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*Published in:*  
 Psychological Assessment

*DOI:*  
[10.1037/pas0000354](https://doi.org/10.1037/pas0000354)

**IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.**

*Document Version*  
 Publisher's PDF, also known as Version of record

*Publication date:*  
 2017

[Link to publication in University of Groningen/UMCG research database](#)

*Citation for published version (APA):*

Reyes, A. D. L., Aldao, A., Qasmieh, N., Dunn, E. J., Lipton, M. F., Hartman, C., Youngstrom, E. A., Dougherty, L. R., & Lerner, M. D. (2017). Graphical Representations of Adolescents' Psychophysiological Reactivity to Social Stressor Tasks: Reliability and Validity of the Chernoff Face Approach and Person-Centered Profiles for Clinical Use. *Psychological Assessment*, 29(4), 422-434.  
<https://doi.org/10.1037/pas0000354>

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# Graphical Representations of Adolescents' Psychophysiological Reactivity to Social Stressor Tasks: Reliability and Validity of the Chernoff Face Approach and Person-Centered Profiles for Clinical Use

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Low-cost methods exist for measuring physiology when clinically assessing adolescent social anxiety. Two barriers to widespread use involve lack of (a) physiological expertise among mental health professionals, and (b) techniques for modeling individual-level physiological profiles. We require a “bridge approach” for interpreting physiology that does not require users to have a physiological background to make judgments, and is amenable to developing individual-level physiological profiles. One method—Chernoff Faces—involves graphically representing data using human facial features (eyes, nose, mouth, face shape), thus capitalizing on humans' abilities to detect even subtle variations among facial features. We examined 327 adolescents from the Tracking Adolescents' Individual Lives Survey (TRAILS) study who completed baseline social anxiety self-reports and physiological assessments within the social scenarios of the Groningen Social Stressor Task (GSST). Using heart rate (HR) norms and Chernoff Faces, 2 naïve coders made judgments about graphically represented HR data and HR norms. For each adolescent, coders made 4 judgments about the features of 2 Chernoff Faces: (a) HR within the GSST and (b) aged-matched HR norms. Coders' judgments reliably and accurately identified elevated HR relative to norms. Using latent class analyses, we identified 3 profiles of Chernoff Face judgments: (a) consistently below HR norms across scenarios ( $n = 193$ ); (b) above HR norms mainly when speech making ( $n = 35$ ); or (c) consistently above HR norms across scenarios ( $n = 99$ ). Chernoff Face judgments

This article was published Online First July 18, 2016.

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Eric A. Youngstrom has consulted about psychological assessment with Pearson, Western Psychological Services, Lundbeck, and Otsuka. TRAILS

has been financially supported by various grants from the Netherlands Organization for Scientific Research NWO (Medical Research Council program Grant GB-MW 940-38-011; ZonMW Brainpower Grant 100-001-004; ZonMw Risk Behavior and Dependence Grants 60-60600-98-018 and 60-60600-97-118; ZonMw Culture and Health Grant 261-98-710; Social Sciences Council medium-sized investment Grants GB-MaGW 480-01-006 and GB-MaGW 480-07-001; Social Sciences Council project Grants GB-MaGW 457-03-018, GB-MaGW 452-04-314, and GB-MaGW 452-06-004; and NWO large-sized investment Grant 175.010.2003.005); the Sophia Foundation for Medical Research (Projects 301 and 393); the Dutch Ministry of Justice (WODC)' and the participating universities.

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displayed validity evidence in relation to self-reported social anxiety and resting HR variability. This study has important implications for implementing physiology within adolescent social anxiety assessments.

*Keywords:* Chernoff Face, psychophysiology, Research Domain Criteria, social anxiety, social stressor task

Social anxiety disorder is a condition characterized by intense and long-standing fears of social situations where a person is exposed to people with whom they are unfamiliar, and where evaluation or scrutiny is possible (American Psychiatric Association [APA], 2013). Social anxiety disorder is a commonly diagnosed psychiatric disorder, with a lifetime prevalence rate in the United States of 13%, and a 12-month prevalence rate of 7.4% (Kessler, Petukhova, Sampson, Zaslavsky, & Wittchen, 2012). Social anxiety spikes in adolescence relative to earlier and later developmental periods (Grant et al., 2005; Kessler et al., 2005), and adolescent social anxiety poses unique risk for the development of poor outcomes in adulthood, such as substance use and abuse (Marmorstein, 2012). This supports a focus on the adolescent period for developing and testing innovative approaches to assessing and treating social anxiety. Among adolescents, a core feature of social anxiety involves experiencing heightened physiological processes (e.g., sweaty palms, increased arousal indexed by heart rate [HR] or blood pressure) and difficulties regulating these processes when exposed to anxiety provoking social situations (e.g., public speaking and attending social events; Rapee & Heimberg, 1997). Thus, maladaptive patterns of arousal and regulation are a core feature of clinical models of the development and maintenance of social anxiety (e.g., Bögels et al., 2010).

The physiological component of clinical models of social anxiety informs two key “best practices” for the condition. First, evidence-based therapies often focus, in part, on providing patients with exposure to anxiety-provoking social situations (e.g., Barlow, 2002). Within these situations, patients receive training on how to monitor and/or cope with maladaptive physiological responses (e.g., Craske et al., 2008; Hope, 2006). Second, patients may exhibit substantial individual differences in symptoms and impairments, and by extension physiological functioning, within and across social situations, namely whether or not they express maladaptive physiological reactions specific to performance-based situations (e.g., public speaking) or to more broadly defined social interactions (e.g., Bögels et al., 2010). Consequently, as with other mental health conditions (e.g., mood, hyperactivity), assessing adolescent social anxiety involves collecting data from multiple informants (e.g., patient, parents, clinicians) and measurement methods (e.g., subjective, behavioral, official records; e.g., De Los Reyes et al., 2012; De Los Reyes, Augenstein, Wang et al., 2015; De Los Reyes, Thomas, Goodman, & Kundey, 2013; Silverman & Ollendick, 2005).

Although evidence-based approaches to assessment incorporate multiple methods, one historically seldom-used method involves direct assessments of physiology (for a review, see De Los Reyes & Aldao, 2015). The lack of use of these methods continues, despite the availability of both wireless, in vivo assessment modalities (e.g., heart rate monitors; Thomas, Aldao, & De Los Reyes, 2012; Youngstrom & De Los Reyes, 2015), and behavioral

tasks for collecting ecologically valid physiological data within socially stressful situations (see Gunnar, Talge, & Herrera, 2009). Treatment studies rarely report physiological functioning as outcome measures, and practitioners rarely incorporate these measures in clinical work (for a review, see Davis & Ollendick, 2005). This lack of direct assessments of patients’ changes in physiology during and after treatment results in an important gap in knowledge as to whether treatments produce changes in this key domain of social anxiety (see also Davis, May, & Whiting, 2011). Further, one cannot solely rely on adolescent patients’ subjective impressions of physiology: Repeated measurements of patients’ subjective arousal ratings (i.e., within social situations) may not track physiological habituation to social stress within these situations (see Anderson & Hope, 2009).

