Altered emotional mind–body coherence in older adults

Akie Saito [1*], Wataru Sato [1,2 *], Sakiko Yoshikawa [2,3]

[1] Psychological Process Research Team, Guardian Robot Project, RIKEN, Kyoto, Japan

[2] Field Science Education and Research Center, Kyoto University, Kyoto, Japan

[3] Faculty of the Art, Kyoto University of the Arts, Kyoto, Japan

*** Correspondence:** Akie Saito Psychological Process Research Team, Guardian Robot Project, RIKEN, 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288, Japan. email: akie.saito@ riken.jp Wataru Sato Psychological Process Research Team, Guardian Robot Project, RIKEN, 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288, Japan email: wataru.sato.ya@riken.jp

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Abstract

Coherence between subjective experience and bodily responses in emotion is assumed to have a positive influence on well-being, which might be particularly valuable in late adulthood. Previous studies of young adults' continuous subjective, behavioral, and physiological responses to emotional films reported emotional mind–body coherence. In contrast, research regarding emotional coherence in older adults has been scarce. In this study, we examined emotional coherence in older adults between continuous valence ratings and behavioral responses (facial electromyography (EMG) of the corrugator supercilii and zygomatic major muscles), as well as between continuous arousal ratings and physiological measures (electrodermal activity (EDA) and fingertip temperature), in response to four emotion-eliciting film clips (anger, sadness, contentment, and amusement) film clips and an emotionally neutral clip. Intra-individual cross-correlation analyses revealed that the coherence between valence ratings and corrugator EMG activity for the anger-eliciting film was weaker in older adults than in young adults, who completed an identical experiment. Age differences also emerged in the coherence of arousal ratings with EDA and fingertip temperature measures, respectively, while participants watched the anger-eliciting and contentment-eliciting films; while negative correlations were found for older adults, positive correlations were found for young adults. These results indicate that emotional mind–body coherence somewhat differs quantitatively and qualitatively between older and young adults.

Introduction

Coherence between subjective experience and bodily responses in emotion is assumed to be associated with well-being (Brown et al., 2020; Levenson, 2014; Mauss et al., 2011). Maintenance of well-being might be particularly pertinent in older populations, who are more likely to face a decline in health and shrinkage of social networks (Baltes, 1997; Carstensen et al., 1999). It has been hypothesized that emotions are deployed as coordinated activities of subjective and bodily responses to emotion-evoking stimuli; that the latter underlies the subjective experience of emotion (James, 1884; Friedman, 2010; Lang, 1994; Levenson, 1999; 2014). The issue of whether and to what extent subjective and bodily responses are coherent has received considerable attention from emotion researchers (Bradley & Lang, 2000; Ekman, 1992; Levenson, 1994; 2014; Mauss et al., 2005; Sze et al., 2010).

Empirical studies of young adults have demonstrated emotional coherence between subjective experience and physiology (reflected in autonomic nervous system [ANS] activity), as well as between subjective experience and behavior as shown by facial electromyography (EMG) in response to emotional stimuli (Bradley & Lang, 2000; Mauss et al., 2005; Sze et al., 2010; Van Doren et al., 2021). Specifically, several studies have reported that continuous valence ratings are negatively and positively associated with facial EMG activity in the corrugator supercilii and zygomatic major muscles, respectively (Mauss et al., 2005; Rattel et al., 2020; Sato et al., 2020); these muscles reflect the emotion-related facial actions of brow lowering and lip-corner pulling, respectively (Dimberg, 1990). Continuous arousal ratings were positively and negatively associated with electrodermal activity (EDA) and peripheral temperature, respectively (Sato et al., 2020), which constitute signals that reflect the activity in the sympathetic branch of the ANS (Boucsein, 2011). These findings are in agreement with ample evidence indicating that facial EMG and ANS measures reflect the degrees of subjective valence and arousal, respectively (Bradley & Lang, 2000; Rattel et al., 2020； Sommerfeldt et al., 2019; Van Doren et al., 2021).

The reported emotional mind–body coherence is assumed to be biologically and socially adaptive because coherent reactions among different emotion systems might enable us to effectively react to environmental demands (Cacioppo et al., 1992; Ekman, 1992; Levenson, 1994; 2014; Mauss et al., 2005). Furthermore, accumulations of adaptive responses to environmental challenges are thought to promote well-being (Brown et al., 2020; Luhmann et al., 2012). Consistent with this supposition, some recent studies have suggested that emotional coherence is related to well-being (Brown et al., 2020; Mauss et al., 2011; Sommerfeldt et al. , 2019). Furthermore, a lack of coherence across emotion systems is reportedly relevant to ill-being (Kaufman et al., 2021; Petrova et al., 2021). Given the influence of emotional mind–body coherence on psychological functioning, examining emotional coherence among subjective experience, behavior, and physiology in older populations could provide hints for healthy aging.

Empirical findings of emotion reactivity and coherence in older adults

Age-comparative studies on reactivity using emotion-evocative stimuli such as film clips have not yielded consistent evidence regarding emotional reactivity in older adults. Some studies have demonstrated that older adults showed heightened reactivity in subjective experience (Fernández-Aguilar et al., 2020; Kunzmann & Grühn, 2005; Seider et al., 2011), behavior (Lwi et al., 2019), and physiology (Seider et al., 2011). However, other studies have revealed diminished reactivity in subjective experience (Kunzmann et al.., 2017), behavior (Kunzmann et al.., 2017), and physiology (Kunzmann et al.., 2017 Levenson et al., 1991; Tsai et al.,2000). Although stronger emotional coherence has been found in young adults under the condition that perceived stimulus intensity was high, suggesting a link between reactivity and coherence (Brown et al., 2020; Rosenberg & Ekman, 1994), testing the same issue in older adults seems to be difficult, considering the inconsistent results of previous studies of emotion reactivity. We, therefore, focus on examining emotional coherence in older adults, without specifically considering the link between emotion reactivity and coherence.

Research regarding emotional coherence in older populations has been scarce; only two studies have examined continuous coherence across emotion systems, using film clips as emotion-eliciting stimuli (Lohani et al., 2018; Wu et al., 2021). Lohani et al. (2018) measured subjective ratings (arousal), facial EMG of the corrugator supercilii, and electrocardiography (ECG; for heart period calculation) while participants watched sadness-eliciting films, and calculated the absolute values for intra-individual cross-correlations of pairs of subjective ratings–EMG and subjective ratings –heart period. In this type of calculations, coherence is estimated without considering the direction of coherence. The results showed that the coherence between subjective sadness ratings and heart period was stronger in older adults than in young adults, though no significant age differences were found in the subjective ratings–EMG coherence. The research conducted by Wu et al. (2021) aimed to investigate the coherence between behavior and physiology by not only calculating the absolute values (i.e., indexed by changes in facial activities associated with heart rate acceleration or deceleration) but also calculating by relative scores, which considers the directions of correlations between behavioral and physiological reactivity (i.e., an inverse association between heart rate and facial behaviors). They found enhanced coherence only when estimations were performed using relative scores.

