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Coherence Between Subjective Experience and Physiology in Emotion: Individual

Differences and Implications for Well-being

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Abstract

Emotion theorists have characterized emotions as involving coherent responding across various emotion response systems (e.g., covariation of subjective experience and physiology). Greater response system coherence has been theorized to promote well-being; yet, very little research has tested this assumption. The current study examined whether individuals with greater coherence between physiology and subjective experience of emotion report greater well-being. We also examined factors that may predict the magnitude of coherence such as emotion intensity, cognitive reappraisal, and expressive suppression. Participants (N=63) completed self-report measures of well-being, expressive suppression, and cognitive reappraisal. They then watched a series of emotionally evocative film clips designed to elicit positive and negative emotion. During the films, participants continuously rated their emotional experience using a rating dial, and their autonomic physiological responses were recorded. Time-lagged cross-correlations were used to calculate within-participant coherence between intensity of emotional experience (ranging from neutral to very negative or very positive) and physiology (composite of cardiac inter-beat interval, skin conductance, ear pulse transit time, finger pulse transit time and amplitude, systolic and diastolic blood pressure). Results indicated that individuals with greater coherence reported greater well-being. Coherence was highest during the most emotionally intense film and among individuals who reported lower expressive suppression. However, coherence was not associated with reappraisal. These findings provide support for the idea that greater emotion coherence promotes well-being and also shed light on factors that are associated with the magnitude of coherence.

Keywords: emotion coherence, well-being, physiological responses, emotion intensity, emotion regulation

Coherence Between Subjective Experience and Physiology in Emotion: Individual

Differences and Implications for Well-being

Starting with Darwin (1872), theorists have argued that emotions involve coherent responses across experiential, physiological, and behavioral response systems (Davidson, 1992; Ekman, 1977, 1992; Lazarus, 1991; Levenson, 1994; Plutchik, 1980; Tomkins, 1962). For example, in response to an emotional stimulus, a person may show covarying changes in heart rate (physiological response system), facial expressions (behavioral response system), and subjective experience of emotion (experiential response system). The term *emotion coherence* is often used to describe this covariation in emotion response systems across time (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005), but other terms have also been used such as emotion concordance (Bulteel et al., 2014), organization of response tendencies (Lazarus, 1991; Levenson, 1994), and response system coupling (Mauss, Wilhelm, & Gross, 2004). Although there is disagreement as to whether coherence should be viewed as a core feature of emotion (c.f., Barrett, 2006; Ekman, 1992), there is wide agreement across theories that emotions can involve changes in physiology and subjective experience (Coan, 2010; Izard, 2007; Levenson, 2014; Russell, 2003; Siegel et al., 2018).

Importantly, empirical studies suggest that individuals differ in their degree of coherence across physiology and subjective experience during emotion (Mauss et al., 2005). Moreover, these individual differences may have important implications. Functionalist theoretical accounts suggest that greater coherence across response systems helps people respond effectively to environmental challenges which may, over time, be associated with greater well-being (Ekman, 1992; Levenson, 2014; Mauss et al., 2005; Plutchik, 1980). Although functionalist accounts of emotion coherence have figured prominently in theoretical discussions of emotion (Ekman, 1992; Levenson, 2003; Levenson et al., 2017; Rosenberg & Ekman, 1994), central hypotheses

stemming from these theories (e.g., whether greater coherence is associated with greater well-being) have not been tested. In addition, if coherence is associated with functional outcomes, it is important to understand factors that may be associated with differences in the magnitude of coherence. Here again, very little research has addressed these questions.

Emotion Coherence and Well-being

Greater coherence between physiology and subjective experience may help individuals respond more effectively to emotional stimuli. For example, imagine a person realizing that their parking meter is about to expire. A coherent response of negative emotional experience (alerting the person of the need to take action) and heightened physiological activation (providing energy to key muscles to support body movement) may mobilize a person to rush to their car, quickly feed the meter, and avoid a costly ticket. In this sense, individuals with high coherence have emotional responses working in synchrony to facilitate effective responses to stressors and challenges. Whereas, the presence of only one activated response system would be less effective or even harmful (e.g., if physiological activation occurred without emotional experience, the person would be less likely to utilize the activation to avoid getting a ticket, and thus more likely to face an onerous ticket). Accruing these kinds of effective responses to life challenges repeatedly over time could promote higher well-being (Luhmann, Hofmann, Eid, & Lucas, 2012). Thus, coherent patterns of emotional responding between the autonomic nervous system (ANS) and subjective emotional experience within individuals may have important implications for well-being (Ekman, 1992; Levenson, 2014; Levenson et al., 2017; Mauss et al., 2005).

Well-being has been conceptualized as a multidimensional construct that encompasses not only the presence of positive indicators of well-being, such as life-satisfaction, but also the absence of negative indicators such as depressive and anxious symptoms (Kern, Waters, Adler, & White, 2014). A lack of coherence between physiology and subjective experience in response

to emotional stimuli may be indicative of mental health problems associated with lower well-being (Taylor, Bagby, & Patker, 1997). Indirect evidence hints that lower coherence among emotional response domains occurs in several psychopathologies. Dissociations between experience and physiology occur in youth with internalizing and externalizing problems (Hastings et al., 2009). Other studies suggest dissociations between expression and experience in schizophrenia (Kring & Neale, 1996), and dissociations between expression and physiology in individuals with repressive coping styles (Weinberger, Schwartz, & Davidson, 1979). The majority of these studies compared clinical groups to non-clinical groups, which does not capture the substantial normative variability in well-being that occurs within non-clinical populations. Only one study we are aware of has examined the relationship between coherence and well-being (Mauss et al., 2011), finding that greater coherence between subjective experience and facial expressions of emotion was related to greater well-being. To the best of our knowledge, no prior research has examined the association between well-being and the coherence between experiential and physiological response systems.

