HHS Public Access
Author manuscript
Eur Child Adolesc Psychiatry. Author manuscript; available in PMC 2018 December 01.

Published in final edited form as:
Eur Child Adolesc Psychiatry. 2017 December ; 26(12): 1423–1432. doi:10.1007/s00787-017-1001-3.

Autonomic arousal in anxious and typically developing youth during a stressor involving error feedback

Michelle Rozenman[1], **Alexandra Sturm**[1], **James T. McCracken**[1], and **John Piacentini**[1]

[1]Division of Child and Adolescent Psychiatry, UCLA Semel Institute for Neuroscience and Human Behavior, 760 Westwood Plaza, 67-455, Los Angeles, CA 90095, USA

Abstract

Anxiety has been proposed to influence psychophysiological reactivity in children and adolescents. However, the extant empirical literature has not always found physiological reactivity to be associated with anxiety in youth. Further, most investigations have not examined psychophysiological reactivity in real time over the course of acute stress. To test the impact of anxiety disorder status on autonomic arousal in youth, we compared youth with primary anxiety disorders ($N = 24$) to typically developing (TD) youth ($N = 22$) on heart rate (HR), heart rate variability (HRV), and respiratory sinus arrhythmia (RSA) during an acute stressor in which youth received error-related feedback. We also conducted exploratory analyses on youth performance during the task. Youth ages 9–17 participated in the arithmetic portion of the Trier Social Stress Test for Children (Buske-Kirschbaum et al., Psychosom 59:419–426, 1997), during which time they received consecutive, standardized feedback that they made calculation errors. Results indicated that, compared to their TD counterparts, the anxious group demonstrated elevated HR and suppressed HRV during initial provision of error feedback and during the recovery period. No group differences were found for RSA. Additionally, overall TD youth made a greater proportion of errors than anxious youth. Clinically, these findings may provide preliminary support for anxious youth exhibiting physiological reactivity in response to receipt of error-related feedback, and may have implications for understanding biological processes during stress. This work underscores the need for further study of when and how anxiety may influence autonomic reactivity over the course of stress.

Keywords

Anxiety; Child; Adolescent; Psychophysiology; Heart rate; Stress

Introduction

Anxiety is the most common mental health problem in children and adolescents (up to 25%) [1]. Anxiety disorders are associated with substantial impairment for youth across social, academic, and home domains [2, 3], and confer significant risk for future medical and

Correspondence to: Michelle Rozenman.

Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest for the current work.

psychiatric illness [2, 4, 5]. Experts have called for clarification of the biobehavioral markers and mechanisms underlying pediatric anxiety [6, 7] to improve illness classification and intervention efforts.

One such putative marker is that of psychophysiological arousal. Theoretical models propose, and some data support, that anxious individuals exhibit aberrant physiological reactivity, particularly during stress [8–10], and that this autonomic hyper-arousal may influence fear- and threat-based learning [11–13]. However, empirical studies of physiological reactivity during acute stress in clinically anxious and typically developing (TD) youth have produced mixed findings. Some work has demonstrated that clinically anxious youth exhibit greater reactivity than TD youth during stress [14, 15]. Other studies suggest that clinically anxious youth exhibit higher baseline levels of arousal than their TD counterparts, although the two groups demonstrate comparable changes in arousal during stress [16, 17]. Still others have found no physiological differences between clinically anxious and TD youth [18–20]. Investigations conducted in non-affected samples parallel these mixed findings: while some studies have found youth with elevated anxiety symptoms to exhibit greater reactivity than those with low anxiety levels during stress tasks [21], other studies have found no group differences between youth with high versus low anxiety symptoms [22, 23].

One potential explanation for these discrepant findings may be due to how arousal is measured and whether the “stressful” components of tasks are introduced once and/or held static or reintroduced throughout the task. Nearly, all the above-cited studies examine mean arousal across the entire experimental stressor. However, some stress tasks provide multiple prompts (e.g., corrective or negative feedback, changes in expectations for participant performance, etc.) during the stressor period, while others do not. Such differences in methodology may impact our ability to generalize across studies, as the mean level of physiological arousal may differ depending on whether and how task demands might change during the task.

The Trier Social Stress Test for Children (TSST-C) [24], one of the most widely utilized stress tasks, provides an excellent example of one such task in which the stressor is reintroduced or made salient throughout the task. During the arithmetic portion of the TSST-C, the experimenter provides four standardized prompts to youth over the course of 5 min. These prompts indicate that the youth made an error, regardless of actual performance, and must start their calculations over; this is presumably done to maintain or increase the “stressful” component of the arithmetic. This version of the task would likely result in different arousal trajectories for youth than a task in which error feedback was not provided. This methodology involving error-related feedback may even differentially influence the course of reactivity for anxious and TD youth. For example, anxious youth might exhibit fast and immediate reactivity, which would be maintained as the stressor is reintroduced, while TD youth may be less reactive initially but exhibit more arousal with subsequent stressor prompts. Thus, obtaining an average score for the entire math portion of the TSST-C could result in loss of information about real-time fluctuations in autonomic functioning as the experimenter successively reintroduces the stressor (in this case, error-related feedback). Examination of patterns of reactivity over the course of a stressor, and not simply the mean

reactivity across the entire stressor period, may provide more a more fine-grained approach towards studying how youths respond to stress in real time.

Moreover, how youths perform over the course of acute stress may supplement our understanding of physiological correlates of youth anxiety, and eventually answer questions about how autonomic reactivity and behavior may interact. With regard to objective measurement of youth behavior, a few investigations have used observational coding to explore youth approach towards (or avoidance of) fearful stimuli [25, 26] or facial expressions, pauses, and other indicators of anxiety during speech tasks [27, 28]. However, as with the physiological literature, surprisingly little work has been done to examine youth cognitive performance over the course of stress despite well-documented relationships between anxiety and cognitive performance [29–31].

With regard to the TSST-C specifically, to our knowledge only one prior study has quantified youth cognitive performance (i.e., mathematical calculations) on a modified version of the TSST-C [24]. In that study, youth were not provided with standardized error prompts, and no group differences were found between youth with social phobia and healthy controls for calculation errors or correct calculations. Again, anxious and TD youth may perform differently under stress, particularly when provided with feedback that they have made an error. A preliminary step towards understanding how trajectories of youth performance and physiological reactivity may interact during stress might involve examining youth performance during a stressor such as the TSST-C math task, particularly in relation to receipt of error-related feedback.

