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A COMPARISON OF STATIONARY AND MOBILE EYE-TRACKING TECHNOLOGY IN MEASURING BEHAVIORAL INHIBITION IN YOUNG CHILDREN

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ABSTRACT

Behavioral Inhibition (BI) is considered the largest risk factor for developing social anxiety. However, most children with BI never go on to develop anxiety. Recent work suggests that an AB towards threat may place children with BI on a trajectory to develop social anxiety. As a result, Attention Bias Modification Treatment (ABMT) has been proposed as a treatment for anxiety by training individuals away from threat. AB towards threat is thought to serve as a causal relationship between BI and anxiety. Yet, the field has had difficulty reproducing the link between AB towards threat and BI, as some studies show AB away from threat or no AB at all. Current methodologies measuring AB have several problems (e.g., unrealistic social settings, non-continuous eye-tracking) which may underline this issue of reproducibility. The current thesis examines the use of mobile eye-tracking as a more naturalistic approach to capturing AB to threat. In doing so, a traditional computer-based AB task (dot-probe) is compared to mobile eye-tracking during a structured laboratory protocol (stranger approach) in a group of 5-year-old children characterized for temperamental risk for anxiety.

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Chapter 1

Information

Not all children have the same enthusiasm when it comes to social engagement. In early childhood, a child's initial reaction to unfamiliar people may vary from crying and extreme reticence to happily speaking, smiling, and laughing (Coll, Kagan & Reznick, 1984). These two cases of individual differences in the emotional response to social novelty are often thought to reflect underlying fearful and exuberant temperaments, respectively. These two characterizations are used to link temperament and personality in the research literature (Buss, Pérez-Edgar, Vallorani, & Anaya, 2019). Temperament can be referred to as the "biologically based predisposition toward specific patterns of behavioral and emotional reactivity to environmental stimuli" (Howarth, Guyer & Pérez-Edgar, 2013). These individual differences in temperament can have big impacts on emotional development. Fearful temperaments are generally associated with more negative outcomes like anxiety, but exuberance can also be associated with aggression and antisocial behavior (Anaya & Pérez-Edgar, 2019).

This thesis will explore a specific type of temperament, Behavioral Inhibition (BI), and its importance to anxiety research via patterns of attention to threat. Specifically, the aim is to explore the effectiveness of a new methodology in researching BI, mobile eye-tracking, compared to standard methods employing stationary eye-tracking. Recent work with stationary eye-tracking has provided inconsistent findings when examining attention biases, a potential mechanistic component in BI and anxiety research (Fu & Pérez-Edgar, 2019). Mobile eye-tracking may bring more consistent results due to its ability to allow the user to move and look around in a more naturalistic manner. Stationary eye-tracking relies on the participant sitting still and completing various tasks on a computer. However, with mobile eye-tracking researchers can move beyond the two-dimensional, and often static, screen-based environment.

BI is an early-emerging fearful temperament that is biologically-based and marked by increased sensitivity to unfamiliarity or novelty in infancy (Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984). A meta-analysis by Clauss & Blackford (2001) found that BI is the largest individual risk factor for developing Social Anxiety Disorder (SAD). Specifically, children high in BI were found to have a seven-fold increase in the risk of developing SAD (Clauss & Blackford, 2012). BI is prevalent in early childhood and is identified in approximately 15% to 20% of preschoolers (Egger & Angold, 2006). Although a great deal of research shows a continuity of BI to anxiety, the majority of highly inhibited children do not develop internalizing disorders into adulthood (Degnan & Fox, 2007). Understanding what drives the minority of children with BI to develop anxiety is a key research issue. Because of the prevalence of BI in children, and the increased risk of children with BI developing anxiety, there is a lot of effort in identifying potential causal links.

Anxiety's Impact

There is some debate regarding at what age we can classify anxiety in children (Egger & Angold, 2006). Because of this, there is a wide range of prevalence rates of anxiety disorders in children. However, researchers agree that anxiety disorders are common in children (Costello & Egger, 2005). One estimate of anxiety's prevalence in preschoolers age 2-5 is 9.4%, which is similar to the rate for children ages 5-17 (Egger & Angold, 2006). Anxiety disorders have great short and long term-effects on daily life, including lower levels of educational achievement (Van

Ameringen, Mancini, & Farvolden, 2003), withdrawal from social interactions (Langley et al., 2004), and a lower reported quality of life (Rapaport et al., 2005).

Anxiety disorders are some of the most persistent mood disorders, and they often last into adulthood from childhood (Lenze & Wetherell, 2011). Anxiety in childhood is linked to increased severity and longevity of the disorder (Pine et al., 1998). Furthermore, anxiety disorders in young adults are preceded by anxiety in adolescence (Pine et al., 1998). According to the Anxiety and Depression Association of America (2018), 18.1 percent of the United States' population over the age of 18 are currently affected by anxiety.

The persistence of anxiety into adulthood may perpetuate the cycle of disorder as parental characteristics, and parenting behaviors, play a large role in the development of anxiety in children. Children of anxious parents are at five times greater risk to develop anxiety, relative to children of non-anxious parents (McClure, Brennan, Hammen & Brocque, 2001). There is a significant role of parental genetic factors for this increase in risk. Genetic predispositions for anxiety (e.g., temperament) are estimated to account for 50% of the development of an anxiety disorder in children (Stein et al., 2002). However, there is also evidence for parenting behavior as a possible transmission mechanism for anxiety disorders (McClure, Brennan, Hammen & Brocque, 2001). Since we cannot prevent genetic dispositions, understanding and identifying behavioral factors is extremely important in stopping the transmission of anxiety to children. A growing line of research suggests that variation in attention patterns, particularly attention to threat, may play a pivotal role in the emergence and course of anxiety.

Attentional Biases

We encounter more information in our visual field than we can process at any one time. Attention mechanisms allow us to selectively process information by prioritizing certain aspects of the environment over others (Carrasco, 2011). Selectively prioritizing one's attention towards a threat versus a neutral component of the environment is characterized as an attentional bias towards threat. A meta-analysis by Bar-Haim and colleagues (2007) found that threat-related attentional biases are heightened in anxious individuals and are minimal or not evident in non-anxious individuals. Attention bias towards threat is thought to be a key factor placing individuals with BI on the trajectory towards developing anxiety.

From birth, we tend to attend to threatening environmental factors, (e.g., snakes and bears) but this precedes the development of fear (Yorzinski et al., 2014). This automatic focus of fear-inducing stimuli is supported by the amygdala, a primitive, automatic system linked with fear processing (Pessoa, 2008). The amygdala is thought to be a key component in the orienting system of attention (Morales, Fu, Pérez-Edgar, 2016). Amygdala activation typically occurs during the initial engagement towards threat (Cisler & Koster, 2010). Of particular importance to this study, social threats, like angry faces, also recruit the amygdala (Phelps, 2006).