One factor that plays a crucial role in the lack of use of physiological measures within clinical work and research in adolescent social anxiety is that mental health professionals often lack the expertise to score and interpret physiological data (see De Los Reyes & Aldao, 2015). This limitation poses an important barrier to integrating physiological data within clinical work and research, because it means that mental health professionals do not have all of the tools available to administer physiological measures to patients and provide them with personalized feedback on their physiological functioning. Consequently, in this study we test an innovative tool for implementing physiological measures in clinical assessments for adolescent social anxiety. Informed by recent work with both adolescents and adults (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn, Aldao, & De Los Reyes, 2015), we test a paradigm for interpreting physiological data via graphical representations. Indeed, graphical depictions of data facilitate reliable and valid decision-making judgments (e.g., Lee, Butavicius, & Reilly, 2003), and allow one to detect patterns in data that often cannot be revealed by interpreting data in numerical form (e.g., Cleveland & McGill, 1984). When compared to alternative data depiction methods (e.g., numerical depictions of data), graphical depictions enhance user engagement and memory retention, as well as decrease decision-making time (e.g., Fienberg, 1979; Kosslyn, 2006).

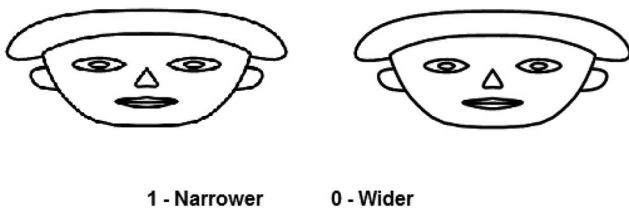
Overall, graphical representations of physiological data may allow assessors to make efficient, reliable, and valid judgments about these data (see also Lipkus & Hollands, 1999). The value of this approach is that graphical methods allow someone to make interpretive judgments of physiological data, and in a way that does not require a background in physiology in order to make the judgments. One method involves graphically representing data using features on the human face (e.g., eyes, nose, mouth, face shape). The method—Chernoff Faces (Chernoff, 1973)—capitalizes on humans’ abilities to discern even subtle variations in human facial features. In fact, since its development multiple fields have leveraged the Chernoff Face paradigm to facilitate decision

making. These fields include business (Huff, Mahajan, & Black, 1981), environmental policy (Apaiwongse, 1995), ecosystem health (Dong, Li, Wang, Wang, & Wu, 2015), education (Ben-David, 2015), mechanical engineering (Zhang et al., 2015), and medical decision making (S. Y. Lee, Lee, Decker, & Roberts, 2012). The number and variety of fields that have leveraged the Chernoff Face technique provided us with a high degree of confidence that we might use Chernoff Faces to graphically represent physiological data for use among coders who do not have a background in physiology.

Of direct relevance to our current study, in recent work researchers used Chernoff Faces to represent patients' physiological arousal (i.e., HR in beats per minute). Specifically, De Los Reyes, Augenstein, Aldao and colleagues (2015) used Chernoff Faces to create facial graphics to represent adolescent social anxiety patients' HR during a social stressor task (Groningen Social Stressor Task [GSST]; Bouma, Riese, Ormel, Verhulst, & Oldehinkel, 2009). The GSST exposes participants to different kinds of physiologically arousing social scenarios, including direct exposure to performance-based social situations (i.e., speech giving). This contextual variation in social stress allowed the researchers to create Chernoff Faces to represent HR within and across these social situations. Further, the researchers created a comparison graphic to represent clinical HR norms matched to participants' ages, and had undergraduate research personnel judge differences between the facial characteristics of graphics representing patients' HR and graphics representing clinical HR norms (e.g., facial width for patient HR vs. HR norms; see Figure 1).

Coders' Chernoff Face judgments displayed evidence of reliability and validity in relation to self-reported social anxiety. Specifically, coders' judgments accurately detected both elevations in patients' HR relative to clinical HR norms, as well as changes in these elevations within different social stress contexts

**For the faces below, is the face shape for the LEFT face narrower than, or wider than the face shape for the RIGHT face?**



**Figure 1.** Sample Chernoff Face comparison trial. Sample Chernoff Face comparison trial between a participant face (left) and a reference face based on clinical norm data (right). In this trial, coders completed a single dichotomous judgment of whether the face shape width for the face on the left-hand side of the screen was wider or narrower than the face on the right-hand side of the screen. For the participant face, the underlying mean HR value for the face shape = 87.85 BPM. For the reference face, the underlying mean HR value for the face shape = 85 BPM. For each participant, coders made a judgment about participants' HR using face shape and three additional facial features: (a) eyes, (b) nose, and (c) mouth, for a total of four judgments for each of 327 participants (i.e., 1,308 judgments across the entire sample).

(e.g., speech-giving phase vs. speech preparation phase). Further, increases in patients' baseline self-reports of social anxiety predicted an increased likelihood of patients experiencing elevations in HR during the GSST, relative to HR norms.

An important feature of this work is that De Los Reyes, Augenstein, Aldao et al. (2015) (a) used relatively low-cost physiological equipment (e.g., heart rate monitors costing less than \$500), (b) leveraged freely available software to construct Chernoff Faces, and (c) relied on relatively novice staff to construct the Chernoff Faces (i.e., research assistants without formal training in computer programming or graphics design). These features increase the generalizability and feasibility of the Chernoff Face approach. Further, the coders making Chernoff Face judgments were undergraduate research assistants who were naïve to both patients' clinical information and to basic principles of physiology and thus interpretations of physiological information. That coders without a background in not only physiology but also clinical assessment could make reliable and valid judgments about patients' physiology highlights the potential for the Chernoff Face method to facilitate integrating physiology into assessments of adolescent social anxiety. In support of this notion, consider that in recent work involving context-based judgments about patients' behavior, both naïve judges and experienced clinicians show the same general pattern of context-based behavioral judgments (cf. De Los Reyes & Marsh, 2011; Marsh, De Los Reyes, & Wallerstein, 2014; Marsh, Burke, & De Los Reyes, 2016). Additionally, recent work on Chernoff Faces replicates these effects with naïve coders' judgments about adults' physiology in response to videotaped vignettes (Dunn et al., 2015). In line with prior work, in our current study we leveraged use of naïve coders' judgments. Yet, validity evidence in support of Chernoff Face judgments is limited to self-reported social anxiety. Indeed, it is an open question as to whether Chernoff Face judgments of arousal display validity evidence in relation to other physiological domains. In particular, resting heart rate variability (HRV) is thought to reflect properties that differ from that of arousal, namely the extent to which one can flexibly regulate their physiology in response to environmental demands (see Aldao & De Los Reyes, 2015; Thomas et al., 2012). In fact, HR and HRV metrics often exhibit only modest correspondence with each other (e.g., Allen, Chambers, & Towers, 2007). Further, prior work using Chernoff Face judgments to represent adolescents' physiological functioning has been based on relatively small samples (De Los Reyes, Augenstein, Aldao et al., 2015), thus limiting the ability to examine Chernoff Face judgments using advanced quantitative modeling techniques. The Chernoff Face judgments only have relevance to clinical work and research with patients insofar as their applicability to detecting individual-level variations in physiological functioning, namely whether physiology changes when exposed to varying social contexts. To this end, prior work has leveraged person-centered approaches to data analysis (e.g., latent class analyses [LCA]; McCutcheon, 1987) to detect individual-level variations in behavioral functioning across various social interactions (e.g., interactions between children/adolescents and adult authority figures; interactions between adult patients and laboratory confederates; De Los Reyes, Alfano, Lau, Augenstein, & Borelli, 2016; De Los Reyes, Bunnell, & Beidel, 2013; De Los Reyes, Henry, Tolan, & Wakschlag, 2009). Similarly, LCA can be applied to characterize individual-level variations in Chernoff Face judgments of physi-

ology within tasks. The value of LCA is that profiles of physiological functioning detected in large samples of adolescents could then be applied to interpret patterns of physiological functioning in individual adolescents. This may facilitate responses to calls for personalized approaches to mental health care (e.g., National Institute of Mental Health, 2015).

