Journal of Gerontology: PSYCHOLOGICAL SCIENCES
2005, Vol. 60B, No. 1, 000–000

Influences of Age on Emotional Reactivity During Picture Processing

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We compared emotional reactivity to affective pictures for 32 older (60–71 years) and 34 younger (18–23 years) adults. We collected the startle-blink reflex, N1 and P3 components of the probe-evoked event-related brain potential, corrugator electromyogram, heart rate, and self-report measures of pleasure and arousal. Self-report findings indicated that older, compared with younger, adults reported greater overall pleasure and arousal. Older adults also exhibited decreased N1 and P3 amplitude, corrugator activity, and heart rate deceleration compared with younger adults. The startle-blink reflex revealed that older adults exhibited increased startle-blink magnitude compared with younger adults during unpleasant pictures, with no age differences observed for pleasant and neutral contents. These age differences suggest that older adults have differential reactivity to affective picture viewing, and they indicate that age-related changes in emotion are not unitary across response systems.

COMMON preconceptions of aging suggest that emotional health follows similar patterns of decline observed in biological and cognitive health with age. However, much of the current research refutes the stereotype that older adults become increasingly negative, depressed, and less emotional with age (Ben-Zur, 2002; Cartensen, Pasupathi, Mayr, & Nesselroade, 2000; Mroczek, 2001). Researchers have challenged the notion that negative affect increases and positive affect decreases with age, and they further support the idea that emotional regulation may actually increase with age (Carstensen et al., 2000; Gross et al., 1997; Labouvie-Vief, 1999; Lawton, 2001; Levenson, Carstensen, Friesen, & Ekman, 1991; Mroczek & Kolarz, 1998; Tsai, Levenson, & Carstensen, 2000). This increase in emotional regulation may be due to a lower incidence of negative affect in older adults and an associated tendency to redefine events by adjusting one's expectations (Labouvie-Vief & DeVoe, 1991). Alternatively, it is possible that decreased negative affect and enhanced emotional regulation with age are the outcomes of age-related declines in autonomic nervous system (ANS) function and cardiovascular reactivity, which result in less emotional responsiveness and less physiological activation for older adults, rendering emotions easier to control (Carstensen & Turk-Charles, 1994; Tsai et al., 2000).

ANS function has been shown to decline with age, affecting ANS reactivity and potentially influencing emotional reactivity (Frolkis, 1977). Unfortunately, as a result of a lack of research regarding aging and emotional reactivity (i.e., subjective, physiological, and behavioral changes that occur in response to emotion-eliciting stimuli and events), it is difficult to establish whether age-related degradation in overall ANS reactivity corresponds directly with reductions in emotional reactivity (Levenson, Carstensen, & Gottman, 1994). However, using ANS measures, researchers (Levenson et al., 1991, 1994; Tsai et al., 2000) have observed decreased psychophysiological reactivity with age. Levenson and colleagues (1991) found that older adults produced similar patterns of emotion-specific ANS activity as younger adults, but the magnitude of change across ANS measures (i.e., heart rate) was smaller for the older adults. Levenson and associates (1994) observed similar decreases in emotion-specific cardiovascular reactivity (i.e., heart rate and pulse transmission time) for older, compared with younger, adults involved in discussions of emotionally evocative conflicts with their spouses. Similarly, Tsai and colleagues (2000) reported decreased cardiovascular responses for older Chinese- and European-American participants compared with younger participants to amusing film clips, but increased cardiovascular responses to sad film clips. Accordingly, emotion-specific changes in ANS reactivity may be affected by aging.

In addition to these ANS findings, research measuring the central nervous system (CNS), particularly electroencephalographic (EEG) activity (Woodruff-Pak & Papka, 1999), event-related brain potentials (ERPs; Ford & Pfefferbaum, 1985), and the startle reflex (Ford & Pfefferbaum, 1991; Ford et al., 1995; Varty, Hauger, & Geyer, 1998), has provided further evidence for a general "underarousal" effect (i.e., reduced physiological activation) with age that is not specific to emotional reactivity. Further support for these physiological findings comes from self-report measures in which older adults report less psychophysiological responsiveness (Lawton, Kleban, Rajagopal, & Dean, 1992) and less emotional expressiveness (Gross et al., 1997) than younger adults.

Given this evidence, our purpose in this study was to examine the influence of age on emotional reactivity by using self-report and psychophysiological measures during a picture-viewing paradigm. The biphasic theory of emotion (Lang, 2000) provided a theoretical framework in which emotional responses were organized along two fundamental dimensions of hedonic valence (pleasant–unpleasant) and arousal (degree of intensity). Within this framework, emotions are considered "action dispositions" that are often representative of motivated states, which precede or occur instead of action. Accordingly, an individual may interact with a stimulus without expressing action directly, while still eliciting emotional cues that are measurable through three reactive systems of self-report, physiological changes mediated by the somatic and autonomic nervous systems, and overt behavior (Lang, Bradley, & Cuthbert, 1997).