The present study

In the current study, we sought to examine psychophysiological arousal in anxious youth, compared to their TD counterparts, over the course of an acute stressor. Secondarily, we explored youth performance (i.e., calculations during the math task) in response to error-related feedback. Rather than focus on a single index, we examined three commonly studied indices of arousal—heart rate (HR), heart rate variability (HRV), and respiratory sinus arrhythmia (RSA)—in order to examine whether psychophysiological responding occurred across indices. All three indices reflect interactions between the two systems comprising the autonomic nervous system: the sympathetic nervous system (or “fight or flight” response), which becomes activated when a stressor is perceived, and the parasympathetic nervous system, which serves to maintain homeostasis during times of rest, and serves as a downregulation mechanism of sympathetic responses. Typically during a stressor, heart rate (HR) is expected to increase, and in response heart rate variability (HRV, the fluctuation in intervals between heart beats) is expected to decrease [32, 33]. HR and HRV have been commonly studied indices in pediatric anxiety samples, although the extant data are mixed with regard to whether anxious and TD youth exhibit similar or distinct HR and HRV during stress. Respiratory sinus arrhythmia, or the variation in heart rate that occurs as a function of synchronization with breathing, reflects parasympathetic influences from both cardiac (HRV) and respiration, and is theorized to become suppressed during stress [34]. RSA suppression, therefore, is viewed as an adaptive process that may help individuals physiologically self-regulate, during stress. While there is some evidence that restricted

baseline RSA and less RSA suppression during stress is associated with broad internalizing problems in community samples [34], less data are available on the role of RSA during acute stress in clinically anxious youth.

Our primary aim in this investigation was to examine whether anxious and TD youth demonstrated comparable or distinct patterns of physiological reactivity over the course of a stressor in which they received successive error-related feedback. Our a priori hypotheses for this primary aim were that anxious youth would exhibit (1) greater increases in HR, (2) greater HRV suppression, and (3) less RSA withdrawal than TD youth.

Our secondary aim was to examine youth performance over the course of the stressor. More specifically, we sought to compare anxious and TD youth on (1) total number of calculations and (2) proportion of correct responses out of total calculations during each phase of the math task. As the extant literature has documented a negative correlation between anxiety and cognitive performance [29–31], we predicted that anxious youth (1) would provide fewer responses as the task progressed and (2) would make more errors than TD youth.

Method

Participants

Youth were recruited with community advertisement (flyers and online postings). Sixty-one families contacted the study. Fifty-three youths and their primary caregiver were deemed initially eligible (e.g., youth in age range), agreed to participate, and completed the assent/consent process; 49 of these families met final diagnostic inclusion criteria described below. A further three youth were excluded due to significant movement during physiological data collection.

The final sample consisted of 46 youth ages 9–17 ($M = 13.18$, SD = 2.70; 50% male). The age range was selected a priori based on prior studies involving assessment/treatment of, or psychophysiological measurement in, pediatric anxiety [10, 20, 21, 28, 35]. The sample was racially/ethnically diverse, with 41% identifying as ethnic/racial minority (15% Hispanic/Latino, 26% African American, 4% Asian, and 13% mixed race/ethnicity).

As with other child anxiety studies [35], anxious youth ($n = 24$) were included if they met DSM-IV-TR criteria for a primary anxiety disorder (Generalized Anxiety Disorder, Social Phobia, Separation Anxiety Disorder) and did not have any contraindications for participation in physiological data collection (e.g., pacemaker). Typically developing youth ($n = 22$) were included if they did not meet criterion for any current or history of psychopathology, had never received any kind of psychological services, and the consenting parent reported that no first-degree relatives had ever received any psychological services or had been diagnosed with or suspected of any mental health problems. Families did not receive any compensation for their participation, although options for additional services were discussed with anxious youth following their participation in the study.

Measures

Diagnostic measure—*Anxiety disorders interview schedule for DSM-IV: child and parent versions* (ADIS) [36] is a semi-structured psychiatric diagnostic interview that assesses for anxiety disorders and other psychopathology. The ADIS is well validated [37, 38] and considered the gold-standard diagnostic tool for diagnosing anxiety in youth [35]. In this study, the ADIS was used to confirm primary anxiety diagnosis for youth in the anxious group, and confirm no current or history of psychopathology in the typically developing group. The ADIS was administered by the first author, a Ph.D.-level clinical psychologist with expertise in anxiety-related disorders.

Stress task—The *Trier Social Stress Test for Children* (TSST-C) [24] is a standardized stressor task, modified from the adult version of the TSST [39]. The TSST-C and its adaptations have been used in several studies to assess stress response in anxious [17, 20] and typically developing youth [40–42]. The original TSST-C [24] first requires youth to prepare (2 min) and deliver (5 min) the ending of a story, and then verbally respond to challenging arithmetic for 5 min during which time they are provided with four standard prompts that they made errors (irrespective of whether they actually made errors). In the present study, we specifically sought to examine youth performance during the arithmetic portion of the stressor, particularly in relation to being provided with feedback about errors. Therefore, the baseline period in this present study refers to the time between the conclusion of the first portion of the TSST-C (story task) through the end of instructions about the math task. During this arithmetic stressor, youth were told to count backwards in increments of 13 from 1023 (ages $\geq$ 11) or in increments of 7 from 758 (ages $\leq$ 10). Four times over the course of the task (at 60, 120, 180, and 240 s), the experimenter notified the youth “you made an error in your last few steps, please go back to 1023 (or 758 for younger youth) and start over” regardless of whether the youth actually made any errors. Finally, during the 3-min recovery period, youth were instructed to sit quietly for 3 min.

Procedure

University Institutional Review Board approval was obtained prior to consenting/assenting any youths in this project. Following consent/assent procedures, youth and parent completed a diagnostic interview. As this study took place within a larger study of youth cognitive and physiological factors that might contribute to anxiety [15], youth also participated in other tasks not relevant to this investigation. Following the diagnostic interview, youth completed two other tasks not relevant to this investigation. Those tasks included a brief reading screener and a performance-based computerized task assessing interpretations of ambiguous situations. Youth then participated in the TSST-C with two experimenters (one providing instructions and the other serving as the physiological data collection technician) in a room separate from their parents. Following the 3-min recovery period, youth were debriefed about the purpose of the TSST-C and notified that error feedback was provided in a standardized fashion and irrespective of whether the youth actually made errors.

Physiological measures

Physiological arousal was measured with three indices: heart rate (HR) as measured in beats per minute, heart rate variability (HRV) as measured in milliseconds by average inter-beat interval between R–R waves, and respiratory sinus arrhythmia (RSA) as measured in milliseconds by the difference between the minimum and maximum change in HR during respiration. An MP150 Biopac Systems, Acknowledge III software, and wireless transmitter, was used to acquire data. The transmitter was calibrated prior to each data acquisition session. Two Ag–AGCl electrodes were filled with GEL 101 gel as a contact medium between electrode and skin, with medical tape used to ensure that electrodes did not shift with movement. Electrodes were placed on the right collarbone and lower left rib, and a respiration belt was tightened around the ribcage. A sampling rate of 500 Hz was used. All recordings were screened for physiological artifacts (i.e., motion) and analyzed offline using MindWare 2.1 software. During data processing, the math stressor was divided into five phases (phase one occurring before the first error prompt, phase two occurring before the second error prompt, etc.).

