Increased pupil dilation to angry faces predicts interpersonal stress generation in offspring of depressed mothers

Cope Feurer,[1] Katie L. Burkhouse,[2] Greg Siegle,[3] and Brandon E. Gibb[1]

[1]Center for Affective Science, Binghamton University (SUNY), Binghamton, NY; [2]Department of Psychiatry, University of Illinois at Chicago, Chicago, IL; [3]School of Medicine, University of Pittsburgh, Pittsburgh, PA, USA

Background: Interpersonal stress generation is one mechanism hypothesized to increase risk for the intergenerational transmission of depression. Although there is some evidence of stress generation in offspring of depressed mothers, specific predictors of stress generation in these youth remain unknown. The goal of this study was to examine a peripheral measure of cognitive-affective reactivity (i.e. pupil dilation) to emotional interpersonal stimuli as a predictor of stress generation in offspring of depressed mothers. **Method:** The study included 129 mothers and their offspring (ages 8–15) recruited from the community who participated at two time points separated by 6 months. Youth's average pupil dilation to emotional faces (angry, happy, sad) as well as maternal lifetime history of major depressive disorder were assessed at baseline. In addition, both time points included assessments of youth's levels of self-generated (dependent) and independent episodic life stress in the preceding 6 months. **Results:** Youth's pupil dilation to angry, but not sad or happy, faces predicted prospective increases in dependent interpersonal stress across the follow-up. This effect was only observed in offspring of depressed mothers and was not seen in offspring of never-depressed mothers. **Conclusions:** This study highlights a potential risk factor (heightened reactivity to facial displays of anger) that may identify which offspring of depressed mothers are at greatest risk for interpersonal stress generation. **Keywords:** Stress generation; pupillometry; depression; intergenerational transmission.

Introduction

Although decades of research has shown that offspring of mothers with a history of depression are at an increased risk for developing depression themselves (for reviews, see Goodman et al., 2011; Tambelli, Cimino, Cerniglia, & Ballarotto, 2015), the precise mechanisms underlying this risk remain unclear. Within the broader depression literature, there is considerable evidence that stressful life events, particularly interpersonal stressors, increase risk for depression in youth (Ge, Lorenz, Conger, Elder, & Simons, 1994; Nolen-Hoeksema, Girgus, & Seligman, 1992; Rudolph et al., 2000). Traditionally, the association between stress and depression has been conceptualized as unidirectional, with theorists and researchers focusing on the impact of stress on depression risk. However, according to the stress generation hypothesis (Hammen, 1991), there is a bi-directional relation between stress and depression, where depressed and at-risk individuals may actively contribute to the generation of additional stress in their lives, as opposed to simply being exposed to elevated levels of stress. Supporting this hypothesis, there is evidence for stress generation in youth, such that depression diagnoses and elevated depressive symptom levels predict prospective increases in self-generated stress (see Liu & Alloy, 2010 for review). Therefore, when considering stress as a risk factor for youth depression, it is important

to consider the extent to which the stressor is at least partially dependent on the actions of the individual.

Interpersonal stress generation may be one mechanism underlying the intergenerational transmission of depression. For example, there is evidence that offspring of depressed mothers generate elevated levels of interpersonal stress in their lives (Adrian & Hammen, 1993; Feurer, Hammen, & Gibb, 2016), which may mediate the link between maternal and youth depression (Hammen, Shih, & Brennan, 2004). In addition, recognizing the variability in stress generation among offspring of depressed mothers, there is evidence that those who generate the highest levels of additional stress are at a greater risk for the onset of major depression during adolescence (Gershon et al., 2011). Therefore, it is important to identify markers of which offspring of depressed mothers are at greatest risk for stress generation.

According to Hammen's (1991) stress generation hypothesis, specific behaviors and characteristics of depressed individuals may increase their risk for stress generation. Indeed, a number of personality and interpersonal vulnerabilities associated with depression have been identified as potential predictors of stress generation (see Liu & Alloy, 2010 for review). For example, one study showed that youth who possess poor coping strategies (e.g. involuntary engagement) in response to social stressors generate elevated levels of interpersonal stress (Flynn & Rudolph, 2011). Because involuntary engagement with stressors involves automatic responses and heightened arousal (Flynn & Rudolph, 2011), it

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Conflict of interest statement: No conflicts declared.

may be that youth who react quickly and intensely to potentially negative interactions with others are most likely to generate interpersonal stress. Additionally, rejection sensitivity is associated with increased stress generation in adults (Liu, Kraines, Massing-Schaffer, & Alloy, 2014), suggesting that those who are quick to perceive rejection may also be more likely to generate interpersonal conflict. Taken together, these studies suggest that the way in which individuals perceive and react to interpersonal stimuli in their environment may play a role in stress generation, particularly within the interpersonal domain.

