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Developmental Variation in the Associations of Attention Bias to Emotion with Internalizing and Externalizing Psychopathology

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Abstract

Attention biases to emotion are associated with symptoms of internalizing and externalizing psychopathology in children and adolescents. It is unknown whether attention biases to emotion and their associations with different symptoms of psychopathology vary across development from early childhood through young adulthood. We examine this age-related variation in the current study. Participants ($N = 190$; ages: 4–25) completed survey-based psychopathology symptom measures and a dot-probe task to assess attention bias to happy, sad, and angry relative to neutral faces. We tested whether linear or non-linear (e.g., spline-based models) associations best characterized age-related variation in attention to emotion. We additionally examined whether attention biases were associated with depression, anxiety, and externalizing symptoms and whether these associations varied by age. No age-related differences in attention biases were found for any of the emotional faces. Attention biases were associated with psychopathology symptoms, but only when examining moderation by age. Biased attention to angry faces was associated with greater symptoms of anxiety and depression in adolescents and young adults, but not children. Similarly, biased attention to happy faces was associated with externalizing symptoms in adolescents and young adults, but not in children. In contrast, biased attention to happy faces was associated with greater anxiety symptoms in children, but not in adolescents or young adults. Biased attention toward social threat and reward becomes more strongly coupled with internalizing and externalizing symptoms, respectively, during the transition to adolescence. These findings could inform when interventions such as attention bias modification training may be most effective.

Keywords Attention bias to emotion · Development · Internalizing psychopathology · Externalizing psychopathology

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Social information processing theories posit that individual differences in perception, attention, and memory for emotionally salient stimuli can contribute to the development of psychopathology (Clark & Beck, 1999; Huesmann, 1998; Lemerise & Arsenio, 2000; Mogg & Bradley, 1998; Pollak, 2003). Specifically, biased attention towards negative emotional stimuli has been associated with both internalizing and externalizing problems in adults (Armstrong & Olatunji 2012; Mellentin et al., 2015) as well as in children and adolescents (Cremone et al., 2018; He et al., 2017; Lau & Waters, 2017). However, it is unclear how biased attention to emotion changes across development and whether these patterns of attention to emotion exhibit

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age-related variation in their associations with different symptoms of psychopathology. The present study addressed this gap by examining developmental variation in attention biases to emotional faces and in the association of these attention biases with symptoms of internalizing and externalizing psychopathology in a community sample spanning childhood, adolescence, and young adulthood.

The ability to appropriately detect and attend to social-emotional information, including facial expressions of emotion, is critical for guiding adaptive behaviors across development (Crone & Dahl, 2012). However, relatively little is known about how biased attention towards negative emotional cues emerges across development, and existing research examining developmental changes in attention to emotion has yielded mixed findings. Numerous studies have reported the presence of an attention bias towards threatening stimuli (i.e., fearful and angry faces) in preferential attention tasks as early as infancy (see Fu & Pérez-Edgar, 2019; Morales et al., 2016 for reviews). However, whether this bias persists after infancy remains unclear. Some studies using dot-probe and visual search tasks have found that attention biases towards threatening faces remains stable from childhood to adulthood (Burris et al., 2017; Lindstrom et al., 2009; LoBue, 2009; Waters & Lipp, 2008), but other studies using emotional Stroop and dot-probe tasks (Lonigan & Vasey, 2009; Reinholdt-Dunne et al., 2012) have found decreasing attentional biases from late childhood into adolescence. Findings on attention biases to positive stimuli across development are also mixed. Although there is evidence for an attention bias towards happy faces in infancy and early childhood (Burris et al., 2017; Pecchinenda & Petrucci, 2019), some studies find that this bias decreases from childhood into adolescence (Broeren & Lester, 2013; Reinholdt-Dunne et al., 2012), and others find an increase in this age range (Lindstrom et al., 2009). Given these mixed empirical findings, more research is needed to clarify whether attention biases to emotion vary across age.

Age-related differences in biased attention to emotion may be related to the development of attentional control, or the ability to flexibly shift attention towards or away from stimuli, a cognitive skill that improves with age (Casey et al., 2002; Rueda et al., 2004). In particular, the ability to appropriately utilize context, (e.g., social and emotional information), when regulating attention continues to develop through adolescence and into young adulthood (Cohen Kadosh et al., 2014; Marotta & Casagrande, 2017; Tottenham et al., 2011). In this case, biased attention to emotion would be expected to decrease with age as cognitive control skills develop. On the other hand, initial orienting to emotional faces—the stage of attention examined in most studies of attention bias to emotion—may be driven largely by non-volitional attentional processes that have little developmental variation following infancy (Brodeur & Enns, 1997; Posner et al., 2012; Rueda et al., 2004), and thus may not be useful for determining individual differences in attention bias to emotion related to age. If so, developmental differences in attention bias to emotion would not be expected past very young childhood. In sum, there is a need for further investigation as to whether attention biases to emotion change across relevant development timeframes, including childhood, adolescence, and young adulthood. The present study aims to do so.

Biased attention to emotional cues has been associated with internalizing (i.e., depression and anxiety) and externalizing (i.e., aggression and oppositionality) psychopathology and is thought to influence symptom onset and maintenance (Armstrong & Olatunji, 2012; Cremone et al., 2018; Lau & Waters, 2017; Mellentin et al., 2015). A strong association between anxiety and biased attention towards threatening stimuli has been documented in adult samples across task (i.e., visual search, dot-probe, free viewing) and stimuli (i.e., pictures, words, faces) type (Armstrong & Olatunji, 2012; Bar-Haim et al., 2007). However, research suggests this association may be less robust in youth samples (Dudeney et al., 2015), with several studies of anxious youth also showing attention biases away from threatening faces in dot-probe tasks (Brown et al., 2013; Monk et al., 2006; Pine et al., 2005; Salum et al., 2013; Waters et al., 2014). Biases both away and towards threat may be associated with cognitive processes (e.g., heighted threat detection, disruptions in threat-safety cue discrimination) and subsequent behavioral patterns (e.g., avoidance of perceived threats) that contribute to the etiology and maintenance of anxious symptoms (Cisler & Koster, 2010; Fu & Pérez-Edgar, 2019; Waters & Craske, 2016). For example, biased attention towards threat cues in a social situation may lead youth to overestimate an immediate risk of peer rejection and subsequently engage in maladaptive avoidant behaviors.