### Purpose and Hypotheses

In this study, we sought to extend the literature on implementing physiology when assessing adolescent social anxiety. In a large sample of adolescents who provided social anxiety self-reports and physiological data within a social stressor task (i.e., GSST), we tested three hypotheses. First, consistent with prior work (e.g., De Los Reyes, Augenstein, Aldao et al., 2015), we expected coders' judgments to detect reliably and accurately the relative differences between Chernoff Face representations of adolescents' HR and normative HR. Second, we expected to observe contextual variation in adolescents' HR, as represented by Chernoff Faces. Specifically, research on subcategories of social anxiety disorder indicate both generalized (i.e., symptoms/impairments across social situations) and performance-only (i.e., symptoms/impairments specific to performance-based situations) subcategories (e.g., Bögels et al., 2010). Consistent with these two subcategories of social anxiety, we expected to identify two profiles of Chernoff Face judgments representing adolescents whose HR (a) consistently rose above HR norms throughout the social scenarios of the GSST or (b) rose above HR norms mainly when speech making. Additionally, as described below, we examined a sample of adolescents who varied as to their risk for mental health concerns, including a substantial number of adolescents who evidenced no such risk for these concerns. This approach provided us with the opportunity to examine a sample that dimensionally varied in both arousal and self-reported social anxiety, consistent with prior work leveraging person-centered modeling techniques (De Los Reyes et al., 2009, 2016). Thus, in our sample we also expected to identify a third profile of adolescents whose HR consistently fell below HR norms throughout the GSST social scenarios.

Third, we examined whether Chernoff Face profiles displayed validity evidence in relation to self-reported social anxiety and resting HRV. Increased arousal among children and adolescents may relate to increased self-reported anxiety (e.g., Weems, Zakem, Costa, Cannon, & Watts, 2005), although studies have been inconsistent (cf. Anderson & Hope, 2009). Further, low resting HRV (i.e., low physiological flexibility) tends to predict greater psychopathology (e.g., Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012). Thus, we expected to find that adolescents whose Chernoff Face profiles reflected HR that either rose above norms throughout the GSST or rose mainly when speech making would self-report greater social anxiety, and display lower resting HRV, relative to adolescents whose profile reflected HR that consistently fell below HR norms throughout the GSST.

### Method

#### Participants and Procedures

Our study involved examining participant data from the TRAILS (Tracking Adolescents' Individual Lives Survey) study.

TRAILS is a prospective longitudinal study that involved recruiting Dutch adolescents from five municipal areas in the Northern Netherlands. Adolescents recruited for the study completed bi- or triennial assessments from ages 11 to 25 years. Our study focused on the assessment wave conducted between September 2005 and December 2007 (T3). The T3 assessment wave involved recruiting 1,816 adolescents; 744 of whom received an invitation to complete a series of laboratory-based assessments and 715 agreed to participate. Our study focused on 327 of these adolescents who had complete self-report social anxiety data, as well as complete HR and HRV data for the social stressor task described below. These adolescents had a mean age of 15.52 years ( $SD = 0.62$ ; age range 14–17), and consisted of 174 females and 153 males. Of the 388 adolescents who were excluded from the study, reasons included: (a) evidence in the data that adolescents knew ahead of time of the purpose of the GSST; (b) missing survey measures used to characterize the sample (e.g., parent and adolescent reports of adolescent psychopathology); (c) missing social anxiety self-report data; and/or (d) missing one or more indices of HR/HRV used as criterion variables or to create Chernoff Faces.

We compared included versus excluded adolescents across the key dependent and independent variable measures used below (i.e., social anxiety self-reports; HR/HRV measures) as well as adolescent age and gender for each of these four reasons for missing data (i.e., 44 tests with a Bonferroni-corrected  $p$  value of .0011). Across these 44 tests, included and excluded adolescents significantly differed by age on missing survey measures and social anxiety self-reports (excluded adolescents were significantly older;  $p < .001$ ). Because a social anxiety self-report served as a criterion variable in analyses reported below, in secondary analyses we controlled for age. Further, as described below, in secondary analyses we controlled for gender. TRAILS is a population-based study. However, roughly two thirds of adolescents recruited for the T3 laboratory tests described below were selected based on prior evidence of risk for mental health concerns (e.g., temperamental risk, environmental risk, or parental psychopathology; see Bouma et al., 2009). Thus, the sample used to address our study aims consisted of adolescents who, by virtue of their targeted recruitment, would evidence a higher likelihood for displaying maladaptive responses to the subjective and physiological measures described below, relative to the larger TRAILS study sample from which they were selected. In fact, based on clinical cutoff data in the TRAILS dataset using the widely used Child Behavior Checklist (parent report;  $\alpha = .95$ ) and Youth Self-Report measures ( $\alpha = .93$ ; Achenbach, 1991), roughly 24% of the adolescents in our sample scored at or above the "borderline" or "clinical" range on the Total Problem Score of at least one of these two checklists. Extensive information regarding T3 participant recruitment and general procedures are available in Bouma and colleagues (2009).

#### Adolescent Self-Reported Social Anxiety

We assessed self-reported social anxiety using the Revised Child Anxiety and Depression Scale (RCADS; Chorpita, Yim, Moffitt, Umemoto, & Francis, 2000), which consists of 47 items rated on a 4-point scale (0 = *never*, 1 = *sometimes*, 2 = *often*, 3 = *always*). Adolescents self-reported current symptoms of social anxiety using a 9-item subscale (i.e., RCADS-Social Anxiety Subscale) that follows *DSM-IV* criteria. Extensive psychometric

work supports the validity of scores taken from the RCADS and its subscales, including the Social Anxiety Subscale (for a review, see Silverman & Ollendick, 2005). In our sample, we observed acceptable levels of internal consistency for the RCADS-Social Anxiety Subscale ( $\alpha = .84$ ).

### Adolescent Social Stressor Task

In the TRAILS sample, adolescents' psychophysiology was assessed within the GSST (Bouma et al., 2009). The GSST elicits biological responses to social stress via social evaluation by authority figures. In particular, the developers designed the GSST to activate social stress using evidence-based strategies, namely including components to elicit social threat as well as sensations of the uncontrollability and unpredictability of task activities (for a review, see Gunnar et al., 2009). Multiple social scenarios within the task were constructed to consistently elicit social stress by activating these stress-inducing components at different time points (e.g., anticipatory stress vs. performance-based stress).

