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Profiles of Naturalistic Attentional Trajectories Associated with Internalizing Behaviors in School-Age Children: A Mobile Eye Tracking Study

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Abstract
The temperament profile Behavioral Inhibition (BI) is a strong predictor of internalizing behaviors in childhood. Patterns of attention towards or away from threat are a commonality of both BI and internalizing behaviors. Attention biases are traditionally measured with computer tasks presenting affective stimuli, which can lack ecological validity. Recent studies suggest that naturalistic visual attention need not mirror findings from computer tasks, and, more specifically, children high in BI may attend less to threats in naturalistic tasks. Here, we characterized latent trajectories of naturalistic visual attention over time to a female stranger, measured with mobile eye tracking, among kindergarteners oversampled for BI. Group-based trajectory modeling (GBTM) revealed two latent trajectories: 1) high initial orienting to the stranger, gradual decay, and recovery, and 2) low initial orienting and continued avoidance. Higher probability of membership to the "avoidant" group was linked to greater report of internalizing behaviors. We demonstrate the efficacy of mobile eye tracking in quantifying naturalistic patterns of visual attention to social novelty, as well as the importance of naturalistic measures of attention in characterizing socioemotional risk factors.

Keywords Behavioral inhibition · Internalizing behaviors · Eye tracking · Attention trajectories · Affect-biased attention · Ecological validity

Introduction

Behavioral inhibition (BI) is a temperament profile characterized by wariness to novelty, particularly social novelty (Kagan et al., 1988; Rubin et al., 2002). BI is also a well-documented risk factor for social anxiety disorder in childhood and adolescence (Chronis-Tuscano et al., 2009; Clauss & Blackford, 2012; Hirshfeld et al., 1992). However, not all children who are high in BI develop impairing symptoms of anxiety (Degnan & Fox, 2007), presenting an interesting situation of multifinality in which children with a seemingly similar temperamental profile considered a "risk" do not all present the same maladaptive developmental outcomes. Thus, there is the open question of what additional characteristics may act as protective factors in some children or exacerbate risk in others.

A body of literature suggests that attention biases to threat may moderate the relation between BI and maladaptive developmental outcomes such as anxiety (Pérez-Edgar et al., 2010, 2011). For example, Pérez-Edgar and colleagues found that an attention bias to threat as measured by the dot probe task moderated the relation between BI and social withdrawal in both young childhood (Pérez-Edgar et al., 2011) and adolescence (Pérez-Edgar et al., 2010). Attentional biases to threat may also in part characterize the BI phenotype (Pérez-Edgar et al., 2010; Shackman et al., 2009; Szpunar & Young, 2012), where these exaggerated responses to threatening emotional stimuli can be seen both behaviorally and neurally (Pérez-Edgar et al., 2010, 2011; Shackman et al., 2009; Szpunar & Young, 2012).

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Additionally, BI children may (mis-) interpret social novelty as a potential threat (Fox et al., 2005). Attention bias to a perceived threat may hinder competing adaptive behaviors, such as socializing with peers, and negatively impact socioemotional functioning (Henderson & Wilson, 2017). Attention biases to threat are also considered a characteristic of anxiety disorders in both adults and children (Roy et al., 2008) and may contribute to the etiology of anxiety disorders (Lonigan et al., 2004). Lonigan et al. (2004) suggest that high levels of attention allocated to negatively valenced stimuli may potentiate negative affect, a hallmark of BI, and promote the experience of anxiety. However, the mixed nature of these findings characterizing associations between BI, attention biases, and social (mal)adaptation across different methods and samples suggest that there may be variability in how these measures relate as a function of developmental stage (Field & Lester, 2010; Stuijfzand et al., 2020) or of tasks used to operationalize these constructs.

It is critical to note that other work suggests that BI and symptoms of anxiety may also be marked by *avoidance* of stimuli identified as threatening. Socially anxious individuals show behavioral avoidance of both negative and positive faces (Heuer et al., 2007), as well as avoidance of eye contact (Schneier et al., 2011; Weeks et al., 2013), and higher levels of experiential avoidance (Kashdan et al., 2014). These avoidant tendencies may also be part of the etiology of internalizing symptomology (Kashdan et al., 2014). Anxious individuals may avoid a stimulus with the aim of mitigating distress but may do so even when the stimulus is indeed "safe" and poses no detriment to their wellbeing (Kashdan et al., 2014).

A unifying feature in the literature suggesting that biases toward and away from threat are characteristic of internalizing behaviors is the nondiscriminatory nature of these biases, such that a child may either misclassify a stimulus as threatening or overextend a fear response to stimuli that are actually benign. Rigidity in attentional patterns and a lack of adaptability to context may constrain an individual's social functioning, perpetuating maladaptive behaviors often to the point of distress and disorder (Henderson & Wilson, 2017; Kashdan et al., 2014). The variability of the findings across this area of research emphasizes the need for continued work in examining the best way to effectively measure attentional biases and the nature of their interaction with socioemotional development.

Many of the tasks classically used to assess attention bias towards or away from threat present emotionally valenced stimuli on a computer screen. These include the dot probe, emotional Stroop, emotional visual search, and emotional spatial cueing (e.g., Affective Posner) tasks (Fu & Pérez-Edgar, 2019). However, these paradigms often come at a cost to ecological validity. That is, attention to static emotional stimuli, often stereotyped facial configurations (Barrett et al., 2019), may not readily translate to attention bias in the "real world" (Ladouce et al., 2017; Risko et al., 2016).

