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Emotion Sensitivity Across the Lifespan: Mapping Clinical Risk Periods to Sensitivity to Facial Emotion Intensity

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Face emotion perception is important for social functioning and mental health. In addition to recognizing categories of face emotion, accurate emotion perception relies on the ability to detect subtle differences in emotion intensity. The primary aim of this study was to examine participants' ability to discriminate the intensity of facial emotions (emotion sensitivity: ES) in three psychometrically matched ES tasks (fear, anger, or happiness), to identify developmental changes in sensitivity to face emotion intensity across the lifespan. We predicted that increased age would be associated with lower anger and fear ES, with minimal differences in happiness ES. Participants were 9,546 responders to a Web-based ES study (age range = 10 to 85 years old). Results of segmented linear regression confirmed our hypotheses and revealed differential patterns of ES based on age, sex, and emotion category. Females showed enhanced sensitivity to anger and fear relative to males, but similar sensitivity to happiness. While sensitivity to all emotions increased during adolescence and early adulthood, sensitivity to anger showed the largest increase, potentially related to the importance of anger perception during adolescent development. We also observed age-related decreases in both anger and fear sensitivity in older adults, with little to no change in happiness sensitivity. Unlike previous studies, the effect observed here could not be explained by task-related confounds (e.g., ceiling effects for happiness recognition), lending strong support to observed differences in ES for happiness, anger, and fear across age. Implications for everyday functioning and the development of psychopathology across the lifespan are discussed.

Keywords: emotion perception, emotion recognition, social cognition, adolescent development, aging

Difficulties in accurately detecting the emotions of others are associated with a range of neuropsychiatric disorders, from autism (see Uljarevic & Hamilton, 2013 for a meta-analysis) to psychosis (Germine & Hooker, 2011; Kohler et al., 2003; Tully, Lincoln, & Hooker, 2014) to anxiety and mood disorders (e.g., Joormann & Gotlib, 2006; Persad & Polivy, 1993; Rocca, van den Heuvel, Caetano, & Lafer, 2009). The ability to accurately perceive others' emotions is thought to contribute to healthy

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The primary results reported in this article have been presented at local and national conferences between 2017 and 2018. The data is deposited to the Open Science Framework, which can be accessed with the following link: https://osf.io/j92dr/. Brent P. Forester reports consulting work with Eli Lilly and research funding from Roche, Biogen, and Assurex. Lauren A. Rutter, David Dodell-Feder, Ipsit V. Vahia, Kerry J. Ressler, Jeremy B. Wilmer, and Laura Germine have no conflicts of interest with respect to the published work. The current manuscript is part of a research program to understand how different aspects of social cognition vary between individuals and across the lifespan, and how these differences relate to vulnerability for psychopathology. The next step in this research is to understand how variations in ES across the lifespan are associated with variations in mental health. We thank all TestMyBrain research participants for contributing to this study. Also, we thank Andrew Sudler, Divya Shah, Eliza Passell, Luke Scheuer, and Sarah Vogel for their assistance in stimulus creation, data analysis, and manuscript preparation.

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and satisfying social relationships (e.g., Fischer & Manstead, 2008). Here, we distinguish between two different components of emotion perception: emotion recognition (ER), or the ability to accurately perceive and identify specific emotional states (categories) in another person, and emotion sensitivity (ES), or the ability to accurately perceive and detect *differences in intensity* of specific emotions (Ekman et al., 1987; Orgeta & Phillips, 2007).

Previous research has indicated that emotion perception is likely not a unitary construct, but instead may dissociate by emotion categories (Ekman, 1992) and/or underlying processes related to visual perception, recognition, and labeling (Vuilleumier & Pourtois, 2007). We know that face processing relies on systems for both categorizing stimuli, as well as detecting differences along a particular perceptual dimension (e.g., Rotshtein et al., 2005). Based on the existing literature on emotion perception, perceptual processing of variations in emotion intensity dissociates from emotion labeling or categorization (e.g., Adolphs, 2002; Blair, Morris, Frith, Perrett, & Dolan, 1999; Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992). For example, early work on the neural mechanisms of face emotion processing found that different brain regions responded to changes in emotion intensity as compared with changes in emotion category (Morris et al., 1998). Brain circuits that support recognition of basic emotions (i.e., occipitotemporal neocortex, amygdala, orbitofrontal cortex, and right frontoparietal cortices) seem to be differently involved in perceptual processing versus categorization of face emotions (Adolphs, 2002; Blair et al., 1999; Calder et al., 1996; Haxby, Hoffman, & Gobbini, 2002). These differences can be observed behaviorally, as in the classic finding of categorical face emotion perception given linear changes in face emotion intensity (Etcoff & Magee, 1992) even where participants are sensitive to differences in emotion intensity between face stimuli (Beale & Keil, 1995; Young et al., 1997).

Despite evidence from the experimental and neural literature that ER and ES are distinct aspects of face emotion perception, research in individual differences in face emotion perception focuses almost exclusively on differences in ER. It is, therefore, unknown whether differences in emotion perception that vary with age, gender, and clinical status are because of differences in emotion categorization or other aspects of emotion perception.

Below, we provide an overview of the relevant literature on emotion perception (based on studies of ER and ES) across age, gender, and neuropsychiatric disorders, as well as discuss some of the ways that methodological and psychometric problems may have led to inconsistencies among studies.

Emotion Perception Across the Lifespan

Age-related differences in ER have been well-studied for both development and aging. In infants as young as 7-months-old, there is a basic human ability to differentiate between faces expressing different basic emotions (Kestenbaum & Nelson, 1990; Nelson & Dolgin, 1985). Accuracy in ER, specifically, increases during childhood, with evidence that accuracy in recognizing happiness develops first, followed by anger or sadness, and then surprise and fear (Herba & Phillips, 2004). Previous reports have indicated that the age at which children achieve ER accuracy at the level of adults (almost 100% accuracy in recognizing happiness, and 80–90% for all negative emotions; Calvo & Lundqvist, 2008) is around age 5 for happiness, 7 for fear, 9 for anger, and 11–12 for disgust (Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007), with no further improvement. In one of the few studies looking specifically at ES for distinct emotion categories over development, Gao and Maurer (2009) found that sensitivity to differences in happy, sad, and fearful emotion improves from age 5 to age 10, and is adult-like from age 10 onward.