In the current study, we used psychophysiological indices including the startle-blink reflex, corrugator electromyogram (EMG), and heart rate to measure valence, and we used startle-elicited ERPs to measure arousal. In addition, we collected self-reported measures of valence and arousal. Corrugator EMG (i.e., a facial muscle activated during the frowning response) has been found to be a consistent index of affective valence such that greater EMG activity is observed for unpleasant stimuli than for pleasant stimuli, with neutral stimuli falling in between (Bradley, Codispoti, Cuthbert, & Lang, 2001). Heart rate has also been found to differentiate between valence categories of affective picture stimuli, because greater heart rate deceleration typically occurs in response to unpleasant pictures compared with the other picture categories (Cuthbert, Bradley, & Lang, 1996). The startle reflex has been observed to be a robust measure of valence, with greater blink magnitude found for aversive foreground stimuli and smaller blink magnitude found for appetitive stimuli, relative to neutral stimuli (Lang, Bradley, & Cuthbert, 1990). Furthermore, Cuthbert and associates (1996) determined that arousal secondarily modulates startle-blink magnitude such that startle potentiation is greatest for aversive pictures rated as the most arousing (e.g., threat, attack), and it is smallest for the most arousing pleasant pictures (e.g., erotica). In addition to eliciting the eye-blink reflex, a startle probe produces a pronounced P3 component of the ERP. P3 amplitude is attenuated in the context of both pleasant and unpleasant pictures when compared with neutral pictures, suggesting a covariation in the arousal dimension of emotion because unpleasant and pleasant stimuli are more arousing than neutral stimuli (Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997).

Accordingly, we hypothesized that older adults would exhibit responses similar to those of younger adults along the valence dimension, but their responses would be indicative of lower levels of arousal (i.e., less intensity). Specifically, we hypothesized that there would be no significant age differences in self-report valence ratings; however, younger adults would report higher arousal, relative to older adults. We also predicted that older and younger adults would exhibit similar patterns of activity for corrugator EMG, heart rate, and the startle-blink reflex; however, older adults would show less overall activity across all valence categories than younger adults (i.e., decreased corrugator EMG, decreased heart rate deceleration, and diminished startle-blink responses). Lastly, we predicted that older adults would exhibit larger P3 amplitude compared with younger adults, consistent with our prediction of decreases in reported arousal.

Methods

Participants

Sixty-six (32 female and 34 male) participants were recruited and placed into two groups on the basis of age. Younger participants consisted of 34 undergraduate students (16 female and 18 male) from the University of Illinois who were between the ages of 18 and 23 years. Older participants consisted of 32 adults (16 female and 16 male) who were between the ages of 60 and 71 years from the Champaign-Urbana community. We excluded the data from 4 older participants from self-report analyses as a result of repeatedly missed ratings ($n = 3$) or computer malfunction ($n = 1$). We excluded 7 older adults from startle analyses because they had age-related high-frequency hearing loss, and we excluded 1 older adult from the startle-blink analyses because the person had no measurable blink response. We excluded 2 younger adults from ERP analyses as a result of excessive EEG artifact, and we excluded 1 younger and 1 older adult from the corrugator EMG analyses as a result of a technical error. Lastly, we excluded data from 8 older and 5 younger adults from the heart rate analyses as a result of excessive artifact.

Interviewers screened participants for depression by using the Beck Depression Inventory (BDI; Beck, Ward, Mendelsohn, Mock, & Erbaugh, 1961), and they screened them for dementia by using the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). Participants reported being free of neurological disorders, cardiovascular diseases, and any medications that influence CNS function as indicated by a health history questionnaire. Participants reported normal (or corrected to normal) vision based on the minimum 20/20 standard, and they had normal hearing (excluding the 7 older adults removed from startle reflex analyses) as determined by a commercially available hearing test.

