with (or predicted by, in the case of Petrova et al., 2021) less depression and anxiety and greater well-being, again when controlling for negative emotion reactivity. On the whole, the few studies that tested the idea that coherence is associated with benefits yielded results consistent with this idea.

A recent study assessed both experience-behavior and experience-physiology coherence in both a film clip and a stressful speech task as predictors of well-being (Zerwas et al., 2023). The study found that experience-behavior coherence during the film clip (but not the speech task) was associated with psychological well-being, satisfaction with life, and social connection, while experience-physiology coherence measured in either context was not associated with these benefits. This lack of association for experience-physiology coherence stands in contrast to earlier studies that found links between experience-physiology coherence and well-being, including when measured during a speech stressor (Brown et al., 2020; Petrova et al., 2021; Sommerfeldt et al., 2019). These differences could be explained by different samples or different coherence metrics (see Table 5). Taken together, these studies suggest that type of coherence and context may matter when it comes to benefits of coherence.

However, this idea needs to be tested by assessing multiple types of coherence in multiple contexts within the same study, and ideally with longitudinal designs.

If coherence is associated with benefits, why might this be the case? One study (Mauss et al., 2011) examined a potential mechanism of experience-behavior coherence: social connection. This process was chosen because the social-functional perspective suggests that greater experience-behavior coherence involves more accurate and authentic communication, which might have social benefits. Consistent with this idea, greater experience-behavior coherence during an amusing film clip predicted greater social connection, which accounted for change in depression symptoms and well-being six months later. These effects held when accounting for levels of positive emotion experience and behavior, indicating they are not due to confounding of coherence with emotional reactivity.

On the whole, research is consistent with the idea that some types of coherence might have benefits in terms of well-being and mental health. Yet, few studies have addressed this notion, and some results were inconsistent. We return to these observations in the future directions.

4. Methodological, theoretical, and well-being implications

Taken together, the proposed integrative view of coherence along with the review of existing research have methodological, theoretical, and well-being implications, which we discuss next.

4.1 Methodological and measurement implications

The present research has broad implications for how we study coherence, specifically, and emotions, more broadly.

4.1.1 What are methodological implications for research on coherence?

The present review has several implications for how we should best go about studying coherence, which are summarized in Table 2. Some of these implications were arrived at by conceptual analysis. These include that coherence is best studied at the within-person level (Row 2.1) and pairwise rather than systemwide (Row 2.2). In terms of experimental design considerations, coherence should be studied in intense emotion inductions that fluctuate across time so as to capture the dynamic range of emotions (Row 2.3.1). Several different comparisons are of interest in giving us more nuanced and specific insights into coherence (Row 2.3.2). When it comes to assessment of emotional responses, more is generally better: More systems, more indicators within each system, and more frequent assessment of these measures, and measures should be obtained concurrently with one another and while a person is in an emotional state (Row 2.4). In our review, we addressed whether composites of physiological activation or individual indicators are preferred. Based on often low reliabilities across measures of physiological responding and based on the fact that results tend to vary across measures of physiological responding (see Table 2), we concluded that individual measures are preferable.

Last, we provided analyses to empirically assess how to go about constructing coherence indices from time series data (Row 2.5). These analyses indicate that a second-by-second resolution is ideal for the time series (along with a 3-second moving average to smooth the data), because it aligns with theorizing on the duration of emotional episodes and with past work, and it provides the most nuanced look at a participant's emotional trajectory. That said, we did not find much evidence for information being lost when coarser, up to 15-second resolutions are used. Thus, researchers have some flexibility in which timing resolution they choose if second-by-second assessments are difficult to obtain.

We also found empirical support that a window of $+10/-10$ s is ideal to calculate cross-correlations on empirical grounds and because it is maximally inclusive of potential lags across measures without being too inclusive by going beyond expected lags. Within that window, the highest correlation should be chosen to indicate coherence. One question was whether to retain the sign of the highest correlation (thus retaining information about the direction of associations), or to use the absolute value of the highest correlation (thus indexing strength of association regardless of the direction). Our recommendation is to use one approach consistently so that results can be compared more easily across studies. Of the two it seems that retaining the sign is advantageous because the direction of associations is often of interest. In cases where this approach is not favored by the experimenters based on theoretical or practical considerations, it should still be reported at least in a supplement to foster replication and knowledge accumulation within this field of study.