An overactive amygdala is a shared characteristic between individuals with BI and anxiety (Pérez-Edgar & Fox 2005). An overactive amygdala may lead children to display hypervigilance towards new, possibly threatening stimuli (social situations), which gradually tunes the visual system towards these threatening situations (Fu & Pérez-Edgar, 2019). This gradual tuning leads to calcified biased attention towards threat, which may act as a tether to bind BI children on a path to develop anxiety (Pérez-Edgar et al., 2014). While attention bias towards threat may be an evolutionary-based mechanism for safety, having a pronounced attention bias towards threat may lay the foundation for developing anxiety, particularly if the child already has a temperamental predisposition (Pérez-Edgar et al., 2014).

Measure Attentional Biases

One of the common ways to assess attention bias is through a dot-probe task. This task presents two images side by side, where one is salient (e.g., threating image), and the other is neutral, or both are neutral. After the images are presented, a probe (often an asterisk) appears behind the salient or neutral image. Quicker reaction times to the probe when it appears behind the salient image compared to the neutral image is interpreted as an attention bias towards threat. Studies trying to examine the attention bias-BI link using the dot-probe have come to inconsistent results finding attention bias towards threat (Pérez-Edgar et al., 2010) attention bias away from threat (Morales, Pérez-Edgar, & Buss, 2015) or no attention bias (Cole et al., 2016).

Mechanisms Behind Attentional Biases

An influential model by Richard Posner characterized the mechanisms of attention as a three-part network system incorporating alerting, orienting, and executive attention (Posner & Petersen, 1990). The alerting system is involuntary, supporting response readiness for incoming stimuli. The orienting system prioritizes information for focus and processing. Orienting can either be covert -- shifting attention without moving the eyes, or overt -- shifting attention by moving the eyes (Posner, 2012). The executive attention system is voluntary and serves to control attention by suppressing brain activity that conflicts with one's goals (Posner, 2012). According to the model, the alerting and orienting networks subserve selective attention -- the process of prioritizing information through disengagement and engagement (Posner & Petersen, 1990).

A conceptual framework by Morales, Fu, and Pérez-Edgar (2016) put forward that attentional biases develop early in infancy, and these attentional biases are then affected by the child's environment (e.g., parenting styles and social interactions) and individual differences (e.g., temperament and attention). Attention biases may trigger a cyclical process of threat-related attention processes shaping socioemotional functioning which can then lead to maladaptive profiles. Attention bias to threat is a possible automatic process produced from pre-tuning of top-down attention selection (Todd et al., 2012). Once these processes become entrenched in a child with BI, they may act as a tether binding these children to develop anxiety problems (Pérez-Edgar et al., 2014).

Visual attention is controlled by an interaction of bottom-up and top-down mechanisms (Desimone & Duncan, 1995). Bottom-up processes are automatic, relying on the stimulus influencing our perception. Top-down processes track what is salient to the individual such as past experiences, stored knowledge, and current goals. There is an interplay between top-down and bottom-up processes as the individual moves through the environment (Corbetta & Shulman 2002) and these processes constantly tune each other over time. As top-down processes constantly orient attention towards what is salient to the individual, a top-down template is created which biases attention towards stimuli that perceived as salient based on previous experiences (Todd et al., 2012).

Threat-related attention is a form of affect-biased attention (Morales, Fu, Pérez-Edgar, 2016). Affect-biased attention is a reflexive process which is produced from the repeated pre-tuning of attention over time (Todd et al., 2012). While a threat can be social or non-social, temperamentally fearful children, like those with BI, display more sensitivity to social threat cues (Morales, Fu, Pérez-Edgar, 2016). To study threat-related attention, researchers first must identify the constituent components. Threat-related attention can be broken into observable and measurable stages which are initial engagement towards threat, difficulty in disengagement of threat, and avoidance of threat (Cisler & Koster, 2010).

There is a clear link between BI and emergence of social anxiety, and BI and social anxiety have a similar behavioral and psychobiological profile. However, most children with BI still do not go on to develop anxiety (Degnan et al., 2014). BI is such a strong predictor of anxiety, yet not all children with BI develop anxiety. Understanding why this subset of children with BI develops anxiety is still a key research issue.

Parental Transmission of Anxiety

Parental Anxiety can impact their children's attention bias by acting as an emotional contagion (Moradi, Neshat-Doost, Taghavi, Yule, & Dalgleish, 1999). The first step in becoming an emotional contagion happens because parents are a significant factor in a children's learning of emotions and emotional regulation (Morris et al., 2007). For example, young children rely on their caregivers to help them regulate their behavior (Rothbart & Derryberry, 1981). However, parents with anxiety often struggle in regulating their negative responses and model those behaviors for their children (Fiask & Grills-Tacquechel, 2007). Individuals with anxiety are often characterized by maladaptive patterns of emotion regulation (Cisler et al., 2010). Children observe and copy their parents' maladaptive emotional regulation, which plays a role in the transmission of anxiety from parent to child. Parents also influence their children's attention to and interpretation of emotional stimuli. (Hadwin, Garner, & Perez-Olivas, 2006). When children observe how their parents respond to certain stimuli, they can teach their children to assign these responses to current and future situations, which will impact their child's development of attentional control (Bögels & Brechman-Toussaint, 2006).

In addition to displaying anxious behaviors for their children, parents with anxiety may provide an overcontrolling environment (Affrunti & Woodruff-Borden, 2015). Negative parenting styles, such as overcontrolling, are associated with children developing attention biases to threat (Gulley, Oppenheimer, & Hankin, 2014). When a child grows up in an overcontrolling environment, they receive the message that they must behave, think, and feel in specific ways, often to avoid threat. This avoidance, in turn, may limit their feelings of autonomy and competence (Van der Bruggen, Stams, & Bögels, 2008).

Treatment Issues

Although anxiety develops early in childhood, and intervening early brings the best results, most of the research in the treatment of anxiety focuses on adults (Pine & Fox, 2015). Due to its high prevalence, the impairment, and the persistence of anxiety, it is important to identify early risk factors and predictors of anxiety to create etiological models, which would allow for early identification and the development of preventive interventions (Grover et al., 2005).

One treatment that may bring promising results, Attention Bias Modification Treatment (ABMT), is an emerging therapy for anxiety with suggestive preliminary data supporting efficacy for reducing anxiety (Bar-Haim, 2010). ABMT directs attention towards positive stimuli or away from threat using an implicit computer-based training task (Liu et al., 2018). A meta-analysis of 10 published reports suggests that individuals who complete ABMT exhibit fewer anxiety symptoms and a decrease in stress response (Hakamata et al., 2010). ABMT is thought to target attention bias as a causal mechanism in anxiety development (Pérez-Edgar et al., 2010). As such, training an individual to minimize attention bias may help alleviate anxiety.