Factors Hypothesized to be Associated with Coherence

If coherence is related to well-being it is important to understand factors that may predict individual differences in the magnitude of coherence. Theoretical accounts, in addition to past research, suggest a number of possible factors that may be associated with coherence. Here, we focus on theoretically-motivated emotional factors that may predict the magnitude of coherence, including the perceived intensity of an emotional stimulus, as well as emotion regulatory tendencies. These specific factors and their hypothesized associations with coherence are described next.

Emotion intensity. Functionalist and evolutionary emotion theories of coherence propose that the coherence of responses is particularly important under conditions of high

intensity emotion, where ones' physical and psychological well-being are at stake. As such, situations perceived as more emotionally intense should engender greater coherence between response systems within an individual (Levenson, 1994). That is, weak emotions may provoke little coherence of response systems, whereas strong emotions may provoke greater coherence. Thus, the perceived intensity of an emotional stimulus may be a key factor that influences the degree of emotion coherence within individuals.

Studies examining the link between subjective emotion intensity and degree of coherence in the laboratory have taken cross-sectional approaches, assessing whether individuals who experience more intense emotions have higher coherence compared to individuals who experience less intense emotions. For example, individuals with intense fear exhibit greater coherence between physiology and experience than those with less intense fear (e.g., snake-phobics versus non-snake-phobics in response to videos of snakes; Schaefer, Larson, Davidson, & Coan, 2014), and individuals with higher intensity amusement (but not sadness) have greater coherence between behavior and physiology compared to individuals with lower intensity amusement (Mauss et al., 2005). However, to test the postulate that coherence is higher within individuals during more intense emotional stimuli (compared to less intense stimuli), research must examine coherence using within-individual designs (e.g., examining whether an individual's coherence is higher when they view emotional stimuli perceived as more versus less emotionally intense). Yet, no research to our knowledge has applied this kind of within-individual methodology to examine whether stimuli perceived as more emotionally intense elicit greater coherence than those perceived as less intense.

Emotion regulation. When considering emotion regulatory tendencies that may be associated with coherence, two candidates seem likely based on theoretical accounts: *expressive suppression*, an emotion regulatory tendency to inhibit emotionally expressive behaviors, and

cognitive reappraisal, an emotion regulatory tendency to alter one's interpretation of an emotional stimulus.

Emotion regulatory tendencies aimed at inhibiting emotion – such as expressive suppression (Levenson, 2014; Gross & Levenson, 1997) – may result in less coherence between physiological and experiential response systems because the inhibition of expressive behavior differentially disrupts the magnitude of responding in physiological and subjective response systems (e.g., maintained negative affect with altered physiological activation during negative emotion; Gross & Levenson, 1993, 1997; Notarius & Levenson, 1979). In line with this supposition, individuals instructed to suppress their expressive or physiological emotional responses exhibit less coherence between physiology and subjective experience while viewing affectively charged images (Dan-Glauser & Gross, 2013). Similarly, individuals instructed to hide their emotions from a partner during dyadic interactions exhibit lower coherence between subjective experience and the inter-beat interval of the heart (Butler, Gross, & Barnard, 2014). However, one study found no effect of instructed suppression on experience-physiology coherence during sad films (Lohani, Payne, & Isaacowitz, 2017). Given these mixed findings, more research is needed to assess whether the tendency to suppress emotion is associated with reduced coherence between experiential and physiological response systems. Prior studies have relied on instructing an individual to suppress their emotions in the laboratory. However, people's ability to regulate their emotions in the laboratory when instructed to do so may not map onto the ways people regulate their emotions in their daily lives (Hay, Sheppes, Gross, & Gruber, 2015). Thus, the present study focuses on whether individual differences in the self-reported tendency to suppress emotions is associated with lower experience-physiology coherence, a question that has not been examined in prior literature.

Cognitive reappraisal is another form of emotion regulation that may alter coherence.

Reappraisal, or shifting the meaning one ascribes to an emotional stimulus, has been shown to increase the intensity of positive emotions and decrease the intensity of negative emotions (Nezlek & Kuppens, 2008; Shiota & Levenson, 2012), and could potentially disrupt the coherence between subjective and physiological response systems. Yet, we are only aware of three studies that have examined associations between reappraisal and coherence. Two of these studies reported associations between reappraisal and coherence but did not measure coherence in ways that capture the synchrony of response systems over time within individuals (Lanteigne, Flynn, Eastabrook, & Hollenstein, 2014; Shiota & Levenson, 2012). The third study did use a within-individual measure of coherence to examine coherence and reappraisal (Butler et al., 2014). In this study, participants were instructed to use reappraisal during social interactions, and results indicated that reappraisal reduced coherence between subjective experience and the inter-beat interval of the heart compared to a control condition, suggesting that reappraisal, like suppression, is associated with less coherence between experience and physiology. Given that there is only a small correlation between reappraisal capacity in the laboratory and self-reported tendencies for reappraisal (i.e., $r = .24$; McRae, Jacobs, Ray, John, & Gross, 2012), it remains unclear whether individuals with high self-reported tendencies for using reappraisal have lower coherence between subjective experience and physiology.

The Current Study

Individual differences in the level of coherence between physiology and subjective emotional experience in response to emotional stimuli may be associated with well-being. However, to the best of our knowledge, no research has directly examined the link between physiology-experience coherence and well-being. In addition, given the potential implications of coherence for well-being, it is important to understand the factors that are associated with differences in coherence. Therefore, in the current study, we examine (a) associations between

coherence and well-being, (b) whether more (vs. less) intense emotional stimuli are associated with greater coherence, and (c) whether individual tendencies to use expressive suppression and cognitive reappraisal are associated with differences in coherence. We hypothesized that participants with greater coherence will have higher well-being. We also hypothesized that experience-physiology coherence will be stronger for more (versus less) emotionally intense stimuli. Lastly, we hypothesized that greater coherence would be associated with lower suppression and lower reappraisal.