Pupil dilation is a peripheral index of neural reactivity to affective stimuli (Bradley, Miccoli, Escrig, & Lang, 2008). Additionally, pupil dilation to these stimuli is correlated with activation in brain regions associated with the regulation of emotions such as the dorsolateral prefrontal cortex (Siegle, Steinhauer, Stenger, Konecky, & Carter, 2003) and the anterior cingulate cortex (Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Urry et al., 2006). Supporting pupil dilation as a marker of depression risk, it has been shown to predict future onset of depression in offspring of depressed mothers (Burkhouse, Siegle, Woody, Kudinova, & Gibb, 2015). Therefore, it may be possible to use pupillometry to assess youths' affective reactivity to socially relevant stimuli (i.e. facial displays of emotion), and this may provide objective information about how youth respond to positive or negative social cues in their environment. In fact, previous research has shown that pupil dilation to peer rejection predicted feelings of social disconnect with peers in daily life (Silk et al., 2012), thereby demonstrating the utility of pupil dilation to socially relevant stimuli as a predictor of youth's real-world interpersonal functioning.

The goal of the current prospective study, therefore, was to examine whether heightened reactivity to affective stimuli, assessed via pupil dilation, predicts increases in youth's stress generation over a six-month follow-up. Building from research showing that offspring of depressed mothers generate more stress in their lives than offspring of never-depressed mothers, we hypothesized that any association between pupil dilation and stress generation would be stronger in offspring of depressed mothers. Consistent with the broader stress generation theory and literature, we also predicted that heightened pupil reactivity would predict increases in interpersonal, but not non-interpersonal, dependent stress. Finally, based on previous research highlighting potential characteristics and personality factors that may be associated with increased reactivity to negative interpersonal contexts (Liu & Alloy, 2010), we hypothesized pupil reactivity specific to negatively valenced emotional images (i.e. sad and angry faces but not happy faces) would be associated with increases in interpersonal stress generation.

Method

Participants

Participants in this study were 129 mother–child dyads participating in a larger longitudinal study on the intergenerational transmission of depression (for details, see Burkhouse, Siegle, & Gibb, 2014; Feurer et al., 2016). Mothers were recruited based on their history of major depressive disorder (MDD) as defined by the *Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition* (DSM-IV; American Psychiatric Association, 1994). Specifically, mothers had to have at least one episode of MDD during their offspring's lifetime ($n = 60$) or have no lifetime history of any DSM-IV mood disorder and any current Axis I disorder ($n = 69$). Exclusion criteria for both groups included symptoms of schizophrenia, alcohol or substance dependence within the last 6 months, or a history of bipolar disorder. If more than one child was eligible for the study, one child was randomly selected for participation. The average age of youth participants was 11.83 years ($SD = 1.89$, Range = 8–15), and 52.7% were female. In terms of race, 84.5% were Caucasian, 4.7% were African American, 9.3% were biracial, and 1.5% identified as another race. The average age of mothers in this study was 41.14 years ($SD = 6.89$, Range = 26–55), 90.7% were Caucasian, 3.9% were African American, 3.1% were biracial, and 2.3% identified as another race. The median family income was $55,001–$60,000.

Measures

Mothers' diagnoses of MDD and other Axis-I disorders were assessed at the initial assessment using the Structured Clinical Interview for *DSM-IV* Axis I Disorders (SCID-I; First, Spitzer, Gibbon, & Williams, 1995). As noted above, 60 mothers met criteria for MDD during their offspring's lifetime and 69 mothers had no lifetime history of any depressive disorder and no current Axis-I disorder. Within the maternal depression group, 12 mothers met criteria for current MDD and 43 had a history of recurrent MDD. Lifetime rates of anxiety disorders in mothers were: 13 with social phobia (12 MDD mothers), 15 with posttraumatic stress disorder (14 MDD mothers), 10 with panic disorder (all MDD mothers), 4 with obsessive-compulsive disorder (3 MDD mothers), 3 with agoraphobia (all MDD mothers), and 1 with generalized anxiety disorder (1 MDD mother). A subset of 20 SCIDs were rated by two independent coders to assess inter-rater reliability, yielding an excellent kappa for all diagnoses (all κs = 1.00).