Behavioral responding during TSST-C arithmetic task

The TSST-C was either video- or audio-recorded (if youth did not want to be video-recorded, they could request for audio recording instead). The arithmetic task was subsequently coded by a team of four undergraduate students, with each recording coded by two different coders for: (a) number of total calculations and (b) number of errors during each portion of the math task. There were no discrepancies across coders. Prior to coding for this study, coders had reached 100% accuracy on sample video/audio recordings. It should be noted that coders each coded six practice tapes, and by the second tape onward every single coder had reached 100% accuracy for both number of total calculations and number of errors during each portion of the math task. Coders were unaware of youth diagnostic status, inclusion criteria, and aims of this study. Video malfunction (i.e., loss of sound, recorder turned off) occurred in 10 cases (4 anxious, 6 TD). Therefore, as described below, all available data for the subset of 20 anxious and 16 TD youth were used for Aim 2 analyses.

Statistical analyses

Prior to conducting data analyses, we examined whether there were any group differences for demographic (age, gender, minority status) and baseline physiological variables. For our primary aim, three separate 2 (Group: anxious, TD) × 6 (time: math start, errors 1–4, recovery) mixed ANCOVAS were conducted to examine potential group differences during the TSST-C math task on HR, HRV, and RSA. Age was included as a covariate in all models due to well-documented developmental differences on indices of autonomic arousal [20, 42, 43]. Group × age interaction effects were also tested, given prior proposals that age may moderate the effects of anxiety symptoms on arousal [44]. However, we did not find significant group × age interactions in the present study and, therefore, excluded these non-significant interaction effects in our final models. For our secondary aim, two separate 2 (Group) × 5 (time: math start, errors 1–4) mixed ANCOVAs were conducted to examine potential group differences during the TSST-C math task on total math calculation responses

provided by youth, as well as the proportion of errors out of total responses provided. Again, age was tested as a covariate, as we expected the speed of math calculations to be affected by age (i.e., older youths should be able to complete calculations more quickly than younger youths). Videotape malfunction resulted in loss of math response data for 6 youth in the control group (N for second aim = 16) and 4 youth in the anxious group (N = 20), so Aim 2 analyses were conducted with a subset of the full sample for whom data was available. For significant effects in ANCOVAS, post hoc comparisons by group over time were conducted to examine specific time point differences where group differences might emerge. Bonferroni and Hyuhn-Feldt corrections were used for all analyses.

Results

Sample characteristics are presented in Table 1. There were no differences between anxious and TD youth on demographic characteristics (age, gender, minority status; Table 1). There were also no group differences on psychophysiological arousal at resting baseline prior to any TSST-C activities [HR (t(44) = −1.33, p = 0.19]; HRV [t(44) = 0.27, p = 0.28], RSA [t(44) = −0.23, p = 0.82] or during the baseline that we used for this investigation (time between end of story task, through math instructions until start of math task; HR [t(44) = −0.68, p = 0.50]; HRV [t(44) = 0.67, p = 0.51], RSA [t(44) = −1.08, p = 0.29].

Aim 1: group differences in HR, HRV, and RSA during stressor with error feedback

Separate repeated-measures ANCOVAs were run for HR, HRV, and RSA to determine group differences over the course of error feedback and recovery. As described in statistical analyses, age (measured in years) was included as a covariate in all models. Per the a priori analytic plan, we tested group × age × time interactions, but these were non-significant [HR, F(4.02, 164.62) = 0.98, p = 0.42, $\eta_p^2 = 0.02$; HRV, F(4.03, 165.15) = 1.29, p = 0.28 $\eta_p^2 = 0.03$; RSA, F(4.57, 187.40) = 1.48, p = 0.20; $\eta_p^2 = 0.04$] and are not included in final models presented below.

Heart rate (HR)—Controlling for the significant effects of age [F(4.01, 168.41) = 3.53, p = 0.009; $\eta_p^2 = 0.08$], we found a significant group × time interaction [F(4.01, 168.41) = 2.99, p = 0.02, $\eta_p^2 = 0.07$] for HR. Post hoc comparisons indicated that the anxious group demonstrated significantly higher HR than the TD group after the first (mean difference = 8.24, SE = 3.42, p = 0.02) and second (mean difference = 6.84, SE = 3.10, p = 0.03) error prompts, and during recovery (mean difference = 6.77, SE = 2.85, p = 0.02), with a parallel trend towards significance after the third error prompt (mean difference = 4.92, SE = 2.65, p = 0.07; Fig. 1). Groups did not significantly differ in HR at the start of the math task (before receiving any error prompts; mean difference = 3.97, SE = 3.22, p = 0.23) or after the fourth error prompt (mean difference = 0.89, SE = 2.65, p = 0.74).

Heart rate variability (HRV)—Controlling for the significant effects of age [F(4.03, 169.22) = 4.85, p = 0.001; $\eta_p^2 = 0.10$], we found a significant group × time interaction [F(4.01, 169.22) = 2.89, p = 0.02; $\eta_p^2 = 0.06$] for HRV. Post hoc comparisons indicated that

the anxious group demonstrated significantly lower HRV than the TD group after the first (mean difference = −69.43, SE = 30.76, $p = 0.03$) and second error prompts (mean difference = −56.33, SE = 27.57, $p = 0.04$), and during recovery (mean difference = −65.83, SE = 28.06, $p = 0.02$; Fig. 2). Groups did not significantly differ in HR at the start of the math task (mean difference = −34.70, SE = 29.56, $p = 0.25$), or after the third (mean difference = −40.32, SE = 24.99, $p = 0.11$) or fourth (mean difference = −6.26, SE = 24.85, $p = 0.80$) error prompts.

Respiratory sinus arrhythmia (RSA)—There were no significant main effects [group $F(1, 43) = 2.09$, $p = 0.16$; $\eta_p^2 = 0.05$]; age [$F(4.31, 181.08) = 1.42$, $p = 0.23$, $\eta_p^2 = 0.03$]; time [$F(4.32, 181.08) = 1.19$, $p = 0.32$, $\eta_p^2 = 0.03$], and no significant group × time interaction [$F(4.31, 181.08) = 0.73$, $p = 0.59$, $\eta_p^2 = 0.02$] for RSA. Removing group or age from the model did not result in detection of significant effects.