Attention bias towards threat has been considered a key factor for developing anxiety leading to the enthusiasm for ABMT, but careful examination of the literature suggests that efforts in ABMT may be premature as there is little evidence for a direct path between attention bias towards threat and BI (Roy, Dennis, & Warner, 2015; Shechner et al., 2014). Rather, the data suggest that BI and attention bias interact to increase the risk for anxiety (Pérez-Edgar et al., 2014). The inconsistent literature may also reflect the difficulty of capturing attention bias through traditional reaction time or stationary eye-tracking methods.

The current study aims to explore the effectiveness of a new methodology, mobile eye-tracking, for measuring visual attention. Specifically, we see if attention patterns measured in mobile eye-tracking episodes better explain the link between BI and attention bias compared to a traditional, stationary, eye-tracking methods.

Measuring attention processes

There are many ways to measure attention processes, but I will primarily focus on mobile and stationary eye-tracking. Eye-tracking is extremely important as it allows researchers to capture overt attention, as well as the process of selective attention, via eye-movements (Mahone, & Schneider, 2012). Eye-tracking is the most widely used tool for measuring overt visual attention as it allows us to follow the user's eye-gaze path.

Behavioral Reaction Times

Traditionally, much of the attention, and attention bias, literature has relied on manual response tasks. Measuring reaction times (RTs) is an easy, low-technological way to measure attention, but it does not allow researchers to capture a continuous and accurate assessment of eye-movements. Because measuring reaction times only provides a snapshot of the end-stage of the attention process, it is difficult to determine which threat-related attention process (engagement towards threat, difficulty disengaging from threat, and avoidance of threat) is related to the expression of attention bias (Shechner et al., 2012).

Eye-tracking Technology

Unlike behavioral measures, eye-tracking provides a continuous way of measuring overt attention. Eye-tracking provides the benefit of seeing more than just snapshots of attention (reaction times), allowing researchers to decompose the components of threat-related attention moment-by-moment (Armstrong & Olatunji, 2012). Also, eye-tracking can provide the exact length of each fixation (Duchowski, 2007). Measuring a continuous visual attention process across a task may be able to improve the reproducibility of attention bias patterns. There are many ways to measure eye-movements, but the most common and effective type of eye-tracking falls under the category of corneal reflection, which uses infrared reflections to create a map of the eye and track eye-movements (Goldberg & Wichanski, 2003). Eye-trackers that use corneal reflection can be either stationary or mobile.

Stationary eye-tracking

Early stationary eye-tracking was able to show researchers that clinically anxious subjects consistently shifted attention towards threat, whereas control subjects did not, indicating that anxious individuals have a predisposition to have an attention bias towards threat (MacLeod, Mathews, & Tata, 1986). However, these studies have had problems with reproducibility and have shown attention bias towards threat, away from threat, or no attention bias at all (Shechner et al., 2012). Stationary eye-tracking allows for a continuous recording of eye-movements but is limited by the fact that it cannot be used in active social settings. Having a socially accurate setting is important as participants often act differently on a screen based-paradigm versus a live interaction. For example, participants often have fewer fixations on an experimenter physically sitting in a room versus on a screen (Laidlaw et al., 2011).

Mobile eye-tracking usefulness

As mentioned earlier, studies investigating attentional biases have relied on either manually coding looking behavior or relying on a static screen-based stimulus. The former allows for a more socially accurate scenario but cannot capture a continuous milliseconds level of eye movements. The latter allows for continuous, millisecond level coding of eye movements. However, it cannot capture a realistic social interaction due to being confined to an electronic environment. Mobile eye-tracking can combine the best of both methods allowing the user to move around while continuously measuring eye-movements.

In the first study of its kind, Franchak and Adolph (2010) used a head-mounted mobile eye-tracking device to record ambulatory visual exploration. Mobile eye-tracking allows researchers to gather continuous eye-track movements from subjects while they walk and move around. Allowing a participant to move around is a strong advantage over stationary eye-tracking, as mobile eye-tracking allows research to shape testing environments to more closely match the real world. Using a real-life context is extremely important as it creates an enhanced opportunity over computer-based paradigms for studying both attention processes and social interaction, which are important components of social cognition (Warnell, Sadikova & Redcay, 2018).

Mobile eye-trackers have two sets of cameras, one to record eye-movement, and one to record the individual's field of vision. While mobile eye-tracking offers advantages over both stationary and behavioral measures, there are limitations. For example, mobile eye-trackers were originally designed only for adults, and until recently, were not reliable for studies in children and infants (Franchak, 2017). The first studies using infant eye-tracking often had high attrition due to the uncomfortable fit of the equipment (Corbetta, Guan, & Williams, 2012). With recent improvements, lower attrition rates have decreased (e.g., Kretch, Franchak, & Adolph 2014). Mobile eye-tracking technology is consistently improving and has shown to be reliable as a way to track gaze.

As current studies have demonstrated mixed findings regarding an association between BI and attention bias, assessing attention bias with mobile eye-tracking may be able to improve reproducibility as stationary eye-tracking misses out on a key component of gaze tracking – in-person social interaction. In addition, studies using mobile eye-tracking will provide greater external validity as these studies better represent situations people will face versus screen-based environments.

The Current Study

BI is considered the strongest individual risk factor for developing social anxiety. However, most children with BI never go on to develop anxiety. Recent work suggests that an attention bias towards threat may place children with BI on a trajectory towards developing social anxiety. As a result, ABMT has been proposed as a treatment for anxiety by training individuals away from threat. Attention bias towards threat is thought to serve as a causal relationship between BI and anxiety. Yet, there are problems reproducing the link between attention bias to threat and BI as some studies show attention bias away from threat or no attention bias at all. Current methodologies measuring AB have several problems (e.g., unrealistic social settings, non-continuous eye-tracking) which are thought to be causing this issue of reproducibility.

This current study aims to test the hypothesis that attention biases recorded by both mobile and stationary eye-tracking will both correlate with BI, but mobile-eye tracking will have a stronger correlation. This study is unique as only one study has currently compared the effectiveness of measuring attention bias with mobile-eye tracking versus stationary eye-tracking (Fu, Nelson, Borge, Buss, & Pérez-Edgar, in press).

Chapter 2

Methods

This analysis drew from an ongoing multi-visit study which examined temperament-related individual differences in affect-biased attention by using both stationary and mobile eye-tracking. One study has already been generated and published (Fu et al., in press) and has helped guide the methods for the current study. All study procedures were approved by the Institutional Review Board at the Pennsylvania State University, and all participants provided written informed constant/assent before participation in the study. Exclusion criteria for participating in the larger study included being a non-English speaker, having gross developmental delays, or severe neurological and medical illnesses.