Associations between attention bias and depression symptoms have been similarly inconsistent. Attention bias to mood-congruent stimuli in depression is characterized by selective attention towards and difficulty disengaging from negative stimuli; accordingly, these biases may serve as a behavioral indicator of cognitive mechanisms that have been well established as underlying the onset and maintenance of depression (e.g., rumination) (Armstrong & Olatunji, 2012; Joormann & Gotlib, 2010; Lau & Waters, 2017). Indeed, depression has been associated with both biased attention towards dysphoric stimuli (e.g., sad faces) and away from positive stimuli (e.g., happy faces) across task type in adult samples (Armstrong & Olatunji, 2012; Peckham et al., 2010). Among youth, some studies observe biased attention toward sad stimuli across task and stimuli type (Hankin et al., 2010; Sylvester et al., 2016; see Platt

et al., 2017; Lau & Waters, 2017 for reviews), while others demonstrate no association between attention to either positive or negative words and depression across several tasks (i.e., emotional Stroop, dot-probe, and memory tasks) (Dalgleish et al., 2003; Neshat-Doost et al., 2000). Evidence for biases towards angry faces have been found in a limited number of studies with depressed youth (Platt et al., 2017), but meta-analyses indicate no association between attention to threatening stimuli and depression in adults (Armstrong & Olatunji, 2012; Peckham et al., 2010).

Fewer studies have examined associations between biased attention to emotion and externalizing symptoms. Findings from adult studies indicate that trait and state anger and aggression are associated with biased attention towards threatening faces, words, and scenes (Cohen et al., 1998; Mellentin et al., 2015; Van Honk et al., 2001), and similar findings have been observed in early childhood (ages 3 to 5 years; Nozadi et al., 2018) and late childhood (ages 8 to 12 years; Miller & Johnston, 2019). In line with social-cognitive theories of aggression (e.g., Crick & Dodge, 1994), attention bias to threatening cues (e.g., angry faces) may increase the likelihood of perceiving threat in potentially ambiguous situations, which may contribute to more aggressive and externalizing behaviors. Externalizing problems have also been associated with attention towards positive or rewarding stimuli (e.g., happy faces) in adults completing a passive viewing eye tracking task (Ford et al., 2010, 2012) and children in spatial cueing and dot-probe tasks (Cremone et al., 2018; He et al., 2017; Morales et al., 2019; Morales et al., 2016). Specifically, in non-clinical samples of young children, attending to happy faces has been linked to both concurrent (Cremone et al., 2018; Morales et al., 2019; Morales et al., 2016) and future externalizing behaviors (He et al., 2017; Morales et al., 2019). Biased attention to socially rewarding information may arise from increased sensitivity to rewarding stimuli, often observed in youth exhibiting externalizing behaviors (He et al., 2017; Hundt et al., 2008). To date, the developmental scope of this work has been limited to early and late childhood, so research with a broader age range is needed.

Inconsistencies in empirical evidence within the attention bias and psychopathology literature suggest the need to study these associations in a sample spanning childhood, adolescence, and young adulthood. Associations between biased attention to emotion and psychopathology symptoms may vary across childhood through adulthood as youth experience increasingly complex social-emotional contexts and acquire the skills to effectively regulate their attention and emotional responses. In particular, the transition across adolescence marks a developmental period of heightened sensitivity to social-emotional information, like emotional faces (Blakemore, 2012; Crone & Dahl, 2012; Nelson et al., 2016; Somerville, 2013). This elevated sensitivity to the emotional expressions of others may confer advantages for social functioning (Crone & Dahl, 2012; Rosen et al., 2018). On the other hand, youths who already exhibit attention biases to emotional cues may experience an increased risk for psychopathology specifically during adolescence, which is a period known to involve increased exposure to emotionally evocative interpersonal stressors (Clarke, 2006; Larson & Ham, 1993; Larson & Lampman-Petraitis, 1989; Rudolph, 2002; Rudolph & Hammen, 1999). However, few studies have empirically examined how associations between attention bias to emotion and psychopathology symptoms vary with age.

Still two studies in community samples of youth ages 6- to 18- (Abend et al., 2018; emotional face dot-probe task) and 6- to 12-years old (Hadwin et al., 2009; emotional face Stroop task) found no evidence of developmental variation in the association between attention bias to threat and anxiety. However, a recent meta-analysis examining attention to threat in youth diagnosed with an anxiety disorder found that anxious youth (ages 5 to 18 years-old) demonstrated a bias towards threat that increased with age compared to non-anxious youth (Dudeney et al., 2015) across a variety of task types and emotional stimuli. As the transition from childhood into adolescence is marked by a significant increase in the presence of both externalizing and internalizing disorders (Kessler et al., 2005), the present study aims to extend previous work in community samples by understanding whether biased attention to emotion may become more strongly associated with psychopathology symptoms including not only anxiety, but also depression and externalizing symptoms, during the transition to adolescence and into young adulthood.