Aim 2: youth behavioral responding during stressor with error feedback

Total responses during math task—With regard to total responses during the math portion of the TSST-C, we found a significant group × time interaction [$F(3.50, 115.43) = 3.90$, $p = 0.007$, $\eta_p^2 = 0.11$] on youth responses during the math task, suggesting overall differences by group over time. However, post hoc comparisons did not reveal significant group differences at any individual time point (task start mean difference = 2.13, SE = 1.48, $p = 0.16$; error 1 mean difference = 2.34, SE = 1.32, $p = 0.09$; error 2 mean difference = −0.45, SE = 1.34, $p = 0.74$; error 3 mean difference = −0.98, SE = 0.86, $p = 0.27$; error 4 mean difference = −1.61, SE = 0.91, $p = 0.09$). Age was not a significant covariate [$F(3.50, 115.43) = 0.94$, $p = 0.44$, $\eta_p^2 = 0.03$] and, therefore, was not included in the final model; group × time interaction results and subsequent post hoc tests did not differ depending on whether age was included.

Proportion errors during math task—Controlling for the significant effects of age [$F(3.96, 130.82) = 3.44$, $p = 0.01$, $\eta_p^2 = 0.09$], there was a significant main effect of group [$F(1, 33) = 5.64$, $p = 0.02$, $\eta_p^2 = 0.15$] but no significant effect of time [$F(3.96, 130.82) = 2.25$, $p = 0.07$, $\eta_p^2 = 0.06$] or group × time interaction [$F(3.96, 130.82) = 0.84$, $p = 0.50$, $\eta_p^2 = 0.03$]. Post hoc comparisons indicated that the TD group made a significantly greater proportion of errors out of total responses than the anxious group after the second (mean difference = 0.22, SE = 0.10, $p = 0.03$) and fourth (mean difference = 0.28, SE = 0.10, $p = 0.006$) error prompts, with a trend towards significance after the third error prompt (mean difference = 0.17, SE = 0.09, $p = 0.07$) error prompt (see Fig. 3). Groups did not differ in the proportion of errors out of total responses before any error prompts (mean difference = 0.15, SE = 0.11, $p = 0.17$), or after the first error prompt (mean difference = 0.16, SE = 0.09, $p = 0.10$).

Discussion

The primary aim of this study was to compare physiological arousal in anxious and TD youth during an acute stressor, during which time one aspect of the stressor (i.e., feedback about arithmetic errors and prompts to restart calculations) was successively reintroduced. We had a priori predictions that anxious youth would demonstrate greater increases in HR and greater suppression of HRV and RSA than their TD counterparts over time. Consistent with our hypotheses, overall, HR and HRV demonstrated different patterns of change by group over time. Contrary to hypotheses, RSA did not significantly change over time or by group.

With regard to HR, as predicted, anxious youth demonstrated greater HR changes over time. Specifically, anxious youth exhibited significantly higher HR than the TD group following the first two error prompts and during the recovery period. Groups did not significantly differ in HR at the start of the task (prior to any error prompts), or during the second two error prompts. The HRV data parallel those for HR: anxious youth demonstrated less HRV change over time. Specifically, the anxious group demonstrated significantly lower HRV than the TD group after the first two error prompts, as well as during recovery. Both HR and HRV interactions with time demonstrated medium effects ($\eta_p^2 = 0.07, 0.06$). Again, groups did not significantly differ in HRV at the start of the task or during the second two error prompts.

In the context of a conflicted literature, these data support theories of autonomic reactivity that propose increases in HR and decreases in HRV during stress [32–34], particularly for clinically anxious youth [14, 15]. Adding to the literature, the present data provide preliminary support that reactivity differences between anxious and TD youth may occur during early phases of acute stress (in this case, error-related feedback), and that anxious youth may not recover from stress as quickly. Our findings are consistent with conceptualizations of anxious arousal as a quick response to perceived threat [45, 46]. Effects occurred for two physiological indices that have previously been linked to anxiety, both of which reflect an interplay between sympathetic (i.e., fight-or-flight) and parasympathetic (i.e., downregulation or inhibitory efforts of the nervous system) influences. In contrast, we did not find effects of anxiety over time for RSA, an index which has previously been found to correlate more strongly with depressive symptoms and broader measures of negative affect and internalizing symptoms rather than anxiety specifically [34, 47]. Future work might clarify whether specific physiological indices may be stronger correlates of anxiety versus other internalizing problems.

In addition, our findings provide support for the notion that heart rate indices (i.e., HR, HRV) exhibit fluctuations, even within task. While this may be an obvious point, much work in this area, particularly with youths, examines average level of arousal over time. Such an approach may be insufficient when experimental procedures within task (e.g., provision of feedback or other standardized experimenter/confederate behavior) may modify or increase stressor intensity. While preliminary, we view this work as the first step towards future investigations that might examine the time course of arousal in pediatric anxiety, especially as it relates to intensity or reintroduction of a stressor. Such work may be especially relevant

to studies examining exposure-based treatment in anxious youth, given that exposure sessions typically involve many of the same exposure, as well as a variety of different exposures, within session, with therapist feedback throughout.

The second aim of this study was to examine youth performance over the course of the stressor. Based on the well-documented literature linking anxiety to cognitive performance impairment [29–31], we predicted that anxious youth would provide fewer total calculation responses and also make a greater proportion of errors than TD youth. However, in contrast to our first hypothesis, for number of calculations, although we found an overall group × time interaction, we did not find group differences at individual time points. With regard to proportion of errors out of total responses during the math task, we found a pattern of results opposite to our predictions. Specifically, we found a large ($\eta_p^2 = 0.15$) and significant main effect of group such that control youth made a greater proportion of errors out of total responses than anxious youth from the second error feedback onward. It may be possible that due to feeling more stressed, the anxious group took more care in their calculations and responses than TD youth throughout. While this work would require replication before drawing conclusions, in the context of the present physiological data we might make initial hypotheses about the influences of physiological and cognitive processes on one another. For example, it might be hypothesized that receipt of error-related feedback made anxious youth concerned about making mistakes and slowed their responding, and this slowed responding influenced the stabilization or downregulation of arousal. Together, these data provide preliminary support for future examination of youth performance on cognitive tasks in which they receive information about error, which may eventually have implications for how anxious youth behave and respond in settings in which they receive feedback (e.g., school, extracurricular activities).