Youths' depressive symptoms were assessed using the Children's Depression Inventory (CDI; Kovacs, 1981). The CDI is a self-report questionnaire, which the youth completed themselves or with the assistance of study personnel if needed. The CDI exhibited good internal consistency at both T1 ($\alpha = .86$) and T2 ($\alpha = .88$).

Youth's experiences of dependent and independent episodic life stressors were assessed using the UCLA Life Stress Interview for Children (LSI-C; Adrian & Hammen, 1993). This semi-structured interview is modeled after contextual threat interviews (Brown & Harris, 1978) and is used to probe for life events occurring in the 6 months prior to the assessment. At the initial assessment, youth and their mothers were interviewed separately about any stressful life events that may have occurred in the prior 6 months. At T2, participants were asked about any events experienced in the interim between their appointments. The dates of events reported at T2 were checked to ensure that they did not predate the T1 appointment, and therefore were not repeated from the T1 assessment. Interviewers asked about the occurrence of any life stressors within a variety of domains and probed any reported events for further objective information about the timing, duration, content, and context in which the stressor occurred. Each reported life event

was then presented to a team of coders, devoid of any subjective information. The team then assigned a negative impact stress score between 1 and 5 to each event. A score of '1' indicated no stress, whereas a score of '5' implied that the stressor was characterized by severe stress and significant impact. Coders also assigned a dependence score to each event to signify the extent to which the occurrence of an event was due to the actions of the participant. A dependence score of '1' indicated that the event was entirely independent of the youth, a score of '3' indicated mixed or indeterminate dependence, and a score of '5' indicated that the event was completely dependent on the youth. Consistent with previous studies, an event was classified as 'dependent' if the event received a dependence score of 3 or higher (Feurer et al., 2016; Flynn & Rudolph, 2011; Hammen, 1991; Rudolph et al., 2000). Finally, each stressor was also coded according to the content of the event, and was classified as either 'interpersonal' or 'non-interpersonal'. To create stress generation scores, negative impact stress scores were summed for dependent interpersonal, dependent non-interpersonal, and independent episodic stress.[1] Before summing the total amount of episodic stress for each category, the objective impact scores were recoded from 1–5 to 0–4 to avoid inflation of the total stress scores.

Youth's pupil dilation to facial displays of emotion was assessed at T1 within the context of a morphed faces computer task, in which youth were presented with emotional faces and were asked to identify the displayed emotion by pressing a button on a box. The stimuli were full-color pictures of actors taken from a standardized stimulus set (Matsumoto & Ekman, 1988) and included several emotional expressions (i.e. angry, happy, sad, neutral). Each emotion is represented by 4 continua (2 male and 2 female actors), for a total of 12 continua. Eleven morphed images were used from each continuum, representing 10% increments of the two emotions ranging from 100% neutral (0% target emotion) to 100% target emotion (e.g. 90% Neutral, 10% Sad; 80% Neutral, 20% Sad; and so on). Each morphed face was presented in the center of the computer screen in a random order for 3000 ms and followed by a fixation cross presented for 500 ms before the participant was asked to indicate if the face was angry, happy, sad, or neutral. The inter-trial interval varied between 750 and 1250 ms, and each participant completed a total of 264 trials (88 trials per emotion). Consistent with previous studies (Burkhouse et al., 2014, 2015; Kudinova et al., 2016), the morphed images were binned together into low (10%–30%), medium (40%–70%), and high (80%–100%) emotional intensity levels in order to have enough trials for pupillary analyses.