Specifically, participants were led into a room where a research assistant instructed them to spend 10 min preparing a speech on their favorite hobby or activity. The participant then gave a 6-min speech in front of three trained confederates with whom the participant did not previously have contact (i.e., activation of social threat). After 6 min had passed, the research assistant who originally led the participant into the speech room informed the participant that the video camera taping their speech malfunctioned, asking the participant to wait until personnel resolved the problem (i.e., activation of unpredictability). After 3 min, the research assistant returned to instruct the participant to complete a mental subtraction task (i.e., subtracting 17 from a large number) for 6 min, again in front of the trained confederates (i.e., activation of uncontrollability). Extensive evidence suggests that the GSST and highly similar tasks (e.g., Trier Social Stress Test) produce acute stress reactions as assessed via multiple physiological metrics (e.g., cortisol, HR, and HRV; Bouma et al., 2009; De Los Reyes, Augenstein, Aldao et al., 2015; Gunnar et al., 2009). We examined adolescents' mean HR within the speech preparation, speech, and numbers task portions of the GSST, and a seated resting baseline period taken before the GSST. We also examined adolescents' mean HRV within the seated resting baseline period.

### HR and HRV Assessment

Adolescents completed the GSST while also being administered a continuous physiological assessment. Research personnel collected physiology throughout the seated resting baseline, speech-preparation, speech-giving, and numbers-task periods; see Bouma and colleagues (2009) for details. Specifically, HR and HRV assessments were carried out using a three-lead electrocardiogram (ECG) and a four-lead impedance cardiogram (ICG) that was registered using 3M/RedDot-Ag/AgCl electrodes (Type 2255, 3M Health Care, D-41453 Neuss, Germany), during which participants breathed spontaneously. Signal amplification and filtration occurred via a BIOPAC Amplifier-System (MP100) and before digitization at 250 samples/second. Consistent with prior work (e.g., Dietrich et al., 2007), the TRAILS team used dedicated software (i.e., PreCARSPAN) to check signal stationarity, correct for artifacts, detect R-peaks, and calculate the interbeat-interval

(IBI) between heartbeats. When calculating HR and HRV metrics, the TRAILS team considered ECG blocks invalid under one or more of three circumstances: (a) block contained artifacts with duration of more than 5 s, (b) total artifact duration in a block was more than 10% of the registration period, or (c) block length was less than 100 s. Prior work supports the validity of scores from these physiological assessments in relation to scores from social anxiety measures (e.g., self-report, behavior; for reviews, see De Los Reyes & Aldao, 2015; Aldao & De Los Reyes, 2015; Thomas et al., 2012).

This study focused on two physiological metrics. The first metric was a measure of arousal—HR in BPM—and we relied on this metric to construct Chernoff Faces. This focus on HR was in keeping with prior work on Chernoff Faces (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015). Specifically, our Chernoff Faces focused on three HR measures taken from the GSST, namely the speech preparation, speech, and numbers task periods. We also examined a HR measurement taken from the seated resting baseline period mentioned previously. In all, we applied the Chernoff Face approach to interpret four HR assessments, and the coders made four Chernoff Face judgments per participant (described below).

We relied on a second physiological metric to test whether Chernoff Face judgments displayed validity evidence in relation to other variables. Specifically, we examined one metric of baseline physiological flexibility available in the TRAILS dataset, namely HRV using the root mean square of successive differences (RMSSD) metric from the resting seated baseline period. Thus, we examined differences among profiles of Chernoff Face judgments using both adolescents' self-reported social anxiety and resting HRV as criterion variables.

### Constructing the Chernoff Faces

Each Chernoff Face contained four features that varied in width depending upon the underlying HR value used to create them. Wider features depicted larger HR values. We used the same features as De Los Reyes, Augenstein, Aldao et al. (2015) and Dunn and colleagues (2015). Specifically, for each participant, coders made four facial feature judgments: eyes, nose, mouth, and face shape. For each participant, coders' judgments were based on distinctions made between two faces meant to represent (a) the participant's physiology and (b) a normative comparison of resting physiology. The first face included a facial feature to represent HR from each of the periods of the GSST: (a) seated resting baseline, (b) speech preparation, (c) speech, and (d) numbers task (i.e., participant face). For each participant ( $n = 327$ ), we took HR data from the TRAILS database that corresponded to the mean HR for each of these four GSST periods. We used a Python script to randomly assign each of the four HR segments to a facial feature, to account for the possibility of differential reliability for judgments about features (e.g., relatively higher reliability for judgments about eye width vs. mouth width; see Chernoff, 1973). This random assignment varied by participant. Each participant face represented the four mean HR measurements corresponding to the four periods of the GSST described previously.

We also constructed a second face that served as a normative comparison against the participant face (i.e., reference face). We took this norm-referencing approach to Chernoff Face judgments

in order to give coders a benchmark against which to judge adolescents' arousal estimates during the GSST. This norm-based approach is consistent with approaches used to interpret scores on a host of clinical tools including mental health surveys (e.g., Child Behavior Checklist; Achenbach, 1991), tests of intellectual functioning (e.g., Wechsler Intelligence Tests; for a review, see Hunsley & Lee, 2014), and tests of neuropsychological functioning (for a review, see Groth-Marnat, 2009). Thus, we took a norm-referencing approach to decision making using Chernoff Face judgments in order to make it comparable to the processes by which clinicians and researchers interpret data from traditional, well-established clinical tools.

We used normative resting HR values from clinical norms for adolescents to construct the reference face. Specifically, the clinical norms we used were based on large samples of infants, children, and adolescents recruited to collect representative data on resting HR for different developmental periods (i.e., Davignon et al., 1980; Park, 1996; see Table 6-4 in Siegfried & Henderson, 2002). To create reference faces to compare against participant faces in our sample, we used two different normative HR values, age matched to adolescent participants. For participants aged 14–16 years, we applied a mean HR value of “85 BPM,” which corresponded to the normative mean resting HR for adolescents in the 12–16 age range (see Table 6-4 in Siegfried & Henderson, 2002). For participants aged 17 years, we used a mean HR value of “80 BPM,” which corresponded to the normative mean resting HR in BPM for adolescents above the age of 16 years. We then imported the entire dataset into RStudio (RStudio, 2014) and created the faces using the Faces plotting function from the *apl* package (Wolf & Bielefeld, 2013). We then used a batch edit feature in Adobe Photoshop CC to crop and label the faces so that each new image file would only contain one face. Extended descriptions of step-by-step procedures for constructing and administering Chernoff Faces have been published elsewhere (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015). Consistent with prior work described previously, our Chernoff Face approach involved use of (a) relatively low-cost physiological equipment, (b) freely available software to construct Chernoff Faces, and (c) relatively novice staff to construct the Chernoff Faces, thus increasing the generalizability and feasibility of the Chernoff Face approach.

### Making Chernoff Face Judgments

We relied on two coders to make all Chernoff Face judgments. These coders were research assistants in the first author's laboratory, and consisted of one female 21-year old senior undergraduate psychology major, and one male 23-year old postbaccalaureate psychology major. These coders were blind to study objectives and hypotheses, and did not have access to any other participant data (e.g., demographics, RCADS-Social Anxiety Subscale Score). Under these conditions, coders made judgments about the participant and reference Chernoff Faces using procedures as described previously (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015). Specifically, when coders made a Chernoff Face judgment between a participant face and a reference face, they were judging whether or not that participant evidenced elevated HR relative to HR norms. Each coder made four Chernoff Face judgments per participant. To accomplish this, we constructed a single

Chernoff Face per participant with all facial features included in the graphic. Coders were exposed to this participant face as well as a reference face four times, with each time focusing on making a judgment about one facial feature (i.e., eyes, nose, mouth, face width). This resulted in a total of 1,308 Chernoff Face judgments per coder.