The current study evaluated age-related variation in attention biases to positive and negative emotion—including angry, sad, and happy faces—in a large developmental sample spanning early childhood through young adulthood (i.e., ages 4- to 25-years-old). Additionally, we evaluated whether associations of attention biases with symptoms of depression, anxiety, and externalizing behaviors differed across this age range. We assessed age-related differences in attention biases by estimating a series of progressively more complex polynomial regression models (i.e., linear, quadratic, cubic) of age in relation to attention bias to emotion. Next, we examined associations of attention biases with symptoms of psychopathology, including internalizing (i.e., anxiety and depression), and externalizing problems. We expected that attention biases towards negative emotional stimuli (i.e., angry and sad faces) would be associated with internalizing and externalizing problems. We also expected that depression symptoms would be associated with attention biases away

from positive emotional stimuli (i.e., happy faces), and that externalizing problems would be associated with heightened attention towards positive emotional stimuli. Finally, we explored whether associations between attention biases and psychopathology symptoms varied as a function of age. We expected that the association between attention bias to emotion and internalizing and externalizing symptoms would be stronger in adolescents and young adults as compared to children.

Method

Participants

Data were drawn from a study designed to examine age-related variation in multiple emotional processes in individuals between the ages of 4 and 25 years ($n = 203$) (Nook et al., 2017; Nook et al., 2018). A total of 190 participants completed the attention bias task reported in the present manuscript (age range = 4.13–25.91; $M_{age} = 14.51$, $SD_{age} = 5.85$; 50.00% female; 60.0% Caucasian, 14.7% African American, 1.1% American Indian/Alaskan Native, 12.6% Asian/Pacific Islander, 8.9% Hispanic, 2.1% Other). Reasons for exclusion from the final sample included technical issues with the task or equipment ($n = 7$), noncompliance ($n = 4$), and difficulty understanding task instructions ($n = 2$).

Participants were recruited from communities surrounding Harvard University and the University of Washington. All participants were native English speakers, were compensated for their time, and provided informed written consent/assent or received written permission for their participation from a parent or legal guardian. The Committee on the Use of Human Subjects at Harvard University and the Institutional Review Board at the University of Washington approved all research procedures.

Measures

Due to the validated age ranges of measures (outlined below), we administered certain surveys to a subset of our sample. Specifically, we assessed self-reported anxiety symptoms in participants ages 8 to 25 years old ($n = 148$); self-reported depression symptoms in participants ages 7 to 25 years old ($n = 158$); externalizing problems in participants ages 4 to 18 years old (parent report only for ages 4 to 6 and combined parent and self-report for ages 7 to 18; $n = 128$). We utilized child-report only for internalizing symptom measurement and combined parent- and child-report for externalizing symptom measurement due to research showing the addition of parent-report improves validity of assessing externalizing problems (Bird et al., 1992; Grills & Ollendick, 2002), but that children are more valid reporters of internalizing symptoms (Aebi et al., 2017; Cantwell et al., 1997; Moretti et al., 1985). We administered a modified dot-probe task to assess attention biases to emotional faces in all participants ages 4 to 25 years old ($n = 190$). The dot-probe task using emotional faces has been widely used as a measure of biased attention to emotional stimuli from early childhood to adulthood (Abend et al., 2018; Briggs-Gowan et al., 2016; Gibb et al., 2009; Hankin et al., 2010; Morales et al., 2016).

Anxiety Symptoms. Anxiety symptoms in participants aged 8 to 17 were assessed with the Screen for Child Anxiety Related Emotional Disorders (SCARED; Birmaher et al., 1997), which measures anxiety disorder symptoms across five domains: panic/somatic, generalized anxiety, separation anxiety, social phobia, and school phobia. Anxiety symptoms in participants aged 18 to 25 were measured with the State Trait Anxiety Inventory (STAI; Spielberger, 2010). The SCARED and STAI have good psychometric properties (Birmaher et al., 1997; Julian, 2011) and demonstrated excellent internal consistency in the current sample (SCARED: $\alpha = 0.93$; STAI: $\alpha = 0.94$). The total scores for both the SCARED and STAI were z-scored in order to create a standardized anxiety symptom score that could be compared across age groups. Higher anxiety symptom scores reflected greater anxiety symptoms.

Depression Symptoms. Depression symptoms in participants aged 7 to 17 were assessed with the Children's Depression Inventory (CDI; Kovacs, 1992), a widely used self-report measure of depressive symptoms in children and adolescents. Depression symptoms in participants aged 18 to 25 were measured with the Beck Depression Inventory (BDI; Beck et al., 1996). The CDI and BDI have demonstrated good reliability and validity among children and adolescents (Craighead et al., 1998) and adults (Steer et al., 1997). The CDI and BDI demonstrated excellent internal consistency in our sample (CDI: $\alpha = 0.90$; BDI: $\alpha = 0.87$). The total scores for both the CDI and BDI were z-scored in order to create a standardized depression symptom score that could be compared across age groups. Higher depression symptom scores reflected greater depression symptoms.

Externalizing Symptoms. Externalizing symptoms were assessed using the Externalizing Problems scale from both child reports on the Youth Self-Report (YSR) among participants aged 6 to 18 and caregiver reports on the Child Behavior Checklist (CBCL; Achenbach, 1991) among participants aged 4 to 18. The YSR/CBCL scales are among the most widely used measures of youth emotional and behavioral problems and use extensive normative data to generate age-standardized estimates of symptom severity. The raw total score from the externalizing

problems composite is standardized to generate the age- and sex-normed T-score. We followed standard practice for combining parent and child report (Merikangas et al., 2010) by using the highest score on the Externalizing Problems scale from either the child (YSR) or parent report (CBCL) for participants aged 6–18 and parent report only for participants aged 4–5.

Attention Bias Task. Attention biases for emotional faces were assessed using an modified visual dot-probe task (MacLeod et al., 1986) administered with MATLAB. Stimuli consisted of face pairs consisting of one emotional (angry, sad, or happy) and one neutral face, or two neutral faces. Photographs within a face pair were from the same actor; images of 32 actors (16 female) were taken from a standardized stimulus set (Tottenham et al., 2009).