All participants completed the stationary eye-tracking dot-probe task, and a sub-sample of the data provided came from mobile eye-tracking that measured attention towards a putative social threat in a live context. Mobile eye-tracking is an extremely novel methodology and because of this, we made sure to follow good practices for reporting eye-tracking data (Oakes, 2010). We have carefully noted the specifications of the equipment and the protocols used.

Participants

Part One: Dot-Probe task. The sample consisted of eight-six healthy children with ages ranging 5 to 7 years old ($Mean_{age}$ = 6.03 years, SD = 0.61; 43 boys). Recruitment was controlled in order to ensure that one-half of the participants met pre-determined cut-offs for elevated BI and half of the children were female to control for or observe sex-linked differences. In order to determine elevated BI, participants were screened based on a parental report on the Behavioral Inhibition Questionnaire (BIQ; Bishop et al., 2003). Cutoff scores (≥ 119 total score or ≥ 60 social novelty subscale) to determine BI came from a previous study of extreme temperament in children ranging from 4 to 15 years (Broeren and Muris, 2010). Participants were recruited throughout central Pennsylvania and the surrounding areas using the Families Interested in Research Studies (FIRSt) database, via community outreach, or word-of-mouth. All participants provided written consent and received monetary compensation for participating in this study.

Part two: Mobile eye-tracking. Fourty-nine ($Mean_{age}$ = 6.13 years, SD = 0.63; 25 boys) of the 86 children who completed the stationary-eye tracking test were included in the analyses of mobile-eye tracking. Data were excluded for a variety of reasons: 19 children were used as technical development of the protocol, 4 datasets were lost to technical problems, one family declined to participate, and we were not able to provide satisfactory calibration for 13 participants.

Apparatus and Procedures

Families made two 90-minute visits (counter-balanced) to our lab within 7 days of each other. One visit focused on mobile eye-tracking tasks and questionnaire assessments. The other visit focused on stationary eye-tracking tasks.

Stationary eye-tracking. Data were collected using a RED-m Eye-tracking System (SensoMotoric Instruments) which uses a binocular 120 Hz RED camera. Prior to the start of a task, the children completed a 5-point calibration requiring the child to look at a target which sequentially appears at five different locations on a screen (Oakes, 2012). After calibration and validation, children completed the dot-probe task.

Mobile eye-tracking. Data were collected by a head-mounted eye-tracking system (Pupil-Labs UG, Berlin, Germany) with a sampling rate of 120hz, 100-degree field of view (0.08-degree precision) and latency of 0.045 seconds. The system contained two eye cameras with infrared illumination for pupil tracking along with a world camera with a fisheye lens. The system integrated eye fixation information with visual information from the participants' perspective. The data were recorded with Pupil Capture v.0.9.12 (Pupil Labs) and the camera was connected to an MSI VR backpack which the child wore.

Prior to the recording of the task, the eye-tracker was placed on the child's head, and each camera was moved in order to ensure that each of the child's pupils was captured by the cameras. To capture the scope of a room, the calibration procedure was done in a conference room using a projector. Before the calibration began, the experimenter asked the child to follow the experimenter's pointing as their finger moved across the screen. This was done to ensure that the eye cameras consistently follow the child's pupils as they move their eyes. The calibration itself then began, and it consisted of 5 different validation points. The child was instructed to fixate on each of these points while keeping their head still. After the calibration task was completed, the experimenter ran an accuracy test by running their hand across the screen and asking the child to follow their hand to verify that the child's gaze is where it is expected. Also, before each of the tasks, the child was asked to complete another accuracy test, which involved looking at different points on a target from the average distance in the task. This was done to prevent any parallax errors as each task took place at different distances from the child. An experimenter watched in the control room to confirm that the child's eye gaze was still moving in the expected directions at each point. This step also allowed for the ability to correct fixations for each task offline if the initial calibration is done correctly.

Measures

Behavioral inhibition (BI). BI scores were determined via reporting from the BIQ (Bishop et al., 2003). The BIQ is a 30-item measure used to assess the frequency of BI-linked behavior on a 7-point scale ranging from 1 ('hardly ever') to 7 ('almost always'). BIQ reports correlate with lab observation of BI (Dyson, Klein, Olino, Dougherty & Durbin, 2011).

Stationary AB. The dot-probe task (Appendix C) is aimed to assess AB towards threat (Morales et al., 2015). This task takes approximately 25 minutes depending on child RTs and the length of the three breaks given. The participants each completed 100 trials. Each trial started with a fixation cross displayed in the middle of the screen for 500ms. After the cross, a pair of faces (angry-neutral, happy-neutral, neutral-neutral) appeared on the screen for another 500ms. One face was located on the left-center of the screen, and another face was located on the right-center of the screen. After the faces were presented, they both disappeared, and a probe was presented in the previous location of one of the faces. The child then indicated whether the probe was on the left or the right of the screen by pressing a button. The dependent variables (DVs) measured: dwell time on each face, reaction time for the button press, and latency of initial fixation to each face and to the probe.

Ambulatory attention. The *Stranger Approach* Episode (Goldsmith et al., 1994) is a standardized observational paradigm which is a way to probe the child's attention patterns in a socially-direct, naturalistic setting. Each child participated in the Stranger Approach fear episode modified from the Preschool version of the Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith et al., 1994). This task involved an experimenter (unknown to child) walking toward the child, sitting down, and initiating a conversation. The stranger followed a set script (Appendix B). Seven research assistants acted as the stranger for children, and all but one of the strangers were male. All strangers were clean-shaven and wore identical closing and a hat in order to minimize individual differences.

Data Processing

Dot-probe manual RTs. Data cleaning was completed based on previously published methods (Morales et al., 2015; 2016). Trials with missing responses, incorrect responses, and RTs outside of the post-probe presentation were excluded. Included trials were averaged for each participant, and trials with RTs +/- 2SDs of the individual child's mean were excluded.

Cleaned RTs from the Happy-Neutral and Angry-Neutral trials were used to create AB scores to emotional faces by subtracting mean RTs to probes on congruent trials from the mean RTs to the probes on incongruent trials. Positive scores denote a bias to emotional faces (happy or angry) where negative scores suggest a bias away from emotional faces (happy or angry)

Stationary eye-tracking. Fixations, which were defined as continuous gazes maintained for at least 80ms within a 100-pixel area, were exported with BeGaze (SensoMotoric Instruments). Each face and probe display was created to be an area of interest (AOI) by using BeGaze.

Indices of AB. Four different indices were computed from the dot-probe task. For each participant, we computed mean fixation latency for each face and the mean dwell time on each face type. Two latency scores were calculated by subtracting the mean fixation latency on the emotional face from the fixation latency on the competing neutral face. Two AB dwell times were calculated by subtracting the mean dwell time on the neutral face from the mean dwell time on the emotional face. Positive values indicate AB toward emotional faces, where negative values indicate a bias away from emotional faces.