From young to middle adulthood, people are generally quite accurate at emotion perception based on performance on most ER tasks. In later adulthood (60+ years), however, a decline in ER begins (e.g., Isaacowitz et al., 2007; see Ruffman, Henry, Livingstone, & Phillips, 2008; Watling, Workman, & Bourne, 2012 for reviews). Sullivan and Ruffman (2004) found a similar decline in ES, with older adults demonstrating more difficulties judging which of two faces was more intense for angry, sad, and fearful faces. In a study examining ratings of emotion intensity from facial expressions and verbal descriptions of emotions in older and younger adults, older adults rated emotional facial expressions and written text as less intense than younger adults (Phillips & Allen, 2004).

Given the relationship between social functioning and emotion perception (e.g., Brackett, Rivers, Shiffman, Lerner, & Salovey, 2006) the large literature on observed differences in ER with age should be associated with differences in social functioning. While this has generally been identified during development (e.g., Blakemore & Choudhury, 2006; Thomas, De Bellis, Graham, & LaBar, 2007), in older age, paradoxically, there has been robust evidence for maintenance and even gains in the quality of relationships (see Luong, Charles, & Fingerman, 2011). A more well-supported hypothesis is that, although ER declines with age, recognition of happiness is preserved and that this difference explains the gains in emotional well-being and social relationships that emerges with age (Richter, Dietzel, & Kunzmann, 2011; Ruffman et al., 2008). Older adults may compensate for losses in ER in one stimulus modality (e.g., faces) by using information from other sources (Isaacowitz et al., 2007). In two studies of healthy older adults, results show an age-related decline in ER and ES that is independent of changes in perceptual abilities, processing speed, fluid IQ, basic face processing, and reasoning about nonface stimuli (Sullivan & Ruffman, 2004), suggesting that emotion perception declines may be mediated by brain circuits different from those associated with general cognitive decline. Orgeta and Phillips (2007) also found that age differences in ER were not the result of decreasing perceptual ability, but rather linked to general cognitive changes (Orgeta & Phillips, 2007). Age-related differences in ER may be both context and emotion specific, with substantial within-person variability in ER well into old age (Richter et al., 2011). Disentangling differences in emotion perception that vary by emotion type is challenging based on current literature, however, as ceiling effects tend to be greater for happiness recognition than other emotions. Thus, preserved recognition of happiness could be entirely an artifact of ceiling effects (McKone, Crookes, Jeffery, & Dilks, 2012), which limits interpretability of such results in the aging literature (see Isaacowitz et al., 2007 for

a review). This general challenge in the interpretation of ER paradigms is discussed more below.

Sex Differences in Emotion Perception

Sex differences in emotion perception have been demonstrated across the literature, with females typically showing an advantage over males based on a meta-analytic review (McClure, 2000). An additional meta-analysis showed that the largest sex differences in ER occur in teenagers and young adults, with smaller sex differences in children under 13 and adults over 30 (Thompson & Voyer, 2014). A more recent study on sex differences in ER found that although females of all ages were better at judging emotional faces, the advantage over males decreased with age (Olderbak, Wilhelm, Hildebrandt, & Quoidbach, 2018). One of the few studies of differences in ES showed that females rated dynamic emotional faces as more intense relative to static emotional faces, as compared with males (Biele & Grabowska, 2006). This study did not look at whether or not female were *better* at distinguishing between differences in emotion intensity as compared with males, however, making findings difficult to interpret.

Emotion Perception in Neuropsychiatric Disorders

The importance of ER for social functioning has led to a large body of literature examining ER in clinical samples, including conclusions regarding differences in processing of specific emotions. In most studies focused on ER in neuropsychiatric disorders (typically using basic emotion identification paradigms), patients show poorer ER than matched healthy controls. In autism spectrum disorder, a meta-analysis showed that impairments in ER have been demonstrated across emotions, and cannot be accounted for by intellectual capabilities (Uljarevic & Hamilton, 2013). A more recent meta-analysis confirmed that the attentional and cognitive processing of emotional faces is atypical in autism spectrum disorders across the developmental trajectory (Black et al., 2017). In bipolar disorder, a critical review showed that ER deficits are linked to mood states such that euthymic patients present with impairment in recognizing disgust and fear, while manic patients demonstrate difficulties in recognizing fearful and sad faces (Rocca et al., 2009). In depression, the results are more nuanced, with some studies showing enhanced ER for sadness (Lopez-Duran, Kuhlman, George, & Kovacs, 2013), and others showing deficits ER for happiness (Joormann & Gotlib, 2006). With regard to unipolar depressive disorders, it is still unclear whether there is a general emotion identification deficit (e.g., Persad & Polivy, 1993) or a deficit in perception of specific emotional expressions (e.g., Gur et al., 1992). One study looking at ES in depression found that people with depression had reduced intensity judgments for happy faces (Yoon, Joormann, & Gotlib, 2009). Lastly, in schizophrenia, a study of 28 stable outpatients with schizophrenia and 61 healthy subjects showed that ER is impaired for all emotions including mild and extreme expressions (Kohler et al., 2003). A later meta-analysis of facial emotion perception in schizophrenia demonstrated a robust finding that ER is broadly impaired and that this impairment is moderated by clinical and demographic factors (Kohler, Walker, Martin, Healey, & Moberg, 2010).

Measurement Issues in Standard ER Paradigms

In addition to the theoretical distinction between ER and ES discussed above, tasks used to measure ER typically suffer from methodological limitations: these tasks were typically designed to measure ER as a general function, and cannot be used to cleanly dissociate between specific emotion categories. Of the basic emotion categories traditionally examined in research, happiness is typically the most easily recognized across tasks (see Ekman et al., 1987). These ceiling effects make findings of preserved or intact happiness recognition in a particular age or clinical group difficult to interpret (McKone et al., 2012).

Moreover, most ER tasks conflate discriminability or sensitivity and response bias. Sensitivity and bias are established concepts in signal detection theory and psychophysics, where the sensitivity of an observer (i.e., discrimination ability) is distinct from response bias (i.e., response criterion; Macmillan & Creelman, 2004). In standard ER paradigms, where multiple emotion categories are judged together, sensitivity and bias are difficult to disentangle. For example, ER errors for fearful faces may be because of (a) difficulty discriminating fear or (b) a bias toward responding to another emotion category. Even high accuracy on a particular emotion is difficult to interpret—if a person correctly classifies a set of faces as angry, for instance, it is unknown whether they are (a) truly sensitive to anger, (b) insensitive to any potential signals of happiness, or (c) have a bias toward selecting anger as a response.

