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Abstract

Studies on aging and emotion suggest an increase in reported positive affect, a processing bias of positive over negative information, as well as increasingly adaptive regulation in response to negative events with advancing age. These findings imply that older individuals evaluate information differently, resulting in lowered reactivity to, and/or faster recovery from, negative information, while maintaining more positive responding to positive information. We examined this hypothesis in an ongoing study on Midlife in the US (MIDUS II) where emotional reactivity and recovery were assessed in a large number of respondents (N=159) from a wide age range (36-84 years). We recorded eyeblink startle magnitudes and corrugator activity during and after the presentation of positive, neutral and negative pictures. The most robust age effect was found in response to neutral stimuli, where increasing age is associated with a decreased corrugator and eyeblink startle response to neutral stimuli. These data suggest that an age-related positivity effect does not essentially alter the response to emotion-laden information, but is reflected in a more positive interpretation of affectively ambiguous information. Furthermore, older women showed reduced corrugator recovery from negative pictures relative to the younger women and to men, suggesting that an age-related prioritization of well-being is not necessarily reflected in adaptive regulation of negative affect.

Keywords: Aging, Emotion Reactivity, Emotional Recovery, Positivity Effect, Psychophysiology

Introduction

As we age, our cognitive and physical performance generally decline, yet it seems that effects of advancing age on emotional experience and expression is mixed. Socioemotional Selectivity Theory (e.g. Carstensen & Lockenhoff, 2003) suggests that increasing age is paired with a shift in motivation to prioritize current well-being and life satisfaction over anticipating the future. In line with this notion, behavioral studies have shown that older adults, relative to their younger counterparts, are biased to memorize affectively positive stimuli (Mather & Carstensen, 2005) and display an attentional bias towards positive information (Isaacowitz et al., 2006). The prioritization of well-being likely extends to the biasing of appraising emotion-relevant situations in a less negative light. Indeed, survey studies indicate increased general positive affect with increasing age (Mroczek & Kolarz, 1998), decreased reactivity to interpersonal stressors (Birditt et al., 2005) paired with more passive regulatory strategies in response to emotional situations (Blanchard-Fields et al., 2004; Coats & Blanchard-Fields, 2008), and a greater investment in and an improved ability to regulate one's response in socioemotional situations (Carstensen & Lockenhoff, 2003). These results suggest that aging is associated with more adaptive responding to potentially negative events, possibly engaging more with positive events.

However, findings concerning aging and emotional reactivity to laboratory-based mood inductions are mixed. Laboratory studies on emotion often present pictures selected from the International Affective Picture System (IAPS, Lang et al., 2005), a picture set that is widely used in neuroscientific research on emotion. Using a large number of pictures from this set to older (63-77 years) and younger (18-31 years) participants,

Grühn & Scheibe (2008) demonstrated that older participants rated negative pictures as more negative but positive and neutral pictures as more positive than the younger participants. The older group also rated negative and neutral pictures as more arousing and positive pictures as less arousing than their younger counterparts.

The more intense reporting of valence and arousal experiences by older-aged participants is not necessarily reflected in other response systems. Studies in which physiological indicators of emotional reactivity were measured suggest lower autonomic nervous system (ANS) activity for older compared to younger participants in response to the emotion inductions, despite a lack of age differences in self-reported responses to relived emotions (Levenson et al., 1991) or emotional film clips (Tsai et al., 2000), or even in the case of higher arousal ratings of pictures (Gavazzeni et al., 2008). Smith and colleagues (2005) measured various indicators of peripheral and central nervous system changes in response to IAPS pictures. Apart from the older relative to the younger aged group displaying stronger response magnitudes to negative pictures in one of the measurements (that of eyeblink startle), no other effects of age on physiological responding to emotional pictures were found. This relative lack of age-related differences in physiological responding contradicted the more extreme valence and higher overall arousal ratings by the older group. Furthermore, Kunzmann & Grühn (2005) demonstrate that while older participants (60-70 years) relative to younger participants (20-30 years) reported stronger feelings of sadness in response to film clips selected to elicit sadness particularly in the older-aged group, there were no substantial age-related differences in physiological responding to these clips. In summary, while most studies have shown

relatively consistent age differences in subjective reporting, these differences are not necessarily reflected in other components of emotional responding.

