Emotion

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Online First Publication, July 6, 2017. http://dx.doi.org/10.1037/emo0000345

CITATION
Lohani, M., Payne, B. R., & Isaacowitz, D. M. (2017, July 6). Emotional Coherence in Early and Later Adulthood During Sadness Reactivity and Regulation. *Emotion*. Advance online publication. http://dx.doi.org/10.1037/emo0000345

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1528-3542/17/$12.00 http://dx.doi.org/10.1037/emo0000345

Emotional Coherence in Early and Later Adulthood During Sadness Reactivity and Regulation

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The current study reports the first investigation of age-related changes in emotional coherence across multiple response systems (experiential, physiological, and expressive) in sadness reactivity and regulation. Some accounts indirectly suggest that blunted physiological responses to emotional stimuli (e.g., Mendes, 2010) may lead to an age-related decline in emotional coherence, whereas a conflicting account suggests that age-relevant content can modulate responses across multiple systems (e.g., Kunzmann & Grühn, 2005), which has the potential to increase emotional coherence in older adults. We therefore examined emotional coherence in 60 younger ($M_{\text{age}} = 20$) and 60 older adults ($M_{\text{age}} = 71$) during emotional reactivity and regulation (suppression and acceptance) while participants watched sadness-eliciting videos. Emotional experience (sadness intensity self-report), physiological (heart period) responses, and behavioral facial expression (corrugator supercilii muscle activity) were assessed while participants viewed these videos. Importantly, older adults showed greater emotional coherence between experience and heart period and maintained coherence between experience and expression responses compared to younger adults. These findings are consistent with the idea that, because of motivational relevance and life experiences, sadness-eliciting content may lead to a greater coupling between sadness experience and physiology in older than in younger adults. Age is therefore an important individual difference factor to consider when examining within-individual associations between emotion systems.

Keywords: emotional coherence, aging, sadness, emotion regulation, psychophysiology

Changes in emotional states can impact multiple response systems (Gross & Barrett, 2013; Lang, 1988; Larsen & Prizmic-Larsen, 2006; Mandler, 1975; Mauss & Robinson, 2009), including subjective experience, expressive behavior (e.g., facial expressions), and peripheral physiological responses (e.g., heart activity). Although emotional responses across different modalities can arise from the same emotional event, they do not necessarily unfold at the same time (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005). These temporal discrepancies in responses across modalities make it challenging to understand how different modalities relate to one another. This temporal covariation between emotional systems is referred to as emotional coherence (Mauss et al., 2005). Although coherence has been shown to be present in early adulthood (e.g., Dan-Glauser & Gross, 2013; Evers et al., 2014; Mauss et al., 2005, 2011), there has been no research directly examining the adult life span development of emotional coherence. To address this potential relationship between aging and coherence, we report the first direct investigation—to our knowledge—of adult age differences in emotional coherence. For a thorough understanding, we examined emotional coherence across younger and older adults during the natural unfolding of emotion (emotional reactivity) and during deliberate attempts to modify emotional responses (emotion regulation).

Emotional Coherence During Emotional Reactivity and Regulation

Emotional reactivity is a change in the emotional state of a person in response to an emotional trigger. Changes in experiential and behavioral responding to emotional reactivity are regarded to be reflective in that they are relatively conscious, deliberate, and effortful responses, whereas changes in physiological responding are considered to be automatic and relatively unconscious, fast, and effortless. In contrast, *emotion regulation* refers to the ability to actively modify emotional states, including when and how these states are experienced and expressed (Gross & Thompson, 2007). Depending on the goals and strategies of an individual, successful emotion regulation attempts lead to either a decrease or an increase

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Portions of this article were submitted as part of Monika Lohani's dissertation in partial fulfillment of the requirements for her PhD from Brandeis University and were presented at the annual meeting for the Society for Psychophysiological Research, Atlanta, GA, 10–14th September, 2014.

We thank Dan Fahey, Karen Quigley, Daniel Rovenpor, and Shauna Tominey for their helpful suggestions on this study.

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in the intensity of experiential, behavioral, and physiological responses to emotions (e.g., Urry, 2009). It is common for researchers to study effects of emotional reactivity and regulation of emotional responses in separate independent modalities—typically by studying mean activity in each response system (e.g., mean sadness rating and mean heart period).

Although the mean provides a good sense of the overall expression or intensity of an individual emotional response system, examining how activity within multiple emotional responses relate to one another over time can provide insights into the degree to which emotion systems are coupling in response to an emotional event—that is, the coherence between response systems. *Emotional coherence* refers to "the coordination, or association, of a person's experiential, behavioral, and physiological responses as the emotion unfolds over time" (Mauss et al., 2005, p. 175). Many theorists (cf., Barrett, 2011; Russell, 2003) have postulated that a core feature of an emotional response involves coordination among emotion systems (e.g., Dolan, 2002; Ekman, 1992; Izard, 1977; Lang, 1988; Lazarus, 1991; Levenson, 1994; Panksepp, 1994). Using the emotional coherence approach can shed additional light on the nature of emotional reactivity and regulation. For example, emotional coherence can be used to understand how self-reported intensity of emotion (a relatively reflective emotion system) covaries with objectively measured physiological intensity (a relatively autonomic emotion system) and emotional expressivity (also relatively reflective), even though these responses to the same emotional trigger may unfold at differing time lags.

Sadness as a Test Case

To test for potential age differences in emotion coherence, we wanted to select an emotional context that was relevant across age groups. Older adults report experiencing fewer negative and more positive emotions than their younger counterparts (Carstensen et al., 2011; Gross et al., 1997; Lawton, Kleban, Rajagopal, & Dean, 1992). But there seems to be one exception to this pattern—sadness. Unlike other negative emotions such as anger, sadness reactivity is maintained or even increases with age (Kunzmann & Grühn, 2005; Kunzmann, Kappes, & Wrosch, 2014; Kunzmann, Richter, & Schumukle, 2013; Kunzmann & Thomas, 2014; Seider, Shiota, Whalen, & Levenson, 2011). Sadness may be more prevalent (e.g., Lindenberger & Baltes, 1997; Palmore, 1981; Smith & Baltes, 1997) and perhaps adaptive in later adulthood, given that it may facilitate disengagement from unrealistic goals and promote social support (Kunzmann et al., 2014). Because of this motivational relevance, older adults may also relate to sadness elicitors more strongly and have more personalized cognitions about sadness-eliciting situations, making them more prone to higher sadness reactivity (Kunzmann & Grühn, 2005; Kunzmann et al., 2013, 2014; Lohani & Isaacowitz, 2014; Seider et al., 2011). As sadness levels are maintained or enhanced in older adults, it is a unique test case to study emotional coherence during sadness reactivity and regulation across the life span.

Emotional Coherence During Sadness Reactivity

Relatively more research on emotional coherence with unspecified negative emotions has been conducted (e.g., Butler, Gross, & Barnard, 2014; Dan-Glauser & Gross, 2013), with only limited studies having examined emotional coherence specifically during sadness (e.g., Mauss et al., 2005). In past work (Mauss et al., 2005) moderate levels of coherence (average absolute coherence for each combination of experience, behavior, and physiology systems: Pearson rs $\sim$ .36) have been found for sadness. Specifically, Mauss and colleagues (2005), found that sadness experience was correlated with skin conductance level but was not correlated with cardiovascular activity. A stronger correlation was found for coherence between experience ratings and facial expression. These findings are in line with the dual-process framework that suggests that the strength of association between emotion systems may depend on the type of emotion systems involved (Evers et al., 2014; Mauss et al., 2005). This framework (Evers et al., 2014) is supported by empirical evidence that coherence is stronger within reflective systems (e.g., experience-expression coherence) but weaker across reflective and automatic systems (e.g., experience-physiology coherence). At the same time, this general principle of a dissociation between within-system and between-system coherence has not been examined across the life span.

Emotional Coherence During Sadness Regulation

Although coherence during sadness reactivity would allow us to examine how strongly response systems covary, we also wanted to examine how age differences in emotional coherence are impacted when active efforts are made to modify the emotional response during emotion regulation. Considering emotional coherence under emotion regulation would enable us to examine the limits of the association between emotional responses while one is deliberately attempting to modify the magnitude of emotional responses. At the same time, limited research has examined the impact of such attempts to regulate emotional responses on emotional coherence (Butler et al., 2014; Dan-Glauser & Gross, 2013; Evers et al., 2014).