The task included 8 practice trials followed by two experimental blocks of 56 trials each. Stimulus pairs were presented in random order over the two blocks. Each trial began with a central fixation cross presented for 500 ms, followed by emotional-neutral (or neutral–neutral) face pair presented for 500 ms, followed immediately by a star (the probe) for 1100 ms. The intertrial interval ranged from 750 to 1250 ms. The star appeared in the space previously occupied by the center of one of the two face pictures. Emotional faces were presented with equal frequency on either the right or left side of the screen. The star appeared with equal frequency in the location of the emotional or neutral face. Youth were instructed to indicate as quickly as possible, while avoiding mistakes, the location of the star (left or right side of the screen) using a keyboard press ("a" for left and "l" for right). The computer recorded the accuracy and response time for each response.

Consistent with prior studies using the dot-probe task, trials were excluded from analysis if responses were not given, inaccurate, less than 200 ms, or less than or greater than 2 SD from each participant's mean response time (Gulley et al., 2014; Pérez-Edgar et al., 2011; Pine et al., 2005). Overall accuracy was high across emotion types, ranging from 96.1% to 96.4%. Mean attention bias scores were calculated separately for each emotion stimulus type (angry, sad, or happy) by subtracting the mean response time for cases in which the star replaced the emotional face from mean response times for cases in which the star replaced the neutral face (Mogg et al., 1995). Once an overall bias score was calculated, we excluded individual participants whose bias scores were greater or less than 2.5 SD from the sample mean per emotion type. This resulted in 8 participants excluded from analysis of attention to sad faces, 5 excluded from analysis of attention to angry faces, and 3 excluded from analysis of attention to happy faces.

Scores were standardized for all analyses. In all figures, higher scores indicate greater attention to the emotional face relative to other participants in the sample, while lower scores indicate less attention to the emotional face relative to other participants in the sample.

Data Analysis

Prior to data analysis, all variables were inspected for assumptions of normality, and no concerns were noted. All variables were standardized prior to data analysis. In order to include a broad age range across analyses, composite psychopathology symptom scores were computed by taking the z-score of child and adult measures (e.g., the depression symptom scores include z-scores on the CDI and BDI).

Main Effects of Age on Attention Bias. To identify whether there were age-related differences in attention biases to emotion we used an analytic approach previously used to examine age-related variation (Nook et al., 2020). We tested whether linear, quadratic, cubic, or other non-linear associations (i.e., spline-based model) best fit age-related patterns for each attention bias to emotion variable. We used linear regression with the *poly* function in R's base statistics package (R Core Team, 2016) to test for linear, quadratic, and cubic age-related patterns in the data. Quadratic and cubic models contained lower-order age terms, and the *poly* function transformed polynominal age terms into orthogonal covariates of interest. For example, the quadratic model included linear and quadratic age regressors, and the cubic model included linear, quadratic, and cubic age regressors. Finally, we used generalized additive modeling (GAM) to test for age-related patterns that did not fit linear, quadratic, or cubic patterns. Thin plate regression smoothing spline analyses were used to create regression equations fitting the data via cross-validation procedures that penalize for the number of parameters to prevent overfitting. These models produce a stable smooth curve that identifies age-related patterns without being limited to linear, quadratic, or cubic shapes (Wood, 2003). Spline analyses were conducted using the *mgcv* package in R (Wood, 2017).

The best fitting model was determined by comparing linear, quadratic, cubic, and spline models to a null (i.e., intercept only) model using Akaike Information Criterion (AIC) values (Akaike, 1974). AIC values provide a measure of goodness of fit that takes into account the number of parameters with lower AIC values indicating better model fit.

Main Effects of Attention Bias on Psychopathology Symptoms. We used linear regression to examine associations between attention bias and psychopathology

symptoms. Separate models were estimated for attention bias to each emotion (i.e., happy, sad, and angry faces) predicting each outcome (i.e., anxiety, depression, and externalizing symptoms). All models included age and sex as covariates.

Age-related Variation in Attention Biases and Psychopathology Symptoms. Moderation models were estimated utilizing the PROCESS Macro Version 3.0 (Hayes ,2017) in SPSS to determine whether the association between attention bias to emotion and psychopathology symptoms was moderated by age (PROCESS Model 1). Separate regression models were estimated with the attention bias variable for each emotion (i.e., happy, sad, and angry faces) as the independent variable and each psychopathology (i.e., anxiety, depression, and externalizing) symptom score as the dependent variable. All models simultaneously included the attention bias variable and age as main effects, the interaction of the attention bias variable and age, and sex as a covariate. In accordance with McCabe's (2018) approach to regions of significance testing, we inspected and visualized significant moderations by probing simple slopes at 1.5 SD and 1 SD below the mean, at the mean, and at 1SD and 1.5 SD above the mean of age. Significant interactions were further explored using regions of significance according to the Johnson-Neyman (J-N) technique (Bauer & Curran, 2005; Johnson & Fay, 1950). This procedure uses regression parameters to derive values of a continuous moderator (i.e., age) at which the conditional effect of the focal predictor (i.e., attention bias scores) on the dependent variable (i.e., psychopathology symptoms) transitions from nonsignificant to significant. Applied to the present study, the J-N technique indicated at what age the association between attention bias to emotion and psychopathology symptoms became significant.

Results

Descriptive Statistics

Descriptive statistics are presented in Table 1 and Supplemental Fig. 1 and correlations for variables of interest are presented in Supplemental Table 1.