Methodological considerations. Much of the research on emotion coherence has focused on associations in the magnitude of responding between different emotion response systems (Bonanno & Keltner, 2004; Ekman, Freisen, & Ancoli, 1980; Hastings et al., 2009; Herring, Burleson, Roberts, & Devine, 2011; Reisenzein, Studtmann, & Horstmann, 2013). Using this "between-subjects" approach, researchers considering physiology and subjective experience have sometimes found that individuals with larger physiological responses also report stronger subjective experience of emotion (e.g., Kleck et al., 1976). However, according to theoretical accounts of coherence (e.g., Levenson, 2014; Mauss et al., 2005), response coherence is defined as coupling across response systems within an individual over time. Studies using a between-subjects approach do not capture this kind of coupling over time. For example, an individual may appear to have high coherence, showing large magnitude responding in subjective experience and in physiology when responses are averaged over the course of an emotion-eliciting stimulus. However, the elevations in subjective experience that drive the higher average score might occur at quite different times than those that occur in physiology. Therefore, in the present study, we utilized a within-individual time-series approach to measuring coherence that captures the coupling of response systems over time (Butler et al., 2014; Mauss et al., 2005; Sze et al., 2010).

Past research on coherence has used a number of emotion eliciting contexts to measure coherence, such as affectively charged still images (Dan-Glauser & Gross, 2013), films (Lohani, et al., 2017; Mauss et al., 2005; Sze et al., 2010), and social interactions (Butler et al., 2014). In the present study, we chose to use films. While the passive nature of films does not allow us to test effective responses to emotional challenges, it has the benefit of allowing us to capture continuous time-series of subjective experience and physiology while emotion is elicited in a comparable manner across participants, which is necessary for quantifying individual differences in coherence. Evidence suggests laboratory tasks can predict real world behavior (e.g., McVay, Kane, & Kwapil, 2009). Thus, we assume that how people respond to emotional films in the laboratory will generalize to emotional events outside of the laboratory. That is, participants' level of coherence during the sad and amusing film clips should predict their level of coherence during sadness, amusement, or other emotions in the real world.

Peripheralist approaches and research on interoception suggest that physiological responses have the potential to modify psychological states via afferent neural pathways (Dunn et al., 2010), while biopsychosocial models emphasize that psychological processes can lead to reliable differences in physiological states (Blascovich, Mendes, Hunter, & Salomon, 1999). Efferent and afferent neural pathways exist for a wide variety of physiological indices, suggesting there are anatomically plausible bidirectional influences between subjective experience and number of different physiological channels (Craig, 2002). Thus, theory and research suggest that bidirectional influences can occur across these emotion response systems. Based on this knowledge and in line with past research on coherence, we use a statistical approach to compute coherence that captures the synchrony between response systems, irrespective of which emotion response system leads to changes in the other response system.

Some studies measuring coherence (including our own) have used only the cardiac inter-beat interval (Sze et al., 2010) due to specific hypotheses focused on the awareness of heartbeat sensation among individuals with specialized training in body awareness. More often, researchers have used a combination of physiological channels (Bulteel et al., 2014; Dan-Glauser & Gross, 2013; Mauss et al., 2005) to provide a more comprehensive indicator of overall physiological activation. There is considerable variation in the nature of responding across multiple physiological channels, and their activities are not strongly correlated at rest. However, any single physiological channel is unlikely to be representative of overall changes in physiological activation compared to a composite measure that includes activity across multiple autonomic indices. Capturing the combined activation of multiple physiological channels is important given that different physiological channels can work in concert (e.g., subjective experience can modify multiple physiological channels simultaneously; Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000) and that individuals can differ in the relative reactivity of particular physiological systems (e.g., individual response stereotypy; Lacey & Lacey, 1958). Importantly, creating a composite of physiological activation also reduces the likelihood of Type 1 errors resulting from multiple comparisons across numerous physiological channels. In light of these considerations, we used a composite of overall physiological activation when computing coherence (as measured by heart rate, skin-conductance level, finger pulse transit time, finger pulse amplitude, ear pulse transit time, systolic blood pressure, diastolic blood pressure, and mean arterial pressure). However, to be sensitive to possible differences associated with individual physiological measures, we also present associations for each physiological measure individually in the Supplemental Content.

Method

Participants

To assess the relationship between emotion coherence and well-being, we analyzed archival data from a study conducted in the Berkeley Psychophysiology Laboratory (Sze et al., 2010) that examined the hypothesis that individuals with greater bodily awareness training had higher coherence between subjective experience and heart period. The sample included participants with varying levels of body awareness training. Participants ($N = 63$, 40 women and 23 men) included 21 experienced Vipassana meditators, 21 dancers, and 21 individuals with no body awareness training. The current study includes five self-report measures (life satisfaction, anxiety, depression, reappraisal, and suppression) that were not reported in Sze et al. (2010). Participants were initially recruited by posting flyers at various locations in the San Francisco Bay Area, such as meditation centers, dance centers, and general stores, as well as by posting announcements online in meditation, dance, and community forums. Participants' ages ranged from 18 to 40 years ($M = 28.42$, $SD = 5.94$). The majority of the participants in this study were Caucasian (77.8%), followed by Asian (12.7%), Latino (3.2%), African American (1.6%), and other ethnicities (4.8%). The sample was generally in good mental health (See Supplemental Content for additional Demographic information). Given the archival nature of the dataset, we had a fixed sample size of 63. Post-hoc power analyses, based on our primary regression analysis (participants with greater coherence reported greater well-being) suggest that, with an effect size of .30, alpha= .05, and 1 predictor variable, power = .99. In our model with additional covariates (including age, gender, and body awareness group as covariates), with an effect size of .31, alpha= .05, and 1 predictor variable, power = .94. Data for the primary study variables can be found at https://osf.io/e4zmq/?view_only=3be3e77f959b43c78a3d75a846792e64.