In a recent study (Dan-Glauser & Gross, 2013), young female participants (mean age = 20.2 years) observed negative, positive, and neutral images displayed in a random order for 8 s each and rated the degree of their negative or positive feelings while experimenters continuously measured their facial behavior (using electromyography) and physiological response (e.g., heart rate and blood pressure). Two emotion regulation strategies were examined: *suppression* (concealing ongoing emotional responses; Gross & Thompson, 2007) and *acceptance* (openness to internal experiences and willingness to fully remain in contact with them without trying to avoid them; Hayes, Strosahl, & Wilson, 2011). Unlike suppression, acceptance is associated with improved openness to experience (Teasdale, Segal, & Williams, 2003) that may result in greater engagement with those emotions (Hayes & Feldman, 2004) and higher emotional coherence. During the suppression strategy, coherence was decreased for experience-physiological and experience-expression systems. However, the acceptance strategy did not modulate coherence relative to the reactivity condition. Therefore, attempts to regulate emotions by using different forms of strategies by younger adults can influence the association between emotion systems differentially (Dan-Glauser & Gross, 2013). In the current study, we directly examined how age-relevant differences in attempts to regulate emotions by using suppression and acceptance strategies can disrupt emotional coherence.

Coherence in the Context of Aging

Emotional coherence may be influenced by individual differences such as health status, physical fitness, and cultural factors (Hollenstein & Lanteigne, 2014). No existing work has examined age-related changes in emotional coherence to date. At the same time, several hypotheses indirectly suggest that emotion response coupling may also vary as a function of age (e.g., Cacioppo, Berntson, Bechara, Tranel, & Hawkley, 2011; Levenson, Carstensen, Friesen, & Ekman, 1991; Mendes, 2010; cf. Charles, 2010 and Kunzmann et al., 2014). Some research supports the notion that there is reduced physiological reactivity (e.g., Cacioppo et al., 2011; Labouvie-Vief, Lumley, Jain, & Heinze, 2003) and expressivity e.g., Pedder et al., 2016; cf. Emery & Hess, 2011; Lohani & Isaacowitz, 2014; Phillips, Henry, Hosie, & Milne, 2008 in older age, which may impact coherence in aging. For instance, circadian cardiac fluctuations change with normal aging (Bonnemeier et al., 2003), and a number of studies have suggested that autonomic responses (especially heart rate) are reduced in aging (e.g., Labouvie-Vief et al., 2003; Levenson et al., 1991; Smith, Hillman, & Duley, 2005; Tsai, Levenson, & Carstensen, 2000). Similarly, according to the aging-brain model (Cacioppo et al., 2011), age-related changes in adrenergic and amygdala functioning may result in a reduction in the emotional impact of negative, but not positive, stimuli. Moreover, a decline in sensory perception of the body with age may disrupt the mind–body connection in older adults. For example, *maturational dualism* refers to the idea of a dissociation between mind and body due to aging that may lead to reduced ability to sense visceral organ activity and to perceive physiological activity during emotional events and thus influence emotional experiences (Mendes, 2010). If physiological and expression responses to emotional stimuli are reduced, whereas subjective responses remain stable with age, these changes may also lead to a reduced association between self-report and physiological or expression responses. Such age-related changes in the intensity of emotional responding and awareness of internal physical states suggest that there may be an age-related decline in emotional coherence during emotional reactivity and regulation. It remains to be seen if the relationship between emotion systems (i.e., within and between relatively reflective and automatic systems) may be reduced in older adults.

At the same time, not all research supports the notion that older adults experience blunted emotional intensity. Compared with their younger counterparts, older adults can have heightened or maintained subjective, expressive, and physiological emotional responses when age-relevant stimuli are used compared with nonrelevant stimuli during emotional reactivity and regulation (e.g., Kunzmann & Grühn, 2005; Kunzmann, Kupperbusch, & Levenson, 2005; Kunzmann et al., 2014; Lohani & Isaacowitz, 2014; Seider et al., 2011; Phillips et al., 2008). This is because older adults may engage in a more personalized cognition when watching videos of age-typical loss and experience higher levels of emotion intensity and autonomic reactions (Kunzmann & Grühn, 2005). Older adults report greater negative emotional responses when shown sadness-eliciting video clips about loss (Kunzmann & Grühn, 2005; Seider et al., 2011), suffering (Kliegel, Jäger, & Phillips, 2007), and injustice (Charles, 2005; Phillips et al., 2008). During personal and social loss or exposure to highly arousing negative information, older adults may show heightened physiological reactivity, expressivity, and experience intense emotions (Charles, 2010; Kunzmann et al., 2014). Consistent with this, the strength and vulnerability integration model (SAVI; Charles, 2010) states that older adults are known to employ behavioral and emotion regulation strategies to avoid or reduce a negative event (such as managing anger); however, older adults are vulnerable to emotional situations that entail personal or social loss, during which they are unable to employ emotion regulation strategies to avoid or reduce the impacts of a negative experience (Charles, 2010). This body of research provides instances when comparable or greater emotional coherence can be expected in older adults relative to their younger counterparts. These accounts suggest that age-relevant content can modulate responses across multiple systems, as may be the case in sadness reactivity and regulation, which has the potential to increase emotional coherence with age.

Indeed, although age-related decline in emotional reactivity of a single channel (e.g., heart period) may occur, this does *not* necessarily mean that it will impact the degree of coherence between that system and other response systems. In fact, it is possible for one (or more) channel mean signals to decline in the presence of an increasing correlation across channels. Thus, different theoretical accounts provide competing predictions for age-related changes in coherence within and between relatively reflective and automatic systems. Simultaneously, previous studies have found that in younger adults, experience-expression coherence is stronger than experience-physiology coherence (Evers et al., 2014). Whether such a relationship holds across the life span remains an open question. This motivated us to test age-related changes in experience-expression (within) and experience-physiology (between) coherence during sadness reactivity and regulation.

Study Overview

To examine emotional coherence, younger and older participants were shown sadness-eliciting video clips to elicit sadness responses. We followed several recommendations that have been made by prior researchers (see Bonanno & Keltner, 2004; Mauss et al., 2005) to avoid methodological issues that could lead to poor estimates of response coherence: First, the overall intensity of emotions elicited should be high in order to detect coherence. Past research suggests that weak emotional stimuli may not elicit observable emotional responses (Tassinary & Cacioppo, 1992). Moreover, the intensity-dependent coherence view suggests that response systems may covary only after reaching a minimum intensity level (Bonanno & Keltner, 2004; Davidson, 1992; Mauss et al., 2005; Rosenberg & Ekman, 1994; Tassinary & Cacioppo, 1992). Greater emotional coherence has been found during the more intense emotional events than less emotionally intense events (Rosenberg & Ekman, 1994), supporting the links between experience intensity and coherence. Second, we used appropriate measures to assess changes across all the three response systems that were sensitive to sadness emotion: Emotional experience (via self-report rating dial), physiological response (heart period), and behavioral facial expression (activity in and corrugator supercilii muscle regions) were continuously measured while participants saw sadness video clips.[1] Third, retrospective and aggregate ratings across mixed emotional periods may not accurately measure real-time emotional experience. We measured near real-time rating responses (Mauss et al., 2005) for sadness specifically. Finally, we adopted a time-series approach to examine within-subject lagged cross-correlations between response systems to measure coherence during emotional reactivity and regulation, incorporating the potential for temporal lags between emotion system measures. Such an analytical approach is suited to estimating near real-time coherence (Mauss et al., 2005).

Research Questions and Hypotheses

We tested the following research questions during sadness reactivity and regulation: Compared with younger adults, do older adults show greater or weaker coherence between experience-physiology coherence and between experience-expression coherence in sadness reactivity or regulation? The proposed emotional blunting and dissociation between mind and body with age may influence the ability to perceive subtle physiological changes (e.g., Cacioppo et al., 2011; Levenson et al., 1991; Mendes, 2010) that might lead to a lower experience-physiology coherence and experience-expression coherence in older than younger adults. On the other hand, the motivational relevance and SAVI accounts (Charles, 2010; Kunzmann & Grühn, 2005; Kunzmann et al., 2014) suggests that emotional vulnerability to relevant emotional content may lead to an increase in experience-physiology coherence and experience-expression coherence in older adults compared to the young during sadness reactivity and regulation.

Furthermore, relevant to the dual-process framework (Evers et al., 2014), we aimed to test whether the general principle of a dissociation within-system (e.g., experience-expression) and between-system (e.g., experience-physiology) coherence extends across the life span in the context of sadness. We predicted that, similar to younger adults, experience-expression coherence may be stronger than the experience-physiology coherence in older adults.