Theoretical background

The magnitude and patterns of emotional coherence in older adults could be predicted by different theoretical frameworks for emotional processing in older adults. According to the view of the weakened mind–body connections in late adulthood (Mendes, 2010), declines in bodily sensory perceptions with increasing age are regarded as the main factor contributing to weakened mind–body connections in older adults. This account thus can assume that blunted reactivity will eventually lead to reduced emotional coherence among older, compared with young adults.

Another theoretical stance toward emotional aging adopts a multidirectional perspective regarding age difference in negative emotional reactivity (Kunzmann et al., 2017), which assumes differential age trajectories for specific emotions, such as sadness; sadness is considered more salient in later adulthood because of age-relevant content (Kunzmann & Grühn, 2005; Seider et al, 2011). This theoretical view, therefore, can predict enhanced sadness emotional coherence among older adults, compared with young adults.

As well as sadness, there are other emotions that may be motivationally age-relevant to older adults (Mather & Carstensen, 2005; Reed et al., 2014); preferential processing of stimuli that evoke pleasant, positive emotions, along with the avoidance of stimuli (i.e., angry faces) that evoke unpleasant, negative emotions (the age-related positivity effect), has been demonstrated in older adults (Charles et al., 2003; Isaacowitz et al., 2009; Mather & Carstensen, 2003), which is underlined by the socioemotional selectivity theory (Carstensen et al., 1999; Carstensen, 2006; Carstensen & DeLiema, 2018). Furthermore, older adults seem to prefer and are more reactive to low-arousal positive stimuli (such as tenderness) over high-arousal positive stimuli (such as amusement) (Chu et al., 2020; Ferández‐Aguilar et al., 2020; Scheibe et al., 2013). Considering the above findings, it is possible to predict that older adults will demonstrate a pattern of emotional coherence that reflects the characteristics of the age-related positivity effect, such as diminished emotional coherence of unpleasant (i.e., anger emotion) in older adults and/or age differences in emotional coherence patterns regarding negative emotions like anger and low-arousal positive emotions.

Methodological considerations

Prior studies of emotional coherence in older adults (Lohani et al., 2018; Wu et al., 2021) have adopted an intra-individual correlation analysis, which is considered superior to between-participants correlation analyses in the examination of young adults (Levenson, 2014; Mauss et al., 2005). Coherence studies of young adults have also revealed that ratings of subjective valence are correlated with facial EMG activity of the corrugator supercilii and zygomatic major muscles (Mauss et al., 2005; Rattel et al., 2020; Sato et al., 2020). Given the evidence, the use of valence in addition to arousal ratings as indicators of subjective experience and then examining coherence between subjective valence ratings and facial EMG activity in older adults could further provide the evidence to clarify the relationship between subjective experience and behavior in older adults. Relatedly, the arousal aspect of subjective experience has been found to be related to physiological measures that predominantly reflect the sympathetic branch of the ANS, such as EDA and peripheral temperature among young adults (Bradley & Lang, 2000; Sato et al., 2020; Van Doren et al., 2021). Along with these lines, whether the previous findings of emotional coherence among older adults could extend to physiological responses measured by EDA and peripheral temperature merits investigation. Assessing association between these physiological measures and arousal ratings may provide further insights regarding experience–physiology coherence in older individuals.

As noted, sadness emotional coherence has been targeted in prior studies of coherence in older adults (Lohani et al., 2018; Wu et al., 2021). It is therefore remains unclear whether emotional coherence of other emotions that are also assumed to be motivationally age-relevant to older adults, such as anger (Isaacowitz et al., 2009; Mather & Carstensen, 2003) and low-arousal positive emotions (Ferández - Aguilar et al., 2020) like contentment, differs from the coherence in young adults. It is, therefore, worth investigating whether emotional coherence emerges during the emotional response to films evoking other types of age-relevant positive and negative emotions.

Another methodological issue that merits investigation is the approach by which emotional coherence is quantified. One previous study of coherence in older adults (Wu et al., 2021) showed enhanced sadness emotional coherence only based on estimations of relative scores. In addition to the hypothesis that exclusive estimation of absolute values provides limited information regarding the factors that potentially influence coherence (Dan-Glauser & Gross, 2013), assessing emotional coherence using both absolute and relative scores may provide further information regarding the extent to which, and how, subjective experience is associated with facial behavior and with physiology.

Potential influences of cultural differences on emotional coherence should also be considered because cultural factors impact emotional processing (Ford & Mauss, 2015; Mauss et al., 2010; Park et al., 2013). For instance, cultural moderations of anger expression have been demonstrated, whereby people living in an interdependent culture (e.g., Japanese culture) exhibit fewer anger expressions because of emotion regulation, compared with people living in an independent culture (e.g., European American culture) (Mauss et al., 2010; Park et al., 2013). Given these findings, cultural factors might exert differential effects on emotional coherence among people in different cultures. Because prior coherence studies of older adults have been conducted in Western populations (Lohani et al., 2018; Wu et al., 2021), it may be useful to investigate whether these studies' findings can be generalized to individuals from different countries (i.e., Japanese) whose cultural values differ from the cultural values of Western populations.

The present study

To examine the issues raised above and expand on the findings of previous coherence research conducted among older adults, we examined emotional coherence in older adults in response to emotion-eliciting films using intra-individual correlation analyses, with a focus on the following five points. First, we assessed both valence and arousal as indicators of subjective experience, then measured behavioral responses (facial EMG of the corrugator supercilii and zygomatic major muscles) and physiological signals (EDA and fingertip temperature). Subsequently, we examined the degree of experience–behavior and experience–physiology coherence in terms of the relationship of the valence ratings to facial EMG and the relationship of the arousal ratings to EDA as well as the relationship of the arousal ratings to fingertip temperature, respectively. Second, considering the motivational relevance of emotions other than sadness in older adults, we presented four emotional films to the participants, including negative (anger and sadness) and positive (contentment and amusement) films, in addition to an emotionally neutral film. Third, we assessed the intra-individual correlations between pairs of experience and behavior and pairs of experience and physiology, by calculating relative and absolute value scores. Fourth, we examined whether the emotional coherence found in Western adults could be generalized to Japanese adults. It is reasonable to hypothesize that Japanese participants would not outwardly display anger expressions to the extent that they consciously feel angry, which may lead to weakened emotional coherence.