Main Effects of Age on Attention Bias

The null (intercept only) model was the best fitting model across all three attention bias to emotion variables (i.e., happy, sad, and angry biases) indicating no main effect of age on attention bias to emotion. Results of the null, linear, quadratic, cubic, and spline models are presented in Table 2 and the best fitting model for each emotion type is presented in Fig. 1a-c. In order to better understand our null effects, we conducted equivalence testing (Lakens et al., 2020; Schuirmann, 1987), which provides information about whether we can reject the hypothesis that there is a meaningfully large linear effect (i.e., larger than a small effect of ± 0.2; see Supplement for details).

Main Effects of Attention Bias on Psychopathology Symptoms

We estimated separate linear regression models, each controlling for age and sex, to examine associations between attention biases to happy, sad, and angry faces and psychopathology symptoms (anxiety, depression, and externalizing). No significant associations emerged between attention biases and psychopathology symptoms (|bs|= -0.002-0.39, *p*s = 0.14-0.99).

Age-related Variation in Attention Biases and Psychopathology Symptoms

Next, we estimated separate regression models to examine age as a moderator of associations between attention biases to each emotion and psychopathology symptoms (controlling for sex). Age moderated the association between attention bias towards anger and depression (b = 0.50, $p = 0.01$) and anxiety (b = 0.54, $p = 0.02$)

Table 1 Descriptive Statistics

Variable	Mean	SD	Min	Max
Age	14.24	5.94	4.13	25.91
Depression	–	–	–	–
CDI	6.18	6.41	0	36
BDI	5.56	6.23	0	26
Anxiety	–	–	–	–
SCARED	13.72	11.82	0	60
STAI-T	17.20	11.33	0	51
Extern	52.72	8.17	34	79
Sad Bias	-1.43	51.37	-368.92	165.16
Angry Bias	12.65	52.89	-183.03	436.82
Happy Bias	6.60	98.86	-407.04	1124.60

Psychopathology variables reflect raw scores

CDI children's depression inventory, *BDI* beck's depression inventory, *SCARED* screen for child anxiety and related emotional disorders, *STAI-T* state-trait anxiety inventory-trait, Extern = YSR/CBCL externalizing t-score;

Table 2 Results of null, polynomial, and thin plate smoothing spline models for each dependent variable

Dependent Variable	Model	*b*	*95% CI*	*p*-value	AIC
Happy Bias	Null				
	Linear	0.31	[-0.69, 1.32]	0.539	258.44
	Quadratic	-0.50	[-1.53, 0.52]	0.335	259.49
	Cubic	0.55	[-0.48, 1.58]	0.291	260.35
	Spline				258.44
Sad Bias	Null				
	Linear	0.16	[-1.28, 1.60]	0.824	369.94
	Quadratic	0.15	[-1.33, 1.63]	0.841	371.89
	Cubic	-0.05	[-1.53, 1.43]	0.948	373.89
	Spline				369.94
Angry Bias	Null				
	Linear	-0.52	[-1.90, 0.85]	0.454	366.61
	Quadratic	-0.75	[-2.16, 0.66]	0.295	367.50
	Cubic	-0.17	[-1.60, 1.26]	0.819	369.44
	Spline				366.61

symptoms (Supplemental Tables 2-3). Attention bias to anger was positively associated with depression (Fig. 2a) and anxiety (Fig. 2b) symptoms in adolescents and young adults at ages 14.68 and 17.75 years-old and older, respectively (Supplemental Figs. 2–3). Additionally, attention bias to anger was negatively associated with

Fig. 1 Age-related pattern of attention bias to emotion. Thin plate regression smoothing splines revealed that the null (intercept only) model was the best fitting model for **a** happy, **b** sad, and **c** angry bias indicating no main effect of age on attention bias to emotion. Note. Attention bias scores are standardized with higher attention bias scores indicating greater attention to the emotional face relative to other participants in the sample and lower scores indicating less attention to the emotional face relative to other participants in the sample

