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Research paper

Using mobile eye-tracking to evaluate gaze behavior during a speech in pediatric anxiety disorders

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ABSTRACT

Background: Altered gaze in social settings is a hallmark of social anxiety; however, little research directly examines gaze in anxiety-provoking contexts among youth with anxiety disorders, limiting mechanistic insight into pediatric anxiety. The present study leveraged mobile eye-tracking technology to examine gaze behavior during a naturalistic stressor in a clinical developmental sample.

Methods: Sixty-one youth (ages 8–17 years; 28 with anxiety disorders, 33 non-anxious controls) completed a naturalistic social stress task (public speaking in front of a videotaped classroom audience) while wearing eye-tracking glasses. Gaze behavior and state anxiety were quantified in each group during two task conditions: while giving a speech and while passively viewing the audience.

Results: Anxiety-related differences emerged in state anxiety and gaze behavior. First, a significant interaction between diagnostic group and task condition on state anxiety indicated that while anxiety increased among non-anxious controls following the speech, youth with anxiety disorders reported persistently elevated anxiety across all assessments. Second, a significant interaction emerged between social anxiety symptom severity and task condition on gaze time on the audience. While youth overall showed low dwell time on the audience during speech delivery, individuals with greater social anxiety showed longer gaze on the audience during the passive viewing condition. This pattern was specific to dimensional analyses of social anxiety symptom severity.

Limitations: The current study was not sufficiently powered to examine age-related differences.

Conclusions: These findings highlight anxiety-related differences in gaze behavior in youth, providing new mechanistic insight into pediatric anxiety using mobile eye-tracking.

1. Introduction

Anxiety disorders typically develop in childhood, persist across the lifespan, and are highly prevalent and debilitating (Kessler et al., 2005). Delineating patterns of altered behavior in youth with anxiety disorders could begin to inform early diagnosis and intervention. In the present study, we focus on one possible indicator of childhood anxiety: alterations in gaze behavior. Fear and avoidance of eye contact are considered to be important characteristics of social anxiety in adults (Schulze et al., 2013). Accordingly, prior research in adults with social anxiety disorder shows reduced fixation on faces in both passive viewing (Horley et al., 2003) and public speaking (Chen et al., 2015) tasks. The primary goal of the present study was to extend these findings to pediatric anxiety using mobile eye-tracking technology.

Recent work has begun to expand insight on gaze behavior to youth. Consistent with the adult literature, anxious youth tend to show less dwell time on threatening stimuli than non-anxious youth (Lisk et al., 2020). Although informative, such work uses tasks with still faces, potentially limiting generalization to real-world settings. Moreover, stimuli used were typically adult faces, whereas diagnostic criteria of pediatric social anxiety disorder require symptoms to manifest in peer settings (American Psychiatric Association, 2013). Given these limitations, it is important to expand findings into situations that youth frequently encounter, such as school settings.

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The present pre-registered study (*https://osf.io/mwbax*) extends extant research on gaze behavior to a naturalistic, peer setting and a clinical developmental sample. Leveraging mobile eye-tracking glasses technology, we measured participants' gaze on audience members' faces while giving a speech and while passively viewing the audience in a realistic, virtual classroom environment. We hypothesized that youth with anxiety disorders would report greater state anxiety following the speech compared to non-anxious controls. Moreover, we predicted that youth with anxiety disorders would demonstrate reduced dwell time on the audience during the speech (i.e., gaze avoidance), compared with non-anxious controls. Finally, we hypothesized a similar pattern of findings using a continuous measure of social anxiety symptom severity. Taken together, this study provides novel insight into links among gaze behavior and anxiety during a naturalistic stressor in youth.

2. Method

2.1. Participants

Seventy youth between the ages of ages 8 and 17 years participated in this study. Of those, 9 were excluded from analyses because they aborted the task prior to completing the task ($n = 2$) or due to technological difficulties ($n = 7$). This resulted in a final sample of 61 youth ($M_{age} = 13.11$, $SD = 2.97$; 38 female; Supplemental Table S1). Of these participants, 28 had a primary anxiety disorder, and 33 did not have any current or past psychiatric disorder (non-anxious controls; see Supplemental Material for full inclusion/exclusion criteria).