As alluded to above, increasing age has been associated with improved emotion regulation capacity. In a cross-cultural study with a large age range, Gross and colleagues (1997) found increased self-reported emotional control with age for all sampled cultures. In addition, older adults endorse passive emotion-focused or inward-focused coping strategies for handling stressful or anger-eliciting encounters more than do younger adults (Blanchard-Fields et al., 2004; Folkman et al., 1987; Phillips et al., 2008). Assessing emotional reactivity and regulation in a laboratory setting, Kliegel and colleagues (2007) found that older individuals reacted more strongly to negative film clips but also showed stronger "mood repair" following the films relative to younger participants. However, when explicitly instructed to suppress expressions to film clips, Kunzmann and colleagues (2005) did not find age differences in the ability to suppress expression nor in the physiological or subjective concomitants of emotion. Importantly, recent findings by Scheibe and Blanchard-Fields (2009) suggest that the instructed down-regulation of disgust takes less effort in older people, given the finding that the impact of downregulation on the performance of a subsequent working memory task was reduced in the older (60-75 years) relative to the younger (20-30 years) group. Thus, emotion regulation may require less effort, likely reflected in the employment – implicit or explicit - of more adaptive coping or regulatory strategies. If adaptive regulatory, or coping, strategies are invoked more readily with increasing age, older-aged individuals should show a stronger recovery from emotional events with advancing age, as suggested

by Kliegel et al.'s findings of better mood repair in the older, relative to the younger, participants.

The aim of the present study is to assess age-related differences in reactivity to and recovery from emotion induced by pictures selected from the IAPS (Lang et al., 2005). The measurement of changes in emotional response systems in an objective fashion, using measures of autonomic nervous system (ANS) and expressive functioning in addition to self-report is imperative if we are to gain a fuller understanding of changes in emotion reactivity and regulation across the lifespan. It has been well established that the eyeblink reflex (EBR) magnitude to an acoustic startle probe shows a linear pattern with the valence of foreground stimuli, i.e. the magnitude is attenuated when the stimulus is positive, and enhanced when it is negative, relative to a neutral stimulus (Lang et al., 1990). Similarly, corrugator activity (COR) is not only an index of negative affect (Cacioppo et al., 1986) but has been shown to be reciprocally related to both positive and negative affect (Larsen et al., 2003), such that COR increases in response to negative and decreases in response to positive compared to neutral stimuli. Work from our laboratory has demonstrated that EBR and COR are useful indicators not only of reactivity to emotion-relevant stimuli but also to assess individual differences in the timeline of recovery (or return to baseline) after stimulus offset by measuring both the EBR to an acoustic probe delivered after stimulus offset (Jackson et al., 2003) and aggregating COR after stimulus offset (Jackson, 2004). Indeed, Jackson and colleagues (2003) have shown that a positive emotional disposition – assessed with relative left frontal activation at rest – is associated with a faster recovery from negative information, but no effect on emotional reactivity. In an older population, however, van Reekum and colleagues (2007)

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provided evidence suggesting that higher reported psychological well-being biased the appraisal of negative information as less salient. We hypothesize that a motivation to prioritize (socio)emotional well-being with advancing age affects emotional responding by evaluating the situation differently, by focusing on a more positive outcome. Indeed, such positive (re)appraisal has been shown to be paired with a dampened emotion response profile (Foti & Hajcak, 2008; Lazarus & Alfert, 1964; Speisman et al., 1964) and likely underlies the observed faster recovery from negative events (Jackson et al., 2003).

Following up on our prior work, we presented positive, neutral and negative IAPS pictures to participants with a large age range (36-84 years) from the "Midlife in the US" sample (MIDUS II, see http://midus.wisc.edu/) whilst recording corrugator activity and eyeblink startle reflex magnitude to acoustic probes presented during the stimulus and after stimulus offset. The positive and negative stimuli were carefully matched on arousal, and across valences, pictures were matched for social content, luminosity, and picture complexity. Based on the notion that older-aged individuals are motivated to prioritize well-being, positively biasing their (re)appraisals, we predicted lower reactivity to negative information and/or a faster recovery from negative information with increasing age, and a stronger maintenance of responses to positive stimuli.