Furthermore, we employed a time-lagged cross-correlation approach to estimate emotional coherence, which allowed a comparison of the obtained results with the results of previous coherence studies conducted among older adults (Lohani et al., 2018; Wu et al., 2021). To examine age-related differences, we adopted the experimental procedures used in a previous study that demonstrated emotional coherence across emotion systems in young adults (Sato et al., 2020) and compared the correlation coefficients of older adults and young adults (Sato & Kochiyama, 2022).

Considering the limited number of studies focused on intra-individual emotional coherence in older adults and the possible effects of cultural differences on emotional coherence, we formulated no specific hypotheses regarding age-related differences in emotional coherence or whether emotional coherence differs depending on the types of emotion. Instead, we sought to explore the issue of emotional coherence in Japanese older adults.

Methods

Participants

Thirty native Japanese-speaking older adults in Japan, who reported having normal or corrected-to-normal vision (15 females and 15 males; mean age ± standard deviation [SD] = 72.6 ± 5.0 years) were recruited from a human resource center in Kyoto, Japan. The participants were compensated for their participation in the experiment via the human resource center. Four participants were excluded because they had scores below the cut-off value of 24 on the Japanese version of the Mini-Mental State Examination (Folstein et al., 1975), vision-related diseases, or used medications for neurological or psychiatric symptoms. Thus, the data of 26 older adult participants were analyzed (14 females and 12 males; mean age ± SD = 72.7 ± 4.8 years). All 26 participants scored above the cut-off value of 24 on the Japanese version of the Mini-Mental State Examination (mean ± SD = 28.5 ± 1.7). The data of 30 young adult participants (16 females and 14 males; mean age ± SD = 22.6 ± 2.7 years) from a previous study (Sato & Kochiyama, 2022), who had completed an identical experiment, were analyzed (all 30 participants were native Japanese-speaking young adults in Japan). Power sensitivity analysis was conducted to evaluate the power using G*Power software (ver. 3.1.9.2; Faul et al., 2007). Assuming two-way repeated-measures analyses of variance (ANOVA) with group (young or older adults) as a between-participant factor and film (anger, sadness, neutral, contentment, or amusement) as a within-participant factor with an α-level of 0.05, power of 0.80, and repeated-measures correlation of 0.5 (default), the results indicated that the current analysis could detect an effect size of $f = 0.15$. Written informed consent was obtained from all participants prior to the study. The study was approved by the Ethics Committee of RIKEN and conducted in accordance with the institutional ethical guidelines and Declaration of Helsinki.

Apparatus

The apparatus, stimuli, and procedure were the same as those in a previous study (Sato et al., 2020). Stimuli were presented on a 19-inch cathode ray tube monitor (HM903D-A; Iiyama, Tokyo, Japan) using a Windows computer (HP Z200 SFF; Hewlett-Packard Japan, Tokyo, Japan), and were controlled by Presentation software (Neurobehavioral Systems, Berkeley, CA, USA). Another laptop Windows computer (CF-SV8; Panasonic, Tokyo, Japan) was used for the cued-recall continuous ratings.

Stimuli

A total of five films were used, of which three were from Gross and Levenson (1995) (negative, i.e., anger and sadness, and neutral stimuli: "Cry Freedom", "The Champ", and "Abstract Shapes", respectively). The effectiveness of these films in eliciting emotions had been validated in a Japanese sample (Sato et al., 2007). The other two films were selected to elicit positive emotions (contentment [a waterside scene with birds flying; Wild Birds of Japan, Synforest, Tokyo, Japan] and amusement [a comedy dialogue between two comedians; M-1 Grand Prix The Best 2007–2009, Yoshimoto, Tokyo, Japan]). The mean ± SD duration of the presentation of the films was 164.4 ± 20.2 s (anger: 156 s, sadness: 172 s, neutral: 150 s, contentment: 148 s, and amusement: 196 s; range: 150–196 s). For practice, a scene from the film "Silence of the Lambs" (Gross & Levenson, 1995) was presented. The size of each stimulus was 640 horizontal × 480 vertical pixels, which subtended a visual angle of approximately 25.5° horizontal × 11° vertical.

Procedure

The experiments were individually conducted in an electrically shielded and dimly lit soundproof room. The room temperature was maintained at 23.5–24.5°C, which was monitored using a TR-76Ui data logger (T&D, Matsumoto, Japan). The participants were informed that the experiment involved recording sweat gland activity while viewing films, as a cover story to prevent them from discovering the aim of the facial EMG. Participants were allowed 10 min to become accustomed to the experimental room. Prior to the presentation of the target five films, a practice film was presented to the participants (the films were presented pseudo-randomly).

Each trial began with the presentation of a fixation point for 1 s, followed by the appearance of a white screen on the monitor for 10 s. Then, each film stimulus was presented to the participants, followed by the white screen again for 10 s. Participants stopped resting and looked at the fixation point when it appeared; they subsequently watched the film. After the initial viewing of each film and the appearance of a white screen for 10 s, the affect grid (Russell et al., 1989), which graphically represents the two dimensions of valence and arousal, was presented; the participants provided their overall subjective ratings of each film using a numeric key on a scale ranging from 1 (very unpleasant for the valence rating, and not aroused at all for the arousal rating) to 9 (very pleasant for the valence rating, and highly aroused for the arousal rating). During the inter-trial interval (randomly set to 24–30 s), a black screen was presented to prevent carryover effects from previous films.

After the initial viewing session, the continuous cued-recall procedure was used to obtain subjective ratings of the same films during the second and third viewing sessions; participants recalled their subjective experience that had held at the initial viewing and provided continuous subjective ratings (valence ratings were assessed in the second viewing session and arousal ratings were assessed in the third viewing session) using a slider-type affect rating dial (Ruef & Levenson, 2007). Thus, each participant viewed each film a total of three times. In the second and third viewing sessions, the participants sat in front of another laptop computer, on which the five films were presented for continuous ratings of valence and arousal, following past research (Sato et al., 2020). During this rating session, horizontal or vertical 9-point scales were simultaneously displayed with each film on the monitor screen; the participants provided continuous subjective ratings of each film by moving the mouse. Continuous ratings (i.e., the location of the mouse) were sampled at 10 Hz and their 1-s mean values were calculated. Although repeated viewings of the same film clip might alter emotional responding, which possibly affects emotional coherence, such cued-recall continuous ratings are reportedly comparable with online continuous ratings (Mauss et al, 2005; Sato et al., 2020). This methodology is also presumed to exclude potential interference effects on the natural flow of physiological responses through online monitoring of inner subjective experience (Mauss et al, 2005).