4.1.2 What are methodological implications for research on emotions more broadly?

Our analysis and findings have measurement implications more broadly in pointing us toward how we can measure emotions (Bradley et al., 2000; Mauss & Robinson, 2009). If coherence is substantial and the norm, then any one response (e.g., specific facial movements) can be taken as indication that a particular emotion has occurred (e.g., anger). We might even assume that we need to measure only one response (e.g., self-reported experience), because it can serve as a proxy for all other responses. If, however, coherence is modest or absent and variable across people and situations, then there is value, and perhaps even necessity, in measuring multiple responses. The latter is what we found to be the case, indicating that as emotion researchers, the more response systems we can capture, the more we can learn.

The present review suggests that not only is there value in measuring multiple emotion response systems but there is value in assessing their relationships with one another. This is important in the study of coherence but also in the study of emotions more broadly, to fully understand emotion and their functions (Kuppens & Verduyn, 2017; Molenaar & Campbell, 2009). One example that illustrates the importance of relationships among measures is a recent study in which we assessed within-person relationship between daily emotion and daily well-being (Willroth et al., 2020). We named the strength of this relationship emotion globalizing, because it indicates the degree to which emotions generalize unduly to satisfaction with life more globally. The study found emotion globalizing was associated with a maladaptive profile of functioning, above and beyond mean levels of emotion or well-being.

Last, these methodological implications apply to other fields concerned with relationships among multivariate, dynamic responses such as those examining interpersonal or group processes. For example, one question these methodological insights are relevant to is that of *inter*personal processes such as empathy. Using the same approaches we developed here can help us understand, for example, how coherent one person's experience, behavior, and physiology are with another person's experience, behavior, and physiology (Butler & Randall, 2013; Chen et al., 2021; Gordon et al., 2021; Levenson & Gottman, 1983; Tomashin et al., 2022; West & Mendes, 2023; Zaki et al., 2008; Zerwas et al., 2021). Thus, other fields can benefit from the insights generated from the research reviewed here.

4.2 Implications for emotion theory

Questions about emotion coherence and its functions address fundamental issues in emotion theory (Barrett, 2006, 2017a; Coan, 2010; Darwin, 1872; Ekman, 1992; Keltner & Haidt, 1999; Lang, 1988; Levenson, 2003; Nussbaum, 2001; Russell, 2003): Are emotions more akin to 'natural kinds' – coherent responses with a latent central mechanism – that help the organism respond to challenges? Or are emotions more akin to constellations of stars – unconnected responses – that *appear* coherent only through socially constructed, culturally imposed patterns? These ideas cut to the heart of what emotions and their functions are, and debate about them goes back centuries. A better understanding of the nature and function of coherence is of basic scientific interest, not just to emotion scientists but also to researchers interested in phenomena that centrally involve emotion (e.g., empathy, aggression, prejudice, relationships, personality, mental disorders involving affect). Next, we discuss implications for theories of coherence and then for emotion theories more broadly.

4.2.1 Implications for our understanding of emotion response system coherence

Although emotion theories agree that emotions involve multiple response systems, they differ in the way they explain whether and how response systems cohere with one another. As we described in Section 1, a strong version of *latent* emotion theories maintains that response systems cohere across different emotions and contexts and that such coherence has benefits. A strong version of *emergent* theories maintains that emotional response systems do not cohere, and that coherence does not have benefits. We proposed, as have others, that both theories are subject to qualifications, which lead us to a set of modified predictions: (a) There is some, but not perfect, coherence; (b) coherence will vary across types of coherence, people, emotions, and contexts; and (c) some types of coherence have benefits, which depend on type of coherence and the context.

Our review of studies that used within-person approaches found overall evidence in favor of some coherence. For studies that used optimal methods (shown in Table 2), the means were $r = .49$ for experience-behavior coherence and $r = .28$ for experience-physiology coherence, across samples, emotions, measures, and contexts. These numbers indicate that coherence exists, but it is far from perfect. That said, these numbers likely underestimate true coherence, because (a) they are usually based on single observations of each response system (versus an aggregate of multiple items that test theory would demand), (b) the measurement error for a coherence estimate is the sum of measurement errors for the studied variable pair and this attenuates the coherence estimate, and (c) they are usually obtained in laboratory emotion inductions versus more intense, real-life emotional experiences (see John & Soto, 2007).

Our review also addressed our second prediction, namely that coherence differs by response systems being compared. We found that experience-behavior coherence ($r = .49$) tends to be greater than experience-physiology coherence ($r = .28$). One could argue this is not a fair comparison because behavior is captured with more subjective measures (e.g., coder ratings) than physiology (e.g., objective measures of physiological responses). However, even when researchers used electromyographic measures of facial behavior that objectively capture physiological responding in facial muscles, we find the same pattern: greater experience-behavior coherence than experience-physiology coherence ($r = .30$ versus $r = .20$ in Constantinou et al., 2023).