Procedure

All participants completed self-report measures of well-being, expressive suppression, and cognitive reappraisal in an online questionnaire session that took place three to five days

prior to a laboratory session. All procedures were approved by the Berkeley Committee for

Protection of Human Subjects.

Upon arrival at the Berkeley Psychophysiology Laboratory, experimenters told

participants that they were interested in "learning about different aspects of people's emotional

experiences". Participants were seated in a chair in the lab and physiological recording devices

were attached. Emotional films were shown on a 27-inch color TV monitor at a distance of 5.75

feet from the participant. During the 90-minute experimental session, participants watched four

films (described below). All films were preceded by a 1-min baseline, in which participants were

asked to clear their minds and try to relax while focusing on a blank screen with a fixation X in

the center. All participants gave informed consent for participation in the research and were paid

$50 for participating in the study.

Emotional films. As in past research on coherence (Mauss et al., 2005), we used

emotion-inducing films that were designed to induce dynamically changing emotional states,

ranging from neutral to intensely positive and intensely negative. Each film consisted of two or

three emotion-inducing scenes (length ranged from 55 s to 65 s) with 15 seconds of blank screen

in between scenes. The emotional scenes were as follows: Film 1 (comedians doing a humorous

improvisational skit, an underwater scene with sea creatures interacting, depiction of atrocities in

Darfur); Film 2 (a man chewing cow intestines, an underwater scene with sea creatures

interacting, comedian Bill Cosby doing stand-up); Film 3 (a woman reacting to news that her

family members have died, an underwater scene with sea creatures interacting, a man injecting

himself with a needle); and Film 4 (a violent scene in which a man crushes his victim's head, an

underwater scene with sea creatures interacting). Lengths of the films were 3.75 min, 3.63 min,

3.70 min, and 2.58 min, respectively. All participants viewed all four films. Films 1 through 3

were presented in counterbalanced orders. Due to its strongly evocative nature, Film 4 was always shown last to avoid potential carry-over effects into the other films.

Apparatus and Measures

Emotion coherence. Emotion coherence was assessed using a continuous measure of subjective emotional experience and a continuous measure of physiology during the emotional films (see Data Reduction section below for the calculation of coherence).

Subjective emotional experience. Similar to past research on response coherence (Mauss et al., 2005), a rating dial (Levenson & Gottman, 1983) was used to obtain continuous ratings of subjective emotional experience during film clips. The dial had a pointer that moved over a 180-degree scale with nine divisions ranging from *very negative* (−4) to *neutral* (0) to *very positive* (+4). A computer sampled the dial position every 3 ms and averaged these readings into 1-s measurement periods using a program written by Robert W. Levenson. Given that the intensity of both positive and negative emotions are associated with physiological changes (Bradley & Lang, 2000), and because our films induced both positive and negative emotions, we computed intensity at each second as the absolute difference of the rating dial position from the midpoint (0). This measure of intensity was also used in our past research (Sze et al., 2010).

Autonomic physiology. During the emotional film clips, physiological activity was monitored using a system consisting of a Grass Model 7 polygraph connected to a computer with analog to digital conversion capability. The sampling rate for each channel of data was 333 hertz. *Inter-beat Interval (IBI)* was monitored with EKG electrodes placed in a bipolar configuration on the participant's torso. IBI was calculated as the time interval between successive R-waves on the EKG. *Skin Conductance Level (SCL*, a measure of changes in sweat gland activity caused by sympathetic arousal) was measured continuously using a voltage device that applies a small constant voltage between Beckman Standard Electrodes that were attached to the palmar surface

of the middle phalanges of the first and third fingers of the non-dominant hand using sodium

chloride in Unibase as the electrolyte. We measured the amount of current that flowed between

the electrodes. *Ear Pulse Transit Time (EPT)* was measured using a UFI plethysmograph

transducer attached to the participant's right ear lobe to capture blood volume in the ear. EPT

was indexed by the time elapsed between the previous R-wave and the upstroke of the peripheral

pulse at the ear. *Finger Pulse Transit Time (FPT)* and *Finger Pulse Amplitude (FPA)* were

assessed using a UFI plethysmograph transducer attached to the tip of the participant's second

finger on the non-dominant hand. FPT and was indexed by the time elapsed between the

previous R-wave and the upstroke of the peripheral pulse at the finger, and FPA was indexed as

the trough to peak amplitude of the finger pulse waveform. *Systolic Blood Pressure, Diastolic*

Blood Pressure, and Mean Arterial Pressure were also measured in millimeters of mercury with

a Finger Arterial Pressure [FINAPRES] monitor). Signals were visually inspected by trained

research assistants and graduate students, and the same computer program that processed the

rating dial data also calculated second-by-second averages for each physiological channel.

Outlier values and physiologically implausible values were removed. Approximately 7% of

physiological data was missing due to artifact or technical problems. The average physiological

composite across films showed high reliability (Cronbach's alpha = .90; see Supplemental

Content for details).

      Well-being. Subjective well-being was assessed using multiple indices, including life

satisfaction, depressive symptoms, and anxiety to encompass the presence of positive indicators

of well-being, but also the absence of negative symptoms (Kern, Waters, Adler, & White, 2014).

Life satisfaction was measured using the Satisfaction With Life Scale (SWLS; Diener, Emmons,

Larsen, & Griffin, 1985), which consists of 5 items (e.g., "I am satisfied with my life") rated on a

scale of 1 (strongly disagree) to 7 (strongly agree), and averaged together (α = .90). *Depressive*

symptoms were assessed using the Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996), which consists of 21 items rated on a scale of 0 (e.g., "I do not feel sad") to 3 (e.g., "I am so sad or unhappy that I cannot stand it") that were summed together (α = .77). *Anxiety* was assessed using the trait form of the State Trait Anxiety Questionnaire (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), which consists of 20 items (e.g., *"I worry too much over something that really doesn't matter")* rated on a scale of 1 (almost never) to 4 (almost always), and averaged together (α = .87). For ease of interpretation we created an overall well-being composite by z-scoring each scale, inverting depressive symptoms and anxiety, and averaging the three scales such that higher scores indicated higher well-being. Cronbach's alpha for the three scale score (i.e., depression, anxiety, and life satisfaction) was high (α = .80). For completeness, we also provide results using each of the measures individually.