Response bias can confound interpretation of scores in standard emotion recognition task designs if an individual has a preference for selecting or not selecting a certain emotion as a response. For example, a general tendency to select a "happy" response (e.g., on trials when the participant is guessing) would change scores for performance on happy trials relative to other emotions and/or reduce the ability to detect true differences in happiness perception (if using a traditional signal detection analytic approach).

In addition to these methodological confounds, psychometric confounds also muddy the interpretability of traditional ER paradigms. First, for most paradigms, emotion categories are not comparably difficult—as described above, judgment of happiness tends to suffer from ceiling effects relative to other emotions. Second, it is not clear for most ER tasks if they are comparably reliable across emotion categories (reliability is rarely reported for specific emotion categories) and studies will have better power for detecting differences for categories where reliability is higher (e.g., May & Hittner, 2003). For these reasons, many ER tasks are only sensitive enough to detect group-related differences for particular emotion categories—and, in some cases, are totally insensitive to detecting variations in perception of emotions such as happiness.

Understanding Clinical Risk Periods

Finally, another central motivation for the current study is to understand how differences in the processing of specific emotions are related to clinical risk periods. Despite our knowledge about the relationship between ER and psychopathology in various samples, less is known how specific ER strengths or weaknesses predict the onset of psychopathology. Because emotion perception deficits are related to psychopathology, we would expect emotion perception to vary with risk for psychopathology across the lifespan. We know, for example, that anxiety disorders tend to emerge

around age 21, based on a meta-analysis (de Lijster et al., 2017), with variation based on the type of anxiety disorder: specific phobia, social phobia, and separation anxiety appear before 15, whereas agoraphobia, obsessive–compulsive disorder, posttraumatic stress disorder, panic disorder, and generalized anxiety disorder have an age of onset between 21 and 34.9 years, with no differences between genders. Mood disorders, based on results of the National Comorbidity Survey (NCS-R), have a median age of onset around 30 years (Kessler, Chiu, Demler, Merikangas, & Walters, 2005). An earlier onset is associated with greater illness burden including more psychosocial impairment, poorer physical health, and greater psychiatric comorbidity (see Zisook et al., 2007). Impulse-control disorders have the earliest age of onset distributions compared with other psychiatric disorders (Kessler et al., 2007), ranging from 7–9 years for attention-deficit-hyperactivity disorder, 7–15 years for oppositional-defiant disorder, 9–14 years for conduct disorder, and 13–21 years for intermittent explosive disorder. Finally, risk of onset for all major mental disorders decreases into older age, with half of mental disorders over the lifetime occurring first between ages 7–24 (Jones, 2013). Although chronic mental disorders can often persist into older age, new mental disorders that are not associated with dementia or other neurological disorders tend to be less common above age 45 (cross-national variation in median age of onset for mood disorders: 25–45; Kessler et al., 2007). Given this data that vulnerabilities to specific emotional conditions emerge at different times throughout the lifespan, and the little data that exist on emotion sensitivity, we wanted to test if differences in emotion sensitivity map onto these differences in emotional experiences, which may be relevant for predicting clinical disorders.

Characterizing Emotion Sensitivity to Anger, Fear, and Happiness Across the Lifespan

In the current study, we seek to (a) replicate and extend previous findings in the developmental and aging literature regarding the relationship between age and facial emotion perception in a large sample, and (b) address methodological and psychometric confounds in traditional ER tasks. Understanding how emotion perception varies across the lifespan is critical to understanding changes in psychosocial functioning with age and understanding age-related risk for psychopathology. To address this goal, we measured sensitivity to facial expressions of anger, fear, and happiness in (a) a large and diverse sample and (b) using measures of ES that are matched and free of confounds related to response-bias, allowing us to interpret any identified dissociations. Our method relies on a two alternative forced choice (left/right decision) task design to separate sensitivity from bias and determine a participant's ES ability, which is a novel approach that preserves our ability to detect differences in sensitivity for particular emotion categories. In our task, any existing response bias (e.g., a tendency to select the "left" face when the participant is guessing) does not confound the measurement of emotion sensitivity because the response options are not systematically linked to a particular perceptual category. Our approach also matches difficulty and reliability across emotion categories, making dissociations in performance between categories much easier to interpret. This bias-free signal detection approach (see Macmillan & Creelman, 2004) allowed us to experimentally isolate ES for each emotion (happiness, anger, or fear).

Based on previous work, we hypothesized that ES would improve across adolescence and early adulthood (Mill, Allik, Realo, & Valk, 2009), followed by a decline in ES, particularly for fear and anger with older age (see Ruffman et al., 2008 for a meta-analysis). We base our hypotheses from the existing literature on ER, as this is where the vast majority of studies have focused. We did not base our hypotheses on existing literature from studies of ES, as only a few studies of individual differences in ES exist with which to form hypotheses. Considering prior research, we expected happiness sensitivity to be less affected by aging as compared with fear and anger sensitivity. We hypothesized that there would be sex differences in ES, but did not make a specific prediction about ages where males and females would differ. We expected that the differences in ages of disorder onset may be related to differences in emotion processing, but do not make any specific predictions about which emotions would be enhanced or impaired based on age. Given the aforementioned methodological limitations of prior research and general tendency toward smaller sample sizes, we also hypothesized that our experimental design and well-powered sample might uncover previously unobservable associations between age and ES. Any such observations would provide the basis for identifying novel mechanisms linking ES, psychosocial change, and risk for psychopathology across the lifespan.

Method

Participants

Participants were 9,546 visitors to TestMyBrain.org, our citizen science research platform where participants take part in research experiments to contribute to science and learn more about themselves through immediate and personalized return of research results. The TestMyBrain.org platform has been approved by the Harvard Committee on the Use of Human Subjects. All participants provided consent to be a part of the study. Participants' ages ranged from 10 to 85 years old, and the average age was 27.56 (SD = 12.33). The sample was predominantly female (62%). The majority of participants identified as White (67%) and non-Hispanic (81%). Participants represented individuals from more than 130 countries and territories. More than half of our participants were from the United States (51.98%), followed by Great Britain (5.76%), Canada (3.13%), India (3.07%), Australia (1.51%), and Germany (1.14%). Educational status based on highest level of completed education was as follows: some college (27.12%), high school (24.85%), college (20.30%), graduate school (18.47%), and middle school (.04%). Data were obtained from 2013 to 2014.