Procedure

After providing informed consent, participants received a brief description of the testing procedures, completed the aforementioned questionnaires, and were screened for hearing loss. Participants then sat in a comfortable chair and assistants cleaned their skin with NuPrep gel (D.O. Weaver & Co., Aurora CO) for electrode placement. Assistants placed two 4-mm Ag-AgCl electrodes (In Vivo Metric, Ukiah CA) filled with Quik Gel (Neuro, Inc., El Paso, TX) adjacently at the bottom arc of the left orbicularis oculi for measurement of the startle-blink reflex. They placed two 4-mm Ag-AgCl electrodes over the left corrugator muscle and one 8-mm Ag-AgCl electrode on each forearm to measure heart rate. They fit an Ag-AgCl Quik-cap (Neuro, Inc., El Paso, TX) over the participants' heads and filled midline sites (Fz, FCz, Cz, CPz, Pz, POz, Oz) with Quik Gel. All EEG sites were referenced to averaged mastoids and FPz served as the ground. The assistants collected bipolar electro-oculographic activity (EOG) to assess eye movement artifact during offline editing of collected EEG data. Once the impedance for all electrodes was $\leq 5\ \mathrm{K}\Omega$, assistants placed headphones over the participants' ears. The lights were dimmed and the participants viewed a counterbalanced presentation of 45 pictures from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention [CSEA-NIMH], 2001). At various times during the picture presentation, a 50-ms burst of 107-dB white noise was presented through the headphones, which participants were instructed to ignore. Following each picture, participants were prompted to make their ratings of valence and arousal by using a computerized version of the Self-Assessment Manikin (SAM; Lang, 1980). The SAM uses a computerized graphical representation of a person to represent feeling states related to pleasure, arousal, and dominance, with figures ranging from happy to unhappy (pleasure) and from calm to excited (arousal). Covariation between reported pleasure and arousal SAM ratings and physiological and behavioral responses have consistently been demonstrated (Bradley & Lang, 1994), suggesting that SAM is an effective method for measuring existing feeling states, relating them to other emotional measures, and analyzing reactions to affective stimuli. Following the final picture, assistants removed all electrodes and briefed participants on the purpose of the experiment.

Apparatus and Response Measures

We controlled stimulus presentation and timing by using an 850-MHz microcomputer with Inquisit (Millisecond Software, Seattle WA) software, which was synchronized with the Neuroscan Synamps amplifier (Neuro, Inc., El Paso TX) responsible for recording the psychophysiological measures. We amplified raw data and routed it through a Neuroscan Synamps amplifier controlled by Acquire 4.2 software. We sampled data were at 2000 Hz with a gain of 150 and a bandpass filter from .01 to 500 Hz.

We used a computerized, 21-point version of the SAM (Bradley & Lang, 1994; Lang 1980) to gather participants' ratings of valence and arousal for each picture. We controlled the SAM with VPM software (Cook, 1994) on a microcomputer with a 14-in. (35.50-cm) computer monitor placed adjacent to the picture presentation screen. Participants used a joystick to manipulate SAM ratings.

Participants viewed 45 (i.e., 15 pleasant, 15 neutral, and 15 unpleasant) IAPS pictures for 6 s each. The pictures for each valence category consisted of 5 pictures from each of three categories depicting scenes of younger adults, older adults, or images that were not age associated. (IAPS: Pleasant, younger adults—2150, 2311, 4641, 4610, 8461; Pleasant, older adults—2340, 2391, 2550, 2530, 2370; Pleasant, control—4607, 4660, 4659, 4670, 4652; Neutral, younger adults—2215, 2200, 2210, 2280, 2214; Neutral, older adults—2480, 2190, 2570, 2520, 2516; Neutral, control—7050, 7004, 7000, 7150, 7175; Unpleasant, younger adults—2100, 3300, 3220, 2800, 2900; Unpleasant, older adults—2120, 2205, 2590, 9220, 2141; Unpleasant, control—6313, 6350, 6250, 6230, 6260.)

Pleasant pictures were families or babies, romantic couples, smiling faces, and erotica; neutral pictures were neutral faces and household objects; unpleasant pictures were scenes of human attack, threatening faces, and grief. Participants were seated in a sound-attenuated, dimly lit room, separated from the experimenter. They viewed the pictures on a 21-in. (53.34-cm) monitor located 1 m directly in front of them (24.3° viewing angle).

Thirty-six pictures, and five intertrial intervals, were accompanied by a startle probe, which occurred at 2 or 4 s after picture onset. We generated the startle probe from a prerecorded digital white noise sound stimulus and calibrated it with a Brüel & Kjær 2235 sound level meter (Brüel & Kjær, Nærum Denmark). We delivered the probe by using Inquisit software and presented it binaurally through calibrated Telephonic TDH-49 headphones. Across participants and valence conditions, we used three different picture orders with counterbalanced startle probes to ensure that each picture was probed equally often.

Data Reduction

We scored startle-blink responses offline for magnitude by using Neuroscan 4.2 software. We epoched the data from 50 ms before until 250 ms after probe onset. The raw signal was amplified, bandpass filtered from 30 to 500 Hz (24 dB/octave), rectified, integrated with a 30-Hz low-pass filter, and baseline corrected according to the prestimulus interval. We selected the peak response for each probe within the epoch window, and we recorded the average startle response for each participant and affective category (i.e., pleasant, neutral, or unpleasant). We applied a z score within each participant's data prior to statistical analysis.

We reduced corrugator activity in 0.5-s intervals and we calculated change scores by subtracting the mean activity 1 s before picture onset from the average response during the picture-viewing period (i.e., 6 s). We calculated the average for the picture-viewing period within each participant for all pictures in an affective category.