Pupil dilation was recorded during this task using Tobii T60 & T60XL eye-trackers (Tobii Technology, Inc, Falls Church, VA) while participants viewed the morphed faces in a moderately lit room. Pupil size was sampled by the eye-trackers at 60 Hz, and was recorded during the 3,000 ms during which the morphed face was presented on the screen. Data were cleaned using Siegle, Ichikawa, and Steinhauer's (2008) standard procedures, and trials were excluded if they were comprised of more than 50% blinks. Following standard procedures, linear interpolation was used to replace blinks and the data were smoothed using a 10-point weighted average filter. Effects associated with a light-reflex that were independent of stimulus type were removed by subtracting the mean waveform across all three valences from the average waveform for each valence (Franzen, Buysse, Dahl, Thompson, & Siegle, 2009). To calculate stimulus-evoked pupil dilation, data were resampled to 3 Hz (one sample every 333 ms). The average pupil diameter over the 333 ms before the presentation of the stimulus was subtracted from the pupil diameter after the stimulus onset in order to calculate stimulus-related pupil dilation. Next, the average pupil dilation for each trial was calculated by taking the average of the epochs within the 3,000 ms window of stimulus presentation. Finally, these dilation scores were averaged for each emotion. Consistent

with prior studies highlighting pupil reactivity to emotional faces at the highest, but not medium or low, levels of morphed intensity as potential mechanisms underlying the intergenerational transmission of depression (Burkhouse et al., 2014, 2015), we focused our analyses on pupil dilation to faces in this highest bin of emotional intensity.[2]

Procedure

Participants were recruited from the community through a variety of means including newspaper ads, bus ads, and flyers. Potential participants were screened over the phone to determine potential eligibility based on the inclusion/exclusion criteria noted above. Those meeting inclusion/exclusion criteria were invited to the laboratory for their initial assessment where informed consent and assent were obtained. At the initial assessment, maternal diagnoses of Axis I disorders were assessed using the SCID-I. During this time, youth completed the morphed faces computer task, during which their pupil dilation was recorded. Additionally, the LSI-C was conducted with both the mother and the youth separately to assess for episodic life stressors. The follow-up assessment was conducted 6 months later, at which point mothers and their offspring were again administered the LSI-C separately. Finally, youth completed the CDI at both assessments. All study procedures were approved by the University's Institutional Review Board.

Results

An initial inspection of the data revealed that each of the episodic stress variables exhibited significant positive skew ($z > 3.29$; cf. Tabachnick & Fidell, 2007). These variables were transformed prior to analyses to meet the assumptions of normality (square root: independent stress, CDI; inverse: dependent interpersonal stress, dependent non-interpersonal stress).[3] Descriptive statistics for all study variables are presented in Table 1. To facilitate comparisons with other studies, values presented in the table are based on untransformed data. As can be seen in the table, the MDD group was less likely to be Caucasian and had a lower family income than the nondepressed group. We then conducted exploratory analyses to determine whether there were demographic differences for any of the life stress variables. We found that Caucasian youth experienced significantly less dependent interpersonal stress at T2 than youth from other racial ethnic groups, $r = -.17$, $p = .05$. Additionally, family income was significantly related to both T1 dependent interpersonal stress, $r = -.20$, $p = .02$, and T2 independent stress, $r = -.34$, $p < .001$. Finally, youth age was correlated with T2 dependent non-interpersonal stress, $r = .17$, $p = .05$. Demographic variables were not significantly associated with any other life stress variables.

We then examined whether pupil reactivity to emotional faces predicted prospective increases in youth's dependent interpersonal stress and whether this relation was moderated by maternal history of MDD. For each regression conducted as part of these analyses, dependent interpersonal stress at T2 was entered as the outcome variable. The results of these

Table 1 Descriptive statistics for study variables

	Depressed mothers ($n = 60$)	Nondepressed mothers ($n = 69$)	$r_{effect\ size}$
Youth age	12.03 (2.01)	11.66 (1.77)	.10
Youth sex (% girls)	48.3%	56.5%	−.08
Youth race (% Caucasian)	76.7%	91.3%	−.20*
Family income (median)	$40,001–$45,000	$65,001–$70,000	−.27**
T1 CDI	7.30 (7.06)	3.64 (3.71)	.35**
T2 CDI	6.77 (7.17)	2.98 (2.78)	.33**
Average pupil (mm): angry	0.011 (0.027)	0.007 (0.026)	.06
Average pupil (mm): happy	−0.002 (0.033)	0.003 (0.028)	−.08
Average pupil (mm): sad	0.045 (0.027)	0.042 (0.026)	.05
T1 dependent interpersonal stress	1.18 (1.48)	0.38 (0.71)	.35**
T2 dependent interpersonal stress	0.84 (1.38)	0.28 (0.55)	.27**
T1 dependent non-interpersonal stress	0.34 (0.56)	0.18 (0.41)	.18*
T2 dependent non-interpersonal stress	0.36 (0.70)	0.18 (0.38)	.13
T1 independent stress	1.36 (1.34)	1.41 (1.47)	−.02
T2 independent stress	1.93 (2.25)	0.99 (1.12)	.23*

CDI, Children's Depression Inventory; T1, time 1. T2, time 2.
*$p < .05$; **$p < .01$.