The lack of correspondence between the attention patterns noted here and patterns generated by computer-based tasks are part of a growing body of research. In an overlapping sample of children with the current study, Fu and colleagues (2019) found that BI and non-BI children were differentiated by the number of gaze shifts toward a stranger during a live social interaction, but not by attention bias to threat on a computerized dot probe task. In other work, within a sample of both neurotypical (NT) adolescents and adolescents on the autism spectrum, Grossman et al. (2019) found that gaze to an experimenter's face during a live action task was significantly related to gaze during a stationary computer eye tracking task with comparable stimuli only among the NT adolescents. Moreover, the NT participants and participants with autism were distinguished by gaze patterns during the screen-based task, but not during the live action task. Furthermore, Isaacowitz et al. (2015) found that while stationary eye tracking suggests a visual attention bias towards positive stimuli in older adults, this pattern is not evident in more naturalistic gaze paradigms where the quantity of visual stimuli is less constrained. Finally, recent work suggests that infants (Franchak et al., 2017), children (MacNeill et al., 2021), and adolescents (Woody et al., 2020) in fact do not spend a large proportion of time attending to their caregivers' faces, contrary to the bias to faces that is often implied in developmental literature based on stationary tasks. Hence, we cannot assume that gaze patterns towards static social stimuli are generalizable to real-life social interactions across all participants, emphasizing the importance of better characterizing gaze patterns in more true-to-life paradigms.

Finally, traditional screen-based laboratory assessments of attention biases to threat typically focus only on momentary presentations of emotionally-valenced stimuli, often averaging these metrics of attention over trials for analysis. Therefore, we have a limited understanding of how attention to a perceived threat may change over a more prolonged period of exposure. An emerging body of work speaks to the potential richness of microlongitudinal data, using repeated sampling to examine how looking behavior may change over the duration of a task rather than relying on an aggerated measure (e.g., Gregory et al., 2019). Moreover, patterns identified over time may be used to characterize individual differences, suggesting the utility of these less traditional analytic approaches.

Specifically, in the domain of visual attention and anxiety, Gregory et al. (2019) showed high and low socially-anxious adults a video of a social exchange and measured eye movements during viewing. They found that high socially-anxious individuals looked more at faces in the video than low socially-anxious individuals only during the first two seconds of the video, with no significant differences between groups on any other metric. Examining attention to faces on a more true-to-life time course is another step in improving the ecological validity of this line of research and may help to identify differences amongst individuals that may not be immediately apparent with more traditional summary statistics.

Leveraging mobile eye tracking technology, the current study examined profiles of trajectories of naturalistic visual attention to a novel adult social figure over a prolonged period of time in early school age children (mean age 6 years). In doing so, we also examined whether these visual attention profiles moderated the known relation between BI and internalizing behaviors in young children and compared whether these trajectories characterized internalizing risk differently than aggregate measures of attention captured during the same task. We focused on this age range because it is prior to the onset of many anxiety disorders (Beesdo et al., 2009), but is often marked by emerging patterns of social withdrawal as children navigate more complex social environments than previously encountered (e.g., formal school settings; Rubin et al., 2009). This age allowed us to examine patterns of gaze that were related to BI as well as anxiety risk, but not necessarily functionally-impairing levels of anxiety.

Given the novelty of mobile eye-tracking and evidence that measures of naturalistic attention may not correlate with attention patterns seen with static, screen-based stimuli (Fu et al., 2019; Grossman et al., 2019), the study is inherently exploratory in nature. Previous work on attention bias to threat in relation to BI and social maladaptation (Pérez-Edgar et al., 2010, 2011) suggests that biased attention to social threat as measured by screen-based tasks would strengthen the relation between BI and internalizing behaviors. However, keeping in mind the discontinuities between screen-based measurements attention and naturalistic attention, as well as findings by Fu et al. (2019), we expect that (1) BI would be associated with greater levels of internalizing behaviors as compared to non-BI children, (2) this relation would be strengthened among children with high probability of displaying an avoidance attention profile to the female stranger (i.e., social novelty) over the course of the episode, and (3) will do so above and beyond variance captured by aggregated measures of attention, such as average gaze to the female stranger over time. We also expect that (4) avoidant patterns of attention conferring risk will be specific to the female stranger and not another highly salient yet non-social object in the room, specifically the Hungry Hungry Hippos toy.

Method

Participants

Participants in the final analyses were 43 children ranging from 5- to 7- years of age (M = 6.21 years, *SD* = 0.60, 47.7% female) identifying as White (88.3%, *n* = 38), Asian (4.7%, *n* = 2), African American (2.3%, *n* = 1), Hispanic (2.3%, *n* = 1), and other (2.3%, *n* = 1), reflecting the demographics of the surrounding semi-rural community. Children and their parents were recruited using a University database of families expressing interest in participating in research studies, as well as community outreach and word-of-mouth. We oversampled for high levels of BI via the Behavioral Inhibition Questionnaire (BIQ; Bishop et al., 2003), such that 14 children (32%) in the final sample were classified as BI. Exclusion criteria for enrollment in the study included non-English speakers, gross developmental delays, or report of severe neurological or medical illnesses. All study procedures were approved by the Institutional Review Board at Penn State University. All parents and children completed written consent/assent and were compensated for their time.

Potential participants (163 children) were pre-screened for levels of parent-reported BI via the BIQ (Bishop et al., 2003). Consistent with the previous literature (Broeren & Muris, 2009; Fu et al., 2019; Poole et al., 2020), children were recruited as a BI participant if their total BIQ score was greater than or equal to 119, and/or if their social novelty subscale score was greater than or equal to 60. Of the 163 children screened, 39 (24%) met the criteria for classification as BI.

Based on a priori planning and grant funding, we aimed to recruit approximately 100 children to the study. 23 children were brought in as pilot participants. An additional 70 children were brought to the lab to complete a battery of episodes assessing different aspects of social novelty, including the "Stranger Working" episode included in these analyses (described further below). Twenty of these 70 children met criteria for BI classification (29%). The mean age of the sample was 6.11 years (*SD* = 0.60) with 34 females (48.8%). The sample predominantly identified as White (*n* = 61, 87.1%).

