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Developmental Trajectories of Skin Conductance Level in Middle Childhood: Sex, Race, and Externalizing Behavior problems as Predictors of Growth

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Abstract

We examined trajectories of skin conductance level (SCL) during baselines and two tasks across middle and late childhood through growth modeling. We also assessed the role of individual differences including child sex, race, and externalizing behavior problems (delinquency, anger, and aggression) in defining these trajectories. At T1, 128 girls and 123 boys (Mean age 8.23 yrs; SD = .73) participated; 64% were European-American and 36% were African-American. Families participated in 2nd and 3rd study waves with a one-year lag between each wave. Mothers and children reported on child externalizing problems. Addressing notable gaps in knowledge, findings demonstrate varying trajectories of SCL over time based on the child's behavior problems, race, and sex, and are of importance for a better understanding of developmental psychopathology processes.

Keywords

skin conductance level; trajectories of skin conductance; externalizing problems; delinquency; aggression; race; sex

Electrodermal activity has been incorporated in numerous studies with the objective of elucidating markers of psychophysiological functioning and children's developmental psychopathology processes. Skin conductance level (SCL) during resting conditions or baselines, SCL responding to stimuli or laboratory challenges and tasks (task SCL), and calculated change or difference scores from baseline levels to task levels are markers of the activity of the sympathetic nervous systems (SNS), and have been associated with symptoms of developmental psychopathology. Despite a rapidly increasing knowledge base regarding relations between the SNS and externalizing problems (e.g., Beauchaine, Hong, & Marsh, 2008; Lorber, 2004), and the development of biopsychosocial models that attempt to explain these relations (Beauchaine, 2001; Raine, 2002), relatively little is known about developmental trajectories of SCL in children. Furthermore, whether and how individual differences shape trajectories of either baseline SCL or task SCL in childhood remain open scientific questions. Our primary study aim was to address these notable gaps in knowledge, by examining the developmental trajectories of baseline SCL and task SCL across middle and late childhood

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through latent growth modeling. Additionally, we assessed the role of individual differences including child sex, race, and externalizing behavior problems (antisocial behavior, defiance, anger, and aggression) in defining trajectories of growth for baseline SCL and task SCL, and examined whether these characteristics interact to predict different developmental SCL trajectories.

A primary function of the SNS is to facilitate the mobilization of an individual's resources for "fight or flight" behavior and functioning (see Beauchaine, 2001; Boucsein, 1992). Effects of increased SNS activity include pupil dilation and increased sensory acuity to facilitate assessment and engagement with the environment, increased blood pressure and heart rate to facilitate movement, and increased perspiration. Notably, increased sweat gland activity in response to stress is controlled by the SNS (in comparison to the parasympathetic) branch of the autonomic nervous system (ANS). Baseline SCL and task SCL are considered to be valid measures of SNS functioning (Boucsein, 1992).

Several conceptual formulations have posited hypotheses regarding the relation between SNS functioning and externalizing symptoms and their development over time. Fearlessness and sensation seeking have been proposed as two key characteristics linking SNS functioning and externalizing behavior, delinquency, and psychopathy (e.g., Raine, 1993; 2002). Beauchaine (2001) and Beauchaine, Gatzke-Kopp, and Mead (2007) integrated elements of the Polyvagal theory (Porges, 2007) and a theory of motivation for approach, avoidance, and inhibition (Gray, 1987; Gray & McNaughton, 2000; McNaughton & Corr, 2004) to construct a more nuanced view of the psychophysiology of developmental psychopathology. Specifically, they hypothesized that externalizing behaviors are related hierarchically to ANS functioning, and that they may be predicted by unique patterns of psychophysiological functioning that include low levels of inhibition and low sensitivity to punishment (i.e., a tendency not to avoid punishment through active or passive inhibition). This lack of inhibition and insensitivity to punishment cues is thought to stem from low levels of functioning in the Behavioral Inhibition System (BIS), a hypothetical construct proposed to have role in inhibiting prepotent behavior (Gray & McNaughton, 2000). Low levels of BIS functioning may translate into aggressive and externalizing problem behavior through the failure to constrain impulses, and failures in instrumental learning that would extinguish behavior under threat of punishment or reward withdrawal. Conversely, inhibited behavior and anxiety are related to high levels of BIS activity as assessed behaviorally (Amodio, Master, Yee, & Taylor, 2007; Newman, Wallace, Schmitt, & Arnett, 1997) and physiologically via SCL (Fowles, Kochanska, & Murray, 2000; Hoffman & Kim, 2006), though nonsignificant results have also been found (Arnett & Newman, 2000).