Method

Following Simmons, Nelson, and Simonsohn's (2012) recommendation, we report how we determined our sample size, all data exclusions, all manipulations, and all measures relevant to testing age differences in coherence in the study.[2] The study protocol was in accordance with the ethical standards of the Institutional Review Boards at Northeastern University and Brandeis University.

Participants

Sixty younger (age range: 18–23, $M = 19.53$, $SD = 1.29$; 57% women) and 60 older adults (age range: 60–87 years, $M = 71.20$, $SD = 7.72$; 71% women) participated in the study. To determine the sample size, power curves of the critical age-differences were calculated on a Cohen's d scale for different values of sample size ($n = 10$–300 per group), effect size ($d = .1$–.9), and Power ($p = .4$–.9), using the pwr package in R. This revealed that, with a sample size of 60 per group, our experiment was powered at 80% to detect a moderate effect size (Cohen's $d = .52$). Participants were recruited from the laboratory's existing database and from requests posted online on a university website, Craigslist, and flyers placed in the local area. All participants either received credit or a monetary compensation for their participation. On average, both age groups reported themselves to be in good health.

Inclusion criteria. Older (59+ years) and younger (18 to 35 years) adults were eligible to participate in this study. A screening process was used to exclude individuals with health conditions that might influence physiological recording such as cardiovascular disease, asthma, history of or current psychopathology, use of cholinergic drugs, and so forth. Individuals with a history of health problems that could have long-lasting autonomic consequences (e.g., cancer in the previous 5 years, prior stroke, peripheral vascular disease, asthma, diabetes, or dementia) or use of psychotropic medications for psychological conditions (e.g., anxiety disorders, depression, schizophrenia, bipolar disorder) were not eligible to participate.

Sadness-Eliciting Video Stimuli

Three video clips that were 2 min long, standardized, and age-relevant were used as sadness-eliciting stimuli. All these clips have been used in previous studies to reliably elicit sadness (Allard & Kensinger, 2014; Lohani & Isaacowitz, 2014) in younger and older adults. These clips depicted scenes of personal loss and death of a close one including scenes from the movies: (a) "Pay it Forward," in which a young boy was stabbed by another boy, followed by reactions from the victim's mother. (b) "A Mighty Heart," in which a woman finds out that her husband has been killed. (c) "Champ," in which a young boy finds out that his father has died. All the clips were used for the no-regulation/reactivity, suppression, and acceptance conditions in a counterbalanced order.[3]

Measures

Physiological data were recorded continuously and digitized using a Bionex data acquisition system and BioLab software (Mindware Technologies Ltd., Gahanna, OH). While participants watched the sadness-eliciting videos, the experiential, behavioral,

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[1] Near real-time valence experience (subjective feeling of positive or negative nature) can be assessed using scales ranging from *extremely sad* to *extremely amused*. However, as this study was theoretically driven to test age differences in emotional coherence during sadness responses, we specifically focused on assessing subjective arousal (subjective feeling of intensity of sadness) while participants watched sadness-eliciting content, similar to previous research (e.g., Schaefer, Nils, Sanchez, & Philippot, 2010). Indeed, several theoretical models of affect suggest different ways to characterize arousal, however a firm conclusion has not been reached (see Kuppens, Tuerlinckx, Russell, & Barrett, 2013). A commonly used perspective is to define arousal as the intensity of negative (or positive) valence (e.g., Lang, 1994; Mandler, 1984; Schaefer et al., 2010), as operationalized in the current study. Another perspective defines arousal as the degree of activation to characterize arousal (e.g., Ito & Cacioppo, 2005).

[2] A separate individual difference battery was also administered to address research questions that were not a part of the targeted investigation of age differences in coherence and thus are not reported in the current article. These include behavioral tasks to measure cognitive function, interoceptive awareness, rumination, and resilience.

[3] Film clips were not included as a factor because film clips were completely counterbalanced across participants and film order was found to be nonsignificant.

and physiological responses to emotional content were continuously sampled at 1,000 Hz.

Emotional experience. A rating dial consisting of a pointer attached to a potentiometer was used to collect continuous online experience ratings (in volts) from the participants. Participants were given the following instructions: "Rate the intensity of sadness you feel at each moment during the film clip," on a scale of 0 (*not at all sad*) to 5 (*extremely intense sadness*) while they watched the sadness-eliciting videos (see Footnote 1). This scale was adapted from past research that has examined arousal experience using film clips (e.g., Schaefer et al., 2010). The near-continuous ratings data were found to be a valid and accurate method to measure emotional experience without cognitive and motor interference (Mauss et al., 2005, 2011). We did not expect an age difference in using rating dial as in past research we have successfully used a rating dial to collect continuous emotional experience from younger and older participants (Isaacowitz & Harris, 2014; Stanley & Isaacowitz, 2011).

Expressive behavior. Facial expressive behavior is objectively measured via electromyography (EMG) over the corrugator supercilii muscle regions. The corrugator activity was used as a measure of negative expressions while watching sad content. The skin was prepared by abrading the skin to reduce impedance across the recording sites (below 5 kΩ), thus enhancing the signal to noise ratio. Two Ag/AgCl recording electrodes were filled with high conductivity gel and affixed with adhesive collars in bipolar configuration on the left corrugator supercilii (frown) muscles in accordance with the recommended guidelines (Fridlund & Cacioppo, 1986). This provided an assessment of the level of negative expressivity (frowns) displayed by participants while watching video clips.

Physiological response. Electrocardiography (ECG) records electrical activity of the heart over time and it was used to measure the heart rate of the participants. After cleaning the site, pregelled standard electrodes were placed under the left and right collarbones and on the lower rib on the left side of the chest. The inverse of heart rate (i.e., *heart period*, also called *interbeat interval*) was used as the measure of physiological activity. Heart period has been found to be a good measure to assess moment-by-moment changes in emotional states (Berntson, Quigley, & Lozano, 2007; McCraty & Tomasino, 2006; Quigley & Berntson, 1996). Heart activity changes more linearly with heart period compared to heart rate (Quigley & Berntson, 1996). Change in heart period is a recommended measure of change in autonomic activity from baseline (Berntson et al., 2007; Quigley & Berntson, 1996) and has been used in previous work with younger as well as older adults (e.g., Gyurak, Goodkind, Kramer, Miller, & Levenson, 2012; Sze, Gyurak, Yuan, & Levenson, 2010). Heart period has also been successfully used as a single measure to investigate group differences in emotional coherence between experience and physiology due to body awareness training (Sze et al., 2010). Furthermore, Sze et al. (2010) found consistent pattern of group differences in emotional coherence estimates based on heart period to that of coherence estimates based on 8 measures (skin conductance, finger pulse transmission time, ear pulse transmission time, respiration period, respiration depth, systolic blood pressure, diastolic blood pressure, and general somatic activity) suggesting that heart period could be used to accurately estimate emotional coherence and compare age-group differences.

Procedure

Upon arrival in the lab, the participants first signed the consent form and then the EMG and ECG sensors were attached to the participants. After about a 15-min stabilization period, for participants to feel comfortable with physiological sensors, three sadness-eliciting videos were shown. The first clip shown was always the emotional reactivity condition (typically done so that the regulation conditions do not bias the reactivity condition, e.g., Lohani & Isaacowitz, 2014; Shiota & Levenson, 2009) followed by two regulation conditions (suppression and acceptance). The order of the two regulation conditions was counterbalanced across participants. The experience, expression, and physiological responses were measured throughout these sections. Every film clip was preceded by a precondition 1-min period in which participants saw a fixation point on the screen. This was used as the precondition baseline for the respective condition.

Reactivity (no-regulation) condition. A sadness-eliciting video was shown to the participant with instructions to "Watch the film clips as if you are watching TV" (similar to Lohani & Isaacowitz, 2014). Next, participants rated how difficult it was to use the rating dial to continuously report intensity of emotion on a 7-point Likert scale (1 = *not at all*, 7 = *extremely difficult*).[4] A distraction task (Gross, Sutton, & Ketelaar, 1998) was used after showing a film clip to eliminate any emotional carryover effects. Participants were instructed to copy an abstract geometric pattern, which was presented for 40 s on the computer screen; they were assured that the quality of the drawings was not important and that they were just getting a break between the films.

Emotion regulation conditions. Before the clips were shown, participants were instructed to implement specific emotion regulation strategies. Suppression instructions were as follows: "If you have any feelings as you watch the film clip, please try your best not to let those feelings show. Watch the film clip carefully, but try to behave so that someone watching you would not know that you are feeling anything at all" (similar to Lohani & Isaacowitz, 2014). Acceptance instructions were as follows: "Try to experience your feelings fully and do not try to control or change them in any way. Please let your feelings run their natural course and allow yourself to stay with your emotions, as fully as possible, without trying to control your feelings in any way" (similar to Hofmann, Heering, Sawyer, & Asnaani, 2009). A distraction task was done after each clip.