As alluded to above, perhaps most interesting is the potential for future study of interactions between objective physiological and performance-related correlates of anxiety as they occur in real time. Theory suggests that interactions between psychophysiological arousal and behavior may, in part, lead to the development and maintenance of anxiety [8]. While autonomic reactivity has been linked to behavioral avoidance [48], little work has been done to examine youth arousal and performance behavior over the course of acute stress. Such investigations may clarify the relationship between physiological and behavioral components of anxious youth in several ways. First, autonomic reactivity may influence behavior and, conversely, verbal and behavioral expressions may aid in downregulation of arousal. For example, it may be possible that anxious youths in this study experienced physiological arousal in response to the error-related feedback; conversely, providing fewer responses over time may have allowed anxious youths to feel either more or less stressed. While we were not able to test which of these verbal/behavioral and physiological processes influenced the other (or whether this relationship is bidirectional), future work might elucidate whether either of these processes are responsible for changes in the other. Next, real-life stressors are not always static with a defined beginning and end period, and youths often receive feedback from parents, peers, and teachers which they may perceive to be stressful. Thus, studying youth performance as it changes and/or stabilizes over the course of a stressor in which they receive feedback may have greater ecological validity than

examining mean arousal for an entire experimental task period or with tasks that introduce the stressor a single time at the start of the task. Relatedly, factors such as stressor intensity, duration, frequency of stressor reintroduction, and so forth may each have additive or multiplicative effects on both autonomic reactivity and performance. Clarification of how such factors may influence anxiety expression via physiological arousal (and recovery) and youth behavior would have clinical implications for the treatment of anxious youth as with exposure-based intervention.

This study had several limitations. First, while we found significant overall effects, and some group differences by time point, the relatively small sample size may have resulted in insufficient power to detect significant effects by time point. Second, the TSST-C involves a story presentation task prior to the math task used for the current investigation. This means that youth may have already been stressed prior to starting the math task, which may have influenced the current findings. We are unable to fully disentangle the potential effects of the story presentation task on arousal, although we did not find group differences on any arousal indices at resting baseline (prior to TSST-C activities) or following the story task. It may be possible that results would have differed if the math task were presented immediately after a true resting baseline and not after the first stress task component of the TSST-C. Third, the adult version of our stressor (the TSST) was initially developed as a social stressor [39]. Subsequent work in both adult and child samples have found it to influence physiological arousal in other anxiety disorders, other non-anxious clinical samples, and non-affected individuals [49]. However, the effects of the TSST-C may be most pronounced for those diagnosed with social phobia. As a substantial proportion of anxious youth in this sample (38%) were diagnosed with more than one anxiety disorder, and due to a relatively small sample size, we were not able to compare youth with only social phobia to those with non-social phobia anxiety disorders (i.e., GAD, separation) on the TSST-C. Future work might extend the existing literature regarding validity of the TSST-C on eliciting psychophysiological responses to stress across anxiety disorders. Finally, our typically developing sample of youth was selected such that all youth, and their first-degree relatives, in this group were free of any psychopathology. Although not the goal of the current investigation, this sample selection may limit our ability to generalize to other samples of youth who have history or family history of mental health problems.

Nonetheless, this study provides preliminary support for examining physiological arousal and its relationship to youth anxiety within the course of a single stressor task to understand real-time fluctuations in autonomic reactivity. We found interactive influences of group and time on two indices—heart rate and heart rate variability—comparing clinically anxious to typically developing youth. We also found preliminary support in exploring an objective measure of youth performance, particularly as anxious youth appeared to make a smaller proportion of errors out of total responses with successive feedback prompts. We hope that these findings lead to future investigations of the relationship between physiological arousal and youth performance during stress, as such work may have theoretical and clinical implications for understanding and targeting the expression and regulation of anxiety in youth.

Acknowledgments

This work was supported by the UCLA Research Program for Psychobiological Sciences T32 MH 17140 (Leuchter) and the UCLA Clinical Translational Science Institute UL1TR000124 (Rozenman). The authors would like to acknowledge and thank the children and their parents who participated in this research.

References

1. Costello EJ, Egger H, Angold A. 10-year research update review: the epidemiology of child and adolescent psychiatric disorders: I. Methods and public health burden. J Am Acad Child Adolesc Psychiatry. 2005; 44:972–986. DOI: 10.1097/01.chi.0000172552.041596.6f [PubMed: 16175102]
2. Bittner A, Egger HL, Erkanli A, Costello JE, Foley DL, Angold A. What do childhood anxiety disorders predict? J Child Psychol Psychiatr. 2007; 48:1174–1183. DOI: 10.1111/j.1469-7610.2007.01812.x
3. Sherrill JT. Commentary: expanding the research agenda on interventions for child and adolescent anxiety disorders. Cogn Behav Pract. 2008; 15:166–171. DOI: 10.1016/j.cbpra.2007.11.002
4. Beesdo K, Knappe S, Pine DS. Anxiety and anxiety disorders in children and adolescents: devleopmental issues and implications for DSM-V. Psychiatr Clin North Am. 2009; 32:483–542. DOI: 10.1016/j.psc.2009.06.002 [PubMed: 19716988]
5. Pine DS, Cohen P, Gurley D, Brook J, Ma Y. The risk for early-adulthood anxiety and depressive disorders in adolescents with anxiety and depressive disorders. Arch Gen Psychiatr. 1998; 55:56–64. DOI: 10.1001/archpsyc.55.1.56 [PubMed: 9435761]
6. March JS. Looking to the future of research in pediatric anxiety disorders. Depress Anxiety. 2011; 28:88–98. DOI: 10.1002/da.20754 [PubMed: 21162058]
7. Pine DS. Research review: a neuroscience framework for pediatric anxiety disorders. J Child Psychol Psychiatr Allied Discip. 2007; 48:631–648. DOI: 10.1111/j.1469-7610.2007.01751.x
8. Barlow DH. Unraveling the mysteries of anxiety and its disorders from the perspective of emotion theory. Am Psychol. 2000; 55:1247–1263. DOI: 10.1037/0003-066x.55.11.1247 [PubMed: 11280938]
9. Clarke LA, Watson D. Tripartite model of anxiety and depression: psychometric evidence and taxonomic implications. J Abnorm Psychol. 1991; 100:316–336. DOI: 10.1037/0021-843x.100.3.316 [PubMed: 1918611]
10. Weems CF. Developmental trajectories of childhood anxiety: identifying continuity and change in anxious emotion. Dev Rev. 2008; 28:488–502. DOI: 10.1016/j:dr.2008.01.001
11. Blechert J, Michael T, Williams SL, Purkis HM, Wilhelm FH. When two paradigms meet: does evaluative learning extinguish in differential fear conditioning? Learn Motivation. 2008; 39:58–70. DOI: 10.1016/j.lmot.2007.03.003
12. Craske MG, Kircanski K, Zelikowsky M, Mystkowski J, Chowdhury N, Baker A. Optimizing inhibitory learning during exposure therapy. Behav Res Ther. 2008; 46:5–27. DOI: 10.1016/j.brat.2007.10.003 [PubMed: 18005936]
13. Lau JYF, Lissek S, Nelson EE, Lee Y, Roberson-Nay R, Poeth K, et al. Fear conditioning in adolescents with anxiety disorders: results from a novel experimental paradigm. J Am Acad Child Adolesc Psychiatr. 2008; 47:94–102. DOI: 10.1097/chi.0b01e31815a5f01
14. Kossowsky J, Wilhelm FH, Roth WT, Schneider S. Separation anxiety disorder in children: disorder-specific responses to experimental separation from the mother. J Child Psychol Psychiatr. 2012; 53:178–187. DOI: 10.1111/j.1469-7610.2011.02465.x
15. Rozenman M, Vreeland A, Piacentini J. Thinking anxious, feeling anxious, or both? Cognitive bias moderates the relationship between anxiety disorder status and sympathetic arousal in youth. J Anx Disord. 2017; 45:34–42. DOI: 10.1016/j.janxdis.2016.11.004
16. Kramer M, Seefeldt WL, Heinrichs N, Tuschen-Caffier B, Schmitz J, Wolf OT, et al. Subjective, autonomic, and endocrine reactivity during social stress in children with social phobia. J Abnorm Child Psychol. 2011; 40:95–104. DOI: 10.1007/s10802-011-9548-9