Behavioral and physiological data recording

During the initial viewing session, behavioral and physiological data were continuously recorded for each participant for each film. EMG data over the corrugator supercilii and zygomatic major muscles were recorded using sets of pre-gelled, self-adhesive, 0.7-cm Ag/AgCl electrodes with 1.5-cm inter-electrode spacing (Prokidai, Sagara, Japan). The electrodes were placed in accordance with established guidelines (Fridlund & Cacioppo, 1986; Schumann et al., 2010). A ground electrode was placed on the left ear lobe. The data were amplified, filtered online (band pass: 20–400 Hz), and sampled at 1,000 Hz using an EMG-025 amplifier (Harada Electronic Industry, Sapporo, Japan), the PowerLab 16/35 data acquisition system, and LabChart Pro v8.0 software (ADInstruments, Dunedin, New Zealand). A low-cut filter at 20 Hz was used because it effectively removes motion artifacts from body movements (De Luca et al., 2010). The video was unobtrusively recorded using a digital web camera (HD 1080 P; Logicool, Tokyo, Japan), and motion artifacts and facial positions were evaluated. EDA data were measured using pre-gelled, self-adhesive, 1.0-cm Ag/AgCl electrodes (Vitrode F; Nihonkoden, Tokyo, Japan; tape cut into 2.5-cm squares). The electrodes were placed on the palmar surfaces of the medial phalanges of the index and middle fingers of the participant's left hand, in accordance with established guidelines (Boucsein, 2011). Skin conductance was recorded by applying a constant voltage of 0.5 V using a Model 2701 BioDerm Skin Conductance Meter (UFI, Morro Bay, CA, USA). Finger temperature data were measured using an ML309 Thermistor Pod (ADInstruments). The probe was placed on the palmar surface of the distal phalanx of the fifth finger of the participant's left hand. The EDA and finger temperature data were measured using the same data acquisition system and recording software as for the EMG, but no online filter was used.

Data analysis

Preprocessing. Data preprocessing was carried out using the same approach as a previous study (Sato et al., 2020). EMG data analysis was performed using Psychophysiological Analysis Software 3.3 (Computational Neuroscience Laboratory of the Salk Institute) and programs created in-house using MATLAB 2021 (MathWorks, Natick, MA, USA). EMG data were sampled during the pre-stimulus baseline (white screen) and stimulus presentation periods for each trial. A blinded author checked the video data and confirmed that no participants generated large motion artifacts. For each trial, the data were rectified, baseline-corrected for the mean value during the pre-stimulus period, and averaged for 1-second intervals. The data for all film conditions were aligned and standardized within each individual (i.e., z-scores were calculated after every second based on the mean and SD data for each participant). The same analyses were performed for the EDA and finger temperature data, except that the data were not rectified.

Statistical analysis. Statistical analysis was performed using MATLAB 2021 (MathWorks) and JASP 0.14.1 (JASP Team, 2020). Cross-correlation functions (r-values) were calculated between the continuous valence ratings and facial EMG for the corrugator supercilii and zygomatic major muscles, and between the continuous arousal ratings and physiological data (EDA and fingertip temperature). For each film for each individual, we estimated both the relative and absolute values of the maximum cross-correlations (i.e., maximum values when set to absolute values) within lags of from -10 s to 10 s. Estimated coherence may constitute a negative or positive correlation by calculations from the relative scores. Calculated absolute values are within the range of 0–1. In both instances, higher scores indicate stronger coherence.

The r-values were normalized using Fisher transformation and then analyzed by two-way ANOVA, with age group (older or young adults) as a between-participant factor and film (anger, sadness, neutral, contentment, or amusement) as a within-participant factor. Follow-up simple effect analyses were performed when a significant two-way interaction was found. Post hoc comparisons were conducted to identify significant main effects of films using Holm's method to report the general (non-age-specific) film effects. Because there were some missing data in the older group due to lack of variation in subjective ratings (6.0% and 5.3% of the valence and arousal ratings, respectively), machine learning-based missing value imputation (Thomas & Rajabi, 2021) was conducted for those data using the method established by Nejatian (2022). Results were considered statistically significant at $p < 0.05$.

As a preliminary analysis, we computed composite scores for the behavioral and physiological measures, then evaluated their coherence with subjective ratings. We also conducted detailed analyses of the data, which are also reported in the Supplementary Material.

Transparency and openness

The authors declare they have no competing financial or other interests to report. We reported the sample size calculation, along with all measures, conditions, manipulations, and data exclusions in this study. Supplementary data are available in the supplementary dataset file. Datasets are available from the corresponding author on request. This study was not pre-registered.

Results

Figures 1 and 2 show the group mean time courses of continuous valence and arousal ratings, as well as the behavioral and physiological activities.

Figure 1. Figure 2.

Cross-correlation functions (r-values) between the valence ratings and behavioral responses, and between the arousal ratings and physiological activity for each film, were calculated for each participant using relative and absolute values, respectively (Figures 3 and 4; see also Supplementary Figure 2 and Supplementary Tables 1 and 2). After Fisher z transformation, r-values were analyzed using two-way ANOVA, with group and film as the factors.

Figure 3. Figure 4.

We first performed ANOVA on the r-values calculated based on relative scores. For the valence–corrugator EMG association, there were significant main effects of group ($F(1, 54) = 5.58$, $p = 0.022$, $\eta 2p = 0.09$, post hoc power [PHP] = 0.56) and film ($F(4, 216) = 10.21$, $p < 0.001$, $\eta 2p = 0.16$, PHP = 1.00), as well as a significant interaction between group and film ($F(4, 216) = 3.34$, $p = 0.011$, $\eta 2p = 0.06$, PHP = 0.90). Post hoc comparisons for the main effect of film revealed that, compared with all other conditions, anger induced significantly higher coherence in the negative direction ($t(216) > 4.94$, $p < 0.001$). Follow-up simple effect analyses for the interaction revealed that the simple effects of group were significant only for anger ($F(1, 270) = 9.14$, $p = 0.004$); a stronger negative correlation observed in young adults compared with older adults. A negative correlation indicates decreased valence ratings (increasing unpleasantness) with increased corrugator EMG activity.

For the valence–zygomatic EMG association, there was only a significant main effect of film ($F(4, 216) = 5.01$, < 0.001, $\eta 2p = 0.09$, PHP = 0.97). Post hoc comparisons revealed that compared with sadness and contentment, amusement induced significantly higher coherence in the positive direction ($t(216) > 3.34$, $p < 0.01$). Neither a significant main effect of group nor an interaction was found ($F(1, 54) = 0.12$, $p = 0.726$, $\eta 2p = 0.00$, PHP = 0.07; $F(4, 216) = 0.41$, $p = 0.801$, $\eta 2p = 0.01$, PHP = 0.13).