Physiological Data Processing and Analyses

Psychophysiological measures were processed using custom software (Mindware Technologies Ltd., Gahanna, OH), followed by visual inspection of data as discussed in the following text.

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[4] No significant differences were found between the two groups in self-reported difficulty in using the rating dial: Younger adults' mean rating was 1.24, whereas older adults' mean rating was 1.30, $t(116) = .40$, $p = .69$, suggesting that the older adults would have used the rating dial similar to their younger counterparts.

EMG data processing. Post data collection, EMG raw data were processed using custom software with recommended settings (van Boxtel, 2001) for corrugator supercilii muscle. EMG activity was bandpass filtered (low-pass cutoff at 500 Hz and high-pass cutoff at 20 Hz) and rectified. This data was visually inspected for artifacts generated by sneezes, yawns, or unnatural eyebrow, facial, or head movements. The raw root-mean-square (RMS) voltage (in μVs) is recommended as the effective signal amplitude (Fridlund & Cacioppo, 1986). Accordingly, RMS values were extracted for condition and precondition phases. The precondition baseline phase was always 1 min long before instruction for the respective conditions were delivered.

Heart period processing. An automatic R-wave peak detection software with recommended settings (Berntson et al., 2007) detected probable heart periods in the ECG signal and marked physiologically unlikely heart periods. All the heart periods were visually examined for accurate detection and then processed to insure that physiologically improbable values were manually corrected if they were, in fact, not correctly detected by the software.

Quantifying emotion coherence. Different emotion systems may have distinct temporal lags, which make it interesting but also methodologically challenging to quantitatively test for relationships between them. Coherence estimation uses temporally sensitive analysis techniques that permit examining bivariate changes during an emotion occurrence (Mauss et al., 2005, 2011). A within-individual approach (correlations among different response systems within the same individual are examined over time) incorporates lags in measures while computing coherence level and is better suited for estimating emotion coherence than a between-individual approach (e.g., Dan-Glauser & Gross, 2013; Evers et al., 2014; Mauss et al., 2005, 2011). Mauss and colleagues (2005, 2011) developed a within-individual approach to examine emotional coherence that addresses the time lag issue. Using this within-individual cross-correlation lagged approach, small-to-moderate levels of emotion coherence have been found between emotional responses in younger adults for amusement, sadness, and unspecified negative and positive emotions (e.g., Dan-Glauser & Gross, 2013; Evers et al., 2014; Mauss et al., 2005, 2011).

To estimate within-subject coherence among response measures, the continuous data were first downsampled to 1 Hz by averaging per second data for each of the three emotion response measures: ratings (experience), corrugator activity (behavioral expression), and cardiac heart period (physiological activity) to generate a time series of 120 samples per subject and condition. Next, baseline correction was performed on each of the measures by subtracting the precondition baseline average (average value of 1 min long baseline period preceding experimental conditions) from the 120-s time series. Thus, observed effects reflect change in response system activation from the prestimulus baseline (e.g., Dan-Glauser & Gross, 2013).

Fourteen participants were removed from analyses because of either recording issues or very high artifact rates. For EMG and heart period values that exceeded the 97.7 percentile (corresponding to three standard deviations above the mean for a normal distribution) were considered as outliers and were removed. A within-subject coherence calculation was conducted for the 2-min segment using the approach recommended by Mauss and colleagues (2005, 2011). Response coherence was estimated by measuring the cross-correlation for each pair of response systems (e.g., second-by-second ratings and heart period data were used to calculate experience-physiology coherence) across time lags ranging from −10 s to 10 s (e.g., Mauss et al., 2005). This approach makes it possible to compare time series with activities that are maximally correlated at some delay. We followed the time window used in prior work (Mauss et al., 2005, 2011; Sze et al., 2010). This time window has been chosen because of theoretical consideration that emotional responses to an emotional trigger lasts less than 10 s (Levenson, 1988) and as a consequence, meaningful lags between response systems were not expected to be greater than 10 s in either direction.[5] The final coherence estimate, calculated separately for each subject, condition, and time-bin was the maximum absolute value of the cross-correlation across lags. Similar to previous studies (Mauss et al., 2005; Sze et al., 2010), the absolute values were estimated because changes in subjective emotional experience may be associated with either an increase or decrease in heart rate (Bradley & Lang, 1997), such that either positive or negative correlations could indicate greater coherence. In this way, coherence can then be treated the same as most common dependent measures. The absolute value of coherence can be interpreted with a value of 0 being no coherence and a value of 1 being perfect cross-correlation between the two systems. In that sense, the coherence scale is readily interpretable. We also report the average lag position at which the maximum absolute cross-correlation between channels was observed, see Figure 2.

Data analyses. Analyses were conducted in two stages. First, we present analyses testing the unfolding of emotional responses in each individual time-series channel (experience, physiology, and expression) as a function of age and condition. In line with prior work (e.g., Mauss et al., 2005), we tested whether systematic changes in activity in each channel occurred over the course of the video. To simplify time-series analyses of the individual channels, we analyzed mean activity in each of the channels in four time windows: early (first 30 s), early middle (31 s to 60 s), late-middle (61 s to 90 s), and late (90 s to 120 s). Linear mixed-effects models were fit to the data with three fixed factors, Age (young, old) × Condition (reactivity, suppression, acceptance) × Time-Bin (1 s to 30 s, 31 s to 60 s, 61 s to 90 s, 91 s to 120 s). In the second stage, experience-physiology coherence and experience-expression coherence were calculated across the entire 2-min window separately for each subject and regulation condition, using the methods described earlier. Linear mixed-effects models were fit to the data with two fixed factors: Age (young, old) × Condition (reactivity, suppression, acceptance). Mixed models were fit using the lme4 package in R.

Random intercepts were defined for participants, and following current best-practices (Barr, 2013; Barr et al., 2013; Bates, Kliegl, Vasishth, & Baayen, 2015; Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017), the maximal random-effects structure

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[5] We additionally ran two follow-up analyses examining the critical age difference in coherence at a very large lag window (lag = 20) and a smaller lag window (lag = 6). Importantly, the pattern of results remained the same. Although increasing the lag window unsurprisingly resulted in an overall mean shift in the magnitude of coherence, it had virtually no effect on the age and condition differences in coherence, which remained stable relative to the effects reported in the current manuscript, where lag = 10.

for all within-subjects effects were first included in the models with a variance-components structure for the random slopes. Including covariance terms between the random-slopes resulted in failures of convergence, so these were removed (Barr, 2013; Bates et al., 2015; Matuschek et al., 2017). Statistical inference on the fixed effects was conducted via separate likelihood ratio tests for each fixed-effects parameter (Barr et al., 2013). The likelihood ratio test for each parameter is calculated as the difference between -2 times the natural logarithm of the likelihood for the full model against a nested (restricted) model without the parameter. This test follows an approximate chi-square distribution with degrees of freedom equal to the difference in parameters between the full and restricted model. Inference on fixed effects was restricted to the highest order interactions that were statistically significant (Venables, 1998). To facilitate interpretation, standardized effect sizes of relevant effects are reported by calculating the model-derived standardized mean difference (SMD) of interest that can be interpreted as the difference between two means in standard deviation units (conceptually analogous to Cohen's *d*). For follow-up tests decomposing higher order interactions, reported *p* values and effect size confidence intervals were corrected for multiple comparisons using exact multiplicity corrections derived from Monte Carlo simulations from the multivariate *t* distribution (Hothorn, Bretz, & Westfall, 2008; Lenth, 2016). Approximate degrees of freedom for follow-up *t* tests are calculated via a Satterthwaite approximation.

Results

Age Differences in Emotional Responses at Baseline

For baseline ratings (0 = *not at all sad*, 5 = *extremely intense sadness*), both younger adults ($M = .15$, $SD = .32$) and older adults ($M = .29$, $SD = .68$) reported negligible sadness, and no age differences were found, $t(82.98) = 1.43$, $p = .16$ (a Welch's *t* test was used to correct for unequal variances). For heart period, consistent with established literature, younger adults had shorter heart periods (i.e., faster heartbeats; $M = 845$ ms, $SD = 121$ ms) than older adults ($M = 969$ ms, $SD = 207$ ms), $t(85.89) = 3.87$, $p < .01$. For expression (EMG), no significant difference was found between younger adults ($M = 4.43$ μV, $SD = 3.18$ μV) and older adults ($M = 4.28$ μV, $SD = 3.32$ μV), $t(107.82) = .24$, $p = .81$.