Mobile eye-tracking coding

The first step in processing mobile-eye tracking data was to perform manual gaze correction using Pupil Player software (Kassner et al., 2014). This process was incorporated in order to make sure the eye-tracking data matches with where the child was looking during the episode. In order to do this, two trained research assistants individually watched each video and determined whether the fixation circles are aligned with where the child was asked to look before each of the tasks. If the gaze was off, the RA made a correction and adjusted the x and y coordinates using the manual gaze correction plug-in that comes with Pupil Player. Corrections were only made if the data had reliable calibration, which was determined by the accuracy tests.

In order to validate the manual gaze correction, each coder selected a frame with the following criteria: 1) the child's gaze matched the point indicated by the experimenter, 2) three frames before and after show the child's pupils are detected by the eye cameras. The master coder then compared the two gaze corrections from the two coders. If they were within 0.03 x or y coordinates of each other, the master coder's coordinates were taken. If they were over 0.03, the coders met and decided which correction best meets the child's gaze. The video was then exported with the manual gaze correction, and the video was then synced with the room recording using Final Cut Pro.

Following the video being exported, trained coders (during training, interrater agreement was at least 90%) then coded child eye gaze using Datavyu 1.2. Each gaze data was coded frame-by-frame at a frame rate of 30 frames per second, coded continuously. Each gaze was tracked with a fixation cross in the center, followed by two outer rings which served as margins of error. A valid gaze fixation was identified when it was stably rested on a location for 3 consecutive frames (100ms) or more. The parameters of each fixation consisted of the AOI and the absolute onset and offset times of the fixation. The following AOIs were coded: stranger body, stranger head, child, room, invalid (e.g. no gaze data), and indeterminant (e.g. 2 frames on the stranger's body then moved to another AOI). One coder coded the entire video, and the master coder would code 20% of the video to ensure reliability.

Mobile eye-tracking indices of AB. The goal of coding the data was to be able to characterize the attention patterns of the children towards the stranger. We computed: 1) Total number of gaze visits to the stranger and 2) proportion of dwell time on the stranger relative to the total duration of valid AOI fixations.

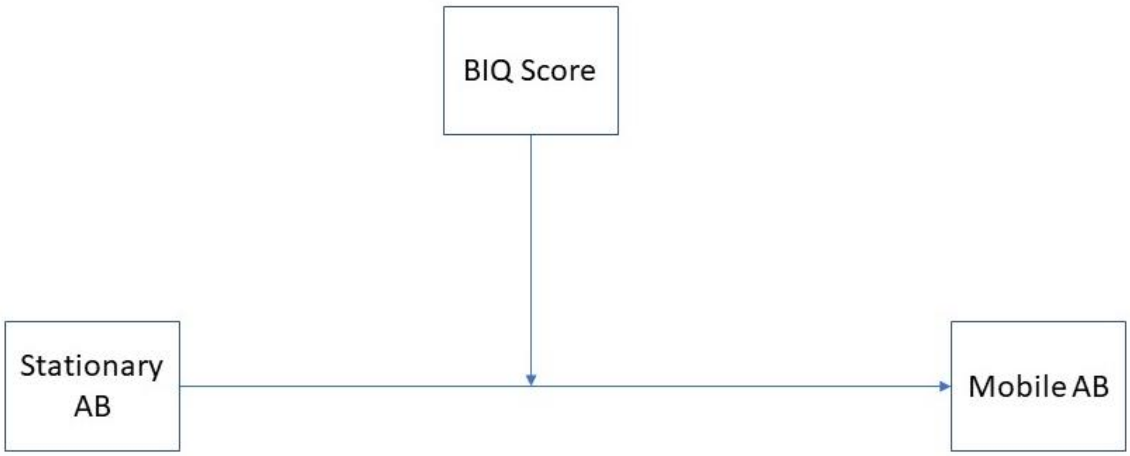
Data Analysis Plan

Initial analyses focused on descriptive statistics for the collected data in order to assess simple relations between variables and the pattern that emerged from the computer-based and mobile tasks.

To examine the relationship between BI status and attention patterns t-tests and repeated-measures ANOVAs were used to compare performance on the RT and eye-tracking patterns using categorical markers of BI. The parallel analyses were completed with simple correlations using the BIQ continuous scores. Correlations were used to compare performance on the RT tasks with performance on the eye-tracking tasks.

Finally, we looked to see if the relation across tasks differs as a function of BI. We relied on the SPSS (version 22; Chicago IL) macro PROCESSS, Model 1, with 10,000 bootstrap samples (Preacher, Rucker, & Hayes; Hayes, 2012). Like regression, PROCESS models allow researchers to examine moderated mediation patterns across multiple variables simultaneously. In each model, the potential moderator was total BIQ score.

Figure 1: Process model example. Model 1 from PROCESS was used to examine the potential moderating role of BI on the relation between stationary and mobile eye-tracking measures of attention bias.



Chapter 3

Results

Part One: Descriptive statistics exploratory analyses

Table 1 presents the demographic information for the sample, while Table 2 presents the values for the core continuous variables in this study.

Table 1: Demographic Information

	Mean	*Std. Dev.*	*Max*
Total BIQ	91.63	28.878	149
Age	6.056	.601	7.02
Sex (M/F)		45/44	

Exploratory analyses using *t*-tests suggested that neither sex (p = .111) nor age (p = .793) were significantly associated with BIQ scores, so neither of these variables were used in the analyses. While outside of the scope of this study, one interesting significant finding emerged: Boys showed a greater happy bias than girls, indicated by mean latency in the dot-probe (p = 0.41).

Table 2: Values of attention bias indices

Variable	*N*	*Mean*	*Std. Deviation*	*Min*	*Max*
Threat Bias (ms)	85	7.93	62.22	-188.34	157.09
Happy Bias (ms)	85	6.41	68.37	-123.61	116.60
Threat Bias (Latency in ms)	86	-1.20	20.95	-56.02	32.85
Happy Bias (Latency in ms)	86	2.53	16.65	-32.80	54.00
Threat Bias (Dwell time in ms)	86	-1.35	22.16	-52.34	50.10
Happy Bias (Dwell time in ms)	86	-0.14	18.80	-36.76	49.37
Visits to Stranger	49	25	10.28	5	51
Total Dwell Time to Stranger (s)	49	38.17	19.15	3.04	89.00

Part Two: Pattern of Bias as a function of BI

A simple correlation was performed to compare the results of behavioral RT, stationary eye-tracking and mobile eye-tracking (Table 3) to see how each of their measures of AB compared to BIQ score.