Of the 70 non-pilot participants, children were excluded from the final analysis for methodological reasons: 24 participants were excluded for poor calibration and/or tracking, one participant was excluded because the stranger was not "novel" to the child, one participant was excluded for technical problems, and one child was randomly selected and excluded for being the twin of another participant. This resulted in 27 excluded participants. In selecting participants for use in the final analysis, we were conservative in setting a threshold for data quality so as to minimize noise in the data, excluding participants where a calibration could not be agreed upon by two independent coders (see methods section/supplement for more details). There were no significant differences in BI or internalizing behaviors between the included and excluded participants, except that the participants excluded (M_{age} = 5.95, *SD* = 0.56) were younger than the participants included (M_{age} = 6.21, *SD* = 0.60) in the analysis at trend level, $t(69)$ = -1.85, p = 0.07. A visualization of participant recruitment can be seen in the supplement (Fig. S1).

Procedure

Prior to arrival to the laboratory, parents completed a series of online questionnaires about themselves and their children.

Temperament and Internalizing Behaviors. The child's level of BI and count of internalizing behaviors were measured via parental report. BI was measured via the Behavioral Inhibition Questionnaire (BIQ; Bishop et al., 2003). The BIQ includes 30 questions that assess the parent's report of the child's response to novelty (i.e., "(My child) will happily approach a group of unfamiliar children to join in their play"), using a likert scale ranging from 1 ("Hardly Ever") to 7 ("Almost Always"). While the BIQ was used to recruit participants and enrich the sample categorically, BI was assessed as a continuous variable in the analyses, such that children with a higher score displayed higher levels of BI behaviors. The mean BIQ score was 92.30 (*SD* = 27.45). The BIQ had good internal consistency in this study (Cronbach's α = 0.95).

Internalizing behaviors were measured via the internalizing subscale of the Child Behavior Checklist (CBCL; Achenback & Edelbrock, 1983) and assessed as a continuous variable, such that higher values reflected a higher count of reported internalizing behaviors. Due to the non-clinical nature of our sample, the T-scores for internalizing behaviors were not normally distributed. We used count of behaviors rather than T-scores to increase analytic variability. The mean count of internalizing behaviors in this sample was 5.73 (*SD* = 4.68, *range* = 0—25). The internalizing subscale of the CBCL also had good internal consistency in this study (Cronbach's α = 0.84). We did compute T scores for the sample for both internalizing and externalizing behaviors due to high comorbidity (Willner et al., 2016). All children were below the clinical cutoff for both internalizing ($M_{t\ score}$ = 43.86, *SD* = 8.64, *range* = 27–65) and externalizing ($M_{t\ score}$ = 46.12, *SD* = 9.06, *range* = 29–65) problems.

Ambulatory Eye Tracker. Participants wore a Pupil binocular ambulatory eye tracker (Pupil Labs; Kassner et al., 2014). The headset consists of two separate cameras, each pointing at an eye, as well as a camera centered on the space immediately in front of the child which captured their "world view". Data were recorded either with Pupil Capture v.0.9.6 (Pupil Labs) installed on a Microsoft Surface Pro 3 tablet with Windows 10 (n = 10), which the child carried the tablet in a school backpack, or with Pupil Capture v.0.9.12 (Pupil Labs) installed on a MSI VR One Backpack PC also running Windows 10 (n = 33). The experience with each system was nearly identical, in that the child carried a computer on their back, but the MSI VR One Backpack was a more streamlined setup for both the experimenter and the participant. There were no significant differences in the proportion of data collected for either setup, $t(42)$ = 0.58, p = 0.57. In order to allow for the real-time monitoring of data quality during the experiment, a monitor located in a separate room was remotely connected to the PC enclosed within the backpack. The headset plus the backpack were light enough so as not to hinder the naturalistic movement of children throughout the session.

Similar to stationary eye tracking paradigms, 5-point gaze calibration was completed using a large projection screen after the eye tracker and backpack were placed on the child. Children participated in other "games" as part of the larger study (e.g., Fu et al., 2019; MacNeill et al., 2021, see supplement for complete list of measures collected), until they were led to the room for the current task of interest. Prior to the task, gaze was validated to five points on a large bullseye held in front of the child at varying distances, matching the distances of areas of interest in the task. A five-point calibration/validation was selected based on procedures in previously published mobile eye tracking paradigms (i.e., Franchak, 2017).

Stranger Working Episode. The Stranger Working episode (adapted from Buss, 2011) was used to assess the child's attention to social novelty over time (http://bit.ly/MET_OSF). In this episode, the child is seated in front of a game of "Hungry Hungry Hippos." However, the marbles necessary to play the game are not present. The primary experimenter departs, saying that they will go find the marbles, at which point an unfamiliar female stranger enters the testing room. The stranger has the marbles in hand as well as some paperwork. The female stranger introduces herself and takes a seat in the room. The marbles are placed on the table, in clear view of the child. The stranger completes the paperwork and does not engage with the child unless the child initiates conversation. After two minutes, the stranger says goodbye and departs.

We intentionally chose an episode in which the stimulus was ambiguous in hopes of drawing out greater individual differences. Specifically, as mentioned in the introduction, BI children have a higher propensity to misinterpret social ambiguity and novelty as social threat (Fox et al., 2005). Rather than using a stimulus that was unequivocally threatening, which would likely yield relative homogeneity in responses, focusing on a social stimulus that was socially ambiguous provides a wider variety of responses (Buss et al., 2011).