Internet-based testing methods allow for rapid recruitment of large samples. Comparisons among laboratory samples versus Internet-based samples have shown that data can be as reliable as data collected in the lab using traditional methods (Germine et al., 2012; Hartshorne & Germine, 2015; Meyerson & Tryon, 2003). Previous studies have validated methods similar to the ones described here for measuring individual differences in emotion discrimination, emotion categorization, and mental state inferencing (Germine & Hooker, 2011; Germine et al., 2012; Hartshorne &

Germine, 2015), including individual differences in emotion perception across the lifespan (Hartshorne & Germine, 2015). Participants were given feedback after the test about their performance relative to other individuals who had completed it. Participants who completed the task more than once were excluded from analyses.

Belmont Emotion Sensitivity Test (BEST)

We used a novel measure of emotion sensitivity to eliminate response bias-related confounds and allows us to match different emotion categories in terms of difficulty and reliability. While other studies have used emotion intensity judgments (e.g., Sullivan & Ruffman, 2004), differences between emotions are hard to interpret because of differences in difficulty or reliability of judgments for each emotion category. Facial stimuli were drawn from the Karolinska Directed Emotional Faces (KDEFS) database (Lundqvist, Flykt, & Öhman, 1998). We chose to limit our study to three emotion categories that were of substantial a priori interest based on previous literature, and to keep the task brief and enjoyable for participants. Sensitivity to anger, happiness, and fear were assessed separately, with two of the three morph continua for each identity used for each subtest (e.g., fear to anger and fear to happiness for the fear subtest). Face pairs were all selected from morphs between two emotional faces (anger, fear, or happiness), to ensure that emotion intensity judgments were related to judgments of a specific emotion rather than general emotion intensity. For each subtest, participants were shown 56 pairs of faces (33 female, 23 male), one pair at a time, with the two faces in a pair presented on screen at the same time, for 1,000 ms. Stimuli included five different face identities. The highest possible score for each subtest was 56. See Figure 1 for an example trial. Participants pressed left or right for each face pair in response to the prompt, "Which face is more angry?", "Which face is more happy?", or "Which face is more fearful?" to evaluate anger ES, happiness ES, and fear ES, respectively.

Trials were ordered so that difficulty increased across three blocks (easy = 8, medium = 20, and hard = 28) for each subtest. For anger, there was a 70% difference along each morph continuum for easy faces, a 40% difference for medium difficulty faces, and a 20% difference for hard faces. For fear, there was an 80% difference for easy faces, a 50% difference for medium difficulty faces, and a 30% difference for hard faces. For happiness, there was a 70% difference for easy faces, a 30% difference for medium difficulty faces, and a 10% difference for hard faces. For example, for an easy anger trial with a 70% difference, one face might contain 90% of the anger face and 10% of the happy face (or 10% fear), while the other face might include 20% anger and 80% happiness (or 80% fear).

In developing this task, stimulus parameters and specific face pairs were selected based on a pilot study of 6,250 participants. For the final tasks, we identified face pairs that showed the highest correlations with the rest of the test (excluding that item) at different difficulty levels to construct three new subtests for each face emotion that were comparable in terms of difficulty (anger: 0.83 [*SD* = 0.09], fear: 0.8 [*SD* = 0.1], happiness: (0.81 [*SD* = 0.08]) and reliability (Cronbach's α: anger = 0.75, fear = 0.8, happiness = 0.72). The final set of tests was then fielded once more to collect data to understand lifespan related changes for the current study.

The final analytic sample for this study includes 9,546 participants who completed a single ES test, with 9,227 participants who completed all three ES tests. Because the age distribution was skewed, with many more young participants than older participants, we excluded ages with fewer than 10 participants, which restricted our age range to 68. Following this, our final sample size consisted of 9,190 participants who completed all three tests and had 10 or more observations within an aggregated age. For all emotion categories (i.e., happiness, fear,

Figure 1. Belmont Emotion Sensitivity Test*.
* The face pair shown above is for illustration purposes only. Faces above are from the "Act Out for Brain Health" database. Faces in the actual test (not pictured) were from the Karolinska Directed Emotional Faces (KDEFS) database (Lundqvist et al., 1998). See the online article for the color version of this figure.

Table 1
Comparisons of Model Fit for Anger, Fear, and Happiness

Emotion category	Regression model type	R^2	F	p
Anger				
	Linear	.005	46.21	<.001
	2 segment	.030	124.68	<.001
	3 segment	.035	21.61	<.001
	4 segment	.035	1.06	.346
Fear				
	Linear	.016	152.30	<.001
	2 segment	.055	198.55	<.001
	3 segment	.060	23.77	<.001
	4 segment	.035	1.60	.201
Happiness				
	Linear	.011	99.93	<.001
	2 segment	.029	85.84	<.001
	3 segment	.030	5.23	.005

Note. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion. For happiness, while the three segment model was significant, data showed that it did not improve fit from the two segment model, as evidenced by an increase in AIC and BIC. Thus, we prioritize the two segment model.

or anger), higher ES scores are indicative of better performance, or greater sensitivity in recognizing a particular emotion.

Data Analysis

Data were analyzed in RStudio. Effect sizes are reported with 95% confidence intervals (CIs). Results are considered statistically significant at $p < .05$. Given our interest in capturing lifespan changes in ES, we used segmented (piecewise) regression, a method in which multiple linear segments are used to model nonlinear changes (Muggeo, 2003, 2008). This approach has been used by others who have examined lifespan changes in large samples (see Fortenbaugh et al., 2015; Yeatman, Wandell, & Mezer, 2014). Within segmented regression analyses, the point at which the effect of one variable on another changes (breakpoint), is determined by a significant change in slope magnitude and/or direction. We compared the fit of linear (i.e., one segment, no breakpoint) versus multisegment models by evaluating Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Reported F values are derived from likelihood ratio tests. We provide breakpoints and discuss the ages at which the relationship between age and ES transitions for each emotion category. Scores were binned by year of age in Figures 2–5 for visualization purposes only.

Results

Anger Sensitivity

Segmented regression analyses demonstrated that the relationship between age and anger sensitivity was best fit by a three segment (two breakpoint) linear function, $R^2 = .035$, $F(2, 9500) = 21.61$, $p < .001$ compared with a two segment (one breakpoint) linear function, $R^2 = .03$, $F(2, 9502) = 124.68$, $p < .001$. Data showed that a two segmented model was a better fit than a linear model, and that an additional segment (four segment model) did not improve fit, as evidenced by an increase in AIC and BIC.