For the arousal–EDA association, the main effects of group ($F(1, 54) = 5.63$, $p = 0.021$, $\eta 2p = 0.09$, PHP = 0.76) and film ($F(4, 216) = 3.33$, $p = 0.011$, $\eta 2p = 0.06$, PHP = 0.83), and the interaction between those two factors ($F(4, 216) = 3.32$, $p = 0.011$, $\eta 2p = 0.06$, PHP = 0.92), were significant. Post hoc comparisons for the main effect of film revealed that the differences between the sadness (negative) and contentment (positive) were significant ($t(216) = 2.96$, $p = 0.035$). Follow-up simple effect analyses revealed that the simple effect of group was significant only for anger ($F(1, 270) = 12.83$, $p < 0.001$), indicating a difference in the correlation direction between the groups; a negative correlation was identified among young adults (higher arousal ratings with decreased EDA), whereas a positive correlation was identified among older adults (higher arousal ratings with increased EDA).

For the arousal–fingertip temperature association, there was a significant main effect of film ($F(4, 216) = 5.39$, $p < 0.001$, $\eta 2p = 0.09$, PHP = 0.97) and a significant interaction between group and film ($F(4, 216) = 2.54$, $p = 0.041$, $\eta 2p = 0.05$, PHP = 0.75). There was no significant main effect of group ($F(1, 54) = 0.78$, $p = 0.382$, $\eta 2p = 0.01$, PHP = 0.19). Post hoc comparisons for the main effect of film revealed that, compared with all other conditions, sadness induced significantly higher coherence in the positive direction ($t(216) > 3.00$, $p < 0.022$). Follow-up simple effect analyses revealed that the simple effect of group was significant only for contentment ($F(1, 270) = 10.52$, $p = 0.002$), and opposite-direction correlations were present between the age groups; a negative correlation (higher arousal ratings with decreased temperature) was identified among young adults, whereas a positive correlation (higher arousal ratings with increased temperature) was identified among older adults.

Next, the same ANOVA was performed on r-values estimated from the absolute values. Analysis of the valence–corrugator EMG association revealed significant main effects of group ($F(1, 54) = 4.29$, $p = 0.043$, $\eta 2p = 0.07$, PHP = 0.98) and film ($F(4, 216) = 8.27$, $p < 0.001$, $\eta 2p = 0.13$, PHP = 1.00), as well as a significant interaction between group and film ($F(4, 216) = 2.48$, $p = 0.045$, $\eta 2p = 0.04$, PHP = 0.95). Post hoc comparisons for the main effect of film revealed that anger induced significantly higher coherence, compared with all other conditions ($t(216) > 3.91$, $p < 0.001$). Follow-up simple effect analyses revealed that the simple effects of group were significant only for anger ($F(1, 270) = 5.97$, $p = 0.018$); stronger coherence was observed in young adults than in older adults.

A significant main effect of film was detected for the valence–zygomatic EMG association ($F(4, 216) = 2.97$, $p = 0.021$, $\eta 2p = 0.05$, PHP = 0.87). Neither a significant main effect of group nor an interaction between group and film was found ($F(1, 54) = 0.60$, $p = 0.442$, $\eta 2p = 0.01$, PHP = 0.08; $F(4, 216) = 1.27$, $p = 0.285$, $\eta 2p = 0.02$, PHP = 0.47). Post hoc tests did not show any significant differences across films ($t(216) < 2.77$, $p > 0.062$).

Similarly, the analysis of the arousal–EDA association revealed only a significant main effect of film ($F(4, 216) = 6.59$, $p < 0.001$, $\eta 2p = 0.11$, PHP = 1.00). No significant main effect of group was observed, and there was no interaction between group and film ($F(1, 54) = 0.06$, $p = 0.816$, $\eta 2p = 0.00$, PHP = 0.09; $F(4, 216) = 1.63$, $p = 0.167$, $\eta 2p = 0.03$, PHP = 0.61). Post hoc comparisons revealed that anger coherence was significantly higher than contentment coherence or amusement coherence, sadness coherence was significantly higher than amusement coherence, and amusement coherence was significantly lower than neutral coherence ($t(216) > 2.75$, $p < 0.045$).

The same pattern of results was observed for the arousal–fingertip temperature association (i.e., only a significant main effect of film was identified ($F(4, 216) = 5.70$, < 0.001, $\eta 2p = 0.10$, PHP = 0.99). No significant main effect of group or interaction between the factors was found ($F(1, 54) = 0.46$, $p = 0.501$, $\eta 2p = 0.01$, PHP = 0.17; $F(4, 216) = 1.43$, $p = 0.224$, $\eta 2p = 0.03$, PHP = 0.53). Post hoc comparisons for the main effect of film revealed that anger coherence was significantly higher than contentment or amusement coherence, whereas sadness coherence was significantly higher than amusement coherence ($t(216) > 3.01$, $p < 0.024$).

Discussion

We compared emotional coherence between older adults and young adults in response to a range of emotion-eliciting films, using intra-individual correlation analyses. By estimating relative and absolute value scores, we examined emotional coherence between valence ratings and facial activities measured by EMG, emotional coherence between arousal ratings and EDA, and emotional coherence between arousal ratings and fingertip temperature.

The primary finding of the present study was that emotional coherence between valence ratings and corrugator EMG in older adults was smaller than in young adults for the anger-eliciting film; the association between increased brow activity (frowning, which reflects unpleasant feelings) and increased unpleasant emotions was stronger in young adults than in older adults, indicating that weakened emotional coherence between subjective experience and brow activity in older adults for anger emotion. The current study adds a novel finding to the literature by demonstrating weakened experience – behavior coherence for anger in older populations.

Weakened emotional coherence between valence ratings and corrugator EMG for anger emotion is consistent with the proposed weakened mind–body connections in late adulthood (Mendes, 2010). Weaker behavioral reactivity might contribute to weakened coherence between valence ratings and corrugator EMG activity because our older participants frowned less than young adults (see Supplemental Materials).

Our results are also consistent with the framework of emotional aging characterized by the age-related positivity effect (Carstensen, 2006; Carstensen & DeLiema, 2018). Within this theoretical framework, weakened anger coherence might be related to older adults' tendency toward diminished processing of unpleasant compared to pleasant stimuli. For instance, Isaacowitz et al. (2009) reported that older adults showed diminished processing of faces displaying anger via gaze avoidance of such unpleasant faces, suggesting reduced processing of unpleasant information (to generate positive feelings). Given the pervasiveness of the age-related positivity effect in emotional stimulus processing such as memory and attention allocation (Charles et al., 2003; Isaacowitz et al., 2009; Mather & Carstensen, 2003), diminished processing of unpleasant (i.e., anger) stimuli could have occurred in the emotional reactivity/coherence domain; older adult participants might have had diminished reactions to anger-eliciting films due to the decoupling of subjective unpleasant feelings from brow activities, leading to decreased emotional coherence compared with young adults. The present results indicated that such decoupling occurred; older adults exhibited reduced facial reactivity to the anger-eliciting film while demonstrating subjective reactivity comparable with the reactivity in young adults (see Supplemental Materials), which presumably led to weaker coherence for the pairs.