To generate as much consistency as possible between participants, the female stranger was provided a timeline for her movements throughout the room, as well as standardized responses to give to the child. If the child asked for the marbles during the episode, the experimenter was to give them to the child. Coding of the episode began when the female stranger first opened the door to enter the testing room and ended when the door closed upon the female stranger's departure. This standardization yielded relatively similar episode times for each child ($M = 2.4$ min; $SD = 6$ s). Four female research assistants acted as the primary experimenter in the current sample. Gender was constrained due to lab staffing, but also allowed for maximum continuity across participants. Twelve research assistants acted as the female stranger (gender of the stranger was specified in Buss et al., 2011).

Eye Tracking Data Processing. In order to measure gaze to objects in the room, we overlaid gaze data on the child's world view as three concentric circles with crosshairs, using Pupil Player v.0.9.12 (Pupil Labs) (Fig. 1).

Gaze was also corrected to validation targets using Pupil Player v.0.9.12 (Pupil Labs). Before the task, the experimenter cued the child's attention to 5 points along a target while the child was instructed to look where they were pointing (http://bit.ly/MET_OSF). Two independent coders examined each validation procedure to ensure that the indicated points were within the yellow circle of the gaze bullseye.

If gaze was discrepant from the cued locations in a consistent fashion (i.e., consistently skewed to the left), gaze corrections could be made using the manual gaze correction plug-in in Pupil Player. Gaze corrections were completed by two trained independent coders, who adjusted the positioning of the concentric circles/bullseye to make sure that the indicated points were within the yellow circle of the bullseye. If corrections were within 0.03 units of each other on either the x or y axis, the master coder's corrections were used. If the discrepancy was greater than 0.03 units on the x or y axis, the two coders conferenced to determine the best gaze correction. Following agreement, the video was exported with the corrected gaze and synced with synchronous room recordings using Final Cut Pro, and exported at a resolution of 1920 × 1080 pixels at 30 frames per second. If the coders could not agree on a correction that allowed for the indicated points to be within the yellow circle of the gaze bullseye, the participant was removed from the sample for poor calibration/tracking (N = 24).

Mobile eye tracking video data were coded frame-by-frame using Datavyu (Datavyu Team, 2014), using methods in published studies (i.e., Franchak et al., 2011; Fu et al., 2019; Kretch et al., 2014; MacNeill et al., 2021). Gaze to the following AOIs were coded continuously: the stranger, the marbles, the Hungry Hungry Hippos toy, and the room. Frames in which the yellow circle of the crosshairs was not visible were marked as "indeterminate" and thus not usable data. A primary coder coded 100% of each video, and a secondary coder coded at least 20% of each video, to ensure reliability. Coders agreed on an average of 97.3% of frames.

Data were parsed into one-second epochs using custom scripts in R (R Core Team, 2013), and proportions of gaze to AOIs were computed by dividing total gaze to each AOI over the course of the epoch by the total amount of usable data during the epoch. Number of epochs for each child varied by length of the episode, in that children with slightly shorter episodes had fewer epochs of data. Children provided an average of 139.67 epochs of data ($SD = 14.24$, range = 112—164), allowing us to capture nuanced trajectories over time, with each one-second epoch entered as a separate data point in the analyses. Epochs in which gaze was not tracked were treated as missing data. On average, each child had 22.32 missing epochs of data ($SD = 26.88$, range = 0—116). There was no minimum number of frames that a child had to provide to be included in the analysis. On average, 64.3% of frames provided were usable across the entire episode ($SD = 0.42$).

Additionally, we processed these data in a more traditional fashion, generating summaries of proportion of gaze to each AOI across the duration of the episodes. These proportions were generated with the same data as described above, dividing total gaze to each AOI over the course of the episode by the total amount of usable data during the episode.

Threat-Related Attention Profiles. Where much prior work has examined visual attention as a momentary or static construct, we used data from continuous measures of visual

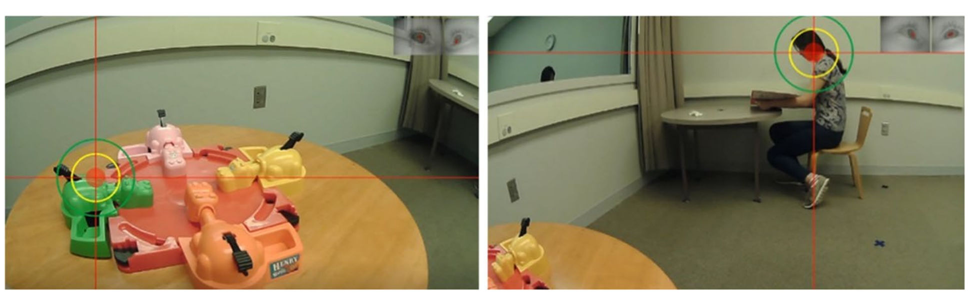


Fig. 1 The screen shot captures the concentric circles with crosshairs, indicating the child's moment-by-moment gaze in the scene

attention to examine interindividual differences in visual attention to the stranger using microlongitudinal analyses. To first determine the general pattern of attention to the stranger over time, linear and quadratic growth curve models were fit to the data to understand the *average* trajectory of attention across all participants, using the nlme package in R (Pinheiro et al., 2012).

In examining linear versus quadratic fit of the data *on average*, the Bayesian Information Criterion (BIC) for a linear growth curve was 2092.78, while the BIC for a quadratic growth curve was 1867.31, suggesting that a quadratic curve was the better fit for the data (Visualized in the supplement; Fig. S2)). This shape also fit theoretically with the progression of the episode as the female stranger entered and exited the room at the beginning and end of the episode. These more active and engaging moments have the potential to elicit greater attention to the stranger.

Next, quadratic group-based trajectory models (GBTM) were fit to examine individual trajectories of proportion of attention to the stranger over the course of the episode (Proust-Lima et al., 2017), allowing us to examine heterogeneity in the data (Nagin, 2005). The analysis was conducted using 5,026 observations nested within 43 individuals.