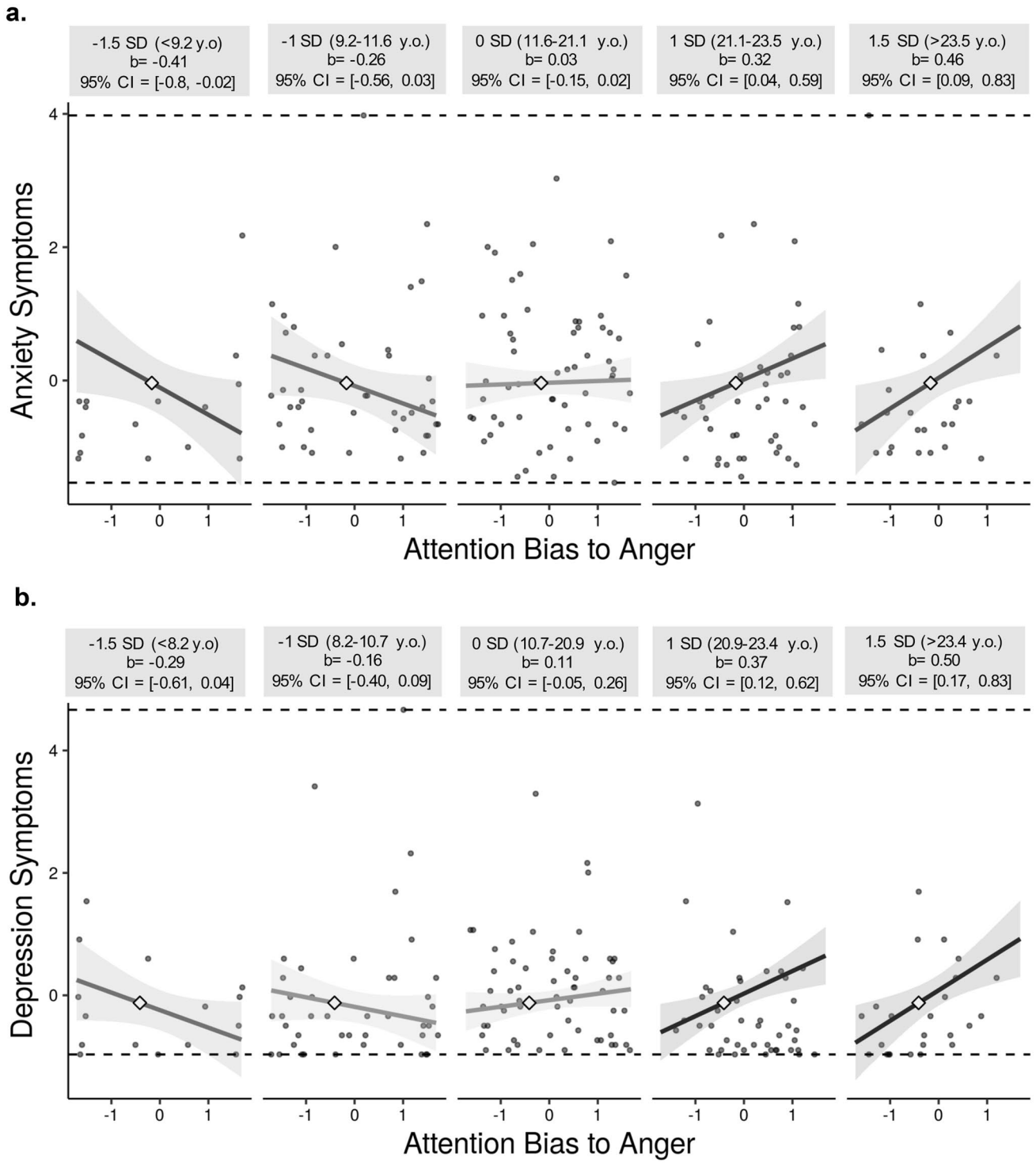

Fig. 2 Age moderates associations between attention bias to angry faces and **a** anxiety symptoms and **b** depression symptoms. Note: Attention bias scores are standardized with higher attention bias scores indicating greater attention to the emotional face relative to other participants in the sample and lower scores indicating less attention to the emotional face relative to other participants in the sample. Visualized associations between symptoms and attention bias are separated by panels that represent age at -1.5, -1, 0, 1, and 1.5 SD from the mean. Line color indicates the size of the effect with darker lines indicating a larger effect. y.o.= years-old