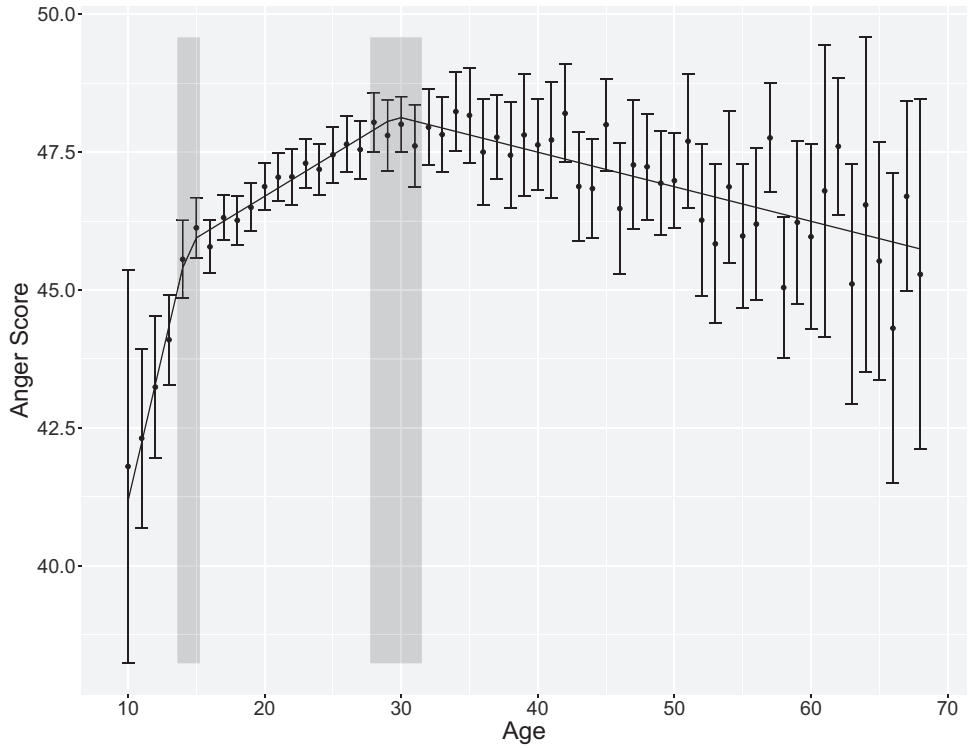

Figure 2. Three segment anger score by age regression.

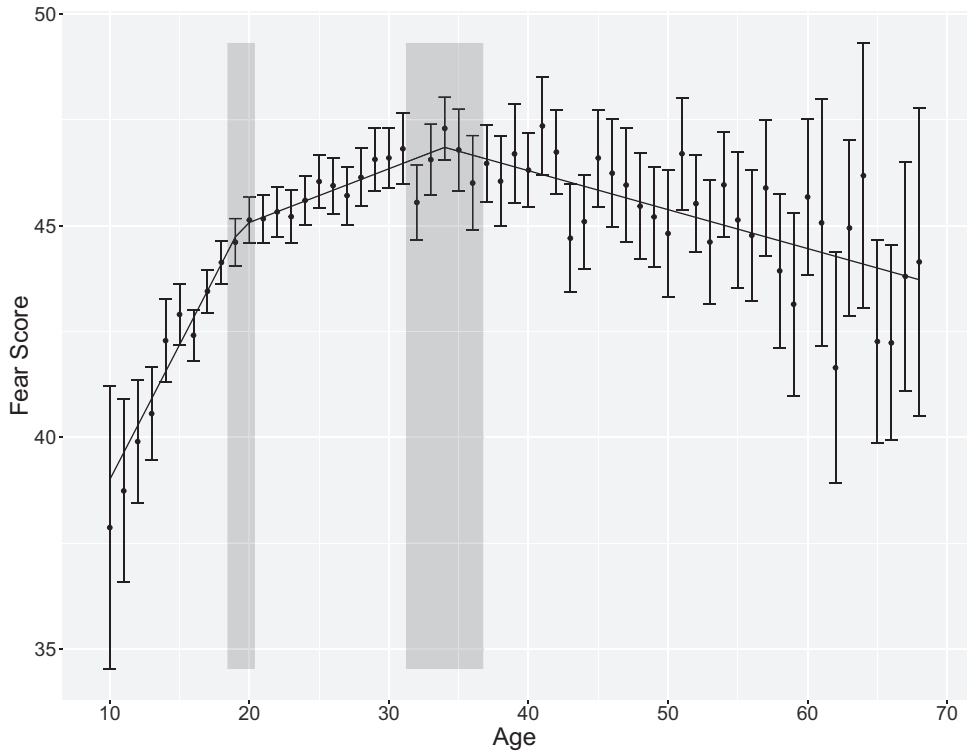

Figure 3. Three segment fear score by age regression.

Model comparison results are presented in Table 1. Specifically, the relationship between age and anger sensitivity changed (i.e., exhibited a breakpoint/change in slope) at ages 14.42, 95% CI [13.61, 15.26] and 29.62, 95% CI [27.73, 31.51], with anger sensitivity steeply increasing from ages 10 to 14.43 $b = 1.06$, 95% CI [.67, 1.45], continuing to increase, but at a slower rate from ages 14.43 to 29.62, $b = .15$, 95% CI [.12, .18], followed by a gradual decrease in performance into late age, $b = -.06$, 95% CI [−.08, −.04]. The peak age of anger sensitivity was 29.62 years. Figure 2 provides a visual depiction of these results.

Fear Sensitivity

Segmented regression analyses demonstrated that the relationship between age and fear sensitivity was best fit by a three segment (two breakpoint) linear function, $R^2 = .06$, $F(2, 9500) = 23.77$, $p < .001$, when compared with a two segment (one breakpoint) function, $R^2 = .055$, $F(2, 9502) = 198.55$, $p < .001$. Model fit results are presented in Table 1. Specifically, the relationship between age and fear sensitivity changed (i.e., exhibited a breakpoint or change in slope) at ages 19.42, 95% CI [18.43, 20.42] and 33.63, 95% CI [30.90, 36.36], with fear sensitivity steadily increasing from ages 10 to 19.42, $b = .63$, 95% CI [.52, .74], continuing to increase, but at a slower rate from ages 19.42 to 33.63, $b = .13$, 95% CI [.08, .18], followed by a slow decline in performance into late age, $b = -.09$, 95% CI [−.12, −.06]. Results are presented in Figure 3.