Expressive suppression. Suppression was measured using the suppression subscale of the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) which consists of 4 items (e.g., "I keep my emotions to myself.") rated on a scale of 1 (*strongly disagree*) to 7 (*strongly agree*) and averaged together (α = .85).

Cognitive reappraisal. Reappraisal was measured using the reappraisal subscale of the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) which consists of 6 items (e.g., "I control my emotions by changing the way I think about the situation I'm in.") rated on a scale of 1 (*strongly disagree*) to 7 (*strongly agree*) and averaged together (α = .80).

Data Reduction

Emotion coherence score calculation. Each of the 8 physiological measures were smoothed using a 3 second moving average. This method reduces random variation in time series and facilitates the detection of common variance among measures in cross-correlations

(Kettunen, Ravaja, & Keltikangas-Järvinen, 2000). We standardized each of the 8 physiological

measures within individuals, multiplied inter-beat interval, finger pulse transit time, finger pulse

amplitude, and ear pulse transit time by -1 so that greater numbers for all measures indicated

greater physiological activation, and for each second averaged the measures (Gross & Levenson,

1997). This resulted in one composite time series reflecting overall physiological activation for

each participant.

Coherence was calculated using time-lagged cross-correlations between the physiological

composite time series and emotion intensity time series (from the rating dial) following

procedures used in previous research (Dan-Glauser & Gross, 2013; Mauss et al., 2005; Sze et al.,

2010). For each participant within each film, we computed cross-correlations for lags of −10 to

+10 s and selected the maximum absolute value correlation coefficients. This resulted in one

correlation coefficient (coherence score) for each participant for each film. The time window of

−10 to +10 s was chosen on the basis of previous research (Dan-Glauser & Gross, 2013; Lohani

et al., 2017; Mauss et al., 2005; Sze et al., 2010), and because it conforms to theoretical

perspectives on the duration and temporal characteristics of emotional and physiological

responses (i.e., the theoretical notion of the brief duration of an emotion, lasting for

approximately 1-10 seconds; (Ekman, 1992; Levenson, 1994, 2003), and the slower response of

some physiological channels such as skin conductance (Bach, Flandin, Friston, & Dolan, 2010).

The absolute value was chosen because previous research has shown that changes in subjective

emotional experience can be associated with either increases or decreases in physiological

activation (Bradley & Lang, 2000).[1]

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[1] We note that selecting the maximum correlation coefficient increases the likelihood that we capture the synchrony that occurs across response channels for each individual (because we are selecting each individual's highest cross-correlation coefficient to represent their coherence level). At the same time, taking the maximum value results in a higher average level of coherence at the group level than if we selected the minimum, average, or zero-lag

Although coherence demonstrated only modest reliability across the four films, $\alpha = .41$,

film did not significantly moderate the link between coherence and well-being, $F(3,183) = 1.53$,

$p = .21$, $\eta^2 = .03$, between coherence and suppression, $F(3,183) = .85$, $p = .47$, $\eta^2 = .01$, or

between coherence and reappraisal, $F(3,183) = .96$, $p = .41$, $\eta^2 = .02$. Given this, and for ease of

interpretation, we averaged the coherence scores across the four films to create one index of an

individual's coherence between subjective emotional experience and physiology and used this in

our primary analyses. This coherence score reflects the degree to which physiological activation

is associated with emotion intensity for each individual, regardless of the direction of the

association or the valence of the emotional experience.

Emotion intensity score calculation. An emotion intensity score (reflecting the intensity

of positive or negative affect) was computed for each individual within each film by averaging

the second-by-second emotion intensity values (i.e., difference from the midpoint) from the

rating dial.

Results

Preliminary Analyses

Average levels of coherence. First, we examined average levels of coherence for

descriptive purposes. The average coherence (i.e., the average cross-correlation between

subjective emotional experience and physiology across all participants) was moderate in

magnitude ($M = 0.37$) and significantly greater than zero, $t(62) = 27.04$, $p < .001$, $d = 3.36$.

Importantly, there was also substantial variability in emotion coherence, $range = .17$ to $.60$ ($SD =$

$.11$), verifying the presence of individual differences.

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coefficient. This inflation in coherence does not limit our main conclusions, however, because it is applied equally across all participants and films, and the present study examines how individuals' relative coherence values are related to well-being and emotion regulation, rather than the average level of coherence. Moreover, previous research suggests that the computational method used in the present study detects systematic response system coherence rather than spurious correlations (see pages 9-10 of Lohani et al., 2017).

Emotion Coherence and Well-Being

To test the association between emotion coherence and well-being, we used linear regression with coherence as the predictor variable and well-being as the dependent variable. Given that these archival data included participants who varied in level of body awareness (trained dancers, trained meditators, or controls), we entered participants' body awareness group as a control variable in the model (dummy coded with the control group as the reference group). Lastly, we added age and gender as covariates. Participants with greater coherence between experiential and physiological response channels reported significantly higher well-being, $\beta =$ .30, $t(61) = 2.49$, $p = .015$, even after accounting for body awareness group, $\beta = .31$, $t(59) = 2.47$, $p = .016$, and after adding age and gender into the model (in addition to body awareness group), $\beta = .31$, $t(57) = 2.41$, $p = .019$. These effects were similar across all of the well-being measures independently; coherence was comparably associated with life satisfaction, $\beta = .33$, $t(61) = 2.69$, $p = .009$, depressive symptoms, $\beta = -.21$, $t(61) = -1.71$, $p = .092$, and anxiety, $\beta = -.23$, $t(61) = -1.84$, $p = .071$, even when accounting for body awareness group, age, and gender (See Supplemental Content).