Method

Participants

A total of 275 participants (aged 36-84 years, average age = 56 years, SD = 11.1, 157 or 57.1% females) of the national Midlife in the US (MIDUS II, see http://midus.wisc.edu/) study who lived in the Midwest region of the United States

agreed to participate in our experiment. For the purpose of this report, we included the data of all participants for whom data records on all 3 measures were complete[1]. This inclusion criterion resulted in a final N = 159, of whom 90 or 56.6% were female, between 36-83 years with an average age of 54 years (SD = 10.43).

Stimuli

We presented a total of 90 digital color pictures (800 x 600) selected from the International Affective Picture System (IAPS; Lang et al., 2005) in a randomized sequence. We identified 30 negative (*M* = 2.89, *SD* = 0.61), 30 neutral (*M* = 5.14, *SD* = 0.52) and 30 positive (*M* = 7.24, *SD* = 0.44) pictures according to the IAPS norms, of which the positive and negative pictures were matched on arousal (negative pictures *M* = 5.35, *SD* = 0.54; neutral *M* = 3.22, *SD* = 0.73; positive *M* = 5.23, *SD* = 0.73), and all valences were matched on picture luminosity, complexity and social content of the scene depicted[2].

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[1] Of these 275 participants, eyeblink startle was recorded from 265 participants and EMG over the brow region ("corrugator activity") was recorded from 231 participants. For a variety of technical, responsivity and other data quality issues, 15.1% of the participants did not provide 10 or more quantifiable eyeblink startle responses. Due to a delayed integration of corrugator activity recordings in the study, 18.2% of the original 275 participants did not have corrugator data. Due to time constraints or technical issues, 19.3% of the participants did not complete the picture ratings data.

[2] Of the original N=275 participant group, the first N=56 participants saw one of two picture sets, counterbalanced across participants. The negative and positive pictures were matched within and across sets for valence and arousal, and the ratio of social content was held constant across valences. The N > 56 participants saw a picture set selected from the two picture sets, in which half of the pictures within each valence contained social content (one or more persons were identifiable), and the other half did not. This final set matched the previous two on valence and arousal ratings. At the time of the design of the study, ratings of the IAPS pictures by older-aged individuals were not available. As summarized in the Introduction, Grühn & Scheibe (2008) have published ratings performed by different age group on a subset of the IAPS pictures. These ratings can be found at: http://www4.ncsu.edu/~dgruehn/page7/page8/page8.html .

Procedure

Upon arrival in the laboratory, participants were informed about the general aim and procedures of the study. After obtaining informed consent, the participants completed questionnaires (data not included here) and performed a hearing test. Participants were then prepared for the collection of electromyogram (EMG) data - eyeblink startle reflex and corrugator – by cleaning the muscle and forehead sites over which the sensors would be placed. The participants were seated in a comfortable armchair in front of a computer monitor; the distance between the eyes and computer screen was approximately 60 cm.

Instructions were provided on a 17-inch LCD flat screen monitor, and the experimenter read the instructions aloud. The participants then performed a brief practice session after which the actual experiment began. The participants watched the positive, neutral, and negative pictures selected from the IAPS, and acoustic startle probes were presented. Acoustic startle probes consisted of 50 ms, 105 dB, white noise bursts with very rapid onset time which were presented through earbuds. To ensure alertness during the task, each picture either had a yellow or purple border around it. Participants were instructed to respond as quickly as possible to the color of the border by pressing one of two keyboard buttons marked with the color with either their index or middle finger of their dominant hand. They were also instructed to keep their gaze on the screen and avoid closing their eyes while the picture was displayed, and to avoid body and head movements during the task.