In Figure 1, we provide an example of a Chernoff Face comparison trial that coders used to make HR judgments. Specifically, coders viewed the participant and reference faces on a single screen, and judged whether each feature (eyes, nose, mouth, face shape) on the participant face was wider or narrower than the reference face. Coders received no information as to which face corresponded to a participant's HR data versus clinical HR norm data. Coders provided their judgments of each feature of each face presented in random order using E-prime Professional 2.0 software. To avoid possible biases related to the side of the screen on which the faces appeared, we counterbalanced the locations of the participant face and reference face.

### Data-Analytic Plan

**Preliminary analyses.** We examined whether means and standard deviations for our criterion variables, namely self-reported social anxiety and HRV, met statistical assumptions for our analyses (i.e., acceptable skewness and kurtosis [ $\approx +/ -1.0$ ]; see Tabachnick & Fidell, 2001).

**Coder reliability.** To assess reliability of coders' Chernoff Face judgments, we computed kappa coefficients and interpreted them using conventional benchmarks (Landis & Koch, 1977). We also estimated percentage accuracy rates, or whether coders' dichotomous Chernoff Face judgments (i.e., participant face features were wider or narrower than reference face features) accurately reflected numerical differences between adolescents' heart rates and normative heart rates. Consistent with prior work (i.e., De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015), we conducted one-sample *t* tests to examine whether these accuracy rates were significantly above chance (test value: .50). As reported below, coders' judgments had acceptable reliability and accuracy. Thus, we selected a random coder as a master coder by toss of a fair coin. We used the master coder's judgments for analyses reported below, consistent with prior work (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015).

**Profiles of Chernoff Face judgments.** As mentioned previously, a key aim of our study was to examine individual differences in physiological functioning (i.e., contextual variations in adolescents' arousal as assessed by HR) within different periods of the GSST. We accomplished this by conducting exploratory LCA (McCutcheon, 1987) on the four dichotomous scores from the Chernoff Face judgments described previously (i.e., judgments for the four assessment periods of the GSST). Like cluster analysis, LCA identifies groups of cases based on similar patterns of indicator variables. Like confirmatory factor analysis, LCA tests the absolute and relative fit of models to examine whether a given model is a parsimonious solution to the data (relative to other model solutions), with lower scores indicating greater parsimony (Raftery, 1986, 1995). LCA uses categorical or ordinal variables to produce classes in which there is local independence of indicators (i.e., indicator variables are statistically independent within levels of each latent class). Thus, LCA allowed us to examine coders'

dichotomous Chernoff Face judgments to identify classes of adolescents who varied in whether their HR rose above clinical norms during the GSST. Probabilities from an LCA solution may be used to assess the confidence with which cases are assigned (McCuth-  
 eon, 1987).

We tested one- through three-class solutions. Larger class numbers would not be identifiable due to degrees of freedom. We took a multimethod approach to assessing model fit. First, consistent with prior work (De Los Reyes et al., 2009; De Los Reyes et al., 2013; Lipton, Weeks, Daruwala, & De Los Reyes, 2016), we assessed model fit using each solution's  $\chi^2$  and  $L^2$  test statistics—lower scores indicating greater model fit. We also checked whether mean assignment probabilities for each latent class were above .70 as recommended by Nagin (2006). Further, we examined each class's patterns of HR in BPM (i.e., the numerical HR values from which we created adolescent participants' Chernoff Faces), and in particular whether classes varied in their indications of elevated arousal relative to the HR norms against which coders made Chernoff Face judgments.

**Testing the validity of Chernoff Face judgments.** We tested the validity of Chernoff Face judgments by examining whether the Chernoff Face profiles identified via LCA varied on levels of baseline self-reported social anxiety and resting physiological flexibility. Specifically, we conducted an analysis of variance (ANOVA) to examine differences in levels of adolescents' self-reported social anxiety (RCADS–Social Anxiety Subscale Score) among the Chernoff Face profiles identified via the LCA approach described previously. Another ANOVA examined differences among Chernoff Face profiles in adolescents' resting HRV during the baseline period. For both ANOVAs, we conducted follow-up univariate comparisons. For these comparisons, we were interested in comparing the two Chernoff Face profile groups that displayed elevated HR relative to HR norms of a single reference group, namely the profile that reflected HR that consistently fell below HR norms. Further, our tests were directional in nature such that in each comparison, we expected the reference group to display lower (self-reported social anxiety) or greater (HRV) values relative to the two other groups. Thus, we conducted directional, univariate tests using the Dunnett *t* test statistic. We chose this test because it implements a consistent control group, thus minimizing Type I error and providing increased statistical power, relative to tests of comparisons of all possible group pairs.

**Secondary analyses.** The normative HR data used to create reference faces were matched by age but not by other characteristics such as gender and adolescents' physical activity. Further, as mentioned previously, adolescents who were included in versus excluded from the final study sample varied in terms of age. We accounted for this issue in two ways. First, secondary analyses examined whether our main findings regarding adolescent self-reported social anxiety and resting HRV were robust to accounting for adolescent age and gender. Second, it is possible that the Chernoff Face profile groups identified via LCA vary not only on self-reported social anxiety and resting HRV, but also in physical activity levels. Importantly, as part of their assessment adolescents self-reported whether they engaged in physical activity in the 24 hours preceding the day of their assessment (319 adolescents provided these data; no physical activity = 269; physical activity = 50). Thus, in secondary analyses we examined whether the Chernoff Face profiles reported below varied in reports of physical

activity. We interpreted all analyses below relative to a *p* value of .05.

## Results

### Preliminary Analyses and Reliability of Coders' Chernoff Face Judgments

Means and standard deviations for adolescents' self-reported social anxiety (RCADS–Social Anxiety Subscale Score;  $M = 6.08$ ;  $SD = 4.10$ ) and resting HRV in RMSSD ( $M = 46.87$ ;  $SD = 24.39$ ), met statistical assumptions for our analyses. In terms of interrater reliability of Chernoff Face judgments, the two coders had good interrater reliability in their individual Chernoff Face judgments ( $\kappa = .69$ ), indicating that coders tended to make the same judgments about the same data. Further, both coders evidenced a high degree of accuracy in detecting whether participants displayed an elevated arousal level relative to clinical norms (i.e., 90% and 88% correct). One-sample *t* tests for each of the coders demonstrated that accuracy was significantly greater than chance (50%;  $t(1307) = 47.64$ ,  $p < .001$ ;  $t(1307) = 41.67$ ,  $p < .001$ ).