Overall, then, we found variation across types of coherence (experience-behavior versus experience-physiology coherence) and across subtypes of response-system coherence (e.g., valence-behavior versus arousal-behavior coherence; experience-skin conductance versus experience-heart rate coherence). This is in line with the integrative coherence view, whereby coherence is not an all-or-none but rather a differentiated process.

What might explain these patterns? The difference between experience-behavior coherence and experience-physiology coherence is consistent with the idea that types of coherence differ from one another as a function of the number of features shared by the emotion response systems involved. Specifically, experience and behavior are both more reflective processes (i.e., slower, more conscious, more subject to conscious control) and should thus exhibit greater coherence with one another. In contrast, most physiological responses represent more automatic processes (i.e., faster, less conscious, less subject to conscious control), and should thus cohere to a lesser degree with more reflective processes like experience (Evers et al., 2014).

Another explanation is that coherence serves primarily social functions (Barrett et al., 1987; Crivelli & Fridlund, 2019; Keltner & Haidt, 1999), at least in the tasks the reviewed studies considered. Experience-behavior coherence involves responses visible to others and thus serves these social functions more directly than experience-physiology coherence. These considerations predict that experience-behavior should be more pronounced in the contexts examined in the studies we reviewed. In other words, the asymmetry we found in our literature review aligns with socio-functional accounts of emotion that suggest emotions are meant to be communicated through our behaviors to help create and maintain social connections (Keltner & Haidt, 1999).

Experience-physiology coherence might be more pronounced in contexts that call the body to prepare for action, such as encountering a threat. But even in a well-controlled fear-inducing task, some variance in the physiological system will always be due to organismic homeostatic regulation, not due to emotional activation. After all, physiological functions like heart rate and electrodermal activity have not evolved to provide researchers with an index of emotional activation (Wilhelm & Roth, 2001). Regardless of the reason for the difference between experience behavior and experience-physiology coherence, however, the conclusion is that coherence does not operate in an all-or-none way across different response systems.

Next, we asked about variability in coherence across individuals. The results were clear and consistent: coherence varies substantially across people, with many people showing some coherence, some people showing near perfect coherence, and some people showing the opposite pattern of what would be expected—negative coherence or incoherence rather than a simple lack of association. One example of this is when *more unpleasant* experience is associated with *more pleasant* facial expressions. This pattern seems contradictory and suggests that regulatory mechanisms are operating here. One explanation is that people with reverse experience-behavior coherence are actively masking unpleasant feelings with facial indicators of positive emotion, such as a smile.

What might explain these substantial individual differences? A handful of studies has examined age, ethnicity, gender, emotion regulation, and mindfulness. Age and ethnicity have so far yielded no or inconsistent effects, which may be due to a lack of power to detect such effects in the available studies. Moreover, ethnicity may need to be operationalized in stronger ways through cross-national collaborations, such as comparing Japanese participants living in Japan to Ghanaian participants living in Ghana to European-Americans living in the US. Of the sociodemographic factors, gender has received the most consistent support, with women showing greater coherence in both experience-behavior and experience-physiology than men.

With regard to emotion regulation, expressive suppression has received the most consistent support, with more suppression linked to lower experience-behavior coherence in both correlational and experimental designs. This makes sense in that suppression selectively alters emotional behavior, which should lower its coherence with experience. Some studies also find that suppression lowers experience-physiology coherence. This is more complicated to explain but one idea is that suppression more generally disrupts emotional responding (Gross et al., 2000). Lastly, mindfulness-related processes such as awareness, ability to describe one's emotions, and experience with mindfulness meditation were found to be associated with greater experience-physiology coherence. This is in line with mindfulness attuning people more to their emotional states, including their physiological aspects.

Five studies tested the prediction that coherence would be associated with benefits. Two studies found experience-behavior coherence was associated with well-being and mental health (Mauss et al., 2011; Zerwas et al., 2023), and three studies found experience-physiology associated with well-being and mental health (Brown et al., 2020; Petrova et al., 2021; Sommerfeldt et al., 2019). Broadly, these findings are consistent with the idea that at least some forms of coherence are beneficial.