Pictures were presented on the screen for 4 seconds and were preceded by a 1 second fixation screen. During the first 500 ms of the picture, the yellow or purple border

was displayed[3]. Acoustic startle probes were inserted at three time points (randomized across trials to maintain an average inter-probe interval of approximately 16 sec). One time point occurred during picture presentation (2900 ms following picture onset), a second probe occurred 400 ms after picture offset (4400 ms following picture onset), and a third probe occurred 1.9 sec following picture offset (5900 ms following picture onset). A total of 9 probes at each of the three time points were presented for each picture valence category, resulting in 3 non-probed trials for each picture valence. The inter-trial interval (ITI) varied randomly between 14-18 s.

After the task, EMG sensors were removed and the participants rated the pictures seen during the task using a computerized version of the evaluative space grid, above which the picture was displayed. For a full description of the grid, the reader is referred to Larsen and colleagues (Larsen et al., 2009). Briefly, the evaluative space grid allows the simultaneous measurement of both positive and negative feelings to pictures by positioning in a 2-dimensional 5x5 grid space. The grid has been validated against unipolar and dichotomous-then-unipolar ratings (Larsen et al., 2009). The first 56 participants provided the valence and then their arousal rating on a 9-point Likert scale using the wording by Lang et al. (2005) with 1 = very unpleasant and 9 = very pleasant for valence, and 1 = very calm and 9 = very excited for arousal. To allow the collapsing

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[3] The border task was included to ensure engagement of the participant in the experiment, based on prior experience where individuals tend to get sleepy and distracted when presented with pictures with a relatively long ITI. The border task was designed to be completed within the first second of picture presentation (average response time was indeed 859 ms, $SD = 20$ ms). Due to the relative complexity of the IAPS pictures, which takes time to decode and appraise, we did not expect this simple task to have an effect on subsequent emotional responsivity – the primary process of interest. Indeed, the response times indicate no effect of picture valence ($F < 1$) nor a main or interaction effect with age (both $F < 1$).

across the different ratings method, the grid data were recoded into 9-point valence

ratings similar to the 9-point valence and arousal scales used.

EMG data acquisition and reduction

Raw EMG data from the *orbicularis oculi* were collected using two Sensormedics 4

mm Ag/AgCl sensors filled with electrogel (Electro-Cap International Inc, Eaton, Ohio)

placed directly below the left or right eye (counterbalanced across participants) in

accordance with guidelines provided by Blumenthal and colleagues (2005). A ground

sensor was placed on the center of the participant's forehead. The sensor regions were

cleaned using distilled water and 70% isopropyl alcohol (Dynarex Inc, Orangeburg, NY),

then slightly abraded using Mavidon Skin Prep (Mavidon Medical Products, Nailsea,

Somerset) prior to sensor placement to reduce skin impedance to an acceptable level

(below 20kΩ)**.** Eyeblink startle EMG were acquired and filtered using SAI Bioelectric

amplifiers (SA Instrumentation Co., Encinitas, CA) with a gain of 10,000 and high-pass

filter setting of 1 Hz. Startle eyeblink data was bandpass filtered at 30 to 800 Hz,

integrated and rectified using a Coulbourn S76-01 contour-following integrator with a

time constant of 20 ms. The EMG data were collected using a PC equipped with an

analog-to-digital board (Analogic Corp., Wakefield, MA). The eyeblink startle signal

was sampled at 1000 Hz, beginning 50 ms before the onset of each startle probe and

ending 250 ms following probe onset. Eyeblink startle magnitude was calculated by

subtracting the amount of integrated *orbicularis oculi* EMG at reflex onset from the

maximum amount of integrated EMG between 20 and 120 ms following probe onset.

Noise-free trials with no perceptible eyeblink reflex (i.e., non-response) were given a

magnitude of zero. Blink magnitudes were z-transformed within-subjects to control for

large individual differences – which can be due to extraneous variables such as skin permeability and other factors which may increase the surface impedance or decrease signal quality - in response amplitude and baseline EMG levels, and log-transformed to normalize the distribution. Startle blink magnitudes were averaged within probe time and condition. Participants who did not respond with a perceptible eyeblink reflex on 10 or more of 81 probed trials were excluded from analyses.