### Profiles of Chernoff Face Judgments

LCA tested whether Chernoff Face judgments captured individual differences among adolescents in elevations of arousal relative to clinical norms during periods of the GSST. The LCA of Chernoff Face judgments representing adolescents' arousal during the GSST revealed superior model fit for a three-class solution,  $\chi^2$  and  $L^2 = 4.90$  and 5.58, respectively. These  $\chi^2$  and  $L^2$  estimates were lower (i.e., more parsimonious a fit) than the  $\chi^2$  and  $L^2$  of the one- ( $\chi^2$  and  $L^2 = 727.67$  and 380.46, respectively) and two-class ( $\chi^2$  and  $L^2 = 17.38$  and 14.19, respectively) solutions. Further, tracking of *p* values for the three classes indicated that the *p* value fell below .05 for each of the solution's  $\chi^2$  and  $L^2$  estimates (i.e., one-class: 6.3e-149 and 8.6e-75; two-class: .008 and .028; three-class: .031 and .021). This led us to rely on  $\chi^2$  and  $L^2$  values to assess model fit. Further, the mean assignment probabilities for all three classes were above the .70 threshold recommended by Nagin (2006), and the overall mean assignment probability for the sample was .90. We present the descriptive statistics of the LCA solution in Table 1.

As mentioned previously, coders made judgments about adolescents' HR relative to resting HR norms. Thus, a key test involves whether the three-class LCA solution characterized individual differences in adolescents' elevated HR, relative to HR norms. Thus, to assist in interpreting these individual differences among the three classes, in Table 1 we also reported adolescents' numerical mean HR values in BPM (i.e., the values represented in the Chernoff Faces) for each of the assessment periods from which coders made Chernoff Face judgments. Below, we describe how each of our classes varied in HR, relative to resting HR norms.

First, one class of adolescents had consistently lower arousal relative to clinical norms throughout the four GSST periods (Below Norms Across Situations). Within the Below Norms Across Situations profile group and for each assessment period, mean HR was below both of the HR clinical norms used in the study (i.e., HR levels below "80 BPM"). Therefore, this first



Table 1

*Latent Class Solution of Chernoff Face Judgments About Adolescents' Physiology During the Groningen Social Stressor Task (n = 327)*

Latent class	N	%	Mean assignment probability	HR: Seated baseline M(SD)	HR: Speech preparation M(SD)	HR: Speech M(SD)	HR: Numbers task M(SD)
Below norms across situations	193	59%	.91	70.57 (7.77)	71.10 (7.38)	77.22 (9.54)	71.84 (7.69)
Above norms within performance-based situations	35	10.7%	.74	80.84 (8.52)	82.66 (7.27)	86.18 (9.94)	78.86 (5.57)
Above norms across situations	99	30.3%	.95	84.58 (8.91)	87.90 (9.53)	99.02 (11.53)	90.78 (7.23)
Total	327	100%	.90	75.91 (10.45)	77.43 (11.17)	84.78 (14.12)	78.32 (11.21)

Conditional probabilities for measured variables

Measured variable	Latent classes		
	Below norms across situations	Above norms within performance-based situations	Above norms across situations
Chernoff Face judgment	Below HR Norms: .73	Below HR Norms: .12	Below HR Norms: .15
Seated resting baseline	Above HR Norms: .04	Above HR Norms: .18	Above HR Norms: .78
Chernoff Face judgment	Below HR Norms: .76	Below HR Norms: .10	Below HR Norms: .13
Speech preparation	Above HR Norms: .01	Above HR Norms: .21	Above HR Norms: .77
Chernoff Face judgment	Below HR Norms: .88	Below HR Norms: .10	Below HR Norms: .01
Speech	Above HR Norms: .17	Above HR Norms: .17	Above HR Norms: .65
Chernoff Face judgment	Below HR Norms: .78	Below HR Norms: .19	Below HR Norms: .02
Numbers task	Above HR Norms: .10	Above HR Norms: .03	Above HR Norms: .86

*Note.* Conditional probabilities are to be interpreted across the row of a given indicator and within each value, probabilities sum to 100% in each row. GSST = Groningen Social Stressor Task; HR = heart rate.

class consisted of adolescents who displayed relatively low arousal across social scenarios.

A second class had higher arousal relative to norms during the GSST speech period (Above Norms Within Performance-Based Situations). Here too, the continuous levels of HR in BPM corroborate our descriptions of this group. Specifically, Table 1 shows that mean HR in BPM was only above both of our HR norms (i.e., HR level above "85 BPM") during the speech portion of the GSST. In fact, mean HR dropped below both HR clinical norms (i.e., HR level below "80 BPM") during the numbers task that followed the speech period. Thus, this second class consisted of adolescents who displayed elevated arousal specifically when speech making.

A third class evidenced consistently higher arousal relative to clinical norms throughout the GSST (Above Norms Across Situations). Once again, the continuous levels of HR in BPM corroborate the composition and characterization of this group. As seen in Table 1, mean HR in BPM was above both of the HR norms used in the study (i.e., HR levels above "85 BPM") for the speech preparation, speech, and numbers task periods of the GSST, and just under the "85 BPM" norm during the resting seated baseline period. Thus, this third class consisted of adolescents who displayed elevated arousal across social scenarios. Overall, Chernoff Face profiles revealed individual differences in elevated arousal during periods of social stress.

One other important observation about our LCA model solution warrants comment. The LCA model solution for the Chernoff Face judgments mapped on quite closely to current DSM-5 nosology for social anxiety disorder. In particular, the Above Norms Across Situations profile consisted of elevations in HR above clinical norms that were relatively invariant across

GSST assessment periods. In contrast, the Above Norms Within Performance-Based Situations profile consisted of elevations in HR above clinical norms that were specific to the speech portion of the task. These two profiles mesh quite well with the two patterns of diagnostic subtypes of social anxiety disorder mentioned previously: (a) patients whose symptoms and impairments manifest generally across situations and (b) patients whose symptoms and impairments manifest within performance-based situations (Bögels et al., 2010). Further, the presence of the third Chernoff Face profile group (i.e., Below Norms Across Situations) is consistent with the composition of the sample, because as mentioned previously, a large portion of the adolescents in the TRAILS sample did not display signs of risk for mental health concerns.

### Relations Between Chernoff Face Profiles and Adolescent Self-Reported Social Anxiety

We expected to find differences among our Chernoff Face profile groups in adolescents' self-reported social anxiety. To test this, we conducted an ANOVA using the analytic plan described previously. Consistent with our hypotheses, we observed a significant Chernoff Face Profile Group omnibus effect,  $F(2, 324) = 3.11$ ;  $p < .05$ . We conducted follow-up univariate tests using the Dunnett  $t$  test statistic described previously. Figure 2a reports mean differences among the Chernoff Face profiles. Relative to the Below Norms Across Situations profile group, the Above Norms Across Situations profile group had significantly higher social anxiety levels ( $mean\ difference = 1.08$ ;  $SE = 0.50$ ;  $p < .05$ ) and we observed nonsignificant differences for the Above Norms Within Performance-Based Situations profile group ( $mean\ differ-$