To begin to better understand which types of coherence might have benefits and which might not, Zerwas et al. (2023) compared links between two types of coherence in two tasks on the one hand and well-being on the other hand. They found that only experience-behavior coherence in the film clip but not the three other measures of coherence (all of which were experience-physiology measures) were associated with greater well-being. This is consistent with the idea that benefits vary based on type of coherence and particular context. In the case of experience-behavior coherence, one study (Mauss et al., 2011) also identified a theoretically motivated mechanistic link: social connection. Specifically, greater experience-behavior coherence during amusing film clips predicted greater social connection, which predicted greater well-being six months later. These findings are in line with the idea that experience-behavior coherence benefits people via social-communicative pathways (Frijda et al., 1994; Keltner & Haidt, 1999; Niedenthal & Brauer, 2012).

In sum, the present findings are consistent with the notion that although we found evidence for moderate levels of coherence when we average across people, emotions, and contexts, the equally important conclusion is that coherence varies substantially across people, emotions, and contexts. In turn, we have found that coherence is associated with well-being benefits but more research is needed to more conclusively support this idea. Broadly, these findings support the view of coherence as a process that flexibly responds to particular contexts.

4.2.2 Implications for theories of emotions beyond coherence

What can these findings tell us about the nature of emotions, more broadly? A first, basic question the present findings speak to is about the two groups of theories of emotion outlined in Table 1. They are inconsistent with the strong latent view of emotions depicted in Fig. 1, whereby a central mechanism coordinates all emotional responses. They are also inconsistent with the strong emergent view of emotions depicted in Fig. 2, whereby emotional responses are independent responses to the environment, and coherence merely emerges in people's perception. Rather, they are consistent with qualifications to *both* views: A latent view that allows for flexibility and context dependence, and an emergent view that allows for coherence afforded by the situations that people encounter or as driven by affective dimensions.

Can we adjudicate between the qualified versions of the two types of theories? One possibility is that the answer depends (see Cacioppo et al., 2000). For example, latent views might be more accurate for some emotions, perhaps those with evolutionarily prepared sets of responses (e.g., fear; Tooby & Cosmides, 2008), and emergent views might be more accurate for other emotional states (e.g., blends, less survival-related, more social emotions like shame or guilt). This idea would translate to the hypothesis that for some emotions we would find greater coherence (more consistent with qualified latent views) and for some emotions we would find less or no coherence (more consistent with qualified emergent views). Given we do not have much evidence that speaks to emotion specificity in coherence, we cannot at present address this possibility.

Another, related possibility is that asking which theory is correct is not the most fruitful avenue to pursue. Perhaps the most fruitful way forward is to transcend the dualism of latent versus emergent views, just like the field transcended the biology versus culture or nature versus nurture dualism (De Houwer, 2011). The integrative view of coherence can serve to reconcile both theories. Such an integration could open up a new research agenda about the nature and benefits of emotions, with questions such as, When and why is there coherence? How and why does coherence vary across people, emotions, and contexts? What predicts individual differences in coherence? What factors decrease (versus increase) coherence? What benefits do different types of coherence have, in which contexts do they have them, and what mechanisms underlie them? We return to these questions in the directions for future research.

Another question that has sometimes been associated with coherence is that of the structure of emotions: Are emotions best understood as discrete categories (e.g., anger, fear, sadness, happiness) versus as located along a limited number of dimensions (e.g., valence, arousal, and approach vs. avoidance; Barrett, 2006; Cowen et al., 2019; Cunningham et al., 2013; Lench et al., 2011; Lindquist et al., 2013)? On the whole, the present findings do not constitute a strong test of these theories because they primarily concern relationships among emotion measures (e.g., the association between emotion experience and facial behavior), rather than about the structure of these measures (see Cowen & Keltner, 2021; Lang, 1988; Levenson, 2014). In addition, they do not allow us to distinguish between discrete and dimensional structure because even if we found distinct patterns of coherence (e.g., different patterns for anger versus sadness versus fear), this could be consistent with dimensional accounts in that each emotional state also varies along combinations of dimensions (e.g., anger is negative, high arousal, and approach while fear is negative, high arousal, and avoidance).

There is one exception, where the findings of the present review speak to questions about the structure of emotion. Specifically, if discrete emotion behaviors (e.g., smiling) cohere more with discrete experiences (e.g., joy) than with dimensional experiences (e.g., positive valence), this would indicate that discrete emotion ratings add information beyond dimensional ratings, which means that a discrete structure represents emotion more accurately (cf. Barrett, 2006). Conversely, if it does not matter whether discrete or dimensional assessments are used, this means that a dimensional structure suffices to represent emotion. The two studies that assessed discrete emotions for experience and behavior (Mauss et al., 2005, 2011) showed the largest effects sizes for experience-behavior coherence, including when compared to one study that used the same emotional film clip stimulus but dimensional ratings of experience and behavior (Zerwas, 2023). Thus, there is some evidence to suggest that information about discrete emotion states adds precision above and beyond dimensions.