Age Differences in Unfolding Emotional Responses for Reactivity and Regulation Conditions

Sadness intensity experience (self-report ratings). Figure 1a plots mean sadness ratings as a function of age-group, time, and condition and the top rows of Table 1 present the results from the omnibus likelihood ratio tests of the fixed-effects factors from the linear-mixed effects model for sadness experience. As can be seen in Table 1, there was a significant interaction between Age and Time, suggesting that age differences in sadness changed over the course of time. Follow-up tests indicated that age-differences in sadness were smaller in the first 30 s (30 s: $t(200.17) = 1.89$, $p = .15$; effect $\text{size}_{SMD} = .21$, 95% CI [.06, .49]), compared with each of the later time-bins (60s: $t(152.79) = 4.86$, $p < .0001$; effect $\text{size}_{SMD} = .51$, 95% CI [.26, .76]; 90 s: $t(147.18) = 6.09$, $p < .0001$; effect $\text{size}_{SMD} = .63$, 95% CI [.38, .87]; 120 s: $t(207.86) = 4.96$, $p < .0001$; effect $\text{size}_{SMD} = .57$, 95% CI [.30, .85]. There was also a significant Condition × Time interaction ($p < .01$), suggesting that the change in sadness experience over time differed for the three conditions with reactivity in particular showing a steeper increase in the initial time-bins. However, the final sadness rating in the 120-s time-bin for all the three conditions ended up being similar, that is, there were no significant difference at the 120-s time-bin between reactivity and suppression, $t(505.34) = 2.26$, $p = .16$, between reactivity and acceptance, $t(260.21) = .03$, $p = .99$, $t(505.34) = 2.26$, $p = .16$, or suppression and acceptance, $t(215.19) = 1.60$, $p = .51$.

Physiology (heart period). The middle rows of Table 1 present the results from the omnibus likelihood ratio tests of the fixed-effects factors from the linear-mixed effects model predicting heart period. Figure 1b plots mean cardiac heart periods as a function of age-group, time, and condition. As can be seen, there was a significant interaction between age and time, indicating age-related changes in the physiological response to sadness-eliciting situations varied over the course of time. Effect sizes (and confidence intervals) of age-differences in sadness were calculated at each time-bin and, as was also the case for experience, illustrated that the age-differences in sadness were smaller in the first 30 s (30 s: $t(133.70) = 3.77$, $p = .0005$; effect $\text{size}_{SMD} = .46$, 95% CI [.18, .74]), compared with each of the later time-bins (60 s: $t(123.31) = 6.06$, $p < .0001$; effect $\text{size}_{SMD} = .73$, 95% CI [.45, .99]; 90 s: $t(122.10) = 6.69$, $p < .0001$; effect $\text{size}_{SMD} = .80$, 95% CI [.53, 1.07]; 120 s: $t(135.01) = 6.96$, $p < .0001$; effect $\text{size}_{SMD} = .86$, 95% CI [.58, 1.13]. There was additionally a main effect of condition, such that heart period was longer in the suppression condition than the reactivity condition, $t(217.73) = 3.39$, $p < .01$; effect $\text{size}_{SMD} = .32$, 95% CI [.10, .53].

Expression (EMG). The bottom row of Table 1 presents the results from the omnibus likelihood ratio tests of the fixed-effects factors from the linear-mixed effects model. Figure 1c plots mean EMG activity as a function of age-group, time, and condition. There was a significant Condition × Time interaction, which was driven by less early increase in EMG activity (negative expression between the first and subsequent time-bins) in the suppression condition (30 s vs. 60 s: $t(554.80) = 1.83$, $p = .54$; effect $\text{size}_{SMD} = .10$, 95% CI [–.06, .27]) compared with the reactivity (30 s vs. 60 s: $t(586.41) = 4.02$, $p = .0011$; effect $\text{size}_{SMD} = .24$, 95% CI [.06, .41]) and acceptance conditions (30s vs. 60s: $t(638.76) = 5.57$, $p < .0001$; effect $\text{size}_{SMD} = .33$, 95% CI [.16, .51]). In addition, the Age × Time interaction was also significant and was driven by an increased change in EMG in younger adults within the first 30s and subsequent time windows (30 s vs. 60 s: $t(235.00) = 4.91$, $p = <.0001$; effect $\text{size}_{SMD} = .29$, 95% CI [.12, .46]) compared with the older adults (30 s vs. 60 s: $t(233.78) = 2.67$, $p = .07$; effect $\text{size}_{SMD} = .15$, 95% CI [–.01, .31]). Finally, there was a significant condition effect, such that suppression resulted in lower EMG activity compared with both reactivity, $t(226.77) = 3.98$, $p = .0003$; effect $\text{size}_{SMD} = .25$, 95% CI [.10, .39] and acceptance, $t(140.69) = 4.72$, $p < .0001$; effect $\text{size}_{SMD} = .45$, 95% CI [-.23, .68].

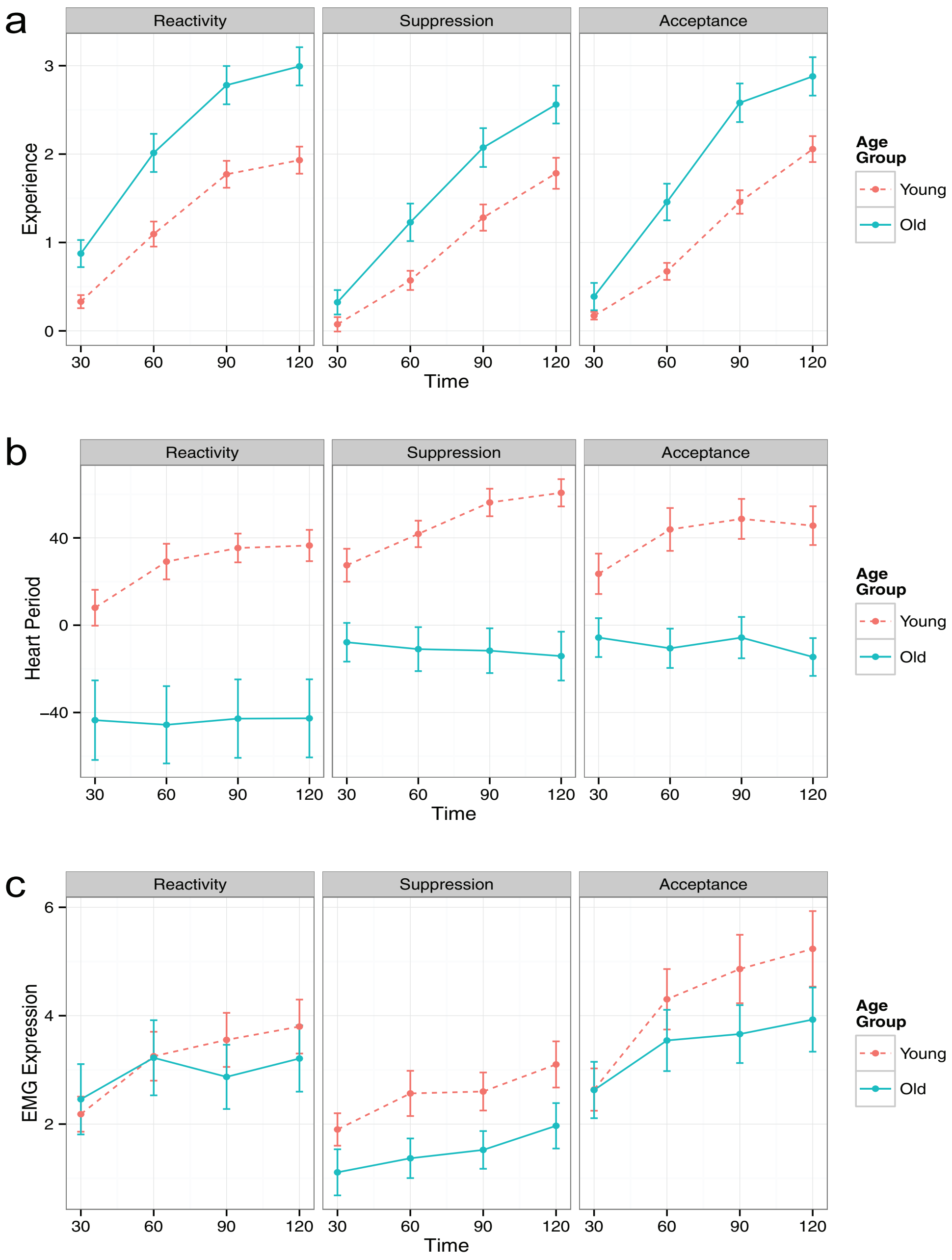

Figure 1. (a) Mean experience ratings as a function of age, time, and condition. (b) Mean physiology (cardiac interbeat interval or heart period) as a function of age, time, and condition. (c) Mean expression (electromyography or EMG) as a function of age, time, and condition. See the online article for the color version of this figure.