Negative relations between SCL and aggression or externalizing behaviors have been reported in many studies (see Boucsein, 1992; Fowles, 1993; Quay, 1993). For example, aggressive individuals exhibit lower SCL, and findings are particularly robust when comparing SCL differences in individuals with undersocialized aggressive conduct disorder and controls (Quay, 1993). Studies with clinical samples of individuals with externalizing problems (e.g., criminals, psychopaths), conducted mostly with adult and adolescent males, are supportive of a negative association between externalizing problems and baseline SCL cross-sectionally (Gatzke-Kopp, Raine, Loeber, Stouthamer-Loeber, & Steinhauer, 2002) and longitudinally (van Bokhoven, Matthys, van Goozen, & van Engeland, 2005). Supporting a specific link between SCL and psychopathy characterizing undersocialized aggression, juvenile delinquent adolescent males high on psychopathy (i.e., callous-unemotional traits) showed lower SCL reactivity to provocation, regardless of their levels of aggression (Munoz, Frick, Kimonis, & Aucoin, 2008). Similar findings appear to extend to community samples, especially in adults (Sylvers, Brubaker, Alden, Brennan, & Lilienfeld, 2008). These findings are consistent with meta-analytic results indicating that externalizing behavior problems, especially psychopathy, are characterized by lower basal SCL and decreased SCL reactivity in adolescents and adults (Lorber, 2004).

Although underarousal across baseline and task SCL has been associated with externalizing problems in many studies with adults and adolescents, the literature has been less consistent with children (Lorber, 2004; Scarpa & Raine, 1997). For example, lower levels of baseline SCL have been reported in clinically diagnosed children with conduct disorder or comorbid conduct disorder and attention deficit hyperactivity (Blair, 1999; Crowell et al., 2006; Herpertz, et al., 2005; Snoek, van Goozen, Matthys, Buitelaar, & van Engeland, 2004; van Goozen, Matthys, Cohen-Kettenis, Buitelaar, & van Engeland, 2000). Nonsignificant or sex dependent results have also been reported (Beauchaine et al., 2008).

It is not clear why the literature linking SCL with externalizing problems is more consistent with adults than children. It is plausible that SCL may develop into a marker of problem aggression or delinquency over development, or aggression and delinquency may become more differentiated and develop into more distinct subtypes as development progresses. In the present study, we address several of these possibilities by examining developmental trajectories of SCL over time as predicted by externalizing problems. In doing so, we use multiple assessments of basal SCL and SCL responses during two laboratory tasks. Furthermore, we examine developmental trajectories of SCL in relation to specific measures of externalizing behavior problems (early delinquency and anger/aggression).

Despite the conceptual and empirical interest in links between SNS functioning and developmental psychopathology processes, relatively little work has charted the development of this system in childhood. Examining continuity, stability, and variability in change are important aspects of understanding a developmental process (Bornstein & Suess, 2000). Furthermore, if SCL functioning is to be used as a correlate and predictor of developmental psychopathology, a better understanding of electrodermal responses in childhood is warranted. Next, we present findings pertinent to stability and continuity of SCL in childhood, and individual and group differences (child sex, race, and behavior problems) associated with SCL.