Factors Hypothesized to be Associated with Coherence

Emotional intensity. Next, analyses were conducted to assess whether experience-physiology coherence was highest (within individuals) in response to the highest intensity film clip. As noted earlier, although the order of the first three films was counterbalanced, the fourth film was highly evocative, and thus was always presented last in the film sequence in an effort to avoid carryover effects. Based on the selection criteria for this film, we expected it to have higher emotion intensity and higher coherence than the other films. To confirm that the fourth film indeed evoked higher intensity emotion relative to the other films, we computed a repeated measures general linear model to examine differences in intensity of emotional experience by

film. Specifically, the model included the average rating dial intensity for each participant for each of the four films (within-subject). Second, we examined differences in coherence between the four films using a repeated measures general linear model with participant's coherence scores on each of the four films (within-subject). Bonferroni corrections were used for all pairwise comparisons. Table 1 displays descriptive statistics for emotion intensity and coherence for each film, along with results from one sample t-tests assessing whether emotion intensity and coherence levels were significantly greater than zero for each film.

Average rating dial intensity was significantly different between films, $F(3,186) = 5.94$, $p = .001$, partial $\eta^2 = .09$. Pairwise comparisons revealed that intensity was significantly higher for Film 4 compared to the intensity for all other films, including Film 1, ($M_{diff} = .28$, $p = .005$), Film 2 ($M_{diff} = .23$, $p = .01$), and Film 3 ($M_{diff} = .24$, $p = .005$). There were no significant differences in intensity between Film 1 and Film 2 ($M_{diff} = -.042$, $p = 1.00$), Film 2 and Film 3 ($M_{diff} = 0.00$, $p = 1.00$), or Film 1 and Film 3 ($M_{diff} = -.04$, $p = .1.00$). See Table 1 for means and standard deviations.

Coherence was also significantly different between films $F(3,186) = 8.73$, $p < .001$, partial $\eta^2 = .12$. Pairwise comparisons revealed coherence was significantly higher for Film 4 compared to coherence scores for all other films, including Film 1, ($M_{diff} = .12$, $p = .002$), Film 2 ($M_{diff} = .08$, $p = .044$), and Film 3 ($M_{diff} = .14$, $p < .001$). There were no significant differences in coherence between Film 1 and Film 2 ($M_{diff} = -.04$, $p = .56$), Film 2 and Film 3 ($M_{diff} = .058$, $p = .33$), or Film 1 and Film 3 ($M_{diff} = .02$, $p = .1.00$). See Table 1 for means and standard deviations.

Next, given that Film 4 was most intense, but was also always shown last, we wondered whether coherence varied as a function of the position of the first three counterbalanced films. We ran a repeated measures general linear model using coherence scores from the first three films, grouping films by the position in which they were viewed rather than by the film content.

Coherence did not differ significantly between films, $F(2,124) = .79$, $p = .46$, partial $\eta^2 = .01$, suggesting that coherence in the first three films did not vary as a function of the position in which films are presented.[2]

Emotion regulation.

Expressive suppression. To test the association between expressive suppression and emotion coherence, we used linear regression with expressive suppression as the predictor variable and coherence as the dependent variable. We then added participant's group (controls, dancers, & meditators) to the model, and lastly we added age and gender as covariates. Participants' who reported greater tendencies for expressive suppression had significantly lower levels of coherence, $\beta = -.34$, $t(61) = -2.79$, $p = .007$, even after adjusting for body awareness group, $\beta = -.33$, $t(59) = -2.69$, $p = .009$, and after adding age and gender into the model (in addition to body awareness group), $\beta = -.33$, $t(57) = -2.65$, $p = .010$.

Cognitive reappraisal. To test the association between reappraisal and emotion coherence, we used linear regression with cognitive reappraisal as the predictor variable and coherence as the dependent variable. We then added participant's group (controls, dancers, & meditators) to the model, and lastly we added age and gender as covariates. We did not find associations between cognitive reappraisal and coherence, $\beta = -.08$, $t(61) = -.64$, $p = .53$, even after adjusting for body awareness group, $\beta = -.07$, $t(59) = -.58$, $p = .56$, and after adding age and gender into the model (in addition to body awareness group), $\beta = -.10$, $t(57) = -.74$, $p = .46$.

Additional Analyses

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[2] The link between intensity and coherence in our study is not statistically tautological. One of the two time-series used to derive coherence (emotional intensity) is averaged, and then compared with coherence scores. Mathematically, the average level of one time-series does not alter the cross-correlation between the two time-series that we use to generate a coherence score. For example, if we took an individual's emotional intensity time-series, and added 1 to every value, this would increase the average emotional intensity, but the coherence score would be exactly the same.

Given the theoretical assumption that coherence is strongest during intense emotion (i.e., individual differences in coherence may be best captured when emotion intensity is high), and the finding that Film 4 induced the highest intensity emotion and highest coherence, it is possible that Film 4 serves as the best measure of individual differences in emotion coherence. As such, we re-ran all analyses only using coherence from Film 4. The relationship between well-being and coherence increased in magnitude when using only the fourth film, $\beta = .34$, $t(61) = 2.82$, $p = .007$, and was significant for each of the well-being measures independently (including life satisfaction, $\beta = .26$, $t(61) = 2.08$, $p = .041$, depressive symptoms, $\beta = -.29$, $t(61) = -2.33$, $p = .023$, and anxiety, $\beta = -.31$, $t(61) = -2.57$, $p = .013$). Relationships were also consistent (compared to the four film composite) between coherence in the fourth film and suppression, $\beta = -.25$, $t(61) = -1.99$, $p = .052$, and reappraisal, $\beta = -.18$, $t(61) = -1.40$, $p = .168$. The full models (including body awareness group, age, and gender) for the fourth film are presented in the Supplemental Content.