17. Schmitz J, Kramer M, Tuschen-Caffier B, Heinrichs N, Blechert J. Restricted autonomic flexibility in children with social phobia. J Child Psychol Psychiatr. 2011; 52:1203–1211. DOI: 10.1111/j.1469-7610.2011.02417.x
18. Alkozei A, Cresswell C, Cooper P, Allen J. Autonomic arousal in childhood anxiety disorders: associations with state anxiety and social anxiety disorder. J Affect Disord. 2015; 175:25–33. DOI: 10.1016/j.jad.2014.11.056 [PubMed: 25590763]
19. Anderson E, Hope D. The relationship among social phobia, objective and perceived physiological reactivity, and anxiety sensitivity in an adolescent population. J Anx Disord. 2009; 23:18–26. DOI: 10.1016/j.janxdis.2008.03.011
20. Dorn L, Campo J, Thato S, Dahl R, Lewin D. Psychological comorbidity and stress reactivity in children and adolescents with recurrent abdominal pain and anxiety disorders. J Am Acad Child Adolesc Psychiatr. 2003; 42:66–75. DOI: 10.1097/00004583-200301000-00012
21. Schmitz J, Tuschen-Caffier B, Wilhelm F, Blechert J. Eur Child Adolesc Psychiatr. 2013; 22:631–640. DOI: 10.1007/s00787-013-0405-y
22. Miers A, Blote A, Sumter S, Kallen V. Subjective and objective arousal correspondence and the role of self-monitoring processes in high and low socially anxious youth. J Exp Psychopathol. 2011; 18:322–333. DOI: 10.5127/jep.019411
23. Schmitz J, Blechert J, Kramer M, Asbrand J, Tuschen-Caffier B. Biased perception and interpretation of bodily anxiety symptoms in childhood social anxiety. J Clin Child Adolesc Psychol. 2012; 41:92–102. DOI: 10.1080/15374416.2012.632349 [PubMed: 22233249]
24. Buske-Kirschbaum A, Jobst S, Wustmans A. Attenuated free cortisol response to psychosocial stress in children with atopic dermatitis. Psychosom. 1997; 59:419–426. DOI: 10.1087/00006842-199707000-00012
25. Reynolds G, Field A, Askew C. Effect of vicarious fear learning on children's heart rate responses and attentional bias for novel animals. Emot. 2014; 14:995–1006. DOI: 10.1037/a0037225
26. Askew C, Hagel A, Morgan J. Vicarious learning of children's social-anxiety-related fear beliefs and emotional Stroop bias. Emot. 2015; 15:501–510. DOI: 10.1037/emo00000083
27. Kramer M, Schmitz J, Heinrichs N, Tuschen-Caffier B. Self-evaluation, social and cognitive performance in children with social phobia. J Exp Psychopathol. 2011; 2:586–600. DOI: 10.5127/jep.0016311
28. Miers AC, Blote AW, de Rooij M, Bokhorst CL, Westenberg PM. Trajectories of social anxiety during adolescence: relations with cognition, social competence, and temperament. J Abnorm Child Psychol. 2013; 41:97–110. DOI: 10.1007/s10802-012-9651-6 [PubMed: 22723078]
29. Ashcraft MH, Faust MW. Mathematics anxiety and mental arithmetic performance: an exploratory investigation. Cog Emot. 1994; 8:97–125. DOI: 10.1080/02699939408408931
30. Eysenck MW, Calvo MG. Anxiety and performance: the processing efficiency theory. Cog Emot. 1992; 6:409–434. DOI: 10.1080/02699939208409696
31. Owens M, Stevenson J, Norgate R, Hadwin JA. Processing efficiency theory in children: working memory as a mediator between trait anxiety and academic performance. Anx Stress Coping. 2008; 21:417–430. DOI: 10.1080/10615800701847823
32. Chalmers JA, Quintana DS, Abott MJA, Kemp AH. Anxiety disorders are associated with reduced heart rate variability: a meta-analysis. Front Psychiatr. 2014; 5:80.doi: 10.3389/fpsyct.2014.00080
33. Friedman BH. An autonomic flexibility-neurovisceral integration model of anxiety and cardiac vagal tone. Biol Psychol. 2007; 74:185–199. DOI: 10.1016/j.biopsycho.2005.08.009 [PubMed: 17069959]
34. Graziano P, Derefinko K. Cardiac vagal control and children's adaptive functioning: a meta-analysis. Biol Psychol. 2013; 94:22–37. DOI: 10.1016/j.biopsycho.2013.04.011 [PubMed: 23648264]
35. Walkup J, Albano A, Piacentini J, Birmaher B, Compton SN, Sherrill JT, et al. Cognitive behavioral therapy, sertraline, or a combination in childhood anxiety. New Engl J Med. 2008; 359:2753–2766. DOI: 10.1056/NEJMoa0804633 [PubMed: 18974308]
36. Silverman, W., Albano, A. Anxiety disorders interview schedule for children-IV. Psychological Corporation; San Antonio: 1996.