Raw EMG from the *corrugator supercilii* was recorded in similar fashion as the *orbicularis* EMG, with the following exceptions: Sensors were placed over the left or right brow region (counterbalanced across participants) in accordance with guidelines provided by Tassinary and colleagues (1986). Corrugator EMG was low-pass filtered at 400 Hz, and data collection was continuous throughout the trial. We performed a Fast Fourier Transform (FFT) on all artifact-free 1 s chunks of data (extracted through Hanning windows with 50% overlap) to derive estimates of spectral power density (μV^2/Hz) in the 45 – 200 Hz frequency band. These values were log-transformed to normalize the data and z-transformed within-subjects to control for large individual differences in response magnitudes. The first 1 second pre-picture (fixation) epoch was used as a baseline and subtracted from subsequent second-by-second data. Corrugator activity was then divided into three distinct epochs for analysis, the first being the 4-second picture period (epoch 1, "emotion reactivity"). The second epoch is the 2 seconds following picture offset (epoch 2, "early emotion recovery") and includes the time around the 2nd startle probe. The last epoch consists of 3rd and 4th second following picture offset (epoch 3, "late emotion recovery"), containing the last startle probe (see Figure 1 for second-by-second corrugator data of these 159 participants with the epochs indicated

with graded areas). Corrugator activity was then averaged for each epoch and condition separately.

After data from the first 56 participants were collected, a laboratory room change was made which resulted in a continuation of data collection using new hardware. EMG was from this moment onwards collected using Biopac software and hardware (BIOPAC Systems, Inc., Goleta, CA). Data acquisition details were similar as described above, with the following modifications: Raw EMG signals were high-pass filtered at 20 Hz, then amplified (using ERS100C amplifiers) 5,000 times prior to digitization at 1000 Hz with 16-bit precision.

Results

Overview of analyses

We performed mixed-model multivariate analyses of variance (MANOVA, Type III sum of squares) to test the predicted age effects on emotion reactivity and recovery separately. The advantage over analyzing data obtained from within-subjects (or mixed) designs with a multivariate test is that the multivariate tests are not sensitive to issues of compound symmetry or sphericity, which often plagues univariate repeated measures ANOVA tests (see O'Brien & Kaiser, 1985). We demeaned age to avoid changes of the main effects in a repeated measures ANCOVA if the mean of the covariate is not zero (see Thomas et al., 2009). To test whether age had the predicted effects on emotion reactivity and recovery, we entered the demeaned Age as a covariate, together with Gender (male vs. female) and Valence (negative vs. neutral vs. positive) as a within-subjects factor. We controlled for possible effects of differences in data collection methods (see Methods) on our variables by including Recording Method as an additional

blocking factor. Moreover, effects of Time (epoch 2 vs. 3) were tested for emotion

recovery. Effects of Age were tested by examining interaction effects of Age with

Valence, while interaction effects of Age and Gender with Valence were explored. When

interaction effects were significant across measures in the omnibus test (i.e. $p < .05$),

follow-up tests were considered to further assess the source of the significant effect(s)

with Age.

For emotion reactivity, we assessed corrugator activity and eyeblink startle

recorded during the time the picture was presented, as well as the ratings of these pictures

obtained at a later stage. For emotional recovery, we included data acquired from a

comparable time window across measures, i.e. corrugator activity from epoch 2 & 3, after

picture offset, and eyeblink startle magnitude from the 2 probes following picture offset.

To render the emotion recovery period independent from the emotion reactivity period,

we residualized emotion recovery indices by performing regression analyses on each

recovery measure (per condition), entering the emotion reactivity measure as a predictor

and saving the residuals as a new variable.