Response Coherence

Coherence was calculated between experience and physiology as well as experience and expression using the method described above (see Coherence Estimation). Figure 2, Panels a and d, show the frequency distribution of coherence estimates for experience-physiology and experience-expression, respectively. Mean coherence was .43 (95% CI: [.40, .46]) for experience-physiology and was .43 (95% CI: [.39, .47]) for experience-expression.[6] To assess their statistical significance, similarly to previous studies (Mauss et al., 2005, 2011), we used one-sample *t* tests to compare the average cross-correlations to 0. Experience-physiology coherence,

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[6] We also tested whether coherence varied over time by calculating coherence for the four 30-s segments that made up the entire video for every subject. Age differences in coherence were stable across the four 30-s segments. These estimates were similar to the entire 2-min segment and time did not interact with age or condition effects. Results are presented with coherence estimated across the entire 2-min window.

Table 1
Omnibus Likelihood Ratio Tests (LRT) for Linear Mixed Models of Experience, Heart Period, and Electromyography (EMG) Expression

Factor	*df*	LRT (χ^2)	*p*
Experience			
Condition	2	22.79	<.0001
Age	1	22.25	<.0001
Time	3	440.83	.0001
Condition × Age	2	1.64	.44
Condition × Time	6	21.40	<.01
Age × Time	3	32.37	<.0001
Condition × Age × Time	6	5.31	.51
Heart period			
Condition	2	11.54	<.01
Age	1	32.1	<.0001
Time	3	33.81	<.0001
Condition × Age	2	1.11	.57
Condition × Time	6	3.63	.73
Age x Time	3	40.65	<.0001
Condition × Age × Time	6	4.65	.59
EMG expression			
Condition	2	24.82	<.0001
Age	1	1.22	.27
Time	3	38.07	<.0001
Condition × Age	2	1.53	.46
Condition × Time	6	21.54	<.01
Age × Time	3	7.99	.05
Condition × Age × Time	6	4.19	.65

$t(108) = 59.89$, $p < .0001$, as well as experience-expression coherence, $t(109) = 27.27$, $p < .0001$, were statistically significant. Figure 2, Panels b and e, show the frequency distribution of lag estimates, which both show a largely 0-inflated distribution, such that the majority of maximal coherence estimates were found at a lag of zero.

Figure 2, Panels c and f, show the scatterplot of coherence against lag for experience-expression and experience-physiology. To examine if there were any systematic (nonlinear) trends between coherence and lag, we superimposed a thin-plate smoothing spline of lag on coherence (see Wood, 2017). This plot revealed the trend that maximal coherence estimates were typically found at shorter lags, particularly with a peak around lag = 0. Thus, estimates of response coherence were systematically largest at a lag of less than 1 s. Moreover, when maximal coherence estimates were observed at more distal lags, these coherence estimates were typically not as large as trials where maximal coherence estimates were observed at a lag of 0. This pattern was stable and did not diverge across age-groups or conditions. One implication of this clear systematic relationship between lag and coherence is that the "maximum absolute autocorrelation" algorithm used by Mauss and colleagues and adopted in the current study is clearly detecting systematic response-system coherence. If the algorithm was detecting spurious correlations, then this would result in a uniform distribution of lag values and no systematic relationship between lag and coherence.

Figure 3a presents the experience-physiology coherence estimates as a function of regulation/reactivity condition and age group. Figure 3b presents the same plot for experience-expression coherence estimates.[7] Coherence estimates for experience-physiology and experience-expression were examined as a function of age and condition via linear mixed-effects models. Table 2 presents the resulting omnibus likelihood ratio tests of the fixed-effects factors for experience-physiology and experience-expression coherence values. For experience-physiology coherence, the main effect of age was significant.[8] As can be seen in Figure 3a, older adults, on average, showed greater response coherence between experience and physiology (effect size$_{SMD}$ = .30, 95% CI [.13,.47]). For experience-expression coherence, no factors reached traditional levels of statistical significance (see Table 2).[9]

Finally, we tested whether experience-expression coherence was greater than experience-physiology coherence for younger and older adults' data (Evers et al., 2014). For older adults, no difference between experience-physiology ($M = 0.46$) and experience-expression ($M = 0.43$) coherence were found, $t(73.97) = 0.78$, $p = .44$. Similarly, for younger adults, no difference between experience-physiology ($M = 0.41$) and experience-expression ($M = 0.39$) coherence were found, $t(65.53) = .68$, $p = .50$.

Discussion

Although there is a growing literature characterizing adult age-related changes in individual emotional response systems in sadness reactivity and regulation, we currently know very little about how aging impacts emotional coherence between these systems. To our knowledge, this study was the first to examine age-related differences in emotional coherence during sadness reactivity and regulation. Our most striking finding was that older adults showed greater emotional coherence between sadness experience and physiology (heart period) during reactivity and regulation compared to their younger counterparts. In the following, we discuss this key finding as well as other important results of the current study with respect to current theories of emotion and aging.

Age Differences in Emotional Coherence During Sadness Reactivity and Regulation

Some accounts predict negligible emotional coherence in later adulthood, as neural atrophy and decline in end-organ activity are suggested to blunt physiological reactivity, which may lead to increased mind–body dissociation and changes in emotional responses in later adulthood (e.g., Cacioppo et al., 2011; Levenson et

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[7] Correlation between max intensity of experience with both coherence-types was done. Experience–physiology coherence correlation was 0.033 (ns) and experience–expression coherence correlation was 0.06 (ns).

[8] To ensure that the age differences are not due to having a greater number of older women, we tested age differences in the critical coherence finding on the female subsample. The pattern of age-related coherence findings remained consistent with only female participants' data ($p = .008$; for the whole sample, age was $p = .0005$), ruling out the possibility that a greater emotional coherence in older adults' data were due to more females in the older sample. Similar to the finding with data from both women and men, females-only data also did not have significant differences in experience–expression coherence ($p = .48$; for the whole sample, age was $p = .36$).

[9] As a follow-up, we ran the physiology-expression coherence and did not find any significant age differences, $\chi^2(1) = 2.17$, $p = .14$. The condition effect ($p = .83$) or the Age × Condition interaction ($p = .53$) were not significant. In addition, because we did not have a theoretically driven motivation for this comparison, we do not discuss it in further detail.