Basal SCL is moderately to highly stable in adults (see Boucsein, 1992). A few studies have explicitly examined continuity and stability of SCL functioning in childhood. Continuity refers to group level (i.e., mean) change over time while stability refers to consistency in individual rank over time (Bornstein & Suess, 2000). Early work with children aged 6 to 11 suggests that younger children have higher levels of SCL reactivity than their older counterparts (Janes, Worland, & Stern, 1976). A study with 3-year-olds classified children into various groups based on SCL, skin conductance response amplitude, latency, and half recovery time (Venables, 1978). Results indicated that children predominantly fell into the same groups over 18 months. However, there was no clear demonstration of stability in SCL. More recently, El-Sheikh (2007) examined continuity and stability of baseline SCL longitudinally with children aged 9 and 11 years, and found that baseline SCL decreased significantly over the two-year period. Furthermore, in the same study, moderate stability in children's baseline SCL over two years was observed. Other studies comparing children by age group failed to find mean differences in their SCL reactivity (Morrow, Boring, Keough, & Haesly, 1969; Venables & Mitchell, 1996).

Sex-related effects in baseline SCL and SCL reactivity to challenges have been reported. Among children who ranged in age between 7 and 14 years, girls showed greater SCL reactivity than boys, especially during the viewing of emotionally unpleasant pictures (McManis, Bradley, Berg, Cuthbert, & Lang, 2001). In a study with 6 to 13 year-olds, girls had higher baseline SCL than boys, whereas no-sex related effects were reported for SCL reactivity to lab challenges (El-Sheikh, 2007). Generally, the adult literature indicates higher levels of tonic

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electrodermal activity in women in comparison to men (Boucsein, 1992); disparate findings have also been reported (Venables & Mitchell, 1996).

Racial differences in baseline SCL have long been acknowledged and are thought to be due primarily to the inverse relation between the number of sweat glands and darker skin pigmentation (Boucsein, 1992). For example, European-American (EA) children have higher basal SCL (Gatzke-Kopp et al., 2002) and SCL reactivity than African-American children (AA; Janes, Worland, & Stern, 1976; Janes Hesselbrock, & Stern, 1978). However, few studies have examined the role of race in the stability, continuity, and trajectories of SCL. In one study, AA children ranging in age between 6 and 13 years exhibited lower levels of SCL reactivity to a star-tracing task and listening to a conflict challenge in comparison to their EA counterparts (El-Sheikh, 2007). However, there were no significant differences in baseline SCL based on race in this study. In the same investigation, EA children exhibited lower levels of SCL reactivity at age 9 in comparison to age 11. However, no significant differences in SCL reactivity were evident for AA children over time.

Given the inconsistencies in the literature between SCL and externalizing behaviors with children, we proffered no hypotheses in our assessment of relations between these variables over the course of development. Given that SCL tends to decrease with age (El-Sheikh, 2007), we predicted negative slopes of SCL over development. Whether the negative slopes would reflect a steeper decline over development for children higher versus lower in delinquency and anger/aggression was an open scientific question, which we probed. Given sex-related and racial differences in research pertaining to both SCL (El-Sheikh, 2007) and externalizing problems (e.g., Aber, Brown, & Jones, 2003), we also considered children's race and sex as potential moderators for trajectories of baseline SCL and task SCL over time.

Method

Participants

At T1, children (128 girls and 123 boys) and their parents were recruited from three local public schools in the Southeastern USA. Second or third grade children from two parent homes in which parents had cohabitated for at least two years were eligible for participation. To reduce potential confounds, children diagnosed with ADHD, a learning disability, or mental retardation were excluded from the study. Children's mean age was 8.23 years (*SD* = 0.73). The mean pubertal development score based on parents' reports was 1.38 (SD = .27) as indicated by the Pubertal Development Scale (PDS; Pederson, Crockett, Richards, & Boxer, 1988). Specifically, 94% of the sample was classified as pre-pubertal and the rest were considered to be in the early stages of puberty. Families represented the complete spectrum of possible economic backgrounds (Hollingshead, 1975; *M* = 3.21; *SD* = 0.91; range: 1–5), with the median income in the $35,000–50,000 range. The sample was comprised of 64% European-American and 36% African-American children, which is representative of the community from which they were drawn. We recruited European and African American families across a wide socio-economic status (SES) background range. It should be noted that children in the T1 sample participated in another study (Erath, El-Sheikh, & Cummings, 2009), which focused on the relation between harsh parenting and child externalizing problems.