Emotion reactivity

For emotion reactivity, as expected, the MANCOVA showed a strong main effect

of Valence, $F(6,146) = 58.86$, $p < .001$, across all measures. As expected, linear effects of

Valence (negative > neutral > positive) were found for corrugator, $F_{linear}(1,51) = 19.25$, p

$< .001$ and ratings, $F_{linear}(1,151) = 353.26$, $p < .001$, but surprisingly not for eyeblink

startle, $F_{linear}(1,151) = 1.70$, p = .19[4]. Effects of Age on valence were also significant,

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[4] This lack of a valence finding for eyeblink startle is likely due to the relatively low average of
arousal of the positive and negative pictures selected. As highlighted by Cuthbert et al. (1996),
emotion modulation of the eyeblink startle occurs most strongly at high levels of arousal. In terms
of the IAPS pictures, this would translate to pictures rated as 6 or higher on the arousal

Valence x Age, $F(6,146) = 3.27$, $p = .005$. Follow-up analyses indicated that age did not

affect reactivity to negative pictures, all $F < 1$, nor to positive pictures, all $F < 1$, but

instead there was an effect of Age on reactivity to neutral pictures; with increasing age

we observed lower corrugator activity, $F(1,155) = 3.70$, $p = .006$, reduced eyeblink

startle, $F(1,153) = 5.15$, $p = .043$, and – although not quite reaching the conventional $p <$

.05 level – more positive ratings, $F(1,155) = 3.778$, $p = .053$, in response to the neutral

pictures. Figure 2 depicts the age effects for each of the measures separately.

Emotion recovery

The MANCOVA on the corrugator and eyeblink startle measures (corrected for

reactivity) indicated an interaction of Age with Valence and Gender, $F(4,147) = 2.50$, $p =$

.045. Follow-up tests reveal that with increasing age, women recovered less after

negative stimuli for corrugator, $F(1,86) = 4.88$, $p = .030$. This effect was not observed for

men, $F(1,65) = 2.14$, *n.s.* (see Figure 3). No interactions including both Valence and

Time were found.

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dimension. To assess the extent to which emotion modulation does occur across age, we divided
the eyeblink startle responses to positive and negative pictures in high and low arousal, based on
a median split on the normative arousal ratings, and analyzed these in a 2 (Valence: positive vs
negative) x 2 (Arousal: high vs low) GLM with Age, Gender and Recording Method. The
significant interaction between valence, arousal and age ($F_{1, 137} = 11.52$, $p = .001$) is carried by
higher startle responses to negative relative to positive pictures when they are highly arousing for
the younger (average 44 years: $p = .000$) and middle-aged (average 54 years, $p = .005$)
participants. This effect is reversed with the older aged, where negative is higher than positive
when they are low in arousal only ($p = .029$). See Supplemental Figure for a depiction of this
effect. When the main analysis is repeated with the high arousal eyeblink responses to negative
and positive pictures included, the Valence x Age interaction remains significant ($F_{6, 139} = 3.40$, p
$= .004$), and this age effect is still carried by the neutral condition. This analysis also illustrates
that the linear effect of Valence for eyeblink startle is present in the younger participants (average
44 years, $p = .016$) but not in the older participants (lowest $p > .112$). See also Figure 2, middle-
right panel for a depiction of these valence effects across age. (We thank an anonymous reviewer
for highlighting the Cuthbert et al findings to us).

Discussion

In this study, using objective measures of emotional responding in addition to subjective ratings, we assessed whether advancing age is related to reduced reactivity to negative events and whether increasing age is related to a faster recovery from such negative events. We further hypothesized that older-aged individuals would maintain positive responding to positive information relative to their younger peers. Our data suggest that aging effects in emotion reactivity are expressed not as reduced responding to negative stimuli, nor enhanced responding to positive stimuli, but by a more positive responding to neutral stimuli. This age effect was observed in both EBR and COR, with the picture ratings suggesting a similar trend. With regards to recovery from emotional stimuli, we observed that women, but not men, maintain higher levels of corrugator activity with increasing age after the offset of negative events, suggesting reduced recovery from negative events. We discuss these findings further below.