2.2. Procedure

Before starting the task, participants rated their state anxiety on a computerized 30-point visual analog scale (Abend et al., 2014). Participants then completed a modified version of the Leiden Public Speaking Task, an established, validated, and age-appropriate social stressor task (Westenberg et al., 2009). Participants completed the task while wearing Tobii Pro Glasses 2 (Tobii AB, Stockholm, Sweden), which are designed to approximate the look and feel of traditional eyeglasses and to accurately capture gaze data in naturalistic environments. Following a standardized eye-tracking calibration procedure, participants stood in front of a large projector screen and were told that they would be asked to introduce themselves as if they were starting in a new class (see Supplemental Material). They then viewed a pre-recorded video of a virtual audience (eight peers and one teacher) projected onto the screen at life-sized proportions (Fig. 1). Participants were asked to introduce themselves to the classroom for 1 min, with tones prompting them to begin and end ("Speaking Condition"). Following the Speaking Condition, participants rated their state anxiety before viewing the recording a second time, during which they were asked to look at the audience without speaking ("Viewing Condition"). Participants then rated their state anxiety a third time.

All procedures were approved by the National Institute of Mental Health Institutional Review Board. Youth and their parents provided their informed assent/consent prior to participation. All participants received $30 for their participation in this task, and youth with anxiety disorders also received treatment (see Supplemental Material).

2.3. Measures

2.3.1. Gaze behavior

Eye-tracking data were collected using Tobii Pro Glasses 2 and processed using Tobii Pro Lab, Analyzer Edition. Using the Tobii Pro Lab Real-World Mapping program, recorded gaze data were mapped onto a stable snapshot of the virtual classroom. Areas of interest (AOIs) for each audience member's face were predefined within these snapshots. We aggregated the total duration of fixations (minimum gaze duration: 60 ms) within all face AOI (i.e., the "dwell time") for the Speaking and the Viewing Conditions, separately.

2.3.2. Social anxiety symptom severity

Social anxiety symptom severity was assessed using the social phobia subscale of the Screen for Child Anxiety Related Disorders (SCARED; Birmaher et al., 1999; Birmaher et al., 1997). This subscale sums seven items assessing self-reported social anxiety symptoms on a three-point Likert scale. The social anxiety subscale has established acceptable convergent and discriminant validity (Birmaher et al., 1997; Rappaport et al., 2017). Youth and their parents each completed the SCARED, and, in line with previous work (e.g., Abend et al., 2021), scores were averaged across child and parent reports.

2.3.3. Data analysis

To test our first pre-registered hypothesis that youth with anxiety disorders would report greater anxiety following the speech compared to non-anxious controls, we conducted a linear mixed effects regression with time point (baseline, post-Speaking Condition, and post-Viewing Condition) as the within-subject predictor, diagnosis (anxiety disorder versus non-anxious control) as the between-subjects predictor, and state anxiety as the outcome measure.

To test our second hypothesis that youth with anxiety disorders would show less dwell time on faces during the speech compared to non-anxious controls, we conducted a similar linear mixed effects model with condition (Speaking versus Viewing) as the within-subject predictor, diagnosis as the between-subjects predictor, and dwell time as the outcome measure. To test our third hypothesis that a similar pattern would emerge using a continuous measure of social anxiety symptom severity, we conducted a similar linear mixed effects model with social anxiety symptom severity as a continuous between-subject predictor.[1] Linear mixed effects models were conducted using the *lme4* package (Bates et al., 2009) in R (R Core Team, 2021). Significant interaction effects were probed using the *interactions* package (Long, 2019). All analyses used two-sided tests and an alpha of 0.05.[2]

3. Results

3.1. State anxiety

Across the sample, state anxiety significantly differed across time points, $F(2, 117.10) = 6.20$, $p = .003$, with a significant increase in reported anxiety from baseline to post-Speaking Condition, $F(1, 60.35) = 12.65$, $p = .001$, indicating successful anxiety induction. In addition, a main effect of diagnosis emerged whereby anxious youth reported greater state anxiety across time points compared to non-anxious controls, $F(1, 61.33) = 35.01$, $p < .001$ (Fig. 2a; Supplemental Table S2). These main effects were qualified by a significant interaction between diagnosis and time point, $F(2, 117.10) = 3.68$, $p = .028$. Among non-anxious controls, there was a significant effect of time point, $F(2, 64.09) = 8.83$, $p < .001$, with greater reported anxiety following both the Speaking, $F(1, 33.00) = 13.18$, $p = .001$, and Viewing Conditions, $F(1, 32.80) = 6.62$, $p = .015$, compared to baseline. In contrast, among anxious youth, state anxiety remained elevated and did not differ by task condition, $F(2, 52.65) = 1.37$, $p = .264$.