Finally, the present findings speak to another basic question, namely whether any one response system constitutes a gold standard for establishing that an emotion has occurred. In other words, is any one response necessary and sufficient for an emotion? Most laypeople share the intuition that feelings—subjective emotion experience—establish an emotion has occurred and, conversely, the absence of feelings means no emotion has occurred. Similarly, some researchers argue we should consider emotion experience a gold standard. The present findings that there is, at best, loose coherence across response systems suggests that no one system can truly stand in for the others and serve as the gold standard.

How, then, could we establish an emotion occurred? Our findings indicate two options. One option is to examine multiple response systems and establish that someone is more or less in an emotional state, depending on how many response systems are activated. However, this option does not seem quite right, given coherence is far from normative. The second option, more consistent with existing findings, is to not think of an emotion as a single entity but rather that an emotion is a multi-componential state that can be characterized along several loosely coupled response systems. This means we cannot say that an emotion has or has not occurred because the boundaries of the category are fuzzy. This also means we need to be specific in our research and theorizing and make explicit which component (experience, behavior, or physiology) we reference (see Bradley et al., 2000; Lang, 1988; Mesquita, 2003).

4.3 Implications for well-being and mental health

Emotions are crucially involved in many aspects of psychological functioning, such as well-being (Diener et al., 2006; Fredrickson, 2001; Gruber et al., 2013) and mental health (e.g., mood and anxiety disorders, borderline personality disorder, self-harming disorder (Keltner & Kring, 1998; Kring & Mote, 2016; Rottenberg & Johnson, 2007)). In addition, emotions are implicated in performance (Baas et al., 2008; Lane, 2007; van Kleef et al., 2004), decision making (Cohen et al., 2008; Lerner et al., 2015), moral judgments (Feinberg et al., 2012), social functioning (e.g., aggression, empathy, stereotyping (Bushman, 2002; Lyubomirsky et al., 2005; Zaki & Cikara, 2015)), and risk for diseases (e.g., cardiovascular disease, metabolic disorder) (DeSteno et al., 2013; Grossman et al., 1997; McEwen et al., 2009).

Thus, what we learned about coherence also has important applied implications for improving these outcomes. Specifically, it can help us discern (a) what constitutes healthy versus unhealthy emotional responses, (b) how to diagnose unhealthy emotional responses, and (c) how to improve emotional responses and, in turn, their down-stream consequences. To date, much research has focused on characterizing healthy vs. disordered emotion in terms of *mean* levels (e.g., Bylsma et al., 2008;

Gruber, 2011; Kring & Mote, 2016). Although this approach provides important insights, it appears to be incomplete (see Hodgson & Rachman, 1974). Understanding coherence – characterizing emotion in terms of the type and extent of coordinated action among emotional response systems – should allow us to understand better what constitutes healthy vs. disordered emotion processes (Molenaar, 2015).

Our review found that more coherent responses are associated with better well-being and mental health. On the whole, this finding indicates that more coherent emotional responding is healthier. Yet, we found enormous individual and situational variation as well. The best conclusion may be that a wide range of coherence levels (say, from low to high) is healthy, especially in contexts that call for emotion regulation. However, a complete lack of coherence or reverse coherence (in a direction opposite to that expected) may well be unhealthy.

What do the present findings mean for how we can diagnose disorders of emotion and mood? Clinicians may ask, for example: Should someone who reports fear during flying not be treated because a physiological test does not show elevated heart rate during flight? Or, conversely, someone who does not report fear but shows elevated heart rate (see Wilhelm & Roth, 1998)? Individuals with a diagnosis of anxiety or posttraumatic stress disorder often show avoidance behaviors regarding their feared situations or hyperarousal in these situations. Both symptoms constitute an important part of the diagnostic criteria but are solely assessed based on self-report. Thus, experience is still the core criterion for diagnosis (American Psychiatric Association, 2013), despite intensive attempts in the past 30 years to find physiological markers for diagnoses, with little success (Insel, 2022). The present results could help overcome this impasse. They suggest a holistic approach to diagnosis might be best, with no single response system being granted the deciding role; we would need to accept that we cannot expect all measured systems to always point in the same direction (see Wilhelm & Roth, 2001).