Table 3: Intercorrelations between BIQ and AB indices

	N	*Pearson Correlation*	*Significance (2-tailed)*
Threat Bias (ms)	85	0.020	0.858
Happy Bias (ms)	85	-0.007	0.947
Threat Bias (Latency in ms)	86	-0.027	0.803
Happy Bias (Latency in ms)	86	0.035	0.746
Threat Bias (Dwell time in ms)	86	-0.091	0.405
Happy Bias (Dwell time in ms)	86	0.007	0.949
Visits to Stranger	49	-0.347	0.015
Total Dwell Time to Stranger (s)	49	-0.215	0.138

Behavioral RT. No measures of behavioral RT were significantly correlated with levels of BIQ, measured continuously, across the whole sample (happy bias RT: r = -.007; p = .947; threat bias RT: r = 0.20; p = .858).

Stationary Eye-Tracking. No measure of stationary eye-tracking were significantly correlated with levels of BIQ, measured continuously, across the whole sample (threat bias reaction time: r = -.027; p = .803; happy bias reaction time: r = 0.35; p = .746; threat bias dwell time: r = -.091; p = .405; happy bias dwell time: r = .007; p = .949).

Mobile Eye-Tracking. Number of visits to the stranger in Stranger Approach were significantly correlated with levels of BIQ, measured continuously (r = -.347; p = 0.015), but dwell time towards the stranger was not (r = -.215; p = .138).

Part Three: Relation between computer AB and mobile AB

Simple zero-order correlations were performed to compare the measures of computer AB to the measures of mobile AB (Table 4).

Table 4: Correlations between computer AB and mobile AB

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1.Threat Bias (ms)								
2.Happy Bias (ms)	**.620****							
3.Threat Bias (Latency in ms)	-.119	-.214						
4.Happy Bias (Latency in ms)	-.085	-.067	.019					
5.Threat Bias (Dwell time in ms)	-.213	-.214	**.744****	.115				
6.Happy Bias (Dwell time in ms)	-.052	.050	.008	**.627****	-.036			
7.Visits to Stranger	-.050	-.149	.204	**.315***	.083	**.385****		
8.Total Dwell Time to Stranger (s)	.045	-.009	.045	.014	.098	-.171	**.330***	

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

The only behavioral RT measure that was significantly correlated with any measure of stationary or mobile eye-tracking AB was the reaction time to threat and tracking ratio (r = .335; p = .020). All other measures were not significant (p*'s* > 0.54). There were multiple significant relations between stationary AB and mobile AB. The average dwell time towards happy faces in the dot-probe and the number of visits to the stranger in SA were positively correlated (r = .385; p = .006). Also, the average latency towards the happy face was positively correlated towards the number of visits to the stranger in the SA task (r = .315; p = 0.027).

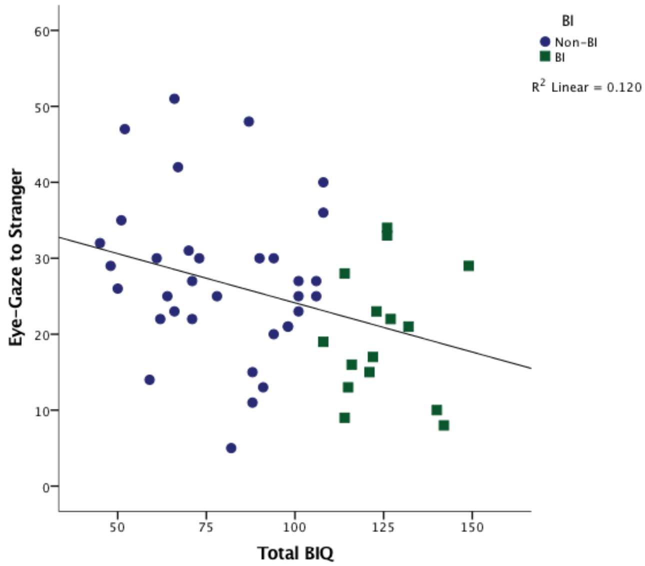
Part Four: PROCESS relation

The first PROCESS model examined the association between RT-based threat bias and stationary eye-tracking threat bias based on latency with total BIQ as a moderator. The overall model was not significant, $F(3,78) = 1.036$, $p = .382$, $r = .196$, and there were no significant individual predictors.

The second PROCESS model examined the association between RT-based threat bias and stationary eye-tracking threat bias based on dwell time with total BIQ as a moderator. Here, the full model approached significance, although there were no significant individual predictors, $F(3,78) = 2.579$, $p = .060$, $r = .300$.

The third PROCESS MODEL examined the association between RT-based threat bias and visits to the stranger during the mobile eye-tracking with total BIQ as a moderator. The full model was not significant, $F(3,44) = 2.33$, $p = .088$, $r = .370$. However, there was a significant main effect of BI, such that increasing levels of BI was associated with fewer visits to the stranger, $t = -2.518$, $p = .016$, 95% CI = -0.240, -0.027 (Figure 2).

Figure 2: Eye-Gaze to Stranger - BIQ relation. The scatterplot presents the zero-order correlation between the BIQ score and number of gaze shifts to the stranger in the mobile eye-tracking task. Participants are designated as BI (green) or non-BI (blue) based on the BIQ cut-off scores.



The fourth PROCESS MODEL examined the association between stationary eye-tracking threat bias latency and visits to the stranger during the mobile eye-tracking with total BIQ as a moderator. The full model was significant, $F(3,45) = 3.07$, $p = .037$, $r = .412$. Again, this was driven by a significant main effect of BI, $t = -2.450$, $p = 0.018$, 95% CI = -0.228, -0.022.

The fifth PROCESS MODEL examined the association between stationary eye-tracking threat bias dwell time and visits to the stranger during the mobile eye-tracking with total BIQ as a moderator. The full model was not significant, $F(3,45) = 2.142$, $p = .108$, $r = .354$, although, again, there was a significant main effect of BI, $t = -2.460$, $p = 0.018$, 95% CI = -0.233, -0.023.

Chapter 4

Discussion

The present study is the second (the first; Fu et al., in press) to examine attention patterns in children with BI by comparing AB indices for behavioral RTs, stationary eye-tracking, and mobile eye-tracking. BI is considered the strongest individual risk factor for developing social anxiety, and the current literature suggests that having an attention bias towards threat places children with BI on a trajectory towards developing social anxiety (Clauss & Blackford, 2001). However, most current research focuses on screen-based paradigms that have had inconsistent results finding attention bias towards threat (Pérez-Edgar et al., 2010), attention bias away from threat (Morales, Pérez-Edgar, & Buss, 2015), or no attention bias (Cole et al., 2016). These studies all focused on screen-based paradigms, which may be the cause of these inconsistent relations. Computer-based paradigms cannot accurately depict naturalistic social settings as people react differently when processing static faces, and perhaps in dynamic computer interactions, compared to in-person interactions (Laidlaw et al., 2011; Risko et al., 2012; Bambach et al., 2018). This study advances attention assessment outside of screen-based paradigms into more naturalistic contexts which may be able to provide more consistency in measuring attention biases.