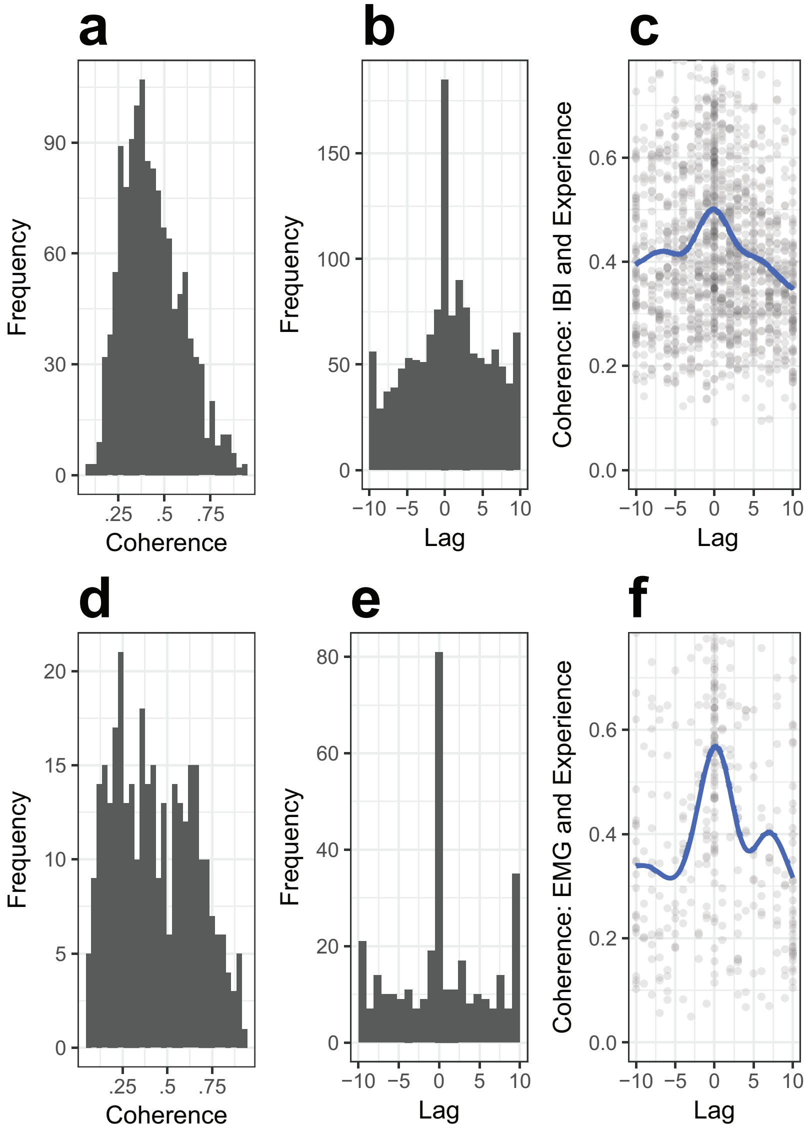

Figure 2. Coherence and lag relationship. (a) Frequency distribution of coherence estimates (maximal cross-correlation) for experience and physiology (heart period). (b) Frequency distribution of maximal coherence lag value (see text for detail) for experience and physiology. (c) scatterplot of coherence by lag for experience and physiology. Fit line is a thin-plate smoothing spline (Wood, 2017). Fit line indicates that maximal coherence estimates were found when lag ~ 0. (d through f) Identical plots for experience and expression coherence. See the online article for the color version of this figure.

al., 1991; Mendes, 2010; cf. Charles, 2010 and Kunzmann et al., 2014). Inconsistent to these accounts, we found that older adults had a greater association between experience and heart period during emotional reactivity, suppression, and acceptance relative to younger adults. The presence of higher experience-physiology coherence in older adults supports the motivational relevance and SAVI accounts, which suggest that during emotional situations that entail heightened arousal older adults have high emotional responses (Charles, 2010; Kunzmann & Grühn, 2005; Kunzmann et al., 2014). In contrast to experience-physiology coherence, we found no age difference for experience-expression coherence during reactivity or regulation conditions. Some have argued that a higher experience-expression coherence might be adaptive and is functional in expressing felt emotions to others (Evers et al., 2014; Mauss et al., 2011). As older adults did not have a lower experience-expression coherence than younger adults, we did not find support for the mind–body dissociation account (e.g., Mendes, 2010). Thus, the current findings indicate that, even though there may be reduced physiological reactivity in older age (e.g., Labouvie-Vief et al., 2003; Levenson et al., 1991; Smith et al., 2005; Tsai et al., 2000), at least during sadness, older adults have greater coupling between sadness experience and physiology and maintained coupling between sadness experience and expression compared with their younger counterparts.

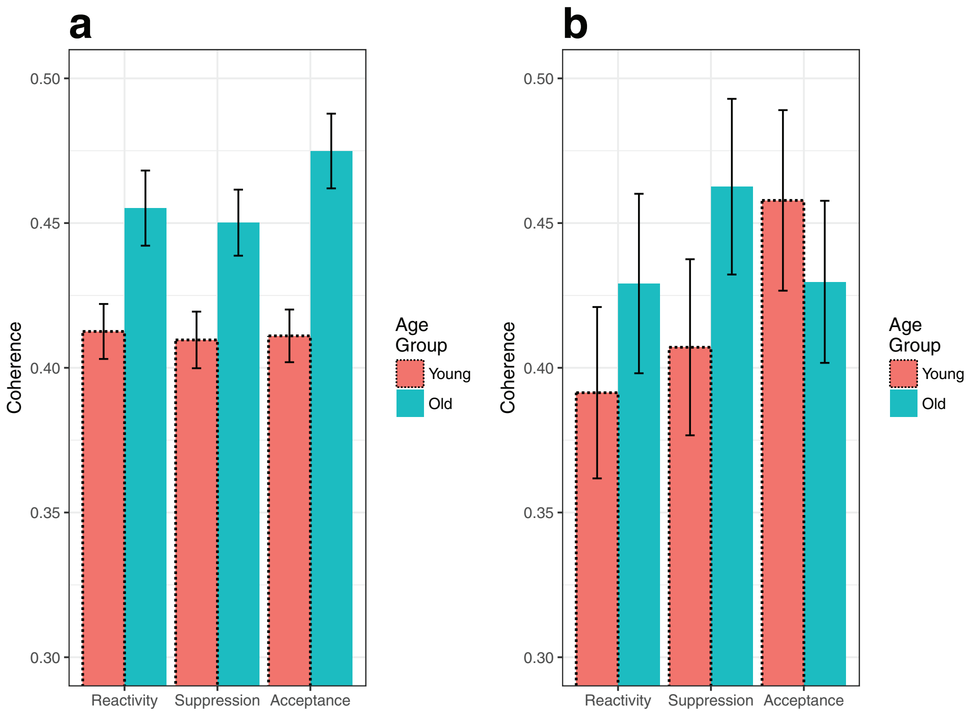

Figure 3. (a) Mean coherence between experience and physiology as a function of age and condition. (b) Mean coherence between expression and experience as a function of age and condition. For experience–physiology coherence there was a main effect of age ($p < .001$) and no effect of condition. For experience–expression coherence there was no significant effect of age ($p = .43$) or condition. See the online article for the color version of this figure.

The current findings show that a mean change in emotional response (or pair of systems) over time within an individual does not imply that there will be a change in the coherence (e.g., correlation between pairs of systems). In fact, we are able to replicate age-related reductions in cardiac reactivity (consistent with physiological blunting), but at the same time an increase in coherence between physiology and experience with age. This forms an important basis for examining age-differences in coherence. A combination of factors may influence emotional coherence beyond intensity level—for example, motivational relevance and life experience in later adulthood. We believe that past findings indicating sadness is highly relevant in older adults may shed some light on the age-related differences we find in coherence in the current study. Previous work has shown that older adults experience greater sadness than younger adults because sadness content is more personally relevant to them (Kunzmann & Grühn, 2005; Kunzmann et al., 2013, 2014; Seider et al., 2011). Sadness responses in later adulthood may be driven by age related changes in an individual's motivations (e.g., goals, beliefs, and expectations) and environmental challenges (Kunzmann et al., 2014). In line with this work, we also found that older adults experienced greater sadness than the young. We argue that, in addition to the increased experience of sadness, the relevance of sadness stimuli may be an underlying mechanism through which older adults elicit greater experience-physiology coherence, and may be responsible for explaining the observed age differences in coherence in the current study. Further research is needed to empirically test how different levels of relevance of emotional content can impact emotional coherence.

Table 2
Omnibus Likelihood Ratio Tests (LRT) for Linear Mixed Models of Coherence

Factor	*df*	LRT (χ^2)	*p*
Coherence (experience-physiology)			
Condition	2	1.76	.51
Age	1	11.98	<.001
Condition × Age	2	1.61	.45
Coherence (experience-expression)			
Condition	2	1.71	.43
Age	1	.62	.43
Condition × Age	2	3.77	.15

Another possible mechanism that may underlie age differences in emotional coherence is that older adults are more in touch with their internal state during sadness experience. Under this premise, accumulated life experiences and better self-knowledge with increasing age (Charles, 2010) may result in older adults' reporting emotional experiences that are more in sync with their physiological states. Given that sadness may affect older adults more than young (Kunzmann & Grühn, 2005; Kunzmann et al., 2013, 2014; Kunzmann & Thomas, 2014; Seider et al., 2011), it still remains to be examined whether higher emotional coherence may be specific to sadness or whether it would extend to other contexts. For instance, findings from several studies suggest that, unlike sadness, older adults experience less anger (Blanchard-Fields & Coats, 2008; Kunzmann & Thomas, 2014) than younger adults. It is possible that older adults may have lower emotional coherence for those negative emotions for which they show reduced responsivity. Further research is required to understand how such contextual factors may influence emotional coherence.

A similar pattern to the reactivity condition was found for the emotion regulation conditions, where older adults showed greater experience-physiology coherence during the active suppression or acceptance of sadness relative to younger adults. In some studies with younger adults, researchers have found suppression to disrupt the degree of emotional coherence (Butler et al., 2014; Dan-Glauser & Gross, 2013) while acceptance has not been found to significantly impact coherence (Dan-Glauser & Gross, 2013). In contrast, in the current study we found that suppression and acceptance strategies did not strongly modulate the coherence response in younger adults. However, it is important to note here that, unlike other studies that have examined the influence of emotion regulation on emotion coherence, we focused on arousal levels (not at all to extremely intense sadness; Schaefer et al., 2010) of sadness experience rather than valence levels (e.g., very negative to very positive emotion; Dan-Glauser & Gross, 2013). This may have led to the lack of significant differences in experience-physiology emotional coherence in suppression or acceptance conditions compared with the no-regulation condition for both younger and older adults.