We tested one, two, and three group solutions, again using BIC as a metric of model fit. For a quadratic GBTM with one latent class, the BIC was 1886.41. Comparatively, for a quadratic GBTM with two latent classes the BIC was 1830.32, and for a quadratic GBTM with three latent classes the BIC was 1785.47. However, for the three model solution, one subgroup only had 4 members. Thus, a two-group solution was deemed most appropriate.

The two latent groups identified were characterized by 1) high initial orienting to the stranger and gradual decay – "orienting" and 2) low initial orienting to the stranger and continued low attention – "avoidant" (Fig. 2).

To maximize analytic variability and account for any error that may be inherent with creating latent classes and binary group memberships, posterior probabilities of membership to latent class 2, the group representing persistently lower attention to the stranger, were extracted for use in subsequent models assessing relations with other socioemotional measures. Probability of membership in latent class 2 was selected for further analyses as it was the group encompassing the largest number of participants (see below), as well as the group most closely matching the avoidant tendencies that we hypothesized as a risk factor for internalizing behaviors in children high in BI.

Results

In the sample at large, BIQ score was significantly positively related to report of internalizing behaviors, $r = 0.57$, $p < 0.001$ (Table 1).

Of the two latent classes identified, the orienting group (Group 1—high initial orienting to the stranger, gradual decay, and recovery) had 13 members (30.2% of the sample) and the avoidant group (Group 2—low initial orienting to the stranger and continued low attention) had 30 members (69.8% of the sample). The groups did not significantly differ in age ($p = 0.21$), count of internalizing behaviors ($p = 0.17$), or level of BI ($p = 0.66$). However, the orienting group (Group 1) had a significantly higher proportion of girls to boys (10 females/3 males) as compared to the avoidant group (Group 2) (11 females/19 males), $X^2 = 4.38$, $p = 0.04$.

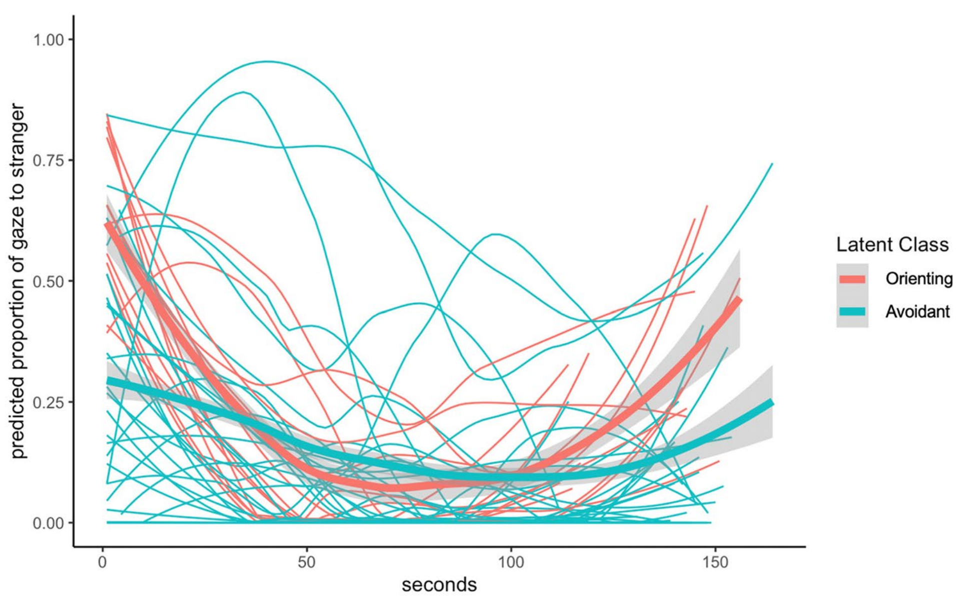


Fig. 2 Plot showing trajectories of attention to the stranger over time, grouped by latent class based on a two-profile solution. Class 1: High initial orienting to the stranger, gradual decay, and then recovery ("Orienting"). Class 2: Low initial orienting to the stranger and rapid decay ("Avoidant"). Analyses used the posterior probabilities of being in the Avoidant group as a continuous measure in the presented analyses

Table 1 Spearman's correlation table showing interrelations between demographic variables, proportions of gaze to AOIs, and probabilities of latent group membership

	1	2	3	4	5	6	7
1. Sex	–						
2. Age	-0.25	–					
3. BIQ total score	0.07	0.04	–				
4. CBCL- Internalizing subscale	0.01	-0.05	0.57***	–			
5. Prop. of gaze to the stranger	0.12	0.07	-0.02	-0.21	–		
6. Prop. of gaze to the toy	-0.35	0.26+	0.15	0.08	-0.49***	–	
7. Prob. Of membership to Avoidant group—Stranger	-0.24	0.12	0.00	0.11	-0.35*	0.33*	–
8. Prob. Of membership to Inc/Dec – Toy	-0.01	-0.12	-0.16	-0.18	-0.23	0.19	-0.28+

$+p<0.10$; $*p<0.05$; $**p<0.01$; $***p<0.001$

Sex: 0 = male, 1 = female

Attention Profile as a Moderator of the Relation Between BI and internalizing Behaviors

To examine relations between BI, attentional pattern, and internalizing behaviors, a Poisson regression was used to evaluate the interaction between probability of latent group membership and BI in relation to count of reported internalizing behaviors. Specifically, we used the continuous posterior probability of membership to latent class 2 (avoidant) and the continuous total BIQ score. The BIQ score was mean-centered in testing this moderation. The probability of avoidant group membership was not mean-centered so as to retain a meaningful zero for this value. A Poisson regression accounts for the non-normal distribution of report of behaviors in the non-clinical sample, as well as the count nature of the internalizing variable as an outcome measure. Age and sex were also entered as covariates. All of the described models were also tested without these covariates, as presented in the supplement (Tables S1 and S2).