My research findings support some of my original hypothesis. My hypothesis was that attention biases recorded by both mobile and stationary eye-tracking will both correlate with BI, but mobile-eye tracking will have a stronger correlation. However, this was only partially proven true. In the second part of the results, we compared different methodologies indices of AB with the level of BIQ. When comparing stationary measures of AB against continuous levels of BIQ, we found that there was no significant correlation. However, when comparing the number of visits to the stranger in SA and BI gathered from mobile eye-tracking, we found that there was a significant negative correlation. This may reflect the fact that interactions with the stranger generate more social anxiety with increases in BI, thus leading to fewer gaze shifts to the stranger. Additional work will be needed to tease apart the potential links.

We found that attention biases recorded by mobile eye-tracking correlated with BI and had a stronger correlation compared to stationary eye-tracking which confirms my part of my hypothesis. However, stationary eye-tracking was not significantly correlated with BI, in contrast to that part of my hypothesis. These results may reflect the known inconsistency of computer-based paradigms in measuring attention biases. However, these results also show the potential ability for naturalistic paradigms to measure attention biases.

In the third part of the results, we compared the relation of computer AB to mobile AB. We found that there was no significant relationship between behavioral RTs and mobile AB or stationary AB. However, we did find that the average dwell time towards happy faces in the dot-probe and the number of visits to the stranger in SA were positively correlated and the average latency towards the happy face was positively correlated towards the number of visits to the stranger in the SA task. A positive bias towards happy may reflect a bias towards social cues and potential social interactions. Previous work (Frewen et al., 2008; Shechner et al., 2012) has shown that bias to happy is associated with more exuberant temperament and may provide a buffering effect against internalizing difficulties for at-risk children.

In the final part of the analysis, we dove deeper into the relation of computer AB and mobile AB by adding total BIQ as a moderator. No significant relationship was found between stationary AB and mobile AB, even when BI was included as a moderator. Initial analyses found no correlation between stationary AB and mobile AB results. However, as noted above, the direct relationship between BI and eye-gaze shifts to the stranger was significant in each of the models including the variable.

There are multiple limitations to this study. First, we are focusing on the level of BI based on parent's reports. While BIQ is a reliable instrument for BI identification (Dyson et al., 2011), it may reflect parental biases when characterizing and interpreting their children's behavior. Further investigation would benefit from using laboratory observations to identify BI children (Kagan, 2003). Next, although our mobile eye-tracking tasks were much more socially interactive than computer-based paradigms, our results were still acquired in a laboratory setting. Our study was a strong illustration or proof-of-concept for our novel methodology, but mobile eye-tracking still requires additional refinements before it is ready for real-world settings. As mobile eye-tracking improves (e.g. smaller equipment, offline calibration, cost), future studies should be able to venture into more realistic settings (e.g., Jung, Zimmerman, Pérez-Edgar, 2018) which would vastly improve the understanding of visual attention in naturalistic settings. Currently, there are many pieces of equipment that require mobile eye-track studies to be completed inside of a lab. However, as the equipment becomes smaller, mobile eye-tracking will be able to be moved outside of the lab environment. In fact, our lab has just purchased phones to replace the bulky backpack that was used to store the eye-tracking data. As technology improves, studies will be able to more easily replicate real-life social interaction.

Third, our study only included a small sample of children who contributed mobile eye-tracking data (n = 48). Mobile eye-tracking studies are extremely labor-intensive which limited the size of our sample given time and staffing constraints. Currently, it is necessary for a researcher to go through and manually code the looking behavior of the participant for each frame. This is extremely time-consuming. Future software that can automatically identify AOIs, this would ease the burden of data processing. With more time freed up, researchers could spend more time recruiting participants and running more naturalistic experiments. Finally, we studied children in a narrow developmental window. Longitudinal studies have shown that there are significant age effects on threat-related attention patterns (Leppänen, Cataldo, Enlow, & Nelson, 2018). Our study is only able to suggest the threat-related attention patterns of children 5-7 years old.

In conclusion, this study demonstrates the benefits and utility of using mobile eye-tracking to explore patterns of attention in naturalistic settings. Specifically, we found that mobile eye-tracking, relative to RT and stationary AB paradigms, can enhance the ability to detect BI-related individual differences in affect-biased attention. While a novel methodology, mobile eye-tracking shows promise as a way to find deeper and more consistent measurements of attention biases in children.

Appendix A

Behavioral Inhibition Questionnaire (Parent Form).

The following statements describe children's behaviour in different situations. Each statement asks you to judge whether that behaviour occurs for your child "*hardly ever*", "*infrequently*", "*once in a while*", "*sometimes*", "*often*", "*very often*", or "*almost always*". Please circle the number "1" if the behaviour "*hardly ever*" occurs, the number "2" if it occurs "*infrequently*", etc. Try to make this judgement to the best of your ability, based on how you think your child compares with other children about the same age.

1 Hardly Ever	**2** Infreque ntly	**3** Once in a While	**4** Someti mes	**5** Often	**6** Very Often	**7** Almost Always

1. Approaches new situations or activities very hesitantly	1	2	3	4	5	6	7
2. Will happily approach a group of unfamiliar children to join in their play	1	2	3	4	5	6	7
3. Is very quiet around new (adult) guests to our home	1	2	3	4	5	6	7
4. Is cautious in activities that involve physical challenge (e.g., climbing, jumping from heights)	1	2	3	4	5	6	7
5. Settles in quickly when we visit the homes of people we don't know well	1	2	3	4	5	6	7
6. Enjoys being the centre of attention	1	2	3	4	5	6	7
7. Is comfortable asking other children to play	1	2	3	4	5	6	7
8. Is shy when first meeting new children	1	2	3	4	5	6	7
9. Happily separates from parent(s) when left in new situations for the first time (e.g., kindergarten, preschool, childcare)	1	2	3	4	5	6	7
10. Is happy to perform in front of others (e.g., singing, dancing)	1	2	3	4	5	6	7

11. Quickly adjusts to new situations (e.g., kindergarten, preschool, childcare	1	2	3	4	5	6	7
12. Is reluctant to approach a group of unfamiliar children to ask to join in	1	2	3	4	5	6	7
13. Is confident in activities that involve physical challenge (e.g., climbing, jumping from heights)	1	2	3	4	5	6	7
14. Is independent	1	2	3	4	5	6	7
15. Seems comfortable in new situations	1	2	3	4	5	6	7
16. Is very talkative to adult strangers	1	2	3	4	5	6	7
17. Is hesitant to explore new play equipment	1	2	3	4	5	6	7
18. Gets upset at being left in new situations for the first time (e.g., kindergarten, preschool, childcare)	1	2	3	4	5	6	7
19. Is very friendly with children he or she has just met	1	2	3	4	5	6	7
20. Tends to watch other children, rather than join in their games	1	2	3	4	5	6	7
21. Dislikes being the centre of attention	1	2	3	4	5	6	7
22. Is clingy when we visit the homes of people we don't know well	1	2	3	4	5	6	7
23. Happily approaches new situations or activities	1	2	3	4	5	6	7
24. Is outgoing	1	2	3	4	5	6	7
25. Seems nervous or uncomfortable in new situations	1	2	3	4	5	6	7
26. Happily chats to new (adult) visitors to our home	1	2	3	4	5	6	7
27. Takes many days to adjust to new situations (e.g., kindergarten, preschool, childcare)	1	2	3	4	5	6	7
28. Is reluctant to perform in front of others (e.g., singing, dancing)	1	2	3	4	5	6	7
29. Happily explores new play equipment	1	2	3	4	5	6	7
30. Is very quiet with adult strangers	1	2	3	4	5	6	7