3.2. Gaze behavior

3.2.1. Diagnostic groups

Across groups, youth showed significantly shorter dwell time on faces during the Speaking Condition ($M = 6.08$ s, $SD = 7.25$) relative to the Viewing Condition ($M = 12.97$ s, $SD = 10.34$), $F(1, 59.00) = 22.34$, $p < .001$ (Fig. 2b), indicating gaze avoidance during public speaking.

[1] Measures did not differ based on sex.

[2] The pattern of results remains consistent when controlling for age.

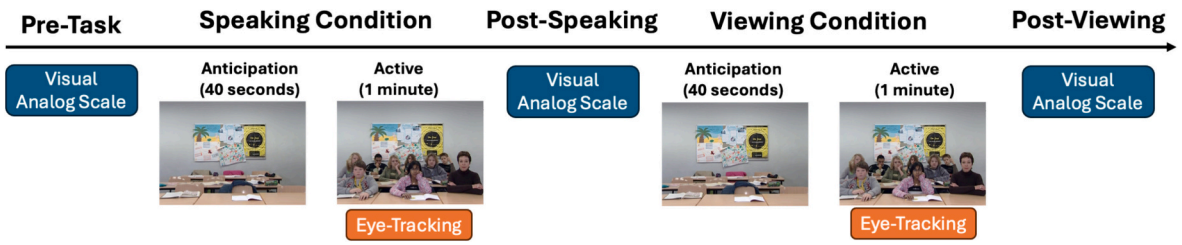

Fig. 1. Schematic of task protocol.

However, diagnosis was not significantly associated with dwell time, $F(1, 60.57) = 0.15$, $p = .699$, and there was no significant interaction between task condition and diagnosis, $F(1, 59.00) = 1.73$, $p = .194$. Results were similar when isolating youth with social anxiety disorder versus non-anxious controls (see Supplemental Material).

3.2.2. *Social anxiety symptom severity*

There was a significant interaction between task condition and social anxiety symptom severity, $F(1, 53.11) = 4.25$, $p = .044$ (Fig. 2c). In the Viewing Condition, there was a trending positive association between social anxiety symptom severity and dwell time, $b = 0.57$, $p = .055$; in the Speaking Condition, symptom severity was not significantly associated with dwell time, $b = -0.19$, $p = .524$. Across the sample, task condition was not significantly associated with dwell time, $F(1, 51.09) = 0.90$, $p = .348$. Further, across conditions, social anxiety symptom severity was not significantly associated with dwell time, $F(1, 54.96) = 0.68$, $p = .413$.

4. Discussion

Using mobile eye-tracking during a naturalistic social stress task, we identified anxiety-related differences in state anxiety and gaze behavior in youth with and without anxiety disorders. Consistent with hypotheses, anxious youth reported elevated state anxiety across task conditions, including after giving a speech. Moreover, across the sample, youth reported elevated state anxiety after giving a speech. While we did not have a priori hypotheses regarding an interaction between diagnosis and time point, we detected a significant interaction, such that state anxiety increased following public speaking among non-anxious controls but was persistently elevated across all task phases among anxious youth. Contrary to hypotheses, both groups showed gaze avoidance during public speaking; further, we detected a trend towards a positive association between social anxiety symptom severity and gaze duration during passive viewing of the audience.

The induced anxiety and gaze avoidance during public speaking across the sample supports the utility of mobile eye-tracking in conjunction with this task as a standardized, effective social stress paradigm for use in clinical developmental samples. The use of this task with mobile eye-tracking technology offers several advantages, including enhanced ecological validity compared to typical trial-based, emotional-faces paradigms completed with stationary eye-trackers. Moreover, the virtual audience allows for a highly standardized and less resource-intensive social stressor compared to public speaking tasks with live judges (e.g., the Trier Social Stress Task).