Another plausible explanation for a similar pattern of coherence during sadness reactivity and regulation could be due to a reduced effectiveness of regulation. Successful emotion regulation attempts have been recognized to disrupt the degree of emotional coherence in past research (Butler et al., 2014; Dan-Glauser & Gross, 2013; Hollenstein & Lanteigne, 2014). On the other hand, emotional dysregulation is characterized by high emotional coherence (Schaefer, Larson, Davidson, & Coan, 2014). The lack of a change in coherence in the regulation conditions relative to reactivity suggests that perhaps the regulation strategies adopted by the participants in this study were not completely effective. Indeed, over the course of the video, continuous reporting suggested that there was a more gradual increase in sadness experience (continuous reporting over time) in the regulation conditions compared to reactivity condition, which is indicative of regulatory attempts in the suppression and acceptance conditions. However, the last sadness rating (experience reported in the final rating) in all the three conditions were not different. On a related note, it is possible that participants were not able to implement acceptance and suppression instructions equally well, which may explain differences in present and previous suppression-related findings. Further research is needed to test how successful versus failed attempts to regulate emotions influence the degree of coherence.

In addition, the current study sheds light on the relationship between emotion systems and extends the dual-process framework (Evers et al., 2014) by considering how individual difference factors and emotion-type play an important role in emotional coherence. We did not find that experience-physiology coherence was reduced relative to experience-expression coherence for either age group. We show that age as an individual difference factor can shift the strength of relationship between emotion systems and can lead to a stronger relationship across relatively reflective and automatic systems than within relatively reflective systems and can even outweigh the original prediction of the dual-process framework. Furthermore, the type of emotional experience matters as well. Unlike in the work of Evers et al. (2014), which used a tedious counting task to induce anger, we used sadness-eliciting videos that are arguably more personally relevant. Another major difference with past work is that we also assessed arousal-intensity based emotional experience. In future work, it will be important to further understand how the covariation between reflective and automatic systems may be conditional upon individual difference factors and emotion-type, as highlighted in the current study.

Caveats, Future Research, and Implications

This study reflects the first step toward understanding changes in emotional coherence in later adulthood. Nevertheless, important caveats and assumptions of the current study need to be addressed, as well as goals for future research. One important consideration is that we used only a single measure of physiological activity—heart period. Heart period was chosen as it is one of the most reliable measures of emotionally salient physiological changes across the life span (e.g., Gyurak et al., 2012). In addition, heart period has been previously used to study emotional coherence (e.g., Sze et al., 2010). However, other studies have used a composite of parasympathetic and sympathetic measures to assess coherence (Butler et al., 2014; Dan-Glauser & Gross, 2013). Researchers have highlighted the importance of measuring both the sympathetic and parasympathetic activations while interpreting cardiovascular reactivity (Berntson, Cacioppo, & Quigley, 1991; Quigley & Barrett, 2014). It is possible that heart period was not able to capture some variation in physiological changes critical for detecting coherence or that there are strategy-specific changes in autonomic activity that can be captured well by using a combination of physiological measures. At the same time, one past study has shown that coherence estimates based on a single measure of heart period resulted in comparable findings relative to coherence estimates that are based on a composite of sympathetic and parasympathetic physiological measures (Sze et al., 2010). Thus, at least for measuring coherence between response systems, heart period appears to be a robust indicator for general physiological activity. However, it will be important to replicate the current coherence findings with multiple physiological measures in future research. Furthermore, the observed age differences in emotional coherence could have been obscured by differences between cohorts. A longitudinal design is needed to understand the effects of age and cohort on emotional coherence over time.

Past research has suggested that experiencing intense emotions may increase coherence between experience and physiology or expression (Bonanno & Keltner, 2004; Davidson, 1992; Mauss et al., 2005; Rosenberg & Ekman, 1994; Tassinary & Cacioppo, 1992). On the basis of these previous findings, we used high-intensity sadness content to elicit a stronger coherence response so that we would be better suited to test for age-differences in coherence. However, we did not observe a systematic graded relationship between sadness intensity and coherence. Another study did not find a significant association between sadness experience and coherence among response systems, but it did find an association between intensity and coherence for amusement

(Mauss et al., 2005). Perhaps because we used only intense sadness-eliciting content (instead of a broad range of emotions including more neutral stimuli), we may have reduced the range with which coherence is elicited, thus reducing the potential to detect relationships between self-reported intensity and coherence. This is even more a possibility if the relationship between intensity and coherence is nonlinear in nature (e.g., coherence appears once a certain "threshold" of emotional intensity is reached), and would also be consistent with our findings showing that mean coherence was stable and invariant over time. This remains an empirical question for future research.

Even though a number of studies have employed the maximal absolute cross-correlation across multiple lags as an index of coherence, limited studies have discussed lag values or systematically examined the relationship between lag and correlation magnitude. Figure 2 plotted the distributions of lag values (the difference in seconds in time-series where the maximal coherence value was detected for each subject and condition). For both experience-physiology and experience-expression coherence, in the majority of cases, lag was likely to be small (within the 1 s). Moreover, we saw a nonlinear relationship between coherence and lag, such coherence was largest near lags of 0. Collectively, these findings suggest that, at least for experience-expression and experience-physiology coherence, there was evidence for stronger temporally synchronous coherence that fell off systematically with increasing delay. Although rarely studied, future work may consider whether lag is also an important aspect of coherence levels. For instance, it is possible that the temporal discrepancy in emotional responses unfolding across modalities may depend upon emotional type, personal relevancy, and intensity. In this case of sadness, there is little or no temporal delay and stronger coupling of emotional responses at short delays. Further work is required to examine the full range of intensity profile of the emotional response to decipher which determinants modulate the temporal unfolding and coupling of emotional responses.

Although many emotion researchers have debated the presence of response coherence and its implications for emotion processing, the functional nature of emotional coherence is still debated. Some researchers consider coherence to be a unique feature of emotions that prepare an individual for actions required to respond optimally to environment (Ekman, 1992; Levenson, 1994; Plutchik, 1982). On the other hand, other researchers (Barrett, 2011; Russell, 2003) have questioned the presence of associations across response systems during emotional responding or suggested that response coherence is entirely context dependent (Quigley & Barrett, 2014). Furthermore, the functionality of coherence still remains to be clarified in future work. The function of emotional coherence has been speculated to be primarily biological, and it may help in instantaneous emotional response coordination to environmental demands (e.g., Ekman, 1992; Levenson, 1994; Plutchik, 1982), coordinate emotional interaction in social contexts (Cacioppo, Berntson, & Klein, 1992; Campos & Barrett, 1984; Mauss et al., 2011), or both (Evers et al., 2014). It is possible that a higher coherence during age-relevant emotional situations may facilitate adaptive behavior in later adulthood, including disengagement from unrealistic goals and promoting social support. Future work is required to test the effect of social context on emotional coherence in older adults.

Our study replicates the presence of coordination among response systems and extends prior work by suggesting adult developmental trajectories of change in experience-physiology coherence but not in experience-expression or expression-physiology coherence. For both younger and older adults, we found small-to-moderate coherence for sadness (average Pearson *r*s = .36); mean experience-physiology coherence was .43 (*SD* = .16; range = .09–.93) and mean experience-expression coherence was .43 (*SD* = .22; range = .05 –.92), which were of a similar magnitude to prior research (e.g., Mauss et al., 2005). We found the presence of emotional coherence in later adulthood during sadness reactivity and regulation; however, age differences in the degree to which response coherence may be present for other negative emotions still needs to be investigated. Although we only investigated sadness, the relationship may very well vary by emotions as well. Further work should examine the influence of different types of emotion on emotional coherence across the adult life span.

Concluding Comments

To our knowledge, this study is the first exploration of age-related changes in emotional coherence. Critically, the current findings provide evidence that, despite age-related blunting of physiological responses (e.g., Cacioppo et al., 2011; Mendes, 2010; cf. Kunzmann & Grühn, 2005), aging does not appear to limit coupling between response systems—coupling between sadness experience and expression was maintained in older age and was actually greater in older adults between sadness experience and physiology. The current work provides evidence that age is an important individual difference factor to consider while understanding associations between emotion response systems.

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Received September 26, 2016
Revision received May 5, 2017
Accepted May 15, 2017 ■