The literature on emotion processing in aging suggests a positivity effect in older-aged individuals (Carstensen & Lockenhoff, 2003; Lockenhoff & Carstensen, 2004), where Carstensen and colleagues have postulated that older-aged individuals are motivated to prioritize socio-emotional goals over knowledge-based or information goals, to maintain well-being. Based on this theory, and combined with findings from others, we posited that this positivity effect could be reflected in a more positively biased (re)appraisal of information with increasing age, thereby dampening reactivity to and/or recovery from negative events, and maintaining higher levels of positive affect after the offset from positive pictures. Instead, what we found is a more positive response to neutral information. This finding is in line with the conceptualization of the "positivity

offset" by Cacioppo and colleagues (Cacioppo et al., 1997; Ito & Cacioppo, 2005) which postulates that in the situation of relatively low levels of evaluative activation or affect, a positive motivational system maintains a level of activation which determines the formation of attitudes, behavior selection, and action. In other words, the positivity offset biases the perception and evaluation of neutral states or stimuli that are mildly positively. Consistent with this postulate, Ito and Cacioppo (2005) found that individuals characterized by a stronger positivity offset judge a fictional character that had been described in neutral terms more positively, an effect not found when the character was then described with negative descriptions.

Our finding of a "positivity offset" with increasing age recurred in our different measures of reactivity, most prominently in corrugator activity and eyeblink startle. A number of studies have reported a linear effect of corrugator activity and eyeblink startle magnitude associated with the valence of the person's state. For example, Larsen and colleagues (2003) illustrated how corrugator activity tracks variation in moderate to strong unpleasantness *and* pleasantness of IAPS pictures and reviewed other evidence supporting the notion that positive affect may inhibit corrugator activity. Our data are in line with their observations: Corrugator activity increased after picture onset in response to negative and, to a lesser extent, neutral pictures, but displayed on average a decrease or deactivation of corrugator for positive pictures relative to baseline. This suggests to us that lower corrugator activity observed with increasing age to affectively neutral or ambiguous stimuli is associated with a relative stronger output of an appetitive motivational system (Lang et al., 1990), inhibiting activation of the muscle group underlying furrowing of the brow. This interpretation is also in line with recent findings

by Neta and colleagues (2009) where individuals who responded with relative decreased corrugator activity to emotionally ambiguous faces of surprise, at levels similar to their corrugator response to positive faces, rated the surprise faces as more positive than those showing levels of corrugator activity in response to surprise faces similar to their corrugator responses to angry faces.

Similar to the linear effect of valence on corrugator activity, a large number of studies (Bradley et al., 1993, 2001; Cuthbert et al., 1996; Vrana et al., 1988) have demonstrated that pleasant pictures attenuate the eyeblink startle response to an acoustic probe compared to neutral and negative pictures. Lang and colleagues (e.g. 1990) have proposed that two opposing motivational brain systems, an appetitive and an aversive system, drive attention and facilitation of information intake and emotion-related behavior through the mobilization of energy and to prompt action. They hypothesize that these systems are engaged by information signaling reward or are otherwise life sustaining, or by threat-related information, carrying importance for survival. Moreover, the stronger one system is engaged, the more likely that actions associated with this system are elicited, thereby inhibiting the non-engaged system. The workings of these opposing systems underlie the emotional modulation of the eyeblink reflex to a startling probe when the foreground stimulus is negative, and the relative inhibition of this reflex when the foreground is positive.

However, it should be noted that we did not obtain the oft-reported valence modulation effect of the eyeblink startle in this study across all participants; as described in footnote 1, a valence effect in EBR was moderated by age. The lack of a strong valence main effect for eyeblink startle is due to two factors: Heterogeneity of age in our

sample and the on average relative low arousing nature of the positive and negative pictures presented. Past studies have overwhelmingly recruited participants from a university student population, and even then, low internal consistency of the emotion modulation of the eyeblink startle has been reported (Larson et al., 2000). Our data suggest that the valence modulation effect is observed in the younger participants, but this effect dissipates with increasing age. Furthermore, when considering the arousingness of the positive and negative pictures (see footnote 3 and Supplemental Figure), we observed that younger participants specifically show eyeblink startle modulation in response to high arousing negative pictures (relative to high arousing positive). This valence modulation on eyeblink startle is evident in older participants in the low arousing pictures only. These findings notwithstanding, the overall effect of relative inhibited responding to neutral information remained reliable.