Additionally, in this model we controlled for the overall proportion of gaze to the stranger, averaged over the course of the episode. We included the average as a control variable to assess the utility of trajectories while accounting for variance captured by more traditional summary statistics of attention. Table 1 displays interrelations between proportion of gaze to the stranger and demographic variables, as well as the attention measures of interest. The described models were also tested without controlling for overall proportion of gaze, as presented in the supplement (Tables S3, S4).

We found a significant main effect of probability of membership in the avoidant group and in relation to internalizing behaviors, $b = -1.07$, $p = 0.03$ (Table 2). There was also a significant main effect of BI, $b = 0.02$, $p < 0.001$ (Table 2).

Although probability of group membership was entered as a continuous variable in the analysis, for visualization purposes we graphed the relation between BI and reported internalizing behaviors with the sample dichotomized by latent class membership (Fig. 3). Also of note, these effects were also significant when group membership was entered as both a continuous posterior probability as well as a dichotomous group membership (Main effect of group membership $b = 0.49$, $p = 0.01$; main effect of BI $b = 0.02$, $p < 0.001$). Results from the full model can be seen in the supplement (Table S5).

Table 2 Poisson model assessing probability of membership in avoidant group based on stranger-oriented gaze as a moderator of the relation between BI and internalizing behaviors. Sex, age, and average proportion of gaze to the stranger were entered as covariates

Parameter	*Estimate*	*SE*	*z-value*
Intercept	1.78*	0.81	2.19
Sex	0.15	0.14	1.02
Age	-0.07	0.12	-0.58
Overall proportion of gaze to stranger	-0.50	0.37	-1.34
Probability of avoidant group membership	0.44*	0.19	2.29
BIQ (mean centered)	0.02**	0.01	3.16
Probability of avoidant group membership X BIQ	< 0.01	0.01	0.16

$+p<0.10$; $*p<0.05$; $**p<0.01$; $***p<0.001$

Sex: 0 = male, 1 = female

McFadden's pseudo-$R^2 = 0.41$

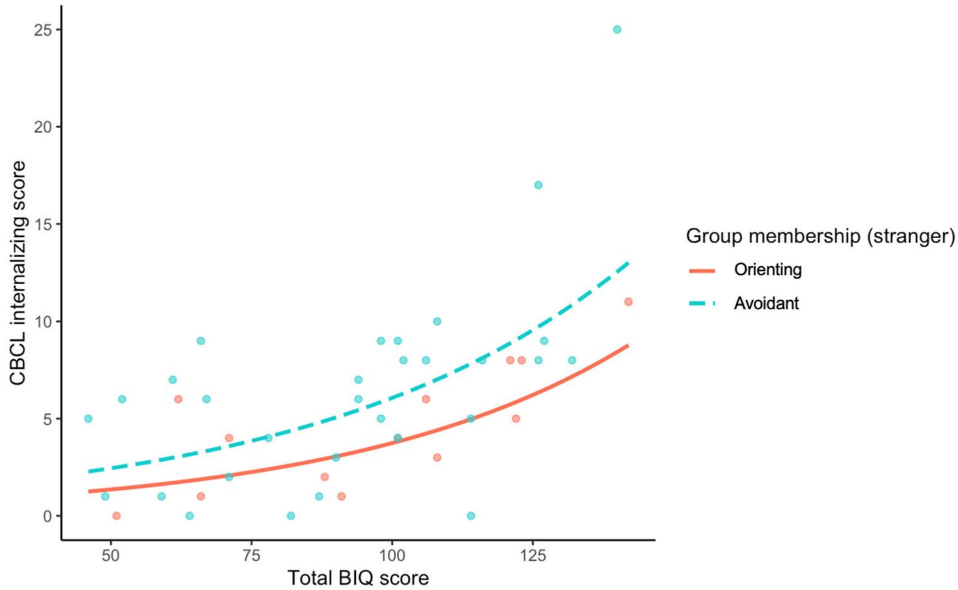
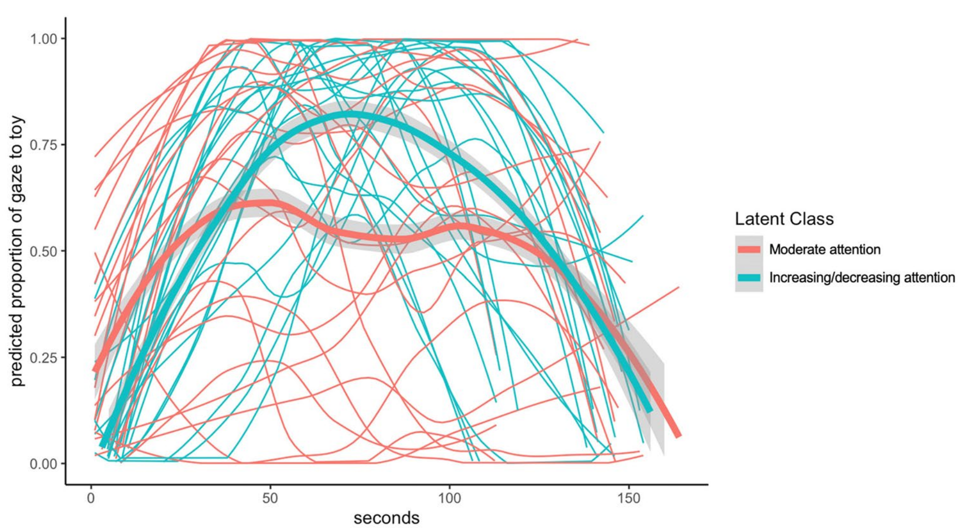