Happiness Sensitivity

Segmented regression analyses demonstrated that the relationship between age and happiness sensitivity was best fit by a two segment (one breakpoint) linear function, $R^2 = .03$, $F(2, 9186) = 85.84$, $p < .001$, which showed better fit statistics than the linear model $R^2 = .01$, $F(1, 9188) = 99.93$, $p < .001$. Specifically, the relationship between age and happiness sensitivity changed (i.e., exhibited a breakpoint or change in slope) at age 21.68, 95% CI [20.55, 22.81], with happiness sensitivity increasing between ages 10 to 21.68, $b = .29$, 95% CI [.23, .34], followed by a slight decline from 21.68 into late age, $b = -.002$, 95% CI [−.012, .008]. Results are presented in Table 1 and Figure 4.

Differential Sensitivity Across Emotions

Despite the differences in age breakpoints across emotions, the pattern is similar for anger and fear, and can be conceptualized by a steep increase during early adolescence, followed by a more modest increase into early adulthood, followed by a steady decline. For happiness, with only one breakpoint, the pattern is as follows: steep increase until around age 22, followed by a very mild decline or plateau. Figure 5 depicts ES z-scores for each category plotted by binned ages, with risk periods in shaded regions. As shown in Figure 5, the emotion categories have significantly different breakpoints and slopes ($p < .001$), with improvements in anger sensitivity being steepest in adolescence, fear sensitivity highest around age 35, and happiness sensitivity highest in older adults. Looking across the lifespan may reveal important insights about how emo-

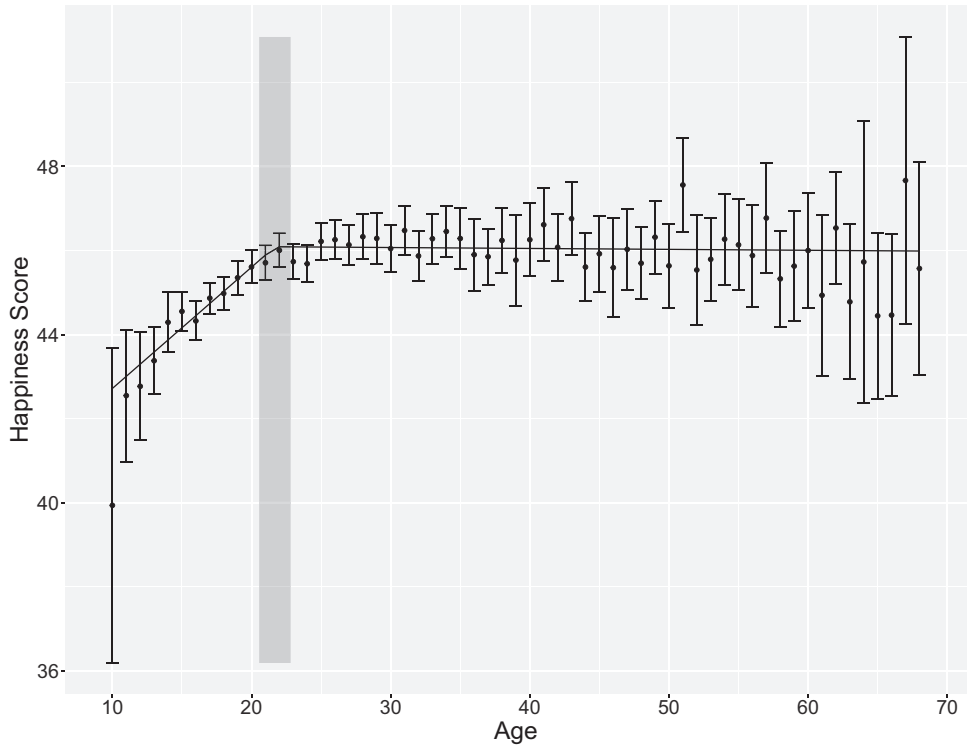

Figure 4. Two segment happiness by age regression.

tion sensitivity and related social processes contribute to mental illness onset.

Sex Differences Across the Lifespan

Overall, females showed significantly higher ES for anger and fear across the lifespan, when compared with men using Welch two-sample t tests (anger: $t = 2.76$, $p < .01$; fear: $t = 6.96$, $p < .001$). Males and females did not differ in their happiness sensitivity ($t = .80$, $p = .42$), but did display significantly different age breakpoints when we tested a segmented model. Cohen's d effect sizes were small for anger ($d = .06$) and fear ($d = .15$). There were no significant differences in performance between males and females based on the sex of the face shown for anger ($p = .50$) or

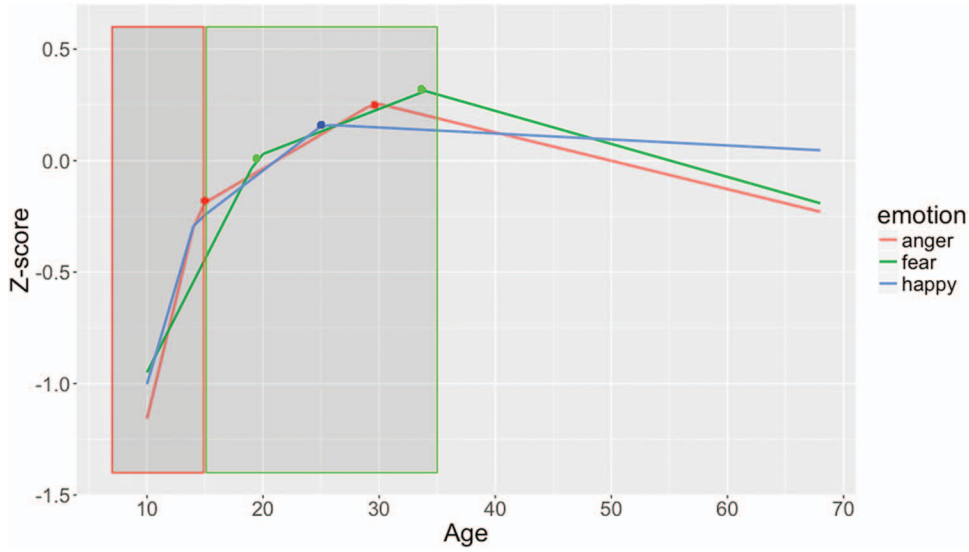

Figure 5. Differential emotion sensitivity across the lifespan with risk periods. The shaded region in red (black) represents the range of ages at which externalizing disorders onset, whereas the region shaded in green (dark gray) represents age of onset ranges for internalizing disorders. See the online article for the color version of this figure.

happiness ($p = .75$). For fear, men showed more difficulty in recognizing female fearful faces (Cohen's $d = .14$, $p < .001$). Future work is needed to determine if this effect replicates in other study designs.