The present analysis and findings might ultimately help us develop novel, specific, and theoretically derived targets for prevention and intervention (see Fisher, 2015). For example, to improve emotional functioning we may want to target the idiographic linkage of responses in addition to (or instead of) mean levels of emotion. Our findings regarding the antecedents of coherence point to ways in which this could happen, such as via emotion regulation (e.g., avoiding expressive suppression) or mindfulness (e.g., increasing emotional awareness). More research is needed before we should and can confidently implement such techniques and interventions, and we will return to these points in the Future Directions section. However, this approach appears to be a promising avenue.

5. Directions for future research

The present chapter outlined our current understanding of two fundamental questions about emotion response system coherence: (1) To what extent do emotional response systems (i.e., experience, behavior, and physiology) cohere during emotional episodes, and (2) is greater coherence associated with benefits? In closing, we discuss key directions for future research on coherence indicated by our findings and analysis. In many ways, the study of coherence is in its infancy, and this future research agenda will allow for progress in addressing hypotheses that are foundational to affective science. Emotions are centrally involved in many social (e.g., empathy, aggression, prejudice, relationships, personality, well-being) and clinical phenomena (e.g., mood disorders, mental health, physical health), and thus this research agenda is important for social, behavioral, and health sciences more broadly.

Both the methodological considerations and the integrative view of coherence presented here can help guide research that focuses on the *when*, *how*, and *why* more so than the *whether* of coherence. Throughout this chapter, we provide examples for specific hypotheses derived from the integrative view and what the data say about them. At the same time, it will be important to continue developing the theory iteratively with empirical tests, and derive more specific, a-priori hypotheses. Next, we describe particularly important directions for research regarding the basic nature of coherence, differences in coherence across response systems, people, and contexts, and implications for well-being and health.

5.1 Basic advances in the study of coherence

First, at the most basic level, and throughout all future research on coherence, we need larger and more diverse samples that provide better representation of genders, age groups, ethnicities, and other important sociodemographic factors (e.g., socioeconomic status).

Second, and this direction also cuts across various questions, to build knowledge and identify patterns across multiple studies, we need more complete reporting of metrics and greater methodological consistency. For example, it would be useful to report standard deviations and ranges of coherence. As another example, it would be helpful to agree on one type of cross-correlation approach across studies. A third example regards physiological measures in particular, with different studies involving different measures and composites. It would be useful to take a more consistent approach to selecting physiological measures. Table 2 summarizes our recommendations for what features and approaches to reporting could serve to integrate different studies and thereby allow the field to gain a broader knowledge base. Selecting measures more consistently would also reduce Type-I error rates.

Third, to come to a more complete understanding of coherence, we need to measure response systems more comprehensively. Behavior is a good example, with most studies having focused on just facial movements. A greater range of behaviors would help us more completely test ideas about coherence in their full form, namely that emotions affect the entire human organism. Such behaviors could include vocal patterns, gestures, or whole-body-movements (Keltner et al., 2019). Beyond a broader assessment of the response systems of experience, behavior, and physiology, it will be interesting to broaden the scope to other response domains, such as attention, perception, memory, cognitive biases, judgment, action readiness, and decision making (Barrett, 2006; Coan, 2010; Frijda, 1988; Russell, 2003; Scherer, 1984).

Fourth, we emphasized in our analysis pairwise correlations between lagged measures as a starting point that balances complexity with simplicity. Once we have a more nuanced and complete understanding of pairwise coherence, we might move toward more complex idiographic analyses such as dynamic factor analyses to represent coherence in fuller nuance and complexity (Fisher, 2015; Molenaar, 1985, 2015).

Fifth, one particular strength of the cross-correlation approach applied to intensely sampled time series is that it can give insight into lags. Yet, while the studies we reviewed accounted for lags, no study as of yet has considered them a substantive question. In future work, we should examine lags as an interesting outcome in its own right and try to systematically understand how response systems are lagged and whether there are meaningful individual differences in lags. For example, we might ask whether if someone's behavior lags experience by more than is typically the case, does this interfere with communication?