Another plausible explanation of weakened anger emotional coherence between valence ratings and corrugator EMG is that older adults might have regulated anger emotions. Reduced corrugator EMG activity to the anger-eliciting film in older adults suggests that when anger emotion was evoked, older adults were less likely than young adults to display brow activity. Attempt to downregulate behavioral (mainly facial) displays of emotion has been known as a strategy of emotion suppression, and it disrupts the natural unfolding of emotion, leading to a reduction of coherence (Dan-Glauser & Gross, 2013). Thus, our older adult participants might have employed a suppression strategy for emotion regulation by reducing frowning when they were just exposed to the film evoking anger emotion, which consequently might have led to weaker coherence between subjective experience and facial behavior. This explanation is plausible given that increased proficiency regarding emotion regulation is typically observed in late adulthood (Charles & Carstensen, 2008; Scheibe & Blandard-Fields, 2009; Scheibe et al., 2013) and considering the potential link between reduced facial reactivity and emotion regulation in older adults (Pedder et al., 2016). In the context of such a strategy, it is important to discuss why we did not observe weakened sadness coherence; notably, sadness (similar to anger) belongs to the category of negative emotion. It is speculated that because anger generally evokes greater arousal and displeasure, downregulation of anger might be more crucial, compared with regulation of sadness. Thus, older adults presumably used emotion regulation strategies solely to manage anger, which led to diminished anger coherence.

A secondary finding in the present study was the presence of age differences in emotional coherence between the arousal ratings and each physiological measurement (EDA for anger and fingertip temperature for contentment), estimated solely by relative scores. In both instances, older adults exhibited correlations opposite to the correlations exhibited by young adults, which may have led to significant differences in emotional coherence between age groups. The results also revealed age-related differences in emotional coherence for age-relevant emotions other than sadness.

These results are broadly consistent with the account of the age-related positivity effect, considering that both types of emotions have motivational relevance in late adulthood (Charles et al., 2003; Isaacowitz et al., 2009; Mather & Carstensen, 2003; Scheibe et al., 2013). Although age differences in emotional coherence were only found for low-arousal (contentment) but not for high-arousal (amusement) positive emotions, previous studies have documented that older adults exhibit greater preference for and reactivity to low-arousal positive stimuli (Chu et al., 2020; Ferández‐Aguilar et al., 2020). This suggests that low-arousal positive stimuli are more age-relevant for people in late adulthood. In this sense, it is possible to interpret that age differences in emotional coherence for anger and contentment might have emerged, reflecting the age-related positivity effect in older adults.

Our older adult participants demonstrated comparable sadness emotional coherence with that observed in young adults for the valence ratings–behavior (corrugator EMG activity) pair and the arousal ratings–physiological measures (EDA and fingertip temperature) pairs. These findings are not consistent with previous reports of stronger sadness emotional coherence between arousal ratings and physiological signals (heart-period) (Lohani et al., 2018), and that between behavioral (corrugator EMG activity) and physiological responses (heart-rate) (Wu et al., 2021). Multiple factors might have contributed to discrepancies between our study and previous studies.

The maintained sadness emotional coherence observed in our study seems not to be consistent with the multidirectional view of age difference in sadness emotional reactivity, which assumes that older adults demonstrate stronger sadness emotional coherence (Kunzmann & Grühn, 2005; Kunzmann et al., 2017; Seider et al, 2011). It is conceivable that discrepancies between our findings and the results of the previous studies, which support for the multidirectional view of age difference in sadness emotional reactivity, might have derived from several methodological differences employed, such as how to measure subjective ratings, or the types of physiological measures (Lohani et al., 2018; Wu et al., 2021). One potentially important factor is that we did not utilize age-relevant sadness-eliciting stimuli, which can evoke heightened emotional reactivity (Kunzmann & Grühn, 2005; Seider et al, 2011 Ferández ‐ Aguilar et al., 2020), possibly due to elevated arousal (Charles, 2010; Kunzmann & Grühn, 2005). Given that older adults are reactive to age-relevant irreversible losses (e.g., death of a spouse), if we had used films depicting age-relevant sadness, our older adult participants might have shown heightened arousal and emotional reactivity. In turn, this may have resulted in enhanced sadness emotional coherence between arousal ratings and the physiological signals. Further, we did not assess the subjective experience of discrete emotions, such as measuring the subjective feeling of the intensity of sadness. This omission might have led to the absence of stronger sadness emotional coherence in our older adult participants. Further analyses are needed to explain the discrepancies between our study and previous coherence studies of older adults (Lohani et al., 2018; Wu et al., 2021).

We identified links between valence ratings and behavioral measures, as well as links between arousal ratings and physiological measures for most of the pairings, similar to the results pattern of our young adult participants and the young adults examined in previous coherence studies (Bradley & Lang, 2000; Mauss et al., 2005; Rattel et al., 2020; Sato et al., 2020; Van Doren et al., 2021). This suggests the importance of using both valance and arousal ratings as indicators of subjective experience to illuminate the aspects of the mind–body coherence.

Another notable finding in terms of methodological points was that no age differences in emotional coherence were identified by the absolute values of pairs, with the exception of the valence ratings–corrugator EMG pair. For instance, older adults showed a positive correlation only for the relative scores, indicating greater arousal with increased finger-tip temperature. This pattern of coordinated activities contrasts with the pattern observed by our young adult participants and young adults examined in previous studies, where a negative correlation was suggested between subjective arousal and peripheral skin temperature (because reduced, rather than increased, peripheral skin temperature reflects heightened physiological arousal) (Boucsein, 2011; Sato et al., 2020). Thus, analyzing emotional coherence using relative scores allow us to understand how the mind–body coherence in emotion in older adults differs from that of young adults.

Regarding the cultural modulations, we pointed to the possibility that Japanese participants would not outwardly display anger expressions to the extent that they consciously feel angry, leading to weakened emotional coherence. This presumably occurred only in our older adult participants since they frowned less than the young adults, whereas comparable subjective reactivity was found between the age groups. Probably, the extent of cultural values differs across generations, such that older Japanese generations place greater emphasis on traditional Japanese culture (putting a value on interdependence), which might have been reflected in suppressed facial expressions (reduced frowning) in our Japanese older adult participants.

Finally, it deserves mentioning regarding differences in coherence across emotional films, regardless of age. In our study, negative emotions showed slightly higher coherence than positive emotions; this difference was apparent in the results calculated using absolute values, particularly for anger emotions. These results imply that strong negative emotions like anger evoke higher coherence, which aligns with the functionalist perspective in which coherence is essential for high-intensity emotions that arise when physical and psychological well-being are at risk (Levenson, 1994).