We computed heart rate interbeat-interval (IBI) values by determining the time between R-wave peaks to the nearest millisecond. When we could not detect a clear R-wave peak as a result of excessive movement or noise, we rejected the trial. We subsequently transformed IBI values into heart rate in beats per minute (BPM), and then we weighted these proportionally to correctly reflect the time each IBI occupied within each 0.5-s bin. We calculated change scores from the prepicture baseline. We determined the maximum deceleratory change (D1) in the first 3 s and used this as the summary statistic.

We scored N1 and P3 components of the startle-elicited ERP offline by using Neuroscan 4.2 software to determine the base-to-peak amplitudes on averaged waveforms for each participant, affective category, and electrode site. We corrected continuous data for eye movement artifacts by using the Semlitsch, Anderer, Schuster, and Presslich (1986) algorithm, and we epoched the data from 100 ms before to 900 ms after the stimulus for each trial. We baseline corrected the data by using the prestimulus period, and we filtered the data with a 30-Hz low-pass cutoff frequency (24 db/octave). Epochs were artifact rejected if they contained amplitude excursions $\pm$ 100 μV. We scored the N1 within a window of 50 to 200 ms and the P3 from 250 to 500 ms. For all electrode sites, we defined the N1 and P3 components as the largest negative and positive peaks in their respective time windows.

Statistical Analysis

We separately conducted analyses for startle-blink, corrugator EMG, heart rate, and SAM valence and arousal data by using a 2×3 (Age $\times$ Picture Valence) multivariate with repeated measures for the Picture Valence factor. We analyzed N1 and P3 by using a $2 \times 3 \times 7$ (Age $\times$ Picture Valence $\times$ Electrode Site) multivariate with repeated measures. We used post hoc univariate analyses of variance (ANOVAs) with Bonferroni corrected t tests to break down significant effects when appropriate. We used Wilks' lambda statistic to evaluate effects involving repeated measures with three or more within-subject levels. We used a significance level of $p = .05$ for all analyses prior to Bonferroni correction.

Results

Participant Characteristics

We observed an age effect for the BDI, with older adults ($M = 4.7$, $SD = 3.4$, range 0–14) reporting higher depression scores than younger adults ($M = 2.9$, SD 2.6, range 0–13), $t(1, 64) = 2.6$,

Table 1. Picture Valence Mean (SEM) for Each Measure

Measure	Pleasant	Neutral	Unpleasant	F	p
SAM valence	15.4 (.3)[a]	10.4 (.1)[b]	5.1 (.3)[c]	149.6	<.001
older	16.1 (5)	10.7 (.2)	4.9 (.5)		
younger	14.8 (.4)	10.1 (.2)	5.3 (.5)		
SAM arousal	11.8 (.3)[a]	8.2 (.3)[b]	13.1 (.2)[c]	116.4	<.001
older	12.4 (.4)	8.7 (.4)	13.8 (.3)		
younger	11.3 (4)	7.8 (.4)	12.4 (.3)		
Startle-blink	−0.14 (.03)[a]	−0.03 (.03)[a]	0.14 (.03)[b]	14.1	<.001
older	−0.13 (.05)	−0.11 (.05)	0.24 (.05)		
younger	−0.15 (.04)	0.03 (.04)	0.07 (.04)		
N1 amplitude	−16.4 (1.3)[a]	−17.4 (1.4)[a,b]	−18 (1.3)[b]	4.0	<.024
older	−10.5 (1.6)	−11.6 (1.8)	−12.5 (1.8)		
younger	−21.0 (1.4)	−22.0 (1.6)	−22.3 (1.6)		
P3 amplitude	10.7 (1.0)[a]	14.5 (1.1)[b]	12.5 (1.1)[c]	13.3	<.001
older	9.0 (1.5)	11.7 (1.6)	10.4 (1.6)		
younger	12.0 (1.3)	16.7 (1.4)	14.0 (1.4)		
Corrugator EMG	0.1 (.1)[a]	0.3 (.1)[a]	0.6 (.1)[b]	10.2	<.001
older	−0.1 (.1)	0.1 (.1)	0.3 (.1)		
younger	0.2 (.1)	0.5 (.1)	1.0 (.1)		
Heart rate (D1)	−1.4 (.2)[a]	−1.4 (.3)[a]	−1.5 (.2)[a]	0.4	=.688
older	−0.6 (.3)	−0.8 (.4)	−0.9 (.2)		
younger	−2.2 (.3)	−1.9 (.4)	−2.2 (.2)		

Notes: F tests are for the valence main effect. Values that share a common superscript are not significantly different at $p < .017$. Means (SEMs) are also provided for older and younger adult groups for each measure and valence. SAM = Self-Assessment Manikin; N1 and P3 = components of the event-related brain potential; EMG = electromyogram; D1 = heart rate deceleration.