37. Silverman W, Saavedra L, Pina A. Test-retest reliability of anxiety symptoms and diagnoses with the anxiety disorders interview schedule for DSM-IV: child and parent versions. J Am Acad Child Adolesc Psychiatr. 2001; 40:937–944. DOI: 10.1097/00004583-200108000-00016
38. Wood JJ, Piacentini JC, Bergman RL, McCracken J, Barrios V. Concurrent validity of the anxiety disorders section of the anxiety disorders interview schedule for DSM-IV: child and parent versions. J Clin Child Adolesc Psychol. 2002; 31:335–342. DOI: 10.1207/S15374424JCCP3103_05 [PubMed: 12149971]
39. Kirschbaum C, Pirke KM, Helhammer DH. The 'Trier Social Stress Test'—a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobio. 1993; 28:76–81. DOI: 10.1159/000119004
40. Aldao A, McLaughlin KA, Hatzenbuehler ML, Sheridan MA. The relationship between rumination and affective, cognitive, and physiological responses to stress in adolescents. J Exp Pscychopathol. 2014; 5:272–288. DOI: 10.5127/jep.039113
41. Gilissen R, Bakermans-Kranenburg MJ, van Ijzendoorn MH, Linting M. Electrodermal reactivity during the Trier Social Stress Test for children: interaction between the serotonin transporter polymorphism and children's attachment representation. Dev Psychobio. 2008; 50:615–625. DOI: 10.1002/dev.20314
42. Kudielka BM, Buske-Kirschbaum A, Hellhammer DH, Kurschbaum C. HPA axis responses to laboratory psychosocial stress in healthy adults, younger adults, and children: impact of age and gender. Psychoneuroendocrinol. 2004; 29:83–98. DOI: 10.1016/S0306-4530(02)00146-4
43. Silvetti MS, Drago F, Ragonese P. Heart rate variability in healthy children and adolescents is partially related to age and gender. Int J Cardiol. 2001; 81:169–174. DOI: 10.1016/S0167-5273(01)00537-x [PubMed: 11744133]
44. Burkholder AR, Koss KJ, Hostinar CE, Johnson AE, Gunnar MR. Early life stress: effects on the regulation of anxiety expression in children and adolescents. Soc Dev. 2016; 25:777–793. DOI: 10.1111/sode.12170 [PubMed: 28584408]
45. Lang PJ, Davis M, Öhman A. Fear and anxiety: animal models and human cognitive psychophysiology. J Affect Disord. 2000; 61:137–159. DOI: 10.1016/S0165-0327(00)00343-8 [PubMed: 11163418]
46. Steimer T. State of the art: the biology of fear- and anxiety-related behavior. Dialogues Clin Neurosci. 2002; 4:231–249. [PubMed: 22033741]
47. Gentzler AL, Snatucci AK, Kovacs M, Fox NA. Respiratory sinus arrhythmia reactivity predicts emotion regulation and depressive symptoms in at-risk and control children. Biol Psychol. 2009; 82:156–163. DOI: 10.1016/j.biopsycho.2009.07.002 [PubMed: 19596044]
48. Field AP, Schorah H. The verbal information pathway to fear and heart rate changes in children. J Child Psychol Psychiatr. 2007; 48:1088–1093. DOI: 10.1111/j.1469-7610.2007.01772.x
49. Kudielka BM, Hellhammer DH, Kirschbaum C, Harmon-Jones E, Winkielman P. Ten years of research with the Trier Social Stress Test—revisited. Social neuroscience: Integrating biological and psychological explanations of social behavior. 2007:56–83.

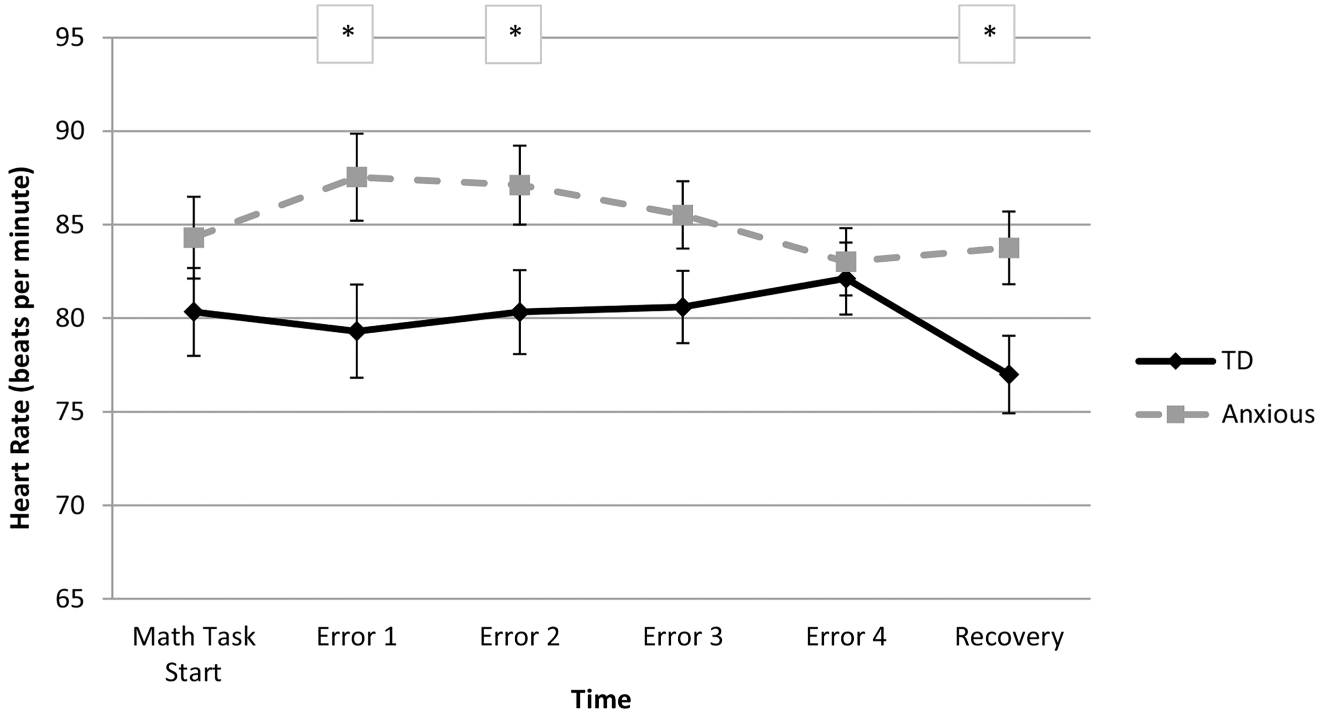

Fig. 1.

Heart rate during TSST-C: group × time interaction. *Asterisk* indicates significant group differences at the specified time point. Age covariate appears in model at 13.26 years