Table 2 Summary of regression analyses predicting prospective increases in dependent interpersonal stress

	Angry				Happy				Sad			
Predictor	β	t	$r_{partial}$	ΔR^2	β	t	$r_{partial}$	ΔR^2	β	t	$r_{partial}$	ΔR^2
Step 1				.17**				.17**				.17**
Mom MDD	.15	1.78	.16		.15	1.78	.16		.15	1.78	.16	
T1 dependent interpersonal stress	.34	3.89**	.33		.34	3.89**	.33		.34	3.89**	.33	
Step 2				.01				.00				.00
Pupil dilation	.09	1.06	.09		−.01	−.14	−.01		.05	.56	.05	
Step 3				.04*				.01				.00
MDD × pupil	.28	2.44*	.21		.11	.89	.08		−.08	−.46	−.04	

MDD, major depressive disorder.
*$p < .05$; **$p < .01$.

regression analyses are presented in Table 2. As can be seen in the table, the maternal MDD × pupillary reactivity interaction was significant for angry, but not happy or sad, faces.

To examine the form of this interaction, we ran separate regressions for offspring of depressed and never-depressed mothers examining the impact of pupil reactivity to angry faces on prospective changes in dependent interpersonal stress. For each regression, T2 dependent interpersonal stress was entered as the outcome variable and T1 dependent interpersonal stress and pupil dilation to angry faces were entered as predictor variables. Results indicated that, for offspring of depressed mothers, greater pupil dilation to angry faces predicted prospective increases in interpersonal stress generation from T1 to T2, $t(57) = 2.22$, $p = .03$, $r_{partial} = .28$. However, pupil dilation to angry faces did not predict changes in dependent interpersonal stress for offspring of never-depressed mothers, $t(66) = −1.11$, $p = .27$, $r_{partial} = −.14$. The impact of pupil reactivity to angry faces on prospective changes in youth's dependent interpersonal stress among offspring of depressed mothers was maintained even after statistically controlling for the influence of (a) pupil dilation to happy and sad faces, (b) T1 and T2 CDI scores, (c) race/ethnicity

(coded dichotomously as Caucasians vs. youth from other racial/ethnic groups), and (d) family income (all ps < .05).

Next, we examined the specificity of our findings to dependent interpersonal stress versus other forms of episodic stress (dependent non-interpersonal stress and independent stress). These analyses mirrored those reported above for dependent interpersonal stress. For dependent non-interpersonal stress, the only significant finding was a main effect of T1 dependent non-interpersonal stress on T2 dependent non-interpersonal stress, $t(126) = 3.10$, $p = .002$, $r_{partial} = .27$. For independent stress, the only significant finding was a main effect of maternal MDD on prospective changes in independent stress, $t(126) = 2.68$, $p = .01$, $r_{partial} = .23$. In these analyses none of the pupil main effects or pupil × maternal MDD interactions were significant (lowest $p = .17$).

Finally, we examined whether youth's age or sex moderated any of the relations examined. The only significant effect was a maternal MDD × pupil dilation to happy faces × age interaction predicting increases in youth's dependent interpersonal stress, $t(120) = 3.01$, $p = .003$, $r_{partial} = .27$. Probing this interaction revealed a significant pupil × age interaction for offspring of nondepressed, $t(64) = −2.45$, $p = .02$, $r_{partial} = −.29$, but not depressed,

$t(55) = 1.96$, $p = .06$, $r_{\text{partial}} = .26$, mothers. Turning next to the main effect of pupil dilation on increases in youth's dependent interpersonal stress for older and younger (median split) offspring of never-depressed mothers, we found that blunted pupil dilation to happy faces predicted increases in dependent interpersonal stress for older, $t(31) = -2.74$, $p = .01$, $r_{\text{partial}} = -.44$, but not younger, $t(32) = 1.19$, $p = .24$, $r_{\text{partial}} = .21.$, youth. No other main or interaction effects were moderated by either youth age or sex.