Differences in best fit models by sex are described below, although we note that in omnibus tests, Age × Sex interaction effects were not significant for any emotion category. In females, the relationship between age and anger sensitivity changed (i.e., exhibited a breakpoint) at age 25.36, 95% CI [23.96, 26.77], with anger sensitivity increasing between ages 10 to 25.36, $b = .27$, 95% CI [.22, .32], followed by a slight decline from 25.36 into late age, $b = -.06$, 95% CI [−.08, −.04]. In men, a breakpoint occurred at age 29.11, 95% CI [26.16, 32.06], with anger sensitivity increasing between ages 10 to 29.11, $b = .17$, 95% CI [.12, .21], followed by a slight decline from 29.11 into late age, $b = -.05$, 95% CI [−.08, .02]. Females may acquire anger sensitivity at a significantly more rapid rate during adolescence (i.e., steeper slope) and reach adult level sensitivity at an earlier age (i.e., earlier breakpoint) as compared with males.

Male's fear sensitivity appeared to improve at a significantly more rapid rate during adolescence and reaching adult level sensitivity (i.e., compared with other adult males) at an earlier age than females. In males, a breakpoint occurred at age 20.48, 95% CI [19.45, 21.51] with fear sensitivity increasing between ages 10 to 20.48, $b = .71$, 95% CI [.55, .86], followed by a slightly continued increase from 20.48 into late age, $b = .013$, 95% CI [−.01, .04]. In females, a breakpoint occurred at age 27.88, 95% CI [26.52, 29.24], with fear sensitivity increasing between ages 10 to 27.88, $b = .35$, 95% CI [.30, 40], followed by a slight decline from 27.88 into late age, $b = -.09$, 95% CI [−.12, .07].

For happiness, results showed that in females the first breakpoint occurred at age 21.43, 95% CI [20.12, 22.75], with happiness sensitivity increasing between ages 10 to 21.43, $b = .31$, 95% CI [.24, .38], followed by a slight decline from 21.43 into late age, $b = -.01$, 95% CI [−.02, .00]. In males, a breakpoint occurred at age 25.67, 95% CI [23.08, 28.26], with happiness sensitivity increasing between ages 10 to 25.67, $b = .20$, 95% CI [.14, .25], followed by a slight decline from 25.67 into late age, $b = -.006$, 95% CI [−.03, .02]. From these results, females may develop happiness sensitivity at an earlier age than males. However, we again note that because the interaction of Age × Sex on emotion sensitivity was not significant, results suggesting differences in age-related emotion sensitivity for males and females should be interpreted with caution.

Discussion

This is the first study to examine ES across the lifespan in a large, diverse sample. Additionally, this is the first study to investigate sex differences in ES in a sample of this magnitude. Our results provide insight into different patterns of ES by emotion category, which may be related to the development of psychopathology more generally. As hypothesized, both age and sex were associated with ES. We had originally hypothesized that fear and anger ES would decrease with age, and happiness ES would be relatively well-preserved. What we found instead was a more nuanced pattern of emotion-specific age-related differences, suggesting that sensitivity for different emotions change differently across the lifespan. Moreover, our careful design means that such differences cannot be explained by task or psychometric confounds as in previous studies. Here, we explore the implications of these findings.

Our results for anger sensitivity revealed that a three-segment model best fit the data, with age breakpoints around ages 14 and 30. As described, a breakpoint refers to the time at which the relationship (slope) between two continuous variables significantly changes. An interesting find, anger sensitivity had the steepest slope relative to other emotion categories, and also the earliest break point comparatively. This indicates that the ability to discriminate varying degrees of anger in another person develops steeply during early to mid-adolescence, as compared with development in fear and happiness sensitivity. Anger and fear ES significantly decline in later adulthood, whereas happiness ES is maintained, resulting in preserved happiness ES in older age relative to fear and anger ES.

Theoretically, these results on anger ES may provide insight into the social or environmental context at which sensitivity to recognizing anger is especially important: early adolescence, a time of increased risk for bullying (e.g., Stein, Dukes, & Warren, 2007). It makes sense evolutionarily that being able to discriminate anger would develop dramatically during early and mid-adolescence. As adolescents are learning to navigate their social worlds, knowing if their actions are inciting anger in others is a particularly adaptive skill. Certainly, difficulty in reading the varying emotional expressions of peers in early to mid-adolescence would be considered a deficit as emotion perception has been linked to higher social cognition (Izard et al., 2001) and better academic adjustment (Goodfellow & Nowicki, 2009). Further, based on a meta-analysis modeling emotional, cognitive, and behavioral predictors of peer acceptance, it is clear that adaptive social skills and emotion knowledge contribute to peer acceptance (Mostow, Izard, Fine, & Trentacosta, 2002). A study of emotion recognition and bullying in 373 adolescents from 11 schools in the United Kingdom showed that while bullying perpetrators did not differ from other students in ER skills, victims of bullying scored lower in their ability to recognize anger and fear in particular, and in their overall abilities to identify emotions (Woods, Wolke, Nowicki, & Hall, 2009). A more recent study (Pozzoli, Gini, & Altoè, 2017) that examined the connection between recognition of facial expressions and bullying using a dynamic ER task found that bullying victims had a general difficulty in recognizing emotions, which is consistent with the known social–cognitive and emotional difficulties in victimized youth (Mahady Wilton, Craig, & Pepler, 2000). Thus, learning to discriminate anger and change actions accordingly may serve an important social function.