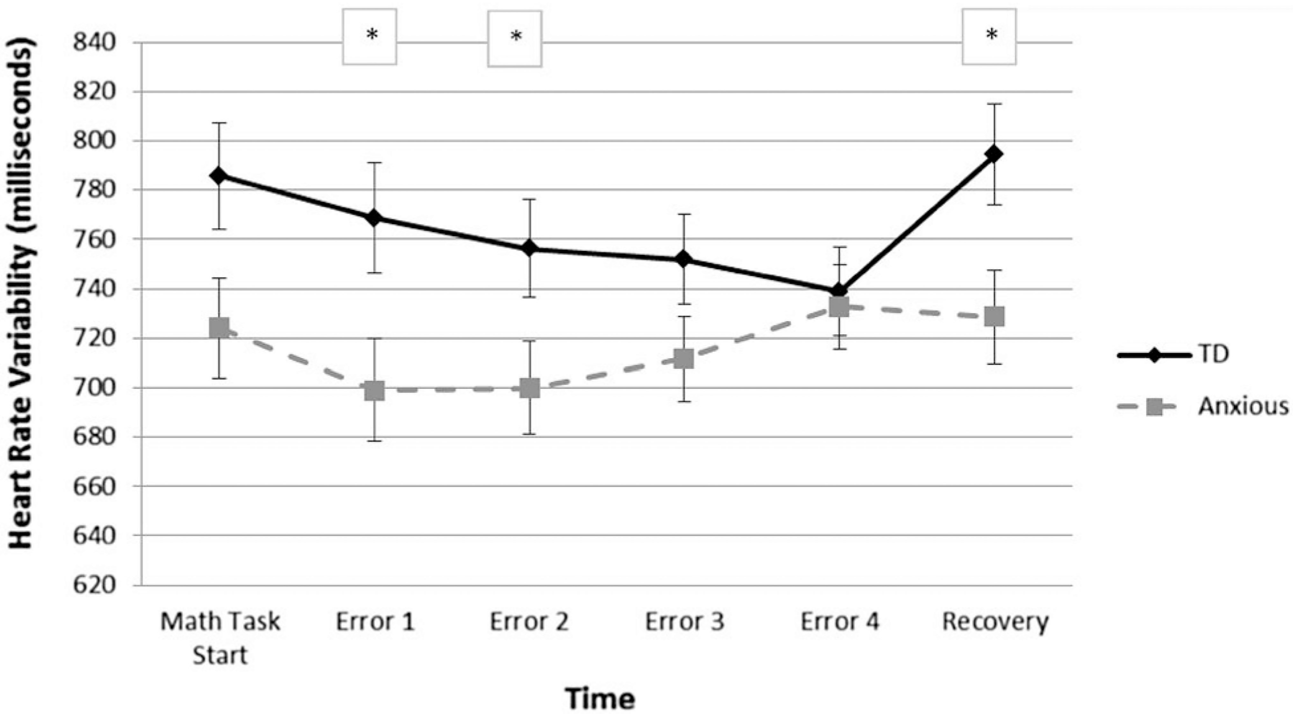

Fig. 2.

Heart rate variability during TSST-C: significant group × time interaction. *Asterisk* indicates significant group differences at the specified time point. Age covariate appears in model at 13.26 years

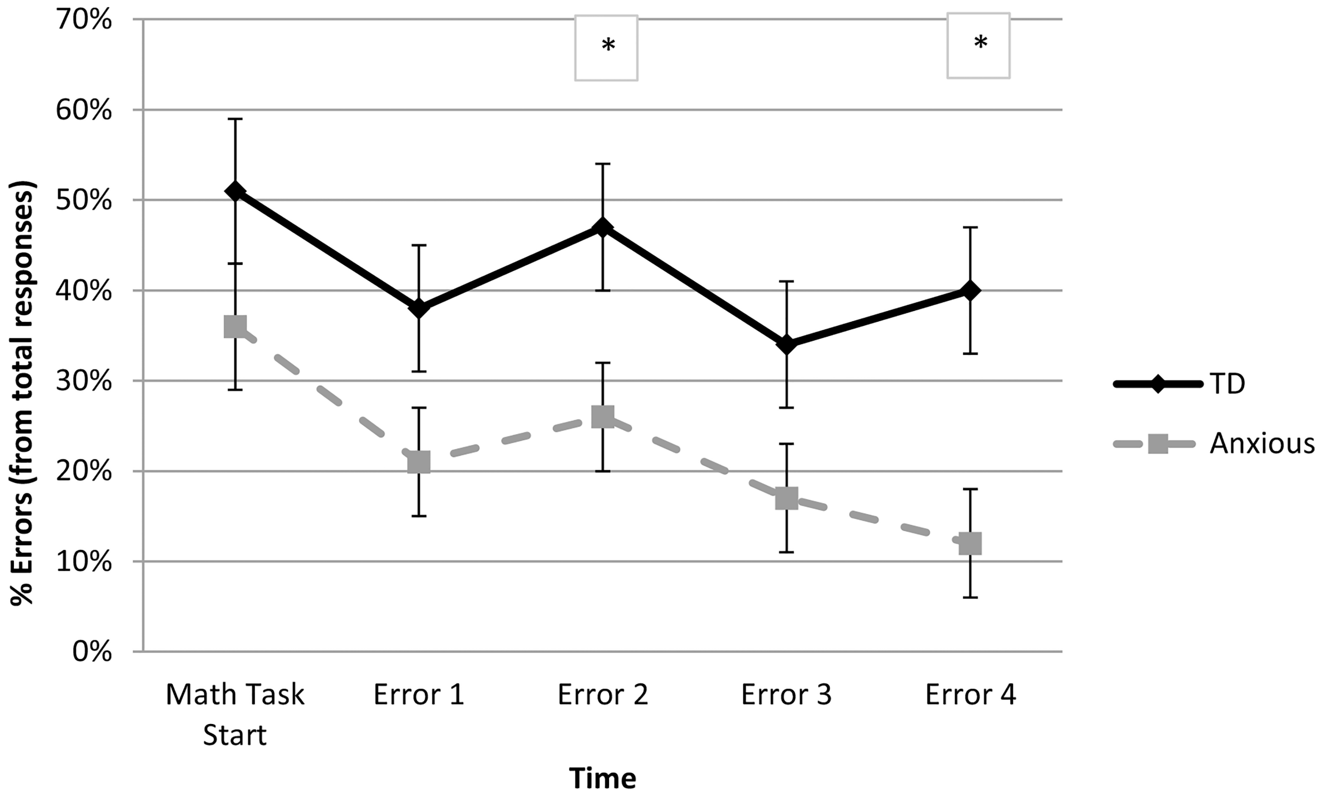

Fig. 3.

Youth math calculation responses by group over time: significant main effect of group. *Asterisk* indicates significant group differences at the specified time point. Age covariate appears in model at 13.26 years

Table 1

Demographic and baseline psychophysiological variables by group

	Anxious	**Typically developing**	**Test**	***p***
N	24	22		
Age	13.57 (2.70)	12.75 (2.68)	$t(44) = -1.04$	0.30
Gender (% Male)	46%	55%	$X(1) = 0.35$	
Minority (%)	54%	64%	$X(1) = 0.43$	
HR	84.04 (11.24)	81.20 (10.40)	$t(44) = -0.89$	0.38
HRV	726.91 (102.41)	750.70 (97.24)	$t(44) = 0.81$	0.43
RSA	7.65 (2.68)	7.10 (1.25)	$t(44) = -0.88$	0.38

HR heart rate, measured in beats per minute, *HRV* heart rate variability, measured in inter-beat interval (milliseconds), *RSA* respiratory sinus arrhythmia, measured as difference score (beats per minute) between minimum and maximum HR change during respiration