We noted several anxiety-specific effects. First, in line with previous research suggesting elevated subjective anxiety across task conditions during speaking tasks in youth with anxiety disorders (Krämer et al., 2012), anxious youth reported elevated state anxiety during public speaking as well as passive viewing, suggesting that presence in social contexts, whether active or passive, may be perceived as a threatening experience. Moreover, the mere anticipation of participating in this task elicited considerable anxiety in anxious youth, pointing to the importance of potential-threat anticipation even prior to the actual social experience in anxiety (Abend, 2023), as well as the potency of all aspects of this social stressor paradigm.

Regarding gaze behavior, anxiety severity tended to positively correlate with gaze duration during passive audience viewing but not public speaking. Public speaking may reflect an acute form of socially evaluative, immediate threat that may mask anxiety-related differences, whereas passively viewing the audience may represent a more ambiguous or less potent task in which anxiety-related differences are more likely to emerge (Lissek et al., 2006). It should be noted that the observed effect was specific to a dimensional analysis examining social anxiety across the sample. Given the dimensionality of social anxiety symptoms (Carragher et al., 2015), this pattern of results highlights the importance of considering social anxiety symptom severity dimensionally in addition to diagnostic categories.

Ultimately, further research advancing the characterization of anxiety-related differences in naturalistic gaze behavior in youth could help to inform specific treatment components, such as social skills training (Spence, 2003). Furthermore, future research with mobile eye-tracking during naturalistic stressors could begin to identify biomarkers of treatment response. For example, such an approach could be used to examine changes in attention in real-world situations following attention-focused approaches to treating pediatric anxiety, such as attention bias modification training.

While this study provides novel insight into anxiety-related changes in gaze behavior in youth, it entails several specific limitations. First, this preliminary study was not sufficiently powered to examine age-related differences; although very few studies exist on anxiety-related changes in gaze across development, preliminary evidence suggests that anxiety-driven alterations in gaze behavior may strengthen during adolescence (Chen et al., 2020). Future work is also needed to examine longitudinal associations between anxiety and altered gaze behavior, as it is possible that disorder duration may impact patterns of gaze avoidance (McTeague and Lang, 2012). Second, this study used a well-validated, naturalistic speech task that reliably evokes stress responses in youth (Westenberg et al., 2009); however, the generalization of observed effects to other socially stressful interactions needs to be established. Third, incorporating physiological measurements (e.g., galvanic skin response) would provide an additional level of evidence for anxiety induction.

In conclusion, the present study leveraged mobile eye-tracking technology in conjunction with a standardized, naturalistic social stressor to examine anxiety-related differences in gaze behavior. While all youth looked less at the audience while giving a speech, youth with greater social anxiety tended to look more towards faces during a passive viewing condition. These results provide new insight into the characterization of social anxiety in youth and encourage continued use of this methodology in future work.

CRediT authorship contribution statement

Elizabeth R. Kitt: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rany Abend:** Writing – review & editing, Conceptualization. **Paia Amelio:** Writing – review & editing, Investigation, Data curation. **Jordan Galbraith:** Writing – review & editing, Investigation, Data curation.