The mechanisms underlying affect modulation in corrugator activity and eyeblink startle are not necessarily the same. Evidence from Davis and colleagues (Davis, 2006; Hitchcock & Davis, 1986) suggests a crucial role of the central nucleus of the amygdala in the fear potentiation of the startle response in rats; lesion work in humans has supported a similar mechanism of startle modulation (Angrilli et al., 1996; Buchanan et al., 2004). The neural mechanisms underlying emotion modulation of corrugator activity are not yet clear. Given the multitude of influences on corrugator activity, including social context (Vrana & Rollock, 1998) and (in)voluntary display of expressions (Rinn, 1984), the neural pathways underlying emotion modulation of corrugator activity are likely more complex than those supporting emotion modulation of the startle response. These differences in neural pathways notwithstanding, our eyeblink startle and corrugator

data both suggest a relative inhibition of the aversive system through a stronger engagement of an appetitive system with increasing age when confronted with affectively ambiguous stimuli. These findings are further supported by the ratings of the neutral pictures, with a more positive trend with increasing age.

During the recovery from negative pictures, we observed that the older-aged women maintained higher levels of corrugator activity relative to both the younger-aged women in this study, and the male participants. This effect was not predicted and is not in line with the literature reviewed earlier suggesting less effortful, more adaptive emotion regulation with increasing age (Kliegel et al., 2007; Scheibe & Blanchard-Fields, 2009). Asking long-term married couples to discuss conflict, Carstensen and colleagues observed more expressions of affection in older relative to middle-aged couples (Carstensen et al., 1995). However, older aged individuals (average 69 years) were more facially expressive than younger adults (average 28 years) when reliving recent strong emotional experiences (Malatesta-Magai et al., 1992), while a more recent study did not detect age differences in ability to suppress the expression to negative film clips (Kunzmann et al., 2005). None of these studies measured facial EMG, with which even visually unnoticeable changes in expressions can be detected, nor did they examine the time course of emotional expressions. Our observed effect of extended corrugator responding in older women was not reflected in eyeblink startle. Given the discrepant results between sex differences in expressivity and experience, as well as the suggestion that aging is associated with adaptive "mood repair" (Kliegel et al., 2007), it is possible that while the expression of negative affect may have persisted in older women, the time course of experiential recovery may have been similar across the ages (and gender).

Further research should examine the time course of emotion reactivity and recovery measuring several indicators of emotional responding.

In conclusion, our findings suggest that aging is associated with an increasing strength in "positivity offset" (cf. Cacioppo et al., 1997) reflected in a more positive appraisal of emotionally ambiguous situations. Whether this positivity offset affects processing at an early or late stage of information processing as well as the extent to which the positivity offset is associated with adaptive responding in daily life and potential better health outcomes is as yet unknown. Drawing from findings obtained in other projects, this aspect will be further explored within the MIDUS study. While this age-related positivity effect was not reflected in more adaptive regulation as indexed by faster recovery from negative stimuli in our study, further research is needed to ascertain whether increased expressivity after the offset of a negative situation is predictive of persisting experiential state.

Acknowledgments

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Figure 1. Baseline-corrected second-by-second EMG activity measured over the brow region (*corrugator supercilii* muscle, log-transformed, z-scored) for each of the picture valences across a 12 second period. Corrugator EMG was aggregated over three distinct epochs: The first 4 sec denote the epoch during picture presentation marked in off-white, the first grey area marks the first 2 sec epoch after picture offset, the second darker grey area marks the second 2 sec epoch after picture offset. The three startle probe times are indicated by the black arrows.

Figure 2. Scatterplots presenting age differences in corrugator ($r_{(157)} = -.23$, top left) and eyeblink startle ($r_{(156)} = -.16$, middle left) responses during the presentation of neutral pictures, and in ratings of the neutral pictures ($r_{(157)} = .19$, bottom left). Bar graphs on the right of each scatter plot depict valence effects at each the average age (44 years) and ± 1SD (10 years) age. Neg = negative; neu = neutral; pos = positive pictures.

Figure 3. Corrugator activity after offset of negative pictures (corrected for reactivity to negative pictures) plotted against age, separately for females ($r_{(88)} = .28$) depicted in pink circles, and males ($r_{(67)} = -.03$) in blue triangles, collapsed across the post-stimulus epochs. F = female, M = male.