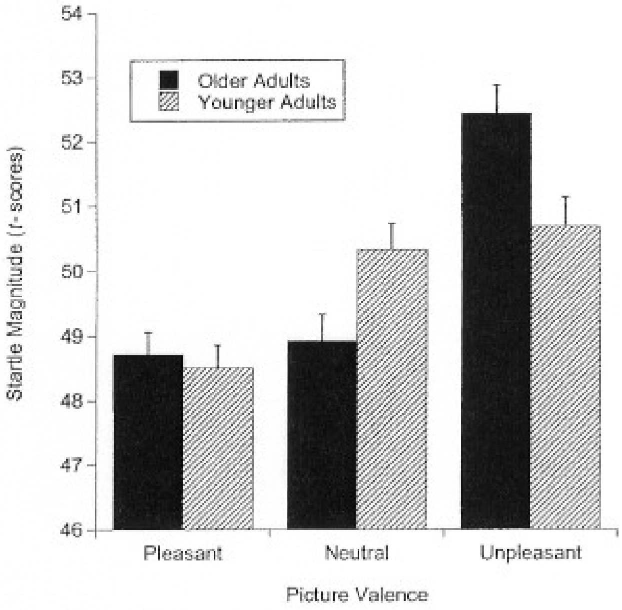

Figure 1. Startle-blink reflex for Age × Picture valence interaction. Note the older adults' significant increase in blink magnitude to unpleasant pictures, relative to younger adults.

$p < .02$. These higher BDI scores are contrary to the typical finding that age is not directly associated with depression (Blazer, 2003); however, it should be noted that the mean age differences reported herein were small and all participants' scores were below the cutoff indicative of moderate depression (i.e., greater than 16 out of a maximum score of 63). For the MMSE, we noted no age differences, $t(1, 63) = 1.7$, $p = .09$, indicating that older adults ($M = 28.5$, $SD = 1.2$, range 26–30) and younger adults ($M = 29.1$, $SD = 1.2$, range 26–30) did not differ on this measure of dementia.

Replication of Prior Research

Table 1 illustrates the picture valence main effect for each measure. In a replication of previous research (Bradley et al., 2001; Cuthbert, Schupp, Bradley, McManis, & Lang, 1998; Lang et al., 1990; Lang, Greenwald, Bradley, & Hamm, 1993; Schupp et al., 1997), we observed picture valence main effects for all measures except for heart rate; however, valence effects for heart rate have typically been found in past studies to be relatively modest compared with the other measures (Bradley et al., 2001).

Subjective Report

We observed an age effect, $F(1, 60) = 5.2$, $p < .03$, for SAM valence ratings, indicating that older adults reported higher overall valence for pictorial stimuli than younger adults. Age also modulated SAM arousal ratings, $F(1, 60) = 9.1$, $p = .004$, such that older adults reported greater overall ratings of arousal than younger adults. We observed no Age × Picture valence interaction.

Startle Reflex

Blink.—The startle eye-blink reflex revealed an Age × Picture valence interaction, $F(2, 55) = 4.6$, $p < .02$. Post hoc t tests with Bonferroni correction examined age for each picture Valence category and indicated that older adults had greater blink potentiation compared with younger adults only for unpleasant pictures, $t(1, 56) = 2.6$, $p < .01$ (see Figure 1). We observed no such age effects for pleasant and neutral categories. Given that differences in depression scores were noted between age groups, we conducted an analysis of covariance (ANCOVA) on the startle-blink data by using the BDI scores, because age and valence interacted. Similar to the ANOVA reported herein, the Age × Picture valence interaction was significant, $F(2, 54) = 3.9$, $p < .03$.

N1 amplitude.—We observed an age effect, $F(1, 55) = 21.5$, $p < .001$, indicating that older adults exhibited a smaller overall N1 amplitude when compared with their younger counterparts (see Figure 2). We observed an electrode site main effect and a Picture valence × Electrode site interaction that were superceded by a three-way interaction of Age × Picture valence × Electrode site, $F(12, 44) = 2.8$, $p = .006$. Follow-up multivariate analyses of variance (MANOVAs) of Age × Picture valence for each electrode site revealed smaller N1 amplitudes for older, compared with younger, adults at each of the seven electrode sites, $Fs(1, 55) \geq 4.8$, $p \leq .03$. In addition, we observed a picture valence main effect, $Fs(2, 54) \geq 3.8$, $p < .03$, at the three most anterior sites (Fz, FCz, Cz), with post hoc tests indicating greater