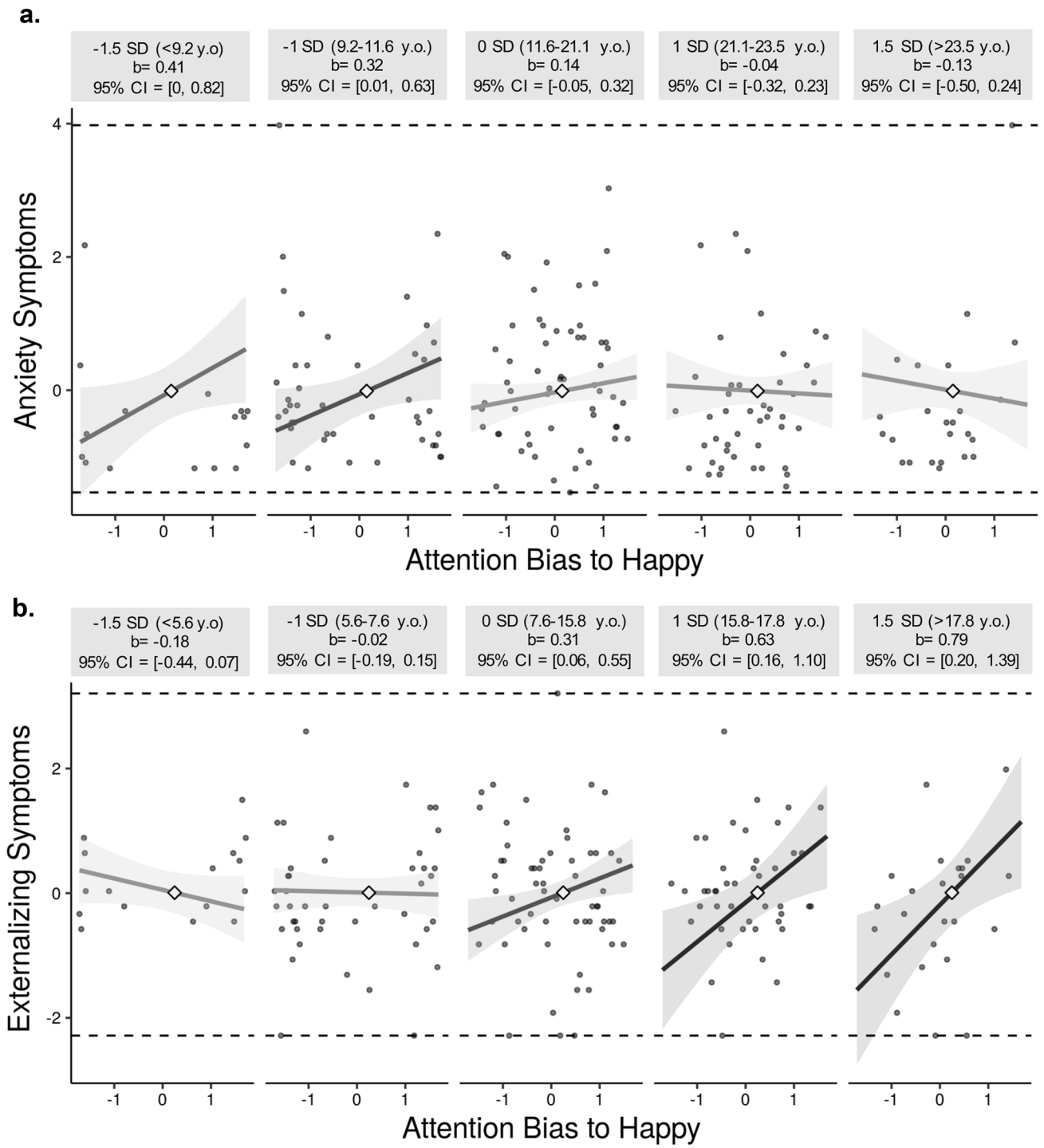

Fig. 3 Age moderates associations between attention bias to happy faces and **a** anxiety symptoms and **b** externalizing symptoms. Note: Attention bias scores are standardized with higher attention bias scores indicating greater attention to the emotional face relative to other participants in the sample and lower scores indicating less attention to the emotional face relative to other participants in the sample. Visualized associations between symptoms and attention bias to emotion are separated by panels representing age at -1.5, -1, 0, 1, and 1.5 SD from the mean age. Line color indicates the size of the effect with darker lines indicating a larger effect. y.o.= years-old

anxiety symptoms in young children (Fig. 2b) J-N regions of significance testing indicated this effect was marginally significant for children aged 8 years-old ($p = 0.08$).

Age moderated the association between attention bias towards happy faces and anxiety symptoms (b = -0.74, $p = 0.04$) (Supplemental Table 3; Fig. 3a) Specifically, attention bias to

happy faces was positively associated with anxiety symptoms only for children age 10.72 years-old and younger, but not adolescents or young adults (Supplemental Fig. 4).

Age moderated the association between attention bias to happy faces and externalizing symptoms (b = 1.20, $p = 0.00$; Supplemental Table 4, Fig. 3b) There was a positive association between attention to happy faces and externalizing symptoms only during late childhood, adolescence and young adulthood at age 9.33 years-old and older, but not during early childhood (Supplemental Fig. 5). These results were unchanged when removing children ages 4–5 years-old who were unable to complete the YSR due to developmental constraints (See Supplement).

No significant interactions between age and attention bias to sad stimuli emerged. As such, the associations between attention to sad stimuli and psychopathology symptoms did not vary by age (|bs|= 0.07-0.42, $ps = 0.06$-0.74; Supplemental Tables 2-4).

Discussion

In this study, we used a large sample spanning childhood to young adulthood to clarify three research questions: (i) are there developmental differences in attention bias to emotional stimuli, (ii) are there broad relationships between psychopathology symptoms and attention biases regardless of age, and (iii) do associations between attention biases and psychopathology symptoms vary across age? We found no associations of age with attention bias to emotion from ages 4 to 25, suggesting that these biases may develop early in childhood and remain relatively stable thereafter. However, we observed consistent age-related variation in the association between attention bias to emotion and psychopathology symptoms across childhood, adolescence, and young adulthood. Specifically, greater attention towards angry faces was positively associated with internalizing symptoms and greater attention towards happy faces was positively associated with externalizing symptoms in adolescents and young adults, but not children. Further, greater attention toward happy faces was positively associated with anxiety symptoms in children, but not in adolescents or young adults. These findings suggest developmental differences in the link between attention biases to emotional stimuli and psychopathology symptoms, which may inform when certain interventions, such as attention bias modification training, may be most effective.

In line with some previous developmental work, we did not find direct associations between age and attention bias to emotion (Lindstrom et al., 2009; Waters et al., 2010). Early orienting to emotional faces may be primarily supported by non-volitional attentional processes. Attentional orienting to sensory stimuli, like emotional faces, has been shown to develop before early childhood and remain fairly stable across development (Brodeur & Enns, 1997; Posner et al., 2012; Rueda et al., 2004), which could explain why we did not find significant variation by age. Further, equivalence testing determined it is unlikely that there is a meaningful effect of age on attention bias to emotion. Additionally, greater variability in attention bias to emotion was observed among younger versus older age groups. It is possible that this increased variability in attention bias is driven by greater variability in other developmental processes supporting task performance, such as fine motor control or response inhibition, across younger versus older individuals. Thus, further work measuring and adjusting for these constructs as well as assessing differences in attention bias to emotion across various stimuli durations is needed for firm conclusions.

We extend upon previous findings showing positive associations between internalizing symptoms and biased attention to negative emotional faces (e.g., Lau & Waters, 2017; Sylvester et al., 2016) by demonstrating that greater attention to faces signaling social threat (i.e., angry faces) was positively associated with both anxiety and depression symptoms in adolescents and young adults, but not in children. While few studies have examined attention to social threat and internalizing symptoms in a broad developmental range, our findings are generally consistent with the extant attention bias literature showing that adolescents and adults with internalizing psychopathology exhibit heightened detection (Heuer et al., 2010; Jenness et al., 2014; Reeb-Sutherland et al., 2015), attention (Cisler & Koster, 2010; Dudeney et al., 2015), and reactivity (Beesdo et al., 2009) to information signaling threat in the environment. Similar to our findings, meta-analytic work examining studies of youth age 5 to 18 years-old suggests that the positive association between anxiety and attention to threatening stimuli strengthens across age (Dudeney et al., 2015). This pattern could reflect that the enhanced sensitivity to social information that characterizes adolescence (Blakemore, 2012; Somerville, 2013) may become maladaptive for youth who exhibit biased attention towards threatening social information. We also observed a developmental shift in the association between attention bias to social threat and anxiety such that greater attention *away* from angry faces predicted higher anxiety symptoms during childhood, though this effect was marginally significant when region of significance was probed.

While many studies have examined attention bias to threatening information in anxious youth, attention bias to threat is a relatively understudied topic in youth depression (Lau & Waters, 2017). Over-attending to anger may play

a role in both depression and anxiety maintenance by contributing to a transactional cycle of detecting social threat within the environment followed by maladaptive behavioral patterns commonly observed with internalizing difficulties, such as anxious avoidance and social withdrawal related to anhedonia (e.g., Dickson & MacLeod, 2004). Overall, our findings suggest that adolescence and young adulthood are points in development when attention biases to social threat may first begin to have negative influences on mental health.