Fig. 3 Graph depicting the relation between BIQ score and reported internalizing symptoms for members to the Orienting latent group (Group 1, salmon) and Avoidant latent group (Group 2, teal), generated using proportions of visual attention to the female stranger over time. Age, sex, and proportion of overall gaze to the stranger were entered as covariates. Relations were graphed using a Poisson distribution. For visualization purposes, BIQ score is not mean-centered in this graph. Group membership was plotted dichotomously for ease of visualization, although all analyses were run with posterior probability to the Avoidant group as a continuous moderator. Main effects of time and group membership were significant, but their interaction was not

Alternate Patterns of Attention

To examine the alternate AOIs to which children could attend throughout the episode and the specificity of these findings to gaze directed towards the female stranger, we ran an additional GBTM using the proportion of looking to the Hungry Hungry Hippos toy AOI. The toy was another visually and situationally salient target of visual attention in the room, but was non-social in nature as compared to the female stranger. A two-profile solution was used for this analysis to mirror the stranger analysis. The BIC for the model was 4382.00 (Fig. 4). In this model, Group 1, labeled as the "moderate attention" group, included 22 members (51.16% of the sample), and Group 2, labeled as the "increasing/decreasing attention" group, included 21 members (48.84% of the sample). There were no significant differences in internalizing behaviors, BI, age, or sex between groups.

Fig. 4 Plot showing trajectories of attention to the Hungry Hungry Hippos toy over time, grouped by latent class based on two-profile solution. Class 1: Moderate attention to the toy throughout the episode. Class 2: Increasing and then decreasing orienting to the toy during the episode. Analyses used the posterior probabilities of being in the Increasing/Decreasing group as a continuous measure in the presented analyses



The probability of membership to the avoidant group in the model using attention to the stranger over time was inversely correlated at trend level with probability of membership to the increasing/decreasing attention in the model using attention to the Hungry Hungry Hippos ($r = -0.29$, $p = 0.051$). In other words, the children who were avoidant to the stranger were possibly showing some attention to the Hungry Hungry Hippos toy instead.

Paralleling the previous analyses, we entered posterior probabilities to increasing/decreasing attention group as a moderator in examining the relation between BI and internalizing behaviors. We covaried for both sex and age for continuity with the previous analysis. As above, we also covaried for proportion of gaze to the Hungry Hungry Hippos toy AOI aggregated over the entire episode.

Here, there was a significant main effect of BI such that a higher BIQ score was significantly related to report of internalizing behaviors, $b = 0.2$, $p < 0.001$ (Table 3). However, in this model group membership was not significantly associated with internalizing behaviors.

As a control, we planned an additional set of analyses using attention to the surrounding room as a non-salient AOI. Much as in neuroimaging studies (Poldrack, 2007), we selected an AOI that was presumed to not reflect our constructs of interest as a test of specificity. As detailed in the supplement, we were unable to create meaningful subgroups for this analysis (Fig. S3).

Discussion

An attention bias to (Pérez-Edgar et al., 2010, 2011; Roy et al., 2008; Shackman et al., 2009; Szpunar & Young, 2012) or away from (Heuer et al., 2007; Kashdan et al., 2014; Schneier et al., 2011; Weeks et al., 2013) perceived threatening stimuli is relevant in considering adaptive or maladaptive socioemotional trajectories including the development of internalizing disorders. Prior work reveals mixed findings not only in the directionality of these biases, but also how they may relate to or moderate risk for (mal) adaptive outcomes (Pérez-Edgar et al., 2010, 2011; Roy et al., 2008; Shackman et al., 2009; Stuijfzand et al., 2020; Szpunar & Young, 2012). Attention biases are traditionally measured using computer tasks based on brief exposures to emotionally-valenced facial stimuli and subsequent behavioral measures such as a button press or the latency for an individual to fixate on a specified stimulus (Fu & Pérez-Edgar, 2019). However, findings established through more standardized laboratory paradigms leave the open question of how attention patterns may operate in more naturalistic scenarios (Pérez-Edgar et al., 2020). Additionally, there is a gap in the present literature when examining how social novelty and perceived threat may be visually attended to over a more protracted time course, beyond the momentary presentation frequently used in computer tasks.

Here, we used a Group-Based Trajectory Model (GBTM) to determine latent classes of trajectories of attention allocated towards a female stranger, representing social novelty. This analytic approach expands on previous work (e.g., Fu et al., 2019) by modeling naturalistic visual attention to social novelty as a dynamic pattern over a more prolonged period of time. A two-profile solution was the best fit for these data, creating two characteristic trajectories: 1) high initial orienting to the stranger, gradual decay, and then recovery and 2) low initial orienting to the stranger and continued low attention. The attention pattern of latent class 1 appeared to reflect the events of the Stranger Working episode, while latent class 2 appeared relatively disengaged. We found that these groups were not significantly related to BI or internalizing symptoms. However, our model testing a potential interaction between BI and group membership on internalizing symptoms found a main effect of likelihood of membership in the avoidant group. Membership to the avoidant group was significantly related to reported internalizing behaviors while controlling for both BI and average gaze to the stranger through the episode, in addition to demographic variables. This pattern was not in line with our hypothesis that attention patterns would moderate the

Table 3 Poisson model assessing probability of membership to the Increasing/Decreasing group based on Hungry Hungry Hippos-oriented gaze as a moderator of the relation between BI and internalizing behaviors. Sex, age, and average proportion of gaze to the toy were entered as covariates

Parameter	*Estimate*	*SE*	*z-value*
Intercept	1.81*	0.77	2.33
Sex	0.09	0.15	0.64
Age	-0.05	0.12	-0.41
Overall proportion of gaze to toy	0.28	0.28	0.98
Probability of Inc/Dec group membership	-0.10	0.16	-0.63
BIQ (mean centered)	0.02***	< 0.01	4.66
Probability of Inc/Dec group membership X BIQ	< -0.01	0.01	-0.76

+$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Sex: 0 = male, 1 = female

McFadden's pseudo-$R^2 = 0.36$

relation between BI and internalizing symptoms, but was consistent with the notion that lower attention to the female stranger would be associated with greater risk.