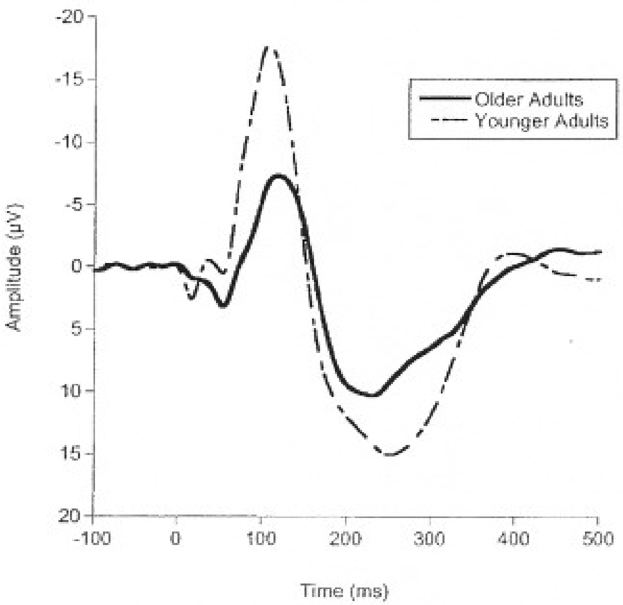

Figure 2. Grand average startle probe-elicited ERP waveforms for older and younger participants. Note that the waveforms for each participant group are averaged across the three picture valence categories and seven electrode sites.

N1 amplitudes for unpleasant, relative to pleasant, pictures, $ts(1, 56) \geq 2.6, p \leq .01$.

P3 amplitude.—We observed a significant age effect, $F(1, 55) = 3.9$, $p = .05$, with older adults exhibiting smaller P3 amplitudes compared with younger adults (see Figure 2). We also found an Age × Electrode Site interaction, $F(12, 44) = 4.5$, $p < .001$, with post hoc tests indicating that older adults exhibited significantly smaller P3 amplitudes at the CPz and Pz sites compared with younger adults, $ts(1, 55) \geq 2.9, p \leq .005$. Older adults also exhibited marginally smaller P3 amplitudes at the Cz site relative to younger adults after Bonferroni correction, $t(1, 55) = 2.5, p < .02$.

Analyses also indicated an electrode site main effect, $F(6, 50) = 31.7, p < .001$, which was superceded by a Picture Valence × Electrode Site interaction, $F(12, 44) = 3.4, p < .001$. Post hoc analyses of picture valence at each electrode site, $Fs(3, 54) \geq 15.5, p \leq .001$, indicated significantly larger P3 amplitudes for neutral pictures compared with both pleasant and unpleasant pictures at Fz, FCz, and Cz sites, $ts(1, 56) \geq 5.3$, $p \leq .001$. Neutral pictures also produced significantly larger P3 responses compared with pleasant pictures at the CPz, Pz, and POz sites, $ts(1, 56) \geq 4.0, p \leq .001$. Unpleasant pictures elicited significantly greater P3 responses than pleasant pictures at the CPz, Pz, and POz sites, $ts(1, 56) \geq 2.5, p \leq .016$.

Corrugator EMG

We observed an age effect, $F(1, 62) = 18.0, p < .001$, for corrugator EMG, indicating less overall EMG activity for older than for younger adults, regardless of picture valence (see Figure 3).

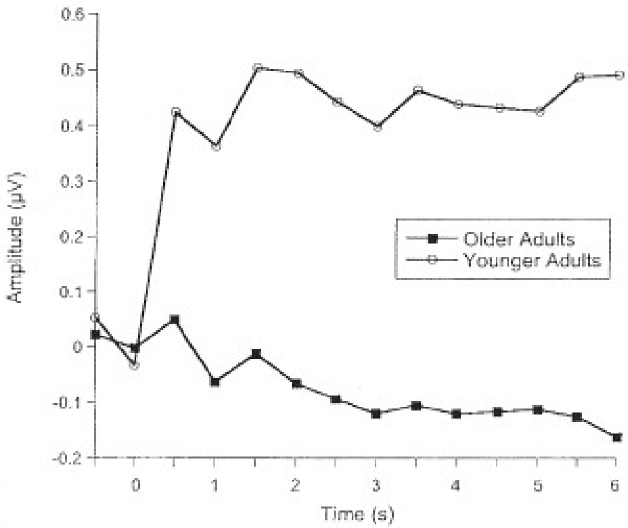

Figure 3. Age main effect for corrugator EMG to picture onset averaged across picture valence categories.

Heart Rate

We found an age effect, $F(1, 51) = 13.2, p < .001$, for the initial deceleratory component (D1) of the heart rate response to picture onset, indicating older adults exhibited less deceleration than younger adults, regardless of picture valence (see Figure 4).

Discussion

In general, the results indicated that age influenced reactivity across all affective picture categories. Specifically, self-report measures indicated that older adults reported an overall increase in pleasure and arousal, compared with younger adults, across picture contents. Older adults also exhibited decreased N1 and

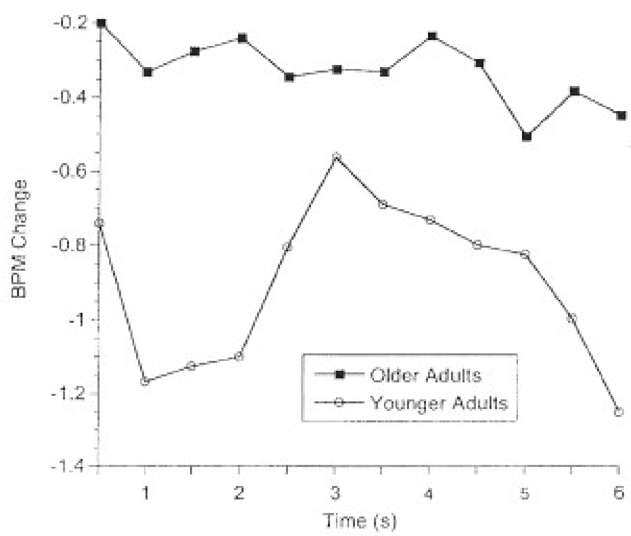

Figure 4. Age main effect for heart rate to picture onset averaged across picture valence categories (BPM = beats per minute).