While empirical evidence suggests that stronger coherence between mind and body underpins emotional well-being in young adults (Brown et al., 2020; Mauss et al., 2011; Sommerfeldt et al., 2019), lower coherence between subjective experience and behavior by concealing facial expressions may not always lead to reduced well-being, given that the adaptive value of emotional coherence differs situationally (e.g., beneficial effects of concealing outward facial expressions for successful adaptation)(Bonanno et al., 2004; Van Doren et al., 2021). Furthermore, the adaptive value of coherence in negative emotions like anger probably differs from the case of positive emotions; stronger positive emotion coherence is considered adaptive because the tight coupling between experience and behavior ensures accurate communication (Mauss et al., 2011). In contrast, weaker coherence in negative emotions like anger could be adaptive to the extent that it involves emotion regulations that are situationally appropriate. Within this framework, weaker emotional coherence in our older adult participants due to the minimization of unpleasant facial expressions may not indicate a decreased level of well-being.

Practical implications of our study relate to the care of older adults, such as individuals with dementia, who are likely to show altered subjective experience, characterized by increased subjective reports of non-target emotions (Chen et al., 2017). To compensate for inaccurate self-reported subjective experiences, inferring patients' feelings such as pain, by observing their facial expressions might be of clinical importance (Sheu et al., 2011). Our reuslts imply that older adults are less likely to frown, even when enduring distressing emotions. In these cases, using an index of emotional arousal, such as facial redness, to determine the intensity of unpleasant feelings might be effective for enhancing interpersonal relationships between patients and their care-givers, and thereby improve their quality of life.

Several limitations of this study should be acknowledged. First, we did not manipulate cultural factors, nor assess the social-economic statuses of our participants. Future studies should manipulate social-cultural factors to investigate whether the relationship between emotional coherence and age varies as a function of culture. Second, our study had several methodological limitations; our study's sample size was small. We did not examine potential influences of parasympathetic activity, or the interaction between sympathetic and parasympathetic activity, on emotional coherence. Our films related to different emotions were not equal in length, and the neutral film clip used occasionally elicited unpleasant subjective experiences and changes in physiological reactivity, generating a unique form of coherence. Further, this was a cross-sectional study so we were unable to distinguish between the effects of generation and age on performance. These issues should be addressed in future research. Third, we did not assess emotional coherence in middle-aged individuals. It is therefore uncertain whether the coherence between valence ratings and corrugator EMG for anger gradually decreases with increasing age or abruptly decreases in the later stages of life. An age-specific association between self-reported anger and well-being has been demonstrated among middle-aged adults (Haase et al., 2012), implying a difference in anger emotional coherence for middle-aged adults compared with older adults. Future studies should examine emotional coherence in adults of all ages to understand the trajectories of changes in emotional coherence.

In conclusion, the present study revealed that, compared with young adults, older adults demonstrate a different emotional coherence pattern between arousal ratings and physiological responses for anger and contentment; these findings constitute new evidence of age differences in coherence for motivationally age-relevant emotions other than sadness in older populations. Although older adults demonstrated weaker emotional coherence for anger between valence ratings and corrugator EMG, our findings may reflect older adults' ability to mitigate the effects of exposure to unpleasant stimuli as a means of emotion regulation, which may be an adaptive response promoting well-being.

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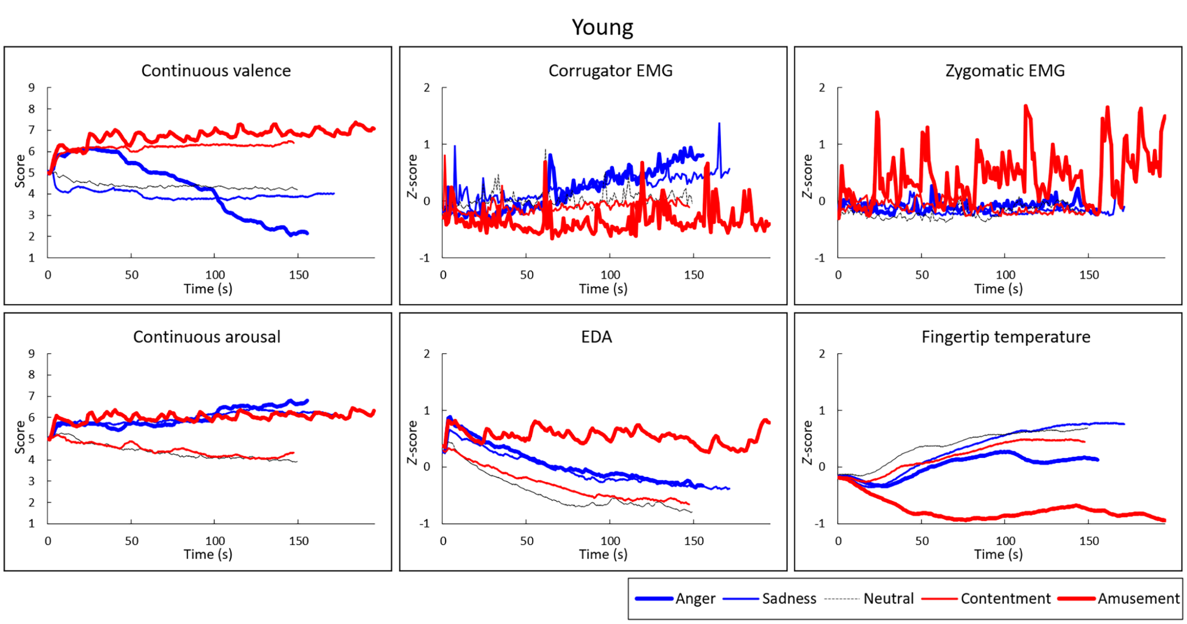

Figure 1. Group mean continuous subjective ratings of valence and arousal, electromyography (EMG) recorded from the corrugator supercilii and zygomatic major muscles, electrodermal activity

(EDA), and fingertip temperature over time in young adults. Physiological data were standardized within each individual (the mean ± standard error data of the overall valence and arousal ratings, along with the group mean of behavioral and physiological activities during each film, are shown in the Supplementary Figure 1).