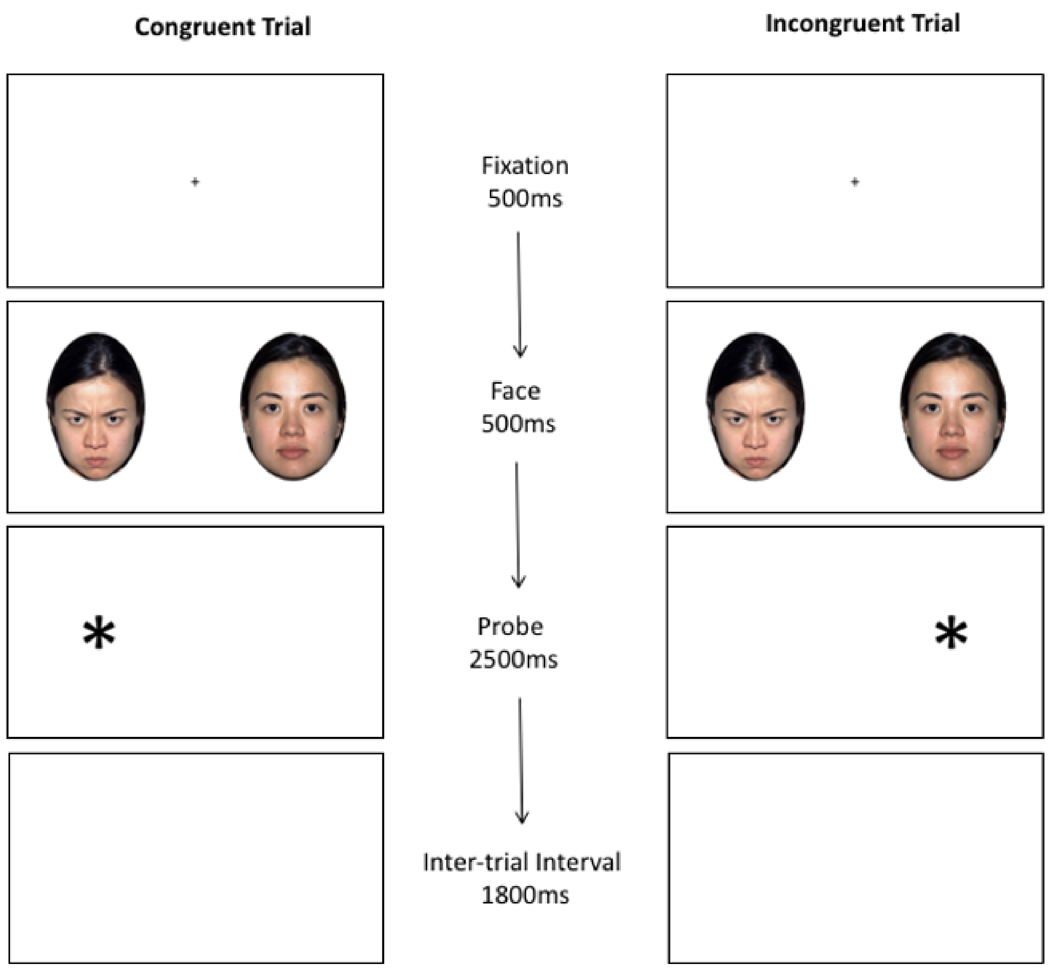
Appendix B

Stranger Approach Script

In the Stranger Approach episode (Figures 1 and 3, Main Text), a stranger (i.e., a research assistant that the child has never met) knocked on the door, entered the room, and stood by the door while saying “Hi”. He paused for 2 seconds and then asked, “Have you ever been here before?”. The stranger waited a maximum of 30 seconds if the child started responding, followed by a 10-second pause after the child finished speaking (a maximum 40-second interval between the stranger’s prompts). He walked towards the child, stood in front of a chair that was placed opposite to the child at a distance of 97 inches, and asked “Are you having a good time here today?”. After a 10-second pause (40-second maximum if the child responded), he sat down and asked, “Do you have a lot of toys?”, followed by another 10-second pause (40-second maximum if the child responded). Then the stranger asked, “What is your favorite toy?”, timed 30 seconds if the child started talking, and immediately responded, “I like (the toy that the child mentioned) too”. After a 10-second pause, the stranger said, “I came to pick up some papers from (the experimenter’s name), do you know where s/he is?” Following the child’s response, the stranger said, “I’ll go look in the hall”. He then walked out of the room.

Appendix C

Dot-Probe Task



Appendix D

Mobile-Eye Tracking Examples

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ACADEMIC VITA

Lucas VanKeuren

Education

The Pennsylvania State University
Schreyer Honors College
Information Sciences and Technology (Design and Development) 2019

Relevant Work Experience

PPG Paints
Software Development Intern

- Created and documented a SQL database to house all sales data which would be used to create an analytics dashboard to show slow-moving inventory
- Developed a console application in C#/.NET to pull data from POS systems and existing inventory record databases
- Created two web applications which allowed users to perform routine data maintenance

Research Experience

Cognitive, Affect and Temperament Lab 2017-19
Undergraduate Research Assistant

- Coded mobile eye-tracking data
- Assisted in running study visits with children of 4- 6 years old
- Edited and synced room and eye-track video footage to be used in manual coding

Research

Poster Presentation **VanKeuren**, L., Gunther, K., Fu, Xi., MacNeill, L., & Pérez-Edgar, K.E. *Naturalistic attention biases to social threat characterize socially withdrawn children* Poster presentation at the 2019 Society For Research in Child Development Biennial Meeting.

Thesis: The Role of Eye-Tracking Technology in Measuring Behavioral Inhibition in Young Children
Thesis Supervisor: Koraly Pérez-Edgar

Extra-Curriculars

Penn State Fightin' Beavs Club Hockey 2015-17

- Voted Defensive Player of The Year by team in 2016
- Received the 2016 Outstanding Academic Achievement Award

Penn State Swing Dance 2018-19

- Participated in set-up and tear-down of events
- Assisted in teaching beginner dance lessons