Families participated in a second and third wave of data collection with a one-year lag (*M* =12.84 months, *SD* = 2.06 months between T1 and T2; *M* = 11.34 months, *SD* = 1.62 months between T2 and T3) between each wave. At T2, 215 children (105 boys) and their parents participated (86% retention rate). The sample at T3 consisted of 183 children (88 boys) and families (85% retention rate from T2). These retention rates are similar to those of other studies with diverse samples in relation to ethnicity and SES (e.g., Calkins, Blandon, Williford, & Keane, 2007). Families lost to attrition included those who could not be located, moved out of the area, declined participation due to busy schedules, and did not respond to phone and letter requests to participate.

Procedures

Children and their parents visited the laboratory located on the University campus to participate in a longitudinal study investigating links between family functioning and children's physiological regulation and adjustment. Only procedures pertinent to the present study will be presented. The study was approved by the University's Institutional Review Board for the protection of human participants. Once informed consent was obtained from participants, children were taken into the physiological assessment room where their height and weight were measured and physiological sensors were attached. The researcher explained the function of the equipment to reduce any anxiety the child may have felt, and mothers were allowed to be present while the sensors were attached. Then, each mother was taken to a separate room where she completed questionnaires. Children were informed that they could stop the session at any time by raising their hand, which could be observed through a one-way mirror; none did. All study procedures were identical across the three waves of assessment except when noted.

Skin Conductance Data Acquisition and Reduction—Children's SCL (expressed in microSiemens) were examined using two Ag-AgCI skin conductance electrodes filled with BioGel (an isotonic NaCI electorolyte gel) and attached with adhesive collars to the volar surfaces on the distal phalanges of the second and third digits of the non-dominant hand (consistent with recommendations of Scerbo, Freedman, Raine, Dawson, & Venables, 1992). A constant sinusoidal (AC) voltage (0.5 V rms.) was used. SCL was assessed continuously via a 16 Channel A/D converter used to digitize and amplify the signals (bio amplifier Model MME-4; James Long Co., Caroga Lake, NY), and was calculated using James Long Company Software. Assessments were collected at 1000 readings per second. The electrodes allowed a gel contact area of 1 cm in diameter. The SCL range was 0 to 25 microsiemens and the SCL resolution was 763 picosiemens (0.000763 microsiemens).

The physiological sessions included the following periods: adaptation period (6 min); baseline 1 (3 min); audio-taped interadult argument (3 min); recovery period (3 min); baseline 2 (3 min); and star-tracing task (3 min). During adaptation, recovery, and baseline conditions, children were asked to sit down quietly and relax. SCL responses may vary based on the nature of the challenging/stressful condition used to induce reactivity, and clarification of SCL responses during various challenges is a recognized need in this literature (e.g., Fowles, Kochanska, & Murray, 2000). For a better elucidation of trajectories of SCL responses, we investigated children's SCL responses during two tasks: listening to an interadult argument (social stressor) and tracing a star (problem-solving stressor). After electrodes were attached, children were given six minutes to acclimate to the equipment before a baseline measure of SCL was obtained. Children then heard an interadult audio-taped argument played through speakers located in the room with them. Two argument themes (i.e., in-laws and leisure activity issues) were used to increase generalizability of the findings, and a similar number of boys and girls, and a similar percentage of European- and African-Americans were exposed to each theme. ANCOVAs were conducted to examine whether argument theme (in-laws or leisure activities) was related to children's SCL during the argument, while controlling for baseline SCL (in accord with the law of initial values); no significant differences were observed during any of the three time points. Thus, the theme of the argument did not significantly influence children's SCL.

Following the