Last, remaining on the question of timing and dynamics, the approaches highlighted in this review converge with calls for examining within-person, dynamic changes in emotions more generally (Kahneman, 2000; Kuppens & Waugh, 2021; Molenaar & Campbell, 2009; though, see Dejonckheere et al., 2019), for a cautionary note. Of note, the dynamics we examined here occur at the level of seconds to minutes. It is interesting to contrast this with other methods concerned with emotion dynamics, such as ecological momentary assessments (EMA) and diaries (Kuppens et al., 2022; Van Doren et al., 2021; Willroth et al., 2020). These approaches are useful in that they capture emotion dynamics in vivid, real-life contexts. However, they usually do so at the level of minutes to days. Our analysis—pointing to the importance of capturing below-minute dynamics—suggests that the above-minute timescale captures a different process. This suggests two interesting directions for research. First, we want to test whether time scale truly matters—that is, does coherence at the second scale differ from coherence at the minute, hour, day, or week scale? And second, we want to unite the fine-grained time scale of laboratory-experimental research with the ecological validity of daily-life assessments to further our understanding of emotions, by further developing methods that allow us to assess emotions at the second scale in daily life (Wilhelm & Grossman, 2010).

5.2 Differences across types of coherence, emotions, contexts, and people

An important theme of the integrative view of coherence and the present findings is that coherence differs across types of coherence, people, emotions, and contexts. Yet, while these themes are important from both a basic-science and a practical perspective, many questions remain.

First, we need more research that examines and directly compares different kinds of coherence. Emerging results indicate that experience-behavior coherence might be greater than experience-physiology coherence. One idea with intriguing implications for the functions of coherence is that this difference is due to the specific tasks in which researchers have assessed coherence: mostly passive film-viewing tasks. Experience-physiology coherence might be more pronounced in tasks that require active coping and call the body to be prepared for action, such as encountering a threat or fleeing from danger. This hypothesis remains to be tested. Similarly, we want to broaden our tests to examine behavior-physiology coherence, which might also be particularly implicated in contexts that demand active coping or that impede insight into conscious experience (Cacioppo et al., 1992).

A second kind of difference is based on different emotions. Very few studies have compared coherence during different emotions to one another, and those that did do not allow for conclusive results yet (Hastings et al., 2009; Saito et al., 2023; Zerwas et al., 2023). One idea is that the latent and emergent views apply to different emotions. For example, more biologically-evolutionary meaningful emotions such as fear might involve a more prepared set of responses and lead to greater coherence compared to other emotional states (e.g., blends, surprise). To test this idea, studies are needed that compare different emotional states to one another while holding constant the mode of induction (e.g., all films, all recall). Beyond comparing different emotions, we want to learn more about whether coherence is specific to emotions versus neutral states, and whether coherence increases with increasing intensity of emotion. Lastly, it would be interesting to learn whether coherence is specific to emotions versus other, more homeostatic or motivational states that involve affect (e.g., hunger, fatigue).

In terms of the third difference, the integrative view of coherence predicts that context modulates coherence. One particularly crucial variable is social versus non-social contexts. Researchers might expect more social (versus less social) contexts to either lead to *less* coherence because they involve more regulatory norms or to *more* coherence because they call for more outward communication. While only two studies speak to these hypotheses, they were consistent in indicating lower coherence in more social contexts (Butler et al., 2014; Zerwas et al., 2023). These results are in line with the idea that social contexts invoke regulatory norms and emotion regulation and thus involve less coherence. Future studies should follow up on these initial results and examine the modulating role of social and other contexts more fully. Development of ambulatory assessment tools are especially useful for these purposes (Chen et al., 2022; Park, Gordon, & Mendes, 2023).

The last important theme of differences was that *people* vary substantially in experience-behavior as well as in experience-physiology coherence. We found a striking range in all indices of coherence, with many people showing some coherence, some people showing near-perfect coherence, and some people showing what we could call reverse coherence (e.g., smiling more when feeling sadder). One basic question that has yet to be addressed is how stable these individual differences are across time and contexts. This is particularly important as it relates to the idea that coherence contributes to well-being insofar as people exhibit more or less coherence consistently over time.

A second line of questions regarding individual differences is what predicts individual differences in coherence. The studies we reviewed suggest two groups of interrelated antecedents of coherence: sociodemographic factors and psychological factors. In terms of sociodemographic factors, several theorists have suggested that age would play an important role (Lohani et al., 2018; Mendes, 2010) but existing research on age and coherence does not yet allow us to come to firm conclusions. Tables 5 and 6 indicate a particular dearth of studies involving children. Yet children might be especially interesting to study, because emotion responses are being shaped and formed in childhood.

Theories also indicate that gender should play a crucial role, usually leading to the prediction that researchers should find more coherence in women compared to men (e.g., Brody et al., 2008). Initial research is consistent with this hypothesis (e.g., Lang et al., 1993; Rattel et al., 2020), but many open questions remain, including about the kinds of coherence that would (or would not) show this gender effect as well as what drives this effect (e. g., differences in learned display rules, emotion regulation, or biologically based organization of the emotion systems).