P3 amplitude of the startle-elicited ERP, had decreased corrugator EMG activity, and less heart rate deceleration (D1) than younger adults. However, startle-blink responses did exhibit differential age-related results across valence categories, such that older, compared with younger, adults had a larger blink response to unpleasant pictures. We did not observe this age effect for pleasant and neutral contents. Taken together, physiological reactivity to emotional pictures was attenuated with age across most measures, yet self-report and the startle-blink reflex were enhanced with age, suggesting that age-related changes in emotional reactivity across response systems are not unitary.

We observed age differences for self-reported measures, indicating that older adults reported overall higher ratings of valence and arousal compared with younger adults. Although many studies have not found significant age-related differences in self-reported emotion (Carstensen et al., 2000; Reminger, Kaszniak, & Dalby, 2000), some support for these findings comes from Prescott (2001), who found higher SAM valence and arousal ratings for older adults than for younger adults in response to pleasant IAPS pictures. Alternatively, Mather and colleagues (2004) observed lower arousal ratings for older adults than for younger adults for unpleasant pictures. Further, other studies have not evidenced differences between older and younger adults during emotional appraisal of IAPS pictures (Charles, Mather, & Carstensen, 2003; Denburg, Buchanan, Tranel, & Adolphs, 2003), which is in direct contrast to the findings just noted (Prescott, 2001; Mather et al., 2004). However, differences in picture content and intensity may account for these disparate findings.

Startle-blink findings replicated previous research (Bradley et al., 2001; Lang et al., 1990) by showing the well-documented affect-startle effect with the greatest potentiation for unpleasant pictures and the greatest inhibition for pleasant pictures, with neutral pictures falling in between. Novel to this report was that older adults exhibited greater potentiation to unpleasant pictures than younger adults, with no differences observed for pleasant and neutral picture contents.

Cuthbert and associates (1996) proposed that drive arousal (motivational intensity) of the perceptual foreground was an important moderating variable for the startle reflex such that substantial modulation (i.e., potentiation for unpleasant and inhibition for pleasant pictures) occurred only for pictures high in arousal (judged or autonomic). Thus, the increased startle-blink reflex observed herein for older adults may reflect changes in emotional reactivity with age, especially with regard to perceived arousal. The unpleasant pictures in this study consisted mainly of depictions of grief and threat. Older adults may find the images of grief and sadness to be more pertinent than younger adults because of their personal experiences with health problems as well as the loss of those close to them (Tsai et al., 2000). Levenson and his colleagues (1991) found a greater increase in finger temperature for sadness than for disgust in older adults than in younger participants for two emotion-eliciting tasks, which they suggested might be reflective of "a relative increase in the arousing quality of sadness in old age" (p. 33). Tsai and her colleagues (2000) found that older, compared with younger, adults exhibited smaller increases in cardiac IBI to a sad film clip, indicating that older adults were more physiologically aroused during the clip. Threatening pictures may also be more salient for older adults because of greater fears of victimization stemming from a higher perceived vulnerability to attack (Cutler, 1980; Greve, 1998; and Lindesay, 1991). Exploratory analyses support this notion, as larger startle-blink responses were observed for older, compared with younger, adults to pictures of threat ($p = .01$). Pictures of grief that are pertinent to older adults exhibited a trend for increased startle blink in older adults than in younger adults ($p = .11$), and pictures of grief involving younger adults and children did not elicit age-related differences ($p = .95$).

We also observed age to modulate N1 and P3 amplitudes to the startle probe such that older adults exhibited decreased amplitude compared with younger adults. One possible explanation is that these decreased ERP responses for older adults are reflective of increased attentional resources allocated to the primary stimulus (i.e., pictures), leaving fewer attentional resources available for the startle probe, as suggested by Schupp and colleagues (1997). Older adults did report increased arousal to the pictures compared with younger adults, so it is also possible that the relationship of increased arousal judgments with decreased P3 amplitude may apply to these age-related findings for P3 data. N1 is typically considered an exogenous ERP component related to selective attention rather than emotional arousal, but the decrease in N1 amplitude may further support the idea that older adults were allocating more attention to the pictures than to the startle probe.