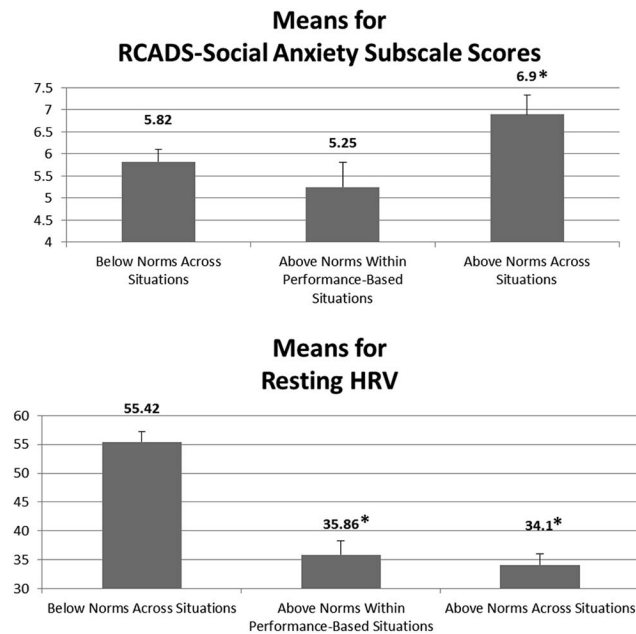


Figure 2. Chernoff Face profiles and mean levels of adolescent self-reported social anxiety and resting baseline heart rate variability. Univariate effects and graphical depiction differences (i.e., means and standard error bars) among Chernoff Face profiles in levels of adolescent self-reported social anxiety (Panel 2a) and resting baseline heart rate variability (HRV; Panel 2b). \*  $p < .05$ .

ence =  $-0.56$ ;  $SE = 0.75$ ;  $p = .92$ ). Thus, the group of adolescents whose arousal was consistently elevated across social scenarios showed more self-reported social anxiety, relative to the group of adolescents whose arousal was relatively low across social scenarios.

### Relations Between Chernoff Face Profiles and Adolescents' Resting HRV

We expected to observe differences among our Chernoff Face profile groups in levels of adolescents' resting HRV. To test this, we conducted an ANOVA using the analytic plan described previously. Consistent with our hypotheses, we observed a significant Chernoff Face Profile Group omnibus effect,  $F(2, 324) = 35.06$ ;  $p < .001$ . We conducted follow-up univariate tests using the Dunnett  $t$  test statistic described previously. Figure 2b reports mean differences among the Chernoff Face profiles. Relative to the Below Norms Across Situations profile group, we observed significantly lower HRV for the Above Norms Across Situations profile group (mean difference =  $-21.32$ ;  $SE = 2.74$ ;  $p < .001$ ) and significantly lower HRV for the Above Norms Within Performance-Based Situations profile group (mean difference =  $-19.57$ ;  $SE = 4.07$ ;  $p < .001$ ). Thus, among the Chernoff Face profile groups, the two groups of adolescents who displayed elevated arousal either within performance-based scenarios or across social scenarios evidenced lower levels of resting physiological flexibility, relative to the group of adolescents who displayed relatively low arousal across social scenarios. Overall, Chernoff Face profiles reflecting naïve coders' judgments about

adolescents' arousal during a social stressor task related to both adolescents' self-reported social anxiety and resting physiological flexibility.

### Secondary Analyses Controlling for Adolescent Age, Gender, and Physical Activity

In secondary analyses we examined whether our main findings were robust to statistically accounting for adolescent age and gender. We carried out analyses of covariance (ANCOVAs), with one model using gender as a covariate, and another model using age as a covariate. The substantive patterns of findings remained identical to those reported previously. Further, using a chi-square analysis we tested distributions of physical activity for the Chernoff Face profiles. This analysis revealed no significant differences among the groups,  $p = .16$ . Specifically, all three groups displayed similar patterns of lack of physical activity in the 24 hours preceding the assessment (i.e., range of no reported physical activity: 81%-91%).

### Discussion

In this study, our key goal was to expand upon prior research on the use of Chernoff Faces to facilitate judgments about physiological data (i.e., De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015). We examined the largest sample to date of Chernoff Face judgments about adolescents' physiological responses to a social stressor task (i.e., GSST; Bouma et al., 2009). Using this sample, we tested both the reliability of Chernoff Face judgments and the validity of these judgments in relation to adolescents' self-reported social anxiety and direct assessments of adolescents' resting physiological flexibility. To facilitate these reliability and validity tests and demonstrate the clinical feasibility of Chernoff Face judgments, we used person-centered models of data analysis (LCA; McCutcheon, 1987) to identify profiles of adolescents' arousal during the social scenarios represented in our social stressor task.

### Main Findings

We discovered four findings. First, as with prior work (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015), coders' judgments reliably and accurately identified elevations in adolescents' arousal relative to indices of normative resting arousal. Second, using person-centered analyses of Chernoff Face judgments, we identified three profiles of adolescents whose arousal (a) consistently fell below resting norms throughout social scenarios (Below Norms Across Situations;  $n = 193$ ); (b) rose above norms specifically when speech making (Above Norms Within Performance-Based Situations;  $n = 35$ ); or (c) consistently rose above norms throughout social scenarios (Above Norms Across Situations;  $n = 99$ ). Third, Chernoff Face profile groups could be differentiated by adolescents' self-reported social anxiety, in that adolescents in the Above Norms Across Situations profile group self-reported significantly greater levels of social anxiety relative to the Below Norms Across Situations profile group. Fourth, Chernoff Face profile groups could be differentiated by adolescents' resting physiological flexibility. Specifically, both the Above Norms Across Situations and Above Norms Within

Performance-Based Situations groups evidenced significantly lower resting physiological flexibility, relative to the Below Norms Across Situations profile group. This suggests that adolescents displaying either of the two “elevated arousal” Chernoff Face profiles displayed lower physiological flexibility, relative to the “low arousal” Chernoff Face profile.

Our latent class profiles of Chernoff Face judgments align quite well with research on subcategories of social anxiety disorder. Specifically, prior work indicates that patients vary as to whether they present with a generalized or performance-only form of the condition (e.g., Bögels et al., 2010). Similarly, we identified two Chernoff Face groups whose physiological profiles resembled either the generalized (i.e., Above Norms Across Situations) or performance-only (i.e., Above Norms Within Performance-Based Situations) clinical presentations of social anxiety patients. In fact, of the 134 participants in our study assigned to an “elevated arousal” profile, roughly 74% were assigned to the Above Norms Across Situations profile group and 26% to the Above Norms Within Performance-Based Situations group. This distribution of profile group assignments is also consistent with the relatively greater prevalence of generalized versus performance-only diagnoses seen in a recent study of clinic-referred adult social anxiety patients (De Los Reyes, Bunnell et al., 2013). Overall, our findings yield key “proof of concept” data supporting the idea that one can use Chernoff Face judgments to identify profiles that reflect individual differences in physiological functioning. Further, our findings contribute to a growing body of work suggesting that Chernoff Face judgments can facilitate use of physiology in assessments of adolescent social anxiety. Chernoff Face judgments have the advantage of being “highly dimensional,” making it possible to present multiple variables in a single, readily interpretable format. This capacity is particularly valuable given the richness and complexity of both physiological processes and the measures used to represent these processes.

### Implications for Clinical Research and Practice

Our findings have important implications for clinical research and practice. Indeed, in recent years scholars have increasingly leveraged insights from neuroscience to advance basic research in developmental psychopathology. This basic research largely supports a key tenet of the developmental psychopathology framework: Mental health concerns arise out of a mix of biological, psychological, and sociocultural factors that offer protection from (or pose risk for) the emergence of maladaptive reactions to one’s environment (Cicchetti, 1984). Work in basic neuroscience will continue to rapidly accelerate. New research initiatives (e.g., Research Domain Criteria for the National Institute of Mental Health; Franklin, Jamieson, Glenn, & Nock, 2015; Insel et al., 2010) look to basic neuroscience to improve understanding of the mechanisms underlying mental health concerns. In turn, this work may then inform new techniques that directly target and treat these mechanisms.