With regard to ethnicity and culture, we again see strong theorizing but dearth of empirical research. Table 5 indicates how little we know about people across the globe, with seven of the nine core studies conducted in the US. This is a vexing gap, given there is interesting and clinically important theorizing regarding response system coherence in some African and Asian cultures (e.g., in Ghana: Chentsova-Dutton & Dzokoto, 2014; Dzokoto & Okazaki, 2006; e.g., in China: Ryder et al., 2008; Zhou et al., 2011). Within the US studies, we note lack of diversity and striking underrepresentation especially of ethnic groups other than European- and Asian-heritage ones. Thus, we need more diverse studies that allow us to compare different groups of people to one another to better understand how sociocultural contexts shapes coherence.

In terms of psychological antecedents of coherence, initial research indicates that emotion regulation and aspects of mindfulness play a role in shaping coherence. The most is known about suppression, with experimental and individual-difference studies converging to indicate that suppression disrupts coherence, perhaps because it alters some but not all response systems. Some research has begun to explore reappraisal, acceptance, and emotional awareness but results are not conclusive yet. We need correlational studies as well as, especially, experiments to better understand the effects of emotion regulation and mindfulness on coherence.

5.3 Implications for well-being and health

Emotions are crucially involved in a wide range of well-being and health outcomes, pointing to the importance of understanding coherence for these outcomes. To date, much research has focused on characterizing healthy vs. unhealthy emotion in terms of mean levels (e.g., Bylsma et al., 2008; Gruber, 2011; Kring & Mote, 2016). While this approach provides important insights, it appears to be incomplete (see Hodgson & Rachman, 1974; Molenaar, 2015), and future research on coherence would allow us to better measure and understand what constitutes healthy vs. unhealthy emotion. For instance, here we found that lower coherence is associated with and predicts lower well-being and mental health, above and beyond mean levels of emotional reactivity. We could next ask whether the same is true for other functioning and health correlates of emotion, thus leading to better description and diagnosis of the emotional component of disorders, and more complete causal models of health and disease.

To address these questions, we especially need more research that uses longitudinal designs to test the idea that coherence plays a lead role in predicting changes in well-being or health. In addition, interventions that target coherence (e.g., through mindfulness or relaxation techniques) are needed to speak to a causal role. Such interventions could include meditation practices that should increase experience-physiology coherence (Sze et al., 2010) or expressive practices that should increase experience-behavior coherence. To arrive at a complete understanding of the putative benefits of coherence, we also need to examine theoretically motivated mechanisms. Some research points to the role of social processes in explaining benefits of experience-behavior coherence but only one study has tested this idea with a correlational design. Theorizing suggests experience-physiology coherence operates through active coping or through awareness, but no studies have tested these ideas.

We might also ask *for whom* and *when* coherence is beneficial by testing emotional, contextual, and person-level moderators; for instance, experience-behavior coherence might be less advantageous in contexts that do not as much value authentic expression of emotion. In sum, then, much remains to be learned about whether, how, when, and why coherence benefits people's well-being and health. However, research on coherence appears to be a promising avenue to help us understand and diagnose the nature of the emotional core of disorders and problematic behavior, and ultimately point to ways in which we can help improve these problems.

6. Conclusion

The present review presents an advance in a question that has long divided emotion theories: Do emotional response systems—experience, behavior, and physiology—cohere tightly during emotions or are they usually uncoordinated? We propose that both views are right but that both views must be qualified as well, and we find support for this integrative view of coherence in our review of the empirical literature.

Looking ahead, the integrative view opens a new research agenda about the nature and benefits of emotions, suggesting methods and a theoretical framework to address questions such as when and why is there coherence? How and why does coherence vary across people, emotions, and contexts? What predicts individual differences in coherence? What factors decrease and what factors increase coherence? What benefits do different types of coherence have, in which contexts do they have them, and what mechanisms underlie them? By transcending existing divisions, the integrative view has the promise to move the study of coherence forward and to generate new questions and insights about emotions and their role in well-being and health.

Acknowledgments

We thank Emily Butler for her contributions to developing the ideas presented here, and Bertram Gawronski, Robert W. Levenson, and Lisa Feldman Barrett for their comments on earlier drafts of this chapter. We also thank Akie Saito for sharing disaggregated data. Part of this work was supported by NSF grant 1941868 to Iris B. Mauss.

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