As reviewed, prior work suggests that internalizing behaviors may be associated with both biases to and away from threatening stimuli. This avoidant pattern of attention is not in line with many previous computer-based findings suggesting that biased visual attention towards threat may exacerbate the link between BI and internalizing behaviors (Pérez-Edgar et al., 2010, 2011). This tension in the literature may be attributed to any number of experimental variables, including how imminent the threat represented by the stimuli may be and the ecological validity of the task. For example, in this task the stranger was in the same room as the child but maintained a moderate physical distance from the child and made minimal social contact. The absence of a group characterized by high orienting may also be due to the time course of the exposure. As discussed earlier, most attention bias tasks include exposure to a stimulus on the order of milliseconds, where our task was nearly 3 min long. It would be very unlikely to find a pattern of static unrelenting gaze to one person for multiple minutes. Differences in findings across paradigms emphasize the importance of considering context as well as task parameters in assessing affect biased attention.

Differences between computerized and naturalistic tasks may reflect the less-constrained locomotion available to the child in naturalistic tasks, where there are far fewer limitations in how they can orient within a scene (Franchak et al., 2017). Additionally, a more visually cluttered environment provides more possible salient targets for preferential visual attention, as compared to computer tasks. With a more complex visual scene at hand, children may deploy attention to various targets as either a reactive or regulatory response (Rothbart et al., 2011), revealing more idiosyncratic attention patterns. This behavior may not even be possible, let alone observable, in more highly controlled tasks. Discrepant findings emphasize the importance of implementing ecologically valid paradigms to better understand how the many facets of behavior and attention may operate and interact naturalistically, and how associations between naturalistic and screen-based measures may vary as a function of individual differences.

Limitations of this study include a modest sample size. Due to the exploratory nature of this study, a high proportion of participants were enrolled as pilot participants. These participants helped refine the calibration, validation, and coding pipeline. Once the protocol was set, a number of other participants had data deemed unusable due to technical errors or poor data quality. It is important to note that our data loss rate is indeed not unusual for developmental research. Relative to work with adolescents and adults, research with young children often works to constrain the complexity of a paradigm or increase sample sizes to account for attrition. As a point of comparison, electroencephalography/event related potentials studies often report up to 36% data loss for artifact rejection and 50% data loss for insufficient task performance as normative patterns of attrition in this age range (Brooker et al., 2019). Mobile eye tracking and other ambulatory methods of data collection also introduce motion artifacts as an added factor for participant attrition (Ladouce et al., 2017). Mobile eye-tracking studies with adolescents report less data loss, although even here levels vary with task (sitting conversation at 12.50% loss vs standing speech at 18.75% loss; Woody et al., 2019, 2020).

Our stringent inclusion criteria yielded a data set that minimized measurement noise, and the use of proportion scores as described in the methods section accounted for any variability in data quality within the sample. Additionally, the use of high-frequency repeated measures (5,026 observations nested within 43 individuals) increased power in our analyses, helping overcome analytic limitations. Additionally, post-hoc power analyses conducted through G*Power, using McFadden's pseudo-R^2 to calculate effect size ($f^2 = 0.69$ for stranger model, $f^2 = 0.56$ for toy model), found that we had adequate power in the regression analysis to detect the two-way interaction in our model. Nonetheless, future research should include larger sample sizes to account for inherent data loss.

Additional limitations include that our study did not collect data on the child's experience of the task. Where our study intentionally used a socially ambiguous stimulus, we did not have the children report on whether they perceived the female experimenter as a threat or not.

Another limitation is the concurrent report of BI and internalizing behaviors by the same reporter (the child's parent), as well as using parent report of BI rather than a behavioral measure. Future analyses of similar research questions would be strengthened by assessing BI earlier in life with behavioral measures and incorporating multiple probes for internalizing behaviors. We also note that as per the report of internalizing behaviors, all children were below the clinical threshold for disorder. This may limit translatability of our findings beyond subclinical samples. Finally, future research should collect additional sociodemographic information such as parental education or income to better understand the generalizability of the findings.

In summary, the current study presents evidence of multiple profiles of visual attention to social novelty in kindergarten-age children. We also replicated associations between BI and internalizing symptoms within this sample and found that patterns of visual avoidance to naturalistic social novelty relate to increased internalizing behaviors in young children. Inconsistencies in previous work based on computerized attention tasks emphasize the importance of implementing ecologically-valid tasks to better understand the interplay between temperament and attention in shaping socioemotional development. Characterizing these naturalistic patterns of avoidance in this specific context and understanding how such patterns may relate to internalizing behaviors may suggest subtle differences in the way in which children engage with their social world. Indeed, behaviorally there was little variation as only 4 children asked the stranger for the marbles. Mobile eye-tracking, however, captured subtle variation in attention patterns associated with internalizing behaviors, above and beyond differences related to BI and traditional summary statistics, suggesting a possible mechanism by which behaviors related to psychopathology may be exacerbated in childhood.

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Data Availability Video data from consenting participants are available on Databrary. The data that support the findings of this study, as well as accompanying code, are available from the corresponding author upon reasonable request. Please contact Kelley Gunther at keg44@psu.edu.

Compliance with Ethical Standards

Conflict of Interest The authors have no conflicts of interest to report.

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