In addition, we examined interactions between body awareness group and coherence in the prediction of all variables of interest including suppression, reappraisal, and well-being. Body awareness group did not moderate any of these effects (all p's >.20; see supplemental content for full details). We also examined coherence and coherence-well-being correlations for each of the physiological channels independently (including IBI, EPT, SCL, FPT, FPA, SBP, DBP, and MAP). Coherence scores for each of the physiological channels were generally positively correlated, and the direction of effects on well-being were similar across channels. Effect sizes ranged from .01 to .29, and suggested that associations between coherence and well-being may be strongest for measures that reflect sympathetic nervous system activity (e.g., skin conductance; see Supplemental Table 7).

Discussion

In this study, we examined a hypothesis stemming from the long-standing, but largely untested, theoretical assertion that higher levels of emotion coherence are associated with greater well-being. In a community sample, we found that individuals with greater coherence between physiology and subjective experience had greater psychological well-being. In addition, we examined factors hypothesized to predict coherence. Specifically, we examined whether coherence was stronger when individual's perceived the stimuli to be more emotionally intense, and we examined how tendencies towards greater expressive suppression and cognitive reappraisal are associated with coherence levels. We found that coherence was higher during stimuli perceived as more (vs. less) emotionally intense. Greater expressive suppression was associated with lower levels of coherence, however, we did not find a significant association between cognitive reappraisal and coherence.

Emotion Coherence and Well-being

Finding that greater well-being was associated with greater coherence between subjective experience and physiology, even after adjusting for level of body awareness training, age, and gender, has important theoretical implications. The finding lends support to a crucial empirical prediction derived from functionalist and evolutionary theories of emotion (Ekman, 1977, 1992; Lazarus, 1991; Levenson, 1994; Plutchik, 1980; Tomkins, 1962)—specifically, that emotion coherence is advantageous. Consistent with these theories, greater experience-physiology coherence may be associated with greater subjective well-being because individuals with greater coherence respond more effectively to emotional challenges. Of course, because the current data are cross-sectional, we cannot be sure of the direction of the relationship between well-being and experience-physiology coherence. It is possible that greater coherence leads to greater well-being or vice-versa (or that the coherence and well-being simply co-occur in a non-causal manner). It is

worth noting that the association between coherence and life-satisfaction crossed the significance

threshold, whereas the associations between coherence and depression and anxiety were only

marginally significant. When we compared the strength of these correlations, the strength of the

correlation between life satisfaction and coherence was not significantly different from that of

depressive symptoms and coherence or that of anxiety and coherence (See Supplemental

Content). Importantly, our sample was generally in good mental health, with no participants

meeting clinical cutoff scores for moderate or severe depression. The associations between

coherence and mental health symptoms may be stronger in samples that include individuals with

greater variability in mental health problems.

If these findings replicate, they likely have practical implications. Interventions aimed at

increasing coherent responses across different emotion response systems may result in

heightened well-being (McCraty & Zayas, 2014) or vice versa. Interestingly, the modulation of

subjective correlates of physiological responding is a component of some existing therapeutic

approaches (Craske, Rowe, Lewin, & Noriega-Dimitri, 1997; Haase et al., 2016). Our findings

highlight increased emotion coherence as a potential mechanism underpinning the effectiveness

of such approaches. Importantly, more research is needed to determine whether coherence leads

to effective responses to environmental demands, and in what situational and emotional contexts

coherence leads to effective responses to environmental demands. In the current study, we

measured coherence in a context where participants viewed film stimuli while sitting by

themselves because we wanted to capture coherence in a context where participants did not feel

external pressure to regulate their emotional experiences. However, in a context where

suppressing emotion would be beneficial (e.g., needing to suppress anger towards a boss), a lack

of coherence may be beneficial for one's well-being. Future research would benefit from

measuring coherence in multiple situational and emotional contexts (e.g., social versus

nonsocial, positive versus negative, metabolically demanding versus passive tasks), and comparing the implications of coherence for well-being across these contexts.

Factors Hypothesized to be Associated with Coherence

      Emotional intensity. Coherence may be higher when an individual is presented with more emotionally evocative stimuli. Although this study was not designed primarily to test this hypothesis, elements in the design allowed us to begin to explore this question. The present study used one very intense emotional film clip in addition to three moderately intense film clips. Results indicated that the film clip chosen to induce high intensity emotion indeed evoked the highest emotional intensity, and also evoked the strongest coherence compared to other films, suggesting that more intense emotional stimuli produce greater emotion coherence. However, in an attempt to avoid carryover effects, this highly intense film was also always shown last; thus, the order of the films was confounded with their intensity. To determine if coherence increased on later trials, we examined coherence for the first three films (which were counterbalanced in order) and found no evidence that films shown later induced greater coherence. Clearly, more research is needed to tease apart the relationship between intensity of emotional experience and level of coherence fully. Nonetheless, the aforementioned association between intensity of emotional stimuli and level of emotion coherence supports theoretical accounts of coherence that suggest an individual's level of coherence should be higher during more intense emotions (Mauss et al., 2005; Rosenberg & Ekman, 1994; Schaefer et al., 2014).

      Emotion regulation. Some forms of emotion regulation may *decrease* coherence. Past research suggests that intentionally suppressing emotional expressions or physiological reactions or reappraising ones emotions may reduce coherence between physiological and experiential response systems (Dan-Glauser & Gross, 2013; Butler et al., 2014). Nonetheless, it remains an open question as to whether habitual tendencies to suppress or reappraise emotions relate to

individual differences in coherence. The present findings suggest that greater tendencies to

suppress emotion were associated with lower coherence between physiology and experience,

whereas tendencies to reappraise emotion were not associated with the magnitude of coherence.