Discussion

The goal of this study was to examine whether youth's reactivity to affective stimuli (i.e. pupil dilation to emotional faces) predicted interpersonal stress generation and whether this effect may be stronger for offspring of depressed mothers than offspring of never-depressed mothers. We found that offspring of depressed mothers who displayed an increased pupillary response to angry faces showed an increase in interpersonal stress generation across the follow-up. Importantly, the association between pupillary reactivity to angry faces and increases in stress generation remained significant for offspring of depressed mothers while statistically controlling for the influence of pupil dilation to happy and sad faces. Therefore, for offspring of depressed mothers, the association between heightened pupil dilation to emotional faces and increases in youth's interpersonal stress generation was specific to angry faces, and was not due to increased reactivity to emotional faces in general. Furthermore, the association between pupil dilation to angry faces and interpersonal stress generation remained significant when controlling for youth's depressive symptoms, suggesting that this association is at least partially independent of youth's depressive symptoms. In addition, consistent with stress generation models, youth's pupillary reactivity to angry faces predicted prospective changes in dependent interpersonal stress but not other forms of episodic stress (dependent non-interpersonal or independent stress).

Our findings contribute to a growing body of research suggesting that markers of interpersonal sensitivity, specifically heightened reactivity to signs of potential interpersonal conflict, are associated with stress generation. Previous studies have shown that interpersonal vulnerabilities, such as maladaptive responses to interpersonal stress (Flynn & Rudolph, 2011) and rejection sensitivity (Liu et al., 2014), predict stress generation. Furthermore, research has shown that rejection sensitivity predicts hostile responses to ambiguous interpersonal situations in youth (Romero-Canyas & Downey, 2005). One interpretation of the current findings is that individuals who are sensitive to cues of rejection may be hyper-reactive to signs of interpersonal stress, thereby leading to automatic responses and hostility which may generate additional stress.

Similarly, it may be that youth who display heightened reactivity to angry faces detect interpersonal conflict more readily than others, and thereby react in such a way that exacerbates the stress.

Although a number of studies have sought to identify markers of risk for stress generation, the current study is the first to do so in offspring of depressed mothers. Interpersonal stress generation has been hypothesized to be one mechanism in the intergenerational transmission of depression (Hammen et al., 2004) and it is important to identify which of these at-risk youth are most likely to generate elevated levels of stress. The current study identifies heightened pupillary reactivity to angry faces as one mechanism implicated in increased stress generation among offspring of depressed mothers. If replicated, interventions designed to target heightened reactivity to angry cues in the environment may be one promising way to reduce depression risk among offspring of depressed mothers.

We should also note that, in contrast to our hypothesis, heightened pupillary reactivity to sad faces was not associated with increases in stress generation for offspring of depressed mothers. Although increased pupil dilation to sad faces has been identified as a predictor of depression risk for offspring of depressed mothers (Burkhouse et al., 2015), pupillary reactivity to angry faces appears to be a better marker of risk for stress generation, perhaps because it signals a heightened reactivity to potential signs of interpersonal conflict, which the youth then acts upon. Consistent with this hypothesis, there is evidence that individuals displaying a hostile, but not sad, mood experience elevated levels of dependent stress (Sahl, Cohen, & Dasch, 2009). This said, it is also possible that heterogeneity in the presentation of maternal depression will contribute to differential patterns of risk. For example, pupillary reactivity to angry faces may be a stronger predictor of interpersonal stress generation among offspring of mothers whose depression is characterized primarily by irritability, whereas pupillary reactivity to sad faces may be a stronger predictor in offspring of mothers whose depression is primarily characterized by withdrawal and sad affect. Future studies, with a more precise characterization of maternal depression, are needed to answer this important question.

It is also important to note the results of the exploratory analyses, which showed that blunted pupil dilation to happy faces predicted increases in interpersonal stress generation for older offspring of never-depressed mothers. Conclusions from these analyses must remain tentative pending replication. This said, there is evidence that decreased social reward reactivity may be associated with lower social proficiency (Gossen et al., 2014). It may be that youth who exhibit blunted reactivity to happy faces are less socially competent. It is possible, therefore, that this lack of proficiency contributes to an increase in stress generation within social settings,

particularly for older youth, as social stress responses increase across the transition to adolescence (Stroud et al., 2009).