Alternatively, a more likely explanation may be that the decreased responses in older adults are due to well-documented declines in neuroelectric functioning with age that have been observed by use of numerous cognitive paradigms (Ford & Pfefferbaum, 1991; Hillman, Weiss, Hagberg, & Hatfield, 2002; McConnell, Snyder, & Valeriano, 1997; Miller, Bashore, Farwell, & Donchin, 1987). Another probable explanation for these age differences may be that the N1 and P3 amplitudes for older adults were affected by the intrusive nature of the intense startle probe. Ford and colleagues (1995) found decreased N1 and P3 amplitudes for older adults than for younger adults to 107-dB startle probes, but they found no such age difference to 70-dB tones. They proposed that this reduced responsiveness in older participants was likely due to an automatic defensive response to the intrusive quality of the startle probe. Because we found no interaction between age and picture valence for either the N1 or P3 amplitude, it is difficult to conclude the extent to which the decreased N1 and P3 responses for older adults were due to increased attentional allocation to the pictures, age-related neuroelectric decline, or a defensive response to the intrusive startle probe.

Corrugator EMG replicated previous picture-viewing research (Bradley et al. 2001; Lang et al. 1993), with significantly greater corrugator activity for unpleasant pictures than for neutral and pleasant pictures. This pattern of corrugator activity was consistent for both age groups; however, age modulated the corrugator EMG such that older adults exhibited overall decreased activity compared with younger adults. These findings correspond with studies by Cuthbert and colleagues (1988) and Prescott (2001), which observed similar patterns of corrugator EMG for older and younger participants but found overall decreased activity for older adults.

Heart rate results were similar to corrugator findings in that they showed a decline in reactivity with age. Younger adults demonstrated a triphasic waveform pattern for the heart rate response, with a large initial deceleration (D1), as observed in previous studies (Bradley et al., 2001; Cuthbert et al., 1996). However, older adults showed a less distinct pattern of the heart rate response, with little reactivity when compared with younger adults, which corroborates numerous studies that have found decreased HR response (Levenson, 2000) and a loss of magnitude in cardiovascular physiology (Levenson et al., 1994; Tsai et al., 2000) in older adults than in younger adults. Unfortunately, it is difficult to determine from the results of this study whether the decreased heart rate response is due to changes in emotion-specific ANS reactivity with age, or if it is reflective of age-related declines in cardiovascular reactivity or neural reactivity in the ANS.

Overall, the findings of this study support recent aging research, which has found that older adults exhibit diminished reactivity in facial expressiveness (Prescott, 2001) and autonomic responsiveness (Levenson, 2000), whereas subjective appraisals of emotional stimuli and environments are equal to or greater in intensity than younger adults (Levenson, 2000; Prescott, 2001). These diminished facial and autonomic responses to emotional stimuli may be due to age-related physiological decrements in the CNS and ANS. Conversely, it is also possible that they may be the result of emotional coping strategies that develop over the life span.

Levenson and colleagues (1991) proposed that older adults may avoid strong emotions to escape the aversive physiological consequences of prolonged autonomic reactivity, as well as to conserve limited energy resources in later life. Lawton (2001) further supported this idea, suggesting that phenomena such as diminished autonomic arousal and less efficient facial expressiveness may be interpreted as "resource-conservational moves appropriate at a time of life when biological resources are diminishing" (p. 121). Labouvie-Vief and DeVoe (1991) have also proposed a cognitive-affective developmental approach to emotion, which hypothesized that, with maturation and aging, individuals rely more on cognitive appraisals of felt or experienced emotion and less on culturally defined rules and references that guide emotional regulation in youth. This might suggest that the emotional responses of older adults are more dependent on cognitive assessments of felt emotion and less reliant on feedback from physiological response systems. Further, our data suggest that this enhanced regulation of emotions found in older adults may not extend to the reflexive system. Given that the blink reflex and neuroelectric responses to the startle probe are obligatory, older adults may have little control over this system. In contrast, facial EMG and cardiovascular responses, which may be modulated through peripheral feedback, may allow for increased control. This may explain why the startle measures were not subject to the same decreases in reactivity found in the other psychophysiological measures collected in this study.

Summary

Findings revealed age differences across self-report and psychophysiological measures, suggesting that older adults differentially respond to affective pictures than younger adults as a result of either greater emotional regulation or age-related declines in physiological reactivity, or a combination of both. The findings presented herein correspond well with the general consensus of contemporary aging research suggesting that, although some autonomic and facial-expressive aspects of emotion may be subject to declines with age, older adults continue to express as much reactivity or more than their younger counterparts.

Acknowledgment

This research (and preparation of this article) was supported by grants from the National Institute on Aging (RO1 AG021188) to Charles H. Hillman and the Center on Aging and Cognition: Health, Education, and Training (CACHET) to Darin P. Smith.

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Received February 17, 2004
Accepted June 28, 2004
Decision Editor: Thomas Hess, PhD