Suppression and reappraisal are thought to influence emotion at different times in the emotional

response. Reappraisal is considered an antecedent focused regulatory strategy, altering the

appraisal of the emotion before the emotional response is triggered, whereas suppression is

considered response focused, inhibiting the emotional response after the emotion has been

triggered (Gross, 1998). It is interesting to consider whether the link between coherence and

suppression is specific to suppression, or whether it applies to any response-focused emotion

regulation strategy aimed at inhibiting a particular response system. We suspect other emotion

regulatory styles that similarly disrupt emotion responses will also be associated with lower

coherence.

Limitations and Future Directions

While the present investigation proposes directional hypotheses (i.e., well-being is an

outcome of coherence, whereas suppression precedes coherence) based on emotion theory; due

to the correlational nature of the study, we cannot answer questions concerning directionality or

causality (e.g., greater coherence could produce greater well-being or vice versa). Future

research could improve upon this methodology by employing experimental or longitudinal

designs to understand the directionality and temporal sequencing of these effects. Future research

should also examine whether individual differences in coherence in response to film clips

generalize to real-world emotional experiences. In addition, although our self-report measures of

well-being are well-validated for capturing the underlying constructs of anxiety, depression, and

life satisfaction (Diener et al., 1985; Beck et al., 1996; Spielberg et al., 1983; Gross and John,

2003; Salovey et al., 1995), our study lacked objective measures of other indices of well-being

such as goal attainment. In addition, although our research suggests that coherence is associated with well-being, thereby providing some support for the idea that coherence is advantageous, the current study design did not allow us to test the mechanisms that link coherence to well-being (e.g., effective or advantageous responses to environmental challenges).

The current study focused on emotional experience and physiology and did not assess expressive emotional behavior (e.g., facial expressions). Past research has shown associations between well-being and the coherence between emotional experience and expressive behavior using a methodology similar to ours (Mauss et al., 2011). In addition, theoretical accounts envision coherence as a feature of emotion that occurs across multiple emotion response domains. Future research should more fully examine coherence across multiple response domains including facial expressive behavior. Additionally, we did not account for an individual's ability to report their subjective experience 'accurately'. The rating dial used in the current design does not allow for assessing mixed emotional states, which could potentially limit the similarity of participant's actual subjective experience and what they can report, thereby constraining the level of coherence found between subjective experience and physiology. Moreover, we cannot disentangle emotion intensity from emotional arousal using the current methodology, or the direction of influences between physiology and subjective experience. Future research should employ varied measures of subjective experience and additional methods for measuring coherence to assess the propagation and integration of physiological activation and conscious emotional experience.

Conclusions

Our study presents some of the first evidence that coherence between physiology and subjective experience is associated with positive outcomes—namely, greater well-being—and that the magnitude of response coherence is associated with perceived stimulus intensity and

individual differences in emotion regulation. The present findings are consistent with the view

advanced in several theories that coherence across response systems is greater during more

intense emotional stimuli. Findings also highlight the value of a measuring coherence within-

individuals over time, an approach that most closely mirrors theoretical accounts. While our

findings illuminate a number of longstanding issues concerning the nature of emotion coherence,

more research is needed to understand the mechanisms by which coherent emotions are related to

functional outcomes such as greater well-being.

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Table 1. Descriptive statistics of coherence and emotion intensity by film.

	Emotion Coherence	Emotion Intensity
	Mean(SD)	Mean(SD)
Film 1	0.33 (0.17)	1.43 (0.46)
Film 2	0.37 (0.17)	1.48 (0.58)
Film 3	0.31 (0.18)	1.48 (0.51)
Film 4	0.45 (0.20)*	1.71 (0.59)*
All Films	0.37 (0.11)	1.52 (0.40)

Note. * indicates the mean coherence and intensity for this film was significantly higher compared to all other films, and no significant differences were observed between any of the other films.

Table 2. Primary regression analyses depicting the association between a given predictor and a given outcome (Model 1), the association when controlling for the two dummy-coded body awareness groups (dancers and meditators, Model 2), and the association when controlling for the two dummy-coded body awareness groups and demographics (age and gender, Model 3).

	Model 1	Model 2	Model 3
	Predictor only	*Predictor and body awareness*	*Predictor, body awareness, and demographics*
Expressive Suppression Predicting Coherence			
Expressive Suppression	$\boldsymbol{\beta = -.34, p = .007}$	$\boldsymbol{\beta = -.33, p = .009}$	$\boldsymbol{\beta = -.33, p = .010}$
Dancers		$\beta = .20, p = .16$	$\beta = .20, p = .16$
Meditators		$\beta = .05, p = .74$	$\beta = .08, p = .58$
Age			$\beta = -.09, p = .51$
Gender			$\beta = -.18, p = .14$
Cognitive Reappraisal Predicting Coherence			
Cognitive Reappraisal	$\beta = -.08, p = .53$	$\beta = -.07, p = .56$	$\beta = -.10, p = .46$
Dancers		$\beta = .23, p = .13$	$\beta = .23, p = .12$
Meditators		$\beta = .14, p = .35$	$\beta = .17, p = .28$
Age			$\beta = -.07, p = .64$
Gender			$\beta = -.21, p = .12$
Coherence Predicting Well-Being			
Coherence	$\beta = .30, p = .015$	$\boldsymbol{\beta = .31, p = .016}$	$\boldsymbol{\beta = .31, p = .019}$
Dancers		$\beta = -.05, p = .73$	$\beta = -.05, p = .72$
Meditators		$\beta = .13, p = .35$	$\beta = .14, p = .35$
Age			$\beta = -.03, p = .84$
Gender			$\beta = .02, p = .90$

Note. "Dancers" represents a dummy code for which dancers are coded as 1 and all others are coded as zero. "Meditators" represents a dummy code for which meditators are coded as 1 and all others are coded as zero (with controls serving as the reference group).