Key strengths of this study included the use of a prospective design to assess for increases in stress generation across a 6-month follow-up, interview-based measures of dependent life stress, and objective measurements of reactivity to emotional faces. However, there were also some limitations that highlight important areas of future research. First, although we can hypothesize that heightened pupillary reactivity to angry faces may lead to increased stress generation through the quick detection of and hyper-reactivity to interpersonal conflict, we cannot draw any definitive conclusions about specific mechanisms underlying this relation. Future studies are needed to identify the specific the mechanisms underlying the association between pupillary reactivity to angry faces and interpersonal stress generation. We should also note that our sample included relatively large age range of youth (aged 8–15 at the initial assessment). Although this was an explicit decision so that we could focus on the transition from childhood to adolescence, which is marked by increased pupillary reactivity to emotional stimuli (Silk et al., 2009) as well as increased physiological reactivity to stress (Stroud et al., 2009), larger multi-wave longitudinal studies are need to determine whether the predictive utility of pupil dilation for interpersonal stress generation changes as children age into adolescence. Additionally, because of the low base rates of non-interpersonal independent stress, we combined non-interpersonal and interpersonal independent stress for analyses and were not able to analyze them separately, which may have limited our ability to test the association between pupillary dilation and increases in independent stress. Finally, although pupillary reactivity to angry faces provided strong predictive validity for stress generation, it is possible that lower-cost assessments (e.g. self-report of rejection sensitivity) may perform as well. This said, there are well-known response and recall biases associated with self-report measures as well as some evidence that physiological and neural indices may provide better predictive validity than self-report or clinician-rated indices (Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015). Future research is needed to compare the differential predictive validity of these measures to determine which is best able to identify youth at greatest risk for stress generation.

In conclusion, the current findings extend previous research on interpersonal stress generation (for a review, see Liu & Alloy, 2010) by showing that heightened pupillary responses to angry faces may help to identify which offspring of depressed mothers are at the greatest risk for prospective increases in interpersonal stress generation. If replicated, pupillary reactivity to angry faces may serve as an important marker of risk for stress generation in offspring of depressed mothers. Furthermore, this heightened reactivity may be targeted in preventative interventions to reduce risk for stress generation. By decreasing the occurrence of dependent interpersonal stress, which has been implicated as a mechanism in the intergenerational transmission of depression (Hammen et al., 2004), such interventions may have a significant impact in breaking the cycle of depression transmission within high-risk families.

Correspondence

Cope Feurer, Department of Psychology, Binghamton University (SUNY), Binghamton, NY 13902-6000, USA; Email: efeurer1@binghamton.edu

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Key points

- Interpersonal stress may mediate the relation between maternal and child depression, but it is unclear which at-risk offspring are more likely to generate elevated levels of interpersonal stress in their lives.
- This study examined whether pupil dilation to emotional interpersonal stimuli predicted increases in stress generation for children of depressed mothers.
- Pupil dilation specifically to angry faces (not happy or sad) predicted increases in interpersonal stress generation for children of depressed mothers.
- Increased pupil dilation to angry faces may be a potential risk factor which could be used to identify which children of depressed mothers may be at increased risk for interpersonal stress generation.

Notes

1. Because the majority of participants reported no independent non-interpersonal life stressors at T1 (76.0%) and T2 (75.2%), we did not differentiate between interpersonal and non-interpersonal independent stress and instead focused on overall levels of independent stress.

2. Furthermore, the pupil dilates in response to stimuli that require greater cognitive load or that have greater emotional intensity (Beatty & Lucero-Wagoner, 2000; Siegle, Steinhauer, & Thase, 2004; Siegle et al., 2003; Silk et al., 2009; Steidtmann, Ingram, & Siegle, 2010). Therefore, using all morph levels would have confounded our results as it would require greater cognitive load to identify emotions morphed at lower levels. Given the primary aim of the current study was to investigate pupil dilation in response to emotional intensity, the current analyses focused solely on high levels of morph.

3. The T2 Dependent Interpersonal, T1 Dependent Non-Interpersonal, and T2 Dependent Non-Interpersonal stress variables did not reach our criteria for normality ($z < 3.29$) following inverse transformations (zs = 4.00, 6.05, and 7.00, respectively). However, because the inverse transformations resulted in lower skew statistics than any of the other transformations, these are what was used for all analyses.

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