Yet, recent work has paid relatively little attention to applied research that seeks to use neuroscience to improve clinical procedures (for a review, see De Los Reyes & Aldao, 2015). This lack of attention may impede translating findings from neuroscience into the development of new clinical techniques. Specifically,

basic clinical neuroscience may yield insights for improving child and adolescent mental health care. Yet, often the implication of this work is that biological data will become key components in clinical care. An important barrier to innovations in care is that researchers rarely use biological data in treatment studies (e.g., Davis et al., 2011), and few mental health professionals have the background to understand and interpret biological data (De Los Reyes & Aldao, 2015). The mental health care workforce (e.g., primary care physicians, psychiatrists, psychologists, social workers) is not equipped to integrate biological data into state-of-the-art clinical care. We need a “bridge approach” that links basic research on patients’ biological functioning to clinical care, with the intent of facilitating clinical decision making. Our group has developed this “bridge approach,” using Chernoff Faces as a system for graphically representing biological data that can be integrated into clinical care.

Our findings point to two important next steps. First, can clinicians make Chernoff Face judgments in “real-time?” That is, can clinicians make reliable and valid Chernoff Face judgments immediately after an assessment of patients’ physiological functioning during a clinical task? For example, if physiological data could be extracted and converted into Chernoff Faces in real-time, a clinician working with a patient could gather their HR using a wireless heart rate monitor during a social stressor task (e.g., GSST). After converting the patient’s HR in BPM into Chernoff Faces, the clinician could make a series of Chernoff Face judgments (e.g., four judgments if based on the assessment periods used in this study). Using the LCA solution of Chernoff Face profiles identified in this study (see Table 1), the clinician could estimate the “fit” between their four Chernoff Face judgments of the patient’s physiological functioning into one of the three Chernoff Face profiles. If a clinician found that the patient was, for instance, in the Above Norms Across Situations profile, then they would also know that not only do the physiological data corroborate baseline self-reported concerns (e.g., high subjective ratings of social anxiety), but that the patient likely will require a treatment that focuses on providing the patient with exposure and training across varying social scenarios. Conversely, if the clinician were to identify a patient as falling into the Above Norms Within Performance-Based Situations profile, then a course of treatment might deal specifically with an exposure-based protocol focused on maladaptive reactions to performance-based social situations.

Second, the coders who made Chernoff Face judgments in our study were undergraduate research assistants. We expect these findings to generalize to clinicians. Indeed, as mentioned previously, Chernoff Faces have been implemented in a variety of fields, including business, environmental policy, ecosystem health, education, mechanical engineering, and medical decision making (e.g., Apaiwongse, 1995; Ben-David, 2015; Dong et al., 2015; Huff et al., 1981; S. Y. Lee et al., 2012; Zhang et al., 2015). Further, prior work involving context-based judgments about patients’ behavior finds that both naïve judges and experienced clinicians show the same general pattern of context-based behavioral judgments (cf. De Los Reyes & Marsh, 2011; Marsh et al., 2014, 2016). In fact, a crucial, conservative test of the generalizability of the Chernoff Face approach would involve having clinicians make Chernoff Face judgments, but also patients and key stakeholders in care. Indeed, Chernoff Faces may provide a

method to involve both providers (e.g., clinicians, school counselors, nurses, social workers) and key stakeholders (e.g., youths, parents, teachers) in decision making about care. Such involvement would be in line with current trends in clinical decision making, in particular the movements in patient-centered and personalized care (National Institute of Mental Health, 2015). An interesting direction for future research would involve examining whether adolescent patients, their parents, and clinicians can make Chernoff Face judgments about adolescents' physiological functioning. In sum, our findings bring us one step closer toward implementing physiological data in applied research and clinic settings. Further, the next steps in future research outlined previously may assist in achieving our primary aim—to use Chernoff Faces to personalize social anxiety assessments, and meet the unique needs of adolescents completing these assessments.

### Limitations

We see three limitations of this study. First, coders made Chernoff Face judgments based on adolescents' physiological functioning during the GSST, based on their HR. Different indices (e.g., HR, HRV), may yield different conclusions as to adolescents' physiological functioning (e.g., Allen et al., 2007). Yet, our Chernoff Face approach is limited to instances in which coders can make judgments between an index of a participant's physiological functioning and an index representing normative functioning (see Figure 1). Importantly, our Chernoff Face profile groups predicted adolescents' resting HRV (Figure 2b), which lends credence to the idea that one can use Chernoff Face profiles of arousal to infer a participant's resting physiological flexibility. Nevertheless, future work ought to replicate and extend our findings with metrics other than HR.

Second, coders made Chernoff Face judgments based on archival data. Thus, we do not know if these judgments can be made in a clinic setting in real time (e.g., judgments made immediately after receiving physiological data from a patient). Future research ought to examine the feasibility of our approach when implemented within real-time, ambulatory assessments.

Third, coders' Chernoff Face judgments were based on comparisons between adolescent participants' HR and resting HR clinical norms. Prior work supports the reliability and validity of judgments made under this approach (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015). Yet, the HR clinical norms we used were based on large samples of adolescents who may have varied from the TRAILS sample in demographic composition and method of HR data acquisition (i.e., Davignon et al., 1980; Park, 1996; see Table 6-4 in Siegfried & Henderson, 2002). Further, our clinical norms were only adjusted for normative variation by age. Importantly, our main findings were robust to statistically accounting for adolescent gender, a demographic characteristic that often covaries with psychophysiological responses to social stressor tasks (Bouma et al., 2009). Nevertheless, future work ought to test HR norms that are adjusted for gender and other potentially meaningful demographic correlates of stress response, such as ethnic or racial background. It may be that calibrating HR clinical norms to demographic characteristics in addition to age may further enhance the validity of norm-based judgments.

### Concluding Comments

Findings from basic neuroscience research informed by such initiatives as the Research Domain Criteria (Franklin et al., 2015; Insel et al., 2010) will, in turn, inform the development of biologically informed techniques for assessing and treating adolescent social anxiety. Yet, our ability to implement these techniques in applied research and practice settings rests, in part, on the development of approaches for integrating biologically informed techniques. Further, clinical procedures that integrate biologically informed techniques ought to “fit” current circumstances. In particular, professionals within our current mental health care workforce (e.g., primary care physicians, psychiatrists, psychologists, social workers) often do not receive training in understanding and interpreting biological data (De Los Reyes & Aldao, 2015). Our findings converge with an emerging body of work (De Los Reyes, Augenstein, Aldao et al., 2015; Dunn et al., 2015), indicating that the Chernoff Face approach for graphically depicting physiological data (see Figure 1) yields reliable and valid judgments about physiological data from naïve coders who do not have training in physiology (Figure 2a–b). Further, the large sample of adolescents from the TRAILS study allowed us to identify clinically relevant profiles of Chernoff Face judgments that also converge with research on subcategories of social anxiety disorder (Bögels et al., 2010). Future work ought to focus on the feasibility of the Chernoff Face approach to facilitate “real-time” judgments about patients' physiological functioning, and test the utility of physiological data taken from Chernoff Face judgments for improving clinical decision making.

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Received January 30, 2016

Revision received April 29, 2016

Accepted May 26, 2016 ■