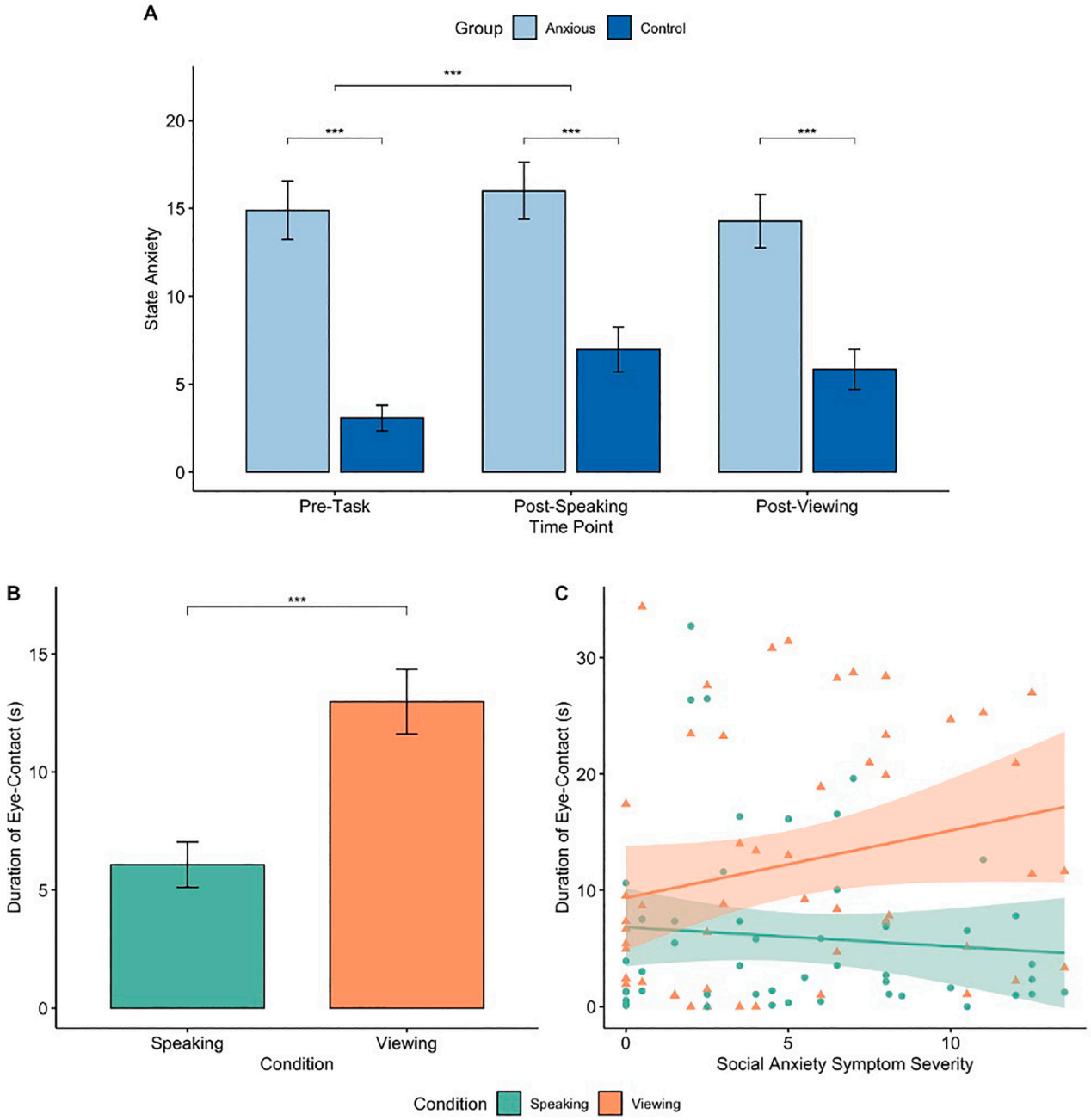

Fig. 2. Results of primary analyses.
A. Across the sample, youth reported greater anxiety post-Speaking Condition compared to pre-task. Across time points, youth with anxiety disorders reported greater anxiety compared to non-anxious youth. Moreover, there was a significant interaction between diagnosis and time point. Non-anxious controls reported elevated state anxiety post-Speaking Condition compared to pre-task, whereas state anxiety remained elevated across conditions in anxious youth.
B. Across the sample, youth showed significantly shorter dwell time on audience faces during the Speaking versus the Viewing Condition.
C. There was a significant interaction between social anxiety symptom severity and condition, with a trending positive association between social anxiety symptom severity and dwell time in the Viewing Condition.

Anjali D. Poe: Writing – review & editing, Investigation, Data curation, Conceptualization. **Dylan G. Gee:** Writing – review & editing, Supervision. **Daniel S. Pine:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Anita Harrewijn:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Role of the funding source

The funding sources were not involved in the study design; in the collection, analysis, or interpretation of data; in the writing of this manuscript; or in the decision to submit the manuscript for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2024.10.024.

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