In our study, the development of fear sensitivity showed a similar pattern to that of anger, although with later age breakpoints (age 19 and 34). This age window interestingly fits the time frame for the onset of fear-based disorders including anxiety disorders (de Lijster et al., 2017). Additionally, this age range is associated with forming close interpersonal and intimate relationships, for which fear detection may aid in bonding (Skuse, 2003). Fear sensitivity is of obvious adaptive value, namely, using cues from others to avoid dangerous situations, and yet a hypervigilance of the fear detection system is likely involved in the etiology of anxiety disorders (Fox et al., 2000). We found that fear sensitivity peaked around age 34 and remained high relative to other emotions until around age 45–50. The relatively enhanced sensitivity to

detect fear around ages 30–40 (see Figure 4) could be because of a number of factors. Around this time in life, many adults who are parents may experience an increase in threat-scanning to protect their children and assist in parent–child attachment. In a recent examination of maternal responses to sad and happy expressions of their child, it was shown that mothers' threat detection network is activated when viewing sad faces of their child, while happy faces activate reward-related areas (Kluczniok et al., 2017). It may also be important for future research to examine brain regions activated by ES tasks, particularly given the differences we found in sexes between fearful and angry faces. Several meta-analyses and reviews (e.g., Cohn, 1991; Eisenberg & Lennon, 1983; Hoffman, 1977) have shown fairly stable gender differences in empathy measures beginning in early infancy (McClure, 2000), which may have neurobiological and evolutionary underpinnings. Indeed, our results are consistent with the established literature on gender differences in empathy development (see Christov-Moore et al., 2014 for a review). Differences in empathy may account for the gender differences in ES that we found.

An additional hypothesis about fear sensitivity age and sex results is related to theory of mind abilities. Women's ER advantage has been observed in infancy, adolescence, and adulthood and reasons for these enhanced abilities are likely linked to both socialization factors and neurobiological differences, according to a meta-analysis (McClure, 2000). While anger sensitivity is essential in observing and responding to a direct threat, fear sensitivity may be more subtle, requiring the ability to interpret what the individual with the fearful face is thinking (Skuse, 2003). And, thus, the ability to read facial expressions and attribute intention is associated with memory, threat-detection, gaze monitoring, and the secondary processing of arousal systems that link to theory of mind abilities (Skuse, 2003). The development of fear sensitivity may be particularly linked to the neural basis of social cognition, as fear recognition ability predicts social–cognitive and neural functioning differences in men (Corden, Critchley, Skuse, & Dolan, 2006). On tests of theory of mind ability in 341 men from the general population, those with low fear recognition scores compared with normal (good) fear score controls, demonstrated significantly reduced activation of the amygdala, fusiform gyrus, and anterior superior temporal cortices when viewing faces with direct versus averted gaze (Corden et al., 2006). Fear recognition seems to play a unique role in the development of social cognition, and sex differences in theory of mind abilities (Adenzato et al., 2017; Baron-Cohen et al., 2015) could be linked to the sex and age differences that we observed.

Compared with anger and fear, happiness sensitivity demonstrated a different trajectory across the lifespan, which was in line with our hypotheses. Specifically, results showed an increase in happiness ES until a breakpoint around age 22, followed by a slight decline or plateau into later age. Our results lend support to the idea that preserved happiness sensitivity might contribute to self-reported successful aging, life satisfaction, and close relationships (Montross et al., 2006). Happiness sensitivity scores can be interpreted through the lens of socioemotional selectivity theory (SST; Carstensen, 1992; Carstensen, Isaacowitz, & Charles, 1999), which posits that aging is associated with a preference for positively valenced information over negatively valenced information in attention and memory ("positivity effect"). SST has been used to explain age-related differences in ER abilities in older adults (Charles & Campos, 2011; Richter et al., 2011), along with the consistent findings of associations between aging and higher quality of life (for a review, see Steptoe, Deaton, & Stone, 2015) and the growing literature of emotional well-being increases with age (cf. Mather & Carstensen, 2003).

Our study expands upon the prior literature through its large sample size (N = 9,546), statistical approach, which allowed for exploration of nonlinear changes (segmented regression), and ES task, for which we sought to eliminate psychometric and methodological confounds of traditional ER paradigms. It is noteworthy that many of the methodological limitations that have been pointed out in prior literature, described above, have been corrected in the current study. Although our task addresses response bias in the signal detection sense (Macmillan & Creelman, 2004), other biases may remain including the question of whether our measures of ES are potentially influenced by other distinct processes such as emotion identification. Overall, our approach provides more nuanced information about sensitivity to emotions across the lifespan, particularly changes in ES, than prior studies have allowed.

Our study design was meant to optimize our ability to uncover sensitivity to discriminating emotional faces across the lifespan through sensitive and reliable tests applied to very large samples. Despite its strengths, our experimental approach has limitations. First, we sought to interpret ES differences in a large, diverse sample in terms of vulnerability to psychopathology. Although an important first step, our data cannot address any potential causal relationship between ES and the development of psychopathology because of our cross-sectional design. Future work might investigate the relationship between ES and psychopathology using clinical outcomes, in specific developmental periods, and with longitudinal designs. Additionally, future work should look at whether sensitivity to other emotions (e.g., disgust, surprise, and sadness) shows similar or dissociable patterns of lifespan-related differences.

Finally, our study suffers from potential self-selection biases. Participants may have been attracted to this study because they felt their abilities were particularly good or particularly bad. Self-selection biases are a virtually ubiquitous problem for large studies where selection of a truly random sample is difficult to achieve. Our study used an entirely Web-based recruitment and assessment approach, however, which is a relatively new methodology for research in cognition and psychopathology where the impact of self-selection biases are not well understood. Such approaches are increasingly being used to recruit larger and more diverse samples (Fortenbaugh et al., 2015; Halberda, Ly, Wilmer, Naiman, & Germine, 2012; Hartshorne & Germine, 2015; Soto, John, Gosling, & Potter, 2011); however, more work is needed to understand how to best combine the benefits of such approaches with the need to account for biases related to a nonrandom sample. Because our sample was self-selected, it is possible that the results are biased toward higher-functioning older adults, with more expertise using computers. However, previous studies conducted by our research team and others have found replication of associations in both direction and overall factors (Germine, Dunn, McLaughlin, & Smoller, 2015; Hartshorne & Germine, 2015; Soto et al., 2011).

In summary, we found differences in sensitivity to facial emotion intensity across age, with the novel finding of rapid development of anger sensitivity in early to mid-adolescence, as compared with anger and fear. On average, females showed superior ES

performance in negative emotions relative to men. Our results correspond with clinical risk periods for externalizing pathology in adolescence and internalizing pathology in adulthood. Our finding that happiness sensitivity remained preserved across the lifespan confirms and expands prior research on the positivity effect. To understand more fully how ES scores relate to clinical risk periods and diagnoses, it is recommended that ES tasks be administered in a variety of clinical groups and in conjunction with validated symptom questionnaires. Finally, research examining the neurobiological mechanisms underlying age and sex differences is a recommended direction for the future.

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