Greater attention to happy faces was positively associated with anxiety symptoms in children but not adolescents or young adults. Although less is known about associations between biased attention to positive emotional stimuli and anxiety, a few studies have found anxious children attend to happy faces more than non-anxious controls (M. L. Reinholdt-Dunne et al., 2012; Waters et al., 2010). In line with our results, Reinholdt-Dunne et al. (2012) found attention to both angry and happy faces was associated with greater trait anxiety only among younger, but not older, youth in a sample spanning ages 7 to 14 years-old. It is unclear how anxious children perceive and interpret happy faces. However, findings in adults suggest that happy faces may signal the possibility of a social interaction (Schofield et al., 2013; Wieser et al., 2009), which could increase anxious symptoms when considering the prospect of social evaluation (Lau & Waters, 2017). Further research is needed to better understand the biases in detection, processing, and interpretation elicited when anxious children attend to positive emotional faces.

We extended past research showing a direct association between greater attention to happy faces and externalizing symptoms (e.g., Morales et al., 2016) by demonstrating this effect was specific to adolescents and young adults but not children. Our work builds on prior literature showing associations between sensitivity to rewards and externalizing psychopathology (Gudiño et al., 2012; Hundt et al., 2008). Heightened sensitivity to social reward cues, like happy faces, may increase risk for engaging in problematic behaviors often associated with externalizing psychopathology, such as drug use or illegal activity (Brown et al., 1996; Fergusson et al., 2007; Mordre et al., 2011). Adolescence may be a particularly risky time for youth who exhibit attention biases for socially rewarding cues as this developmental period is characterized by heightened sensitivity to reward coupled with incomplete maturation of cognitive control ability to regulate impulsive behaviors and emotions (Galvan et al., 2006; Schreuders et al., 2018; Somerville et al., 2011; Somerville & Casey, 2010). These patterns of attention bias to social reward in the context of lower cognitive control may increase risk for externalizing symptoms.

Our findings may have implications for mental health interventions. Biased attention to emotion has been identified as a treatment target for internalizing disorders in youth and adults. Attention bias modification therapy (ABMT) aims to improve anxiety and depression symptoms by retraining attention away from negative emotional stimuli (e.g., angry or sad faces or words, respectively) and toward positive or neutral stimuli using dot-probe tasks (e.g., Hallion & Ruscio, 2011; Lowther & Newman, 2014). Findings examining the effectiveness of ABMT to treat internalizing symptoms have yielded inconsistent results in both symptom attenuation and altering bias direction for adults and youth (e.g., Cristea et al., 2015; Fodor et al., 2019; Grist et al., 2019; Hakamata et al., 2010; Lowther & Newman, 2014; Yang et al., 2016), with some meta-analytic evidence for small, but more consistent effects for treatment of anxiety versus depression symptoms (Fodor et al., 2019; Hallion & Ruscio, 2011; Jones & Sharpe, 2017). Inconsistent findings may partially result from a lack of consideration of developmental changes in associations between attention bias to emotion and psychopathology. We are unaware of any studies examining whether ABMT improves externalizing problems across any age. Findings from the current study point toward the significance of considering both timing and type of attention bias to emotion as relates to specific symptoms of psychopathology. Future work is needed to determine whether the effectiveness of ABMT extends to externalizing problems and may be improved by considering the developmental time frame of intervention delivery.

There are several limitations to the current study. While the present study included a broad developmental range of participants, data were collected only at one time-point. Due to our cross-sectional design, we were unable to determine the directionality of the association between attention bias to emotion and psychopathology symptoms or whether developmental findings were driven by cohort effects. Prospective studies are needed to better understand the temporal association between attention bias to emotion and psychopathology across development. Further, we utilized self-report measures of internalizing and externalizing symptoms. While our measures were well-validated and reliable assessments of psychopathology symptoms, future work utilizing concurrent interview-based measures is necessary to determine whether findings also apply to clinical levels of psychopathology. Further, it was necessary to utilize different validated questionnaires based on a participant's age and standardize scores on these measures in order to examine age moderation across a wide developmental timeframe. It is possible that this approach may introduce bias into our findings due to utilizing different psychopathology measures based on age. Finally, the dot-probe task relies on accuracy and response times as indirect measures of attentional deployment and is unable to measure the time course of attention allocation, like eye tracking methods (Eizenman et al., 2003; Hermans et al., 1999). Additionally, previous

research has demonstrated that attention bias patterns may differ depending on the task utilized (e.g., Isaacowitz et al., 2015; Morales et al., 2017). Consequently, there is a need for developmentally informed studies using tasks that offer a more temporally precise assessment of attention, such as eye-tracking methodologies (Kowler et al., 1995).

The present study advances our understanding of how attention biases to emotional cues are associated with a broad range of psychopathology symptoms across development. We extend prior work by documenting that greater attention to cues signaling social threat is associated with internalizing symptoms while greater attention to social reward is associated with externalizing symptoms during adolescence and young adulthood. Greater attention towards happy faces, potentially a marker of social evaluation, was associated with anxious symptoms in children, but not adolescents or young adults. Clinical implications of findings include the consideration of developmental timing in the study of interventions that target attention bias to emotion, such as attention bias modification training.

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Data Availability and Material Available upon request to senior authors.

Compliance with Ethical Standards

Ethics Approval The Committee on the Use of Human Subjects at Harvard University and the University of Washington Institutional Review Board approved all research procedures.

Consent to Participate All participants consented to participate.

Consent for Publication All participants consented to have de-identified data published.

Conflict of Interest None to disclose.

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