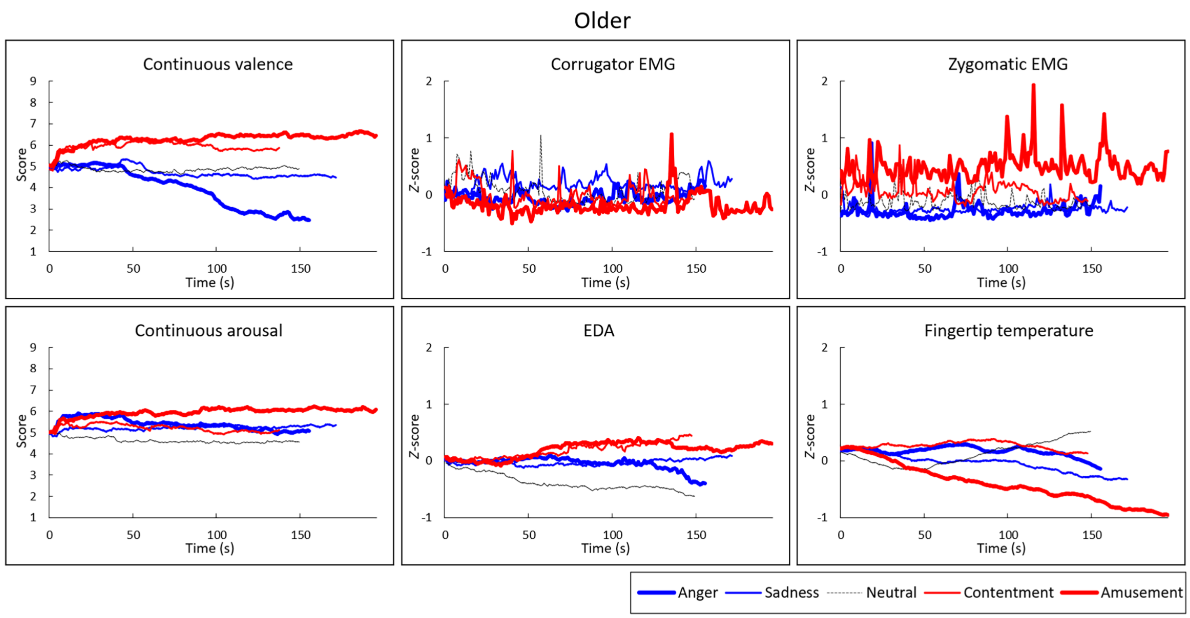

Figure 2. Group mean continuous subjective ratings of valence and arousal, electromyography (EMG) recorded from the corrugator supercilii and zygomatic major muscles, electrodermal activity (EDA), and fingertip temperature over time in older adults. Physiological data were standardized within each individual.

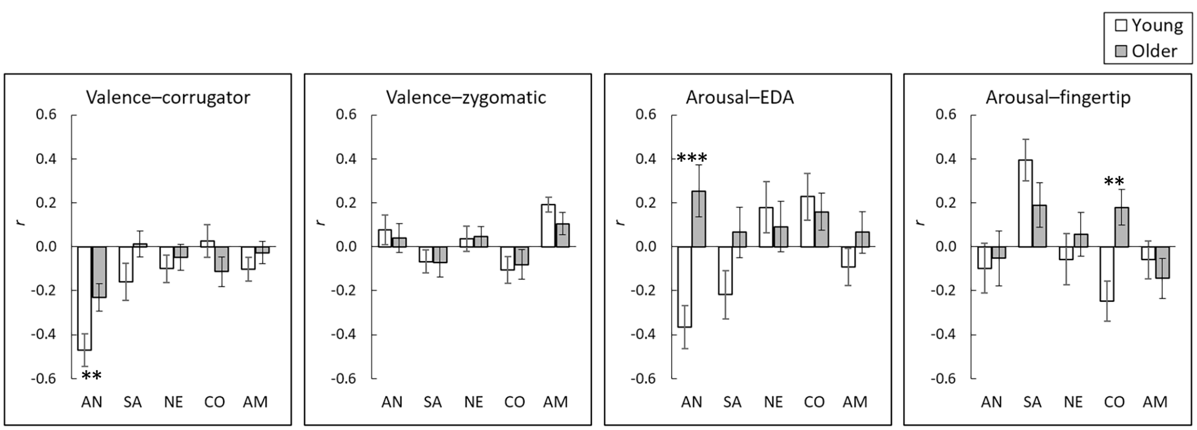

Figure 3. Mean (± standard error) intra-individual cross-correlation coefficients estimated based on relative scores for expected subjective–behavioral and subjective–physiological coherence over time for each film in young (white) and older (gray) adults. Associations were expected between valence ratings and electromyography activity of the corrugator supercilii and zygomatic major muscles, and between arousal ratings and electrodermal activity (EDA) and fingertip temperature. AN = anger; SA = sadness; NE = neutral; CO = contentment; AM = amusement; EDA = electrodermal activity. ***, $p < 0.001$; **, $p < 0.01$.

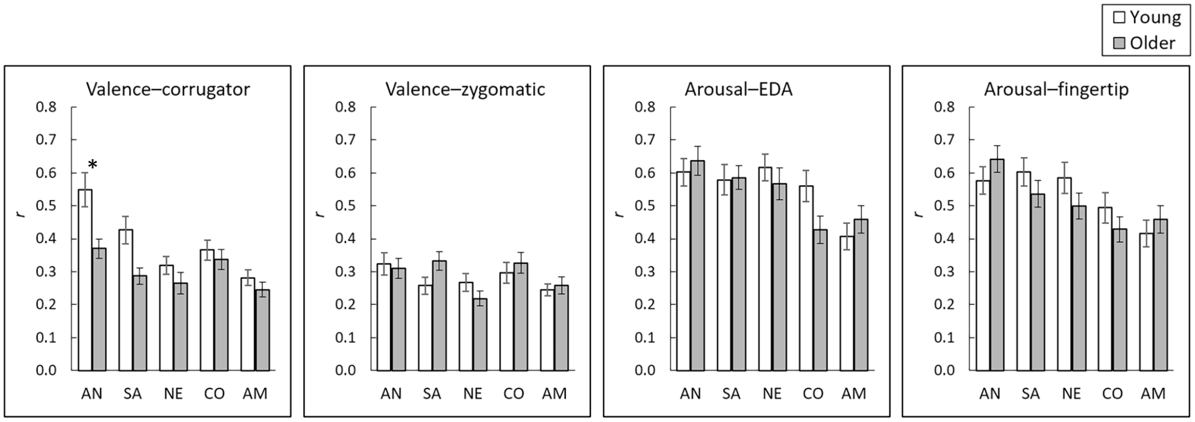

Figure 4. Mean (± standard error) intra-individual cross-correlation coefficients estimated based on absolute value scores for expected subjective–behavioral and subjective–physiological coherence over time for each film in young (white) and older (gray) adults. Associations were expected between valence ratings and electromyography activity of the corrugator supercilii and zygomatic major muscles, and between arousal ratings and electrodermal activity (EDA) and fingertip temperature. AN = anger; SA = sadness; NE = neutral; CO = contentment; AM = amusement; EDA = electrodermal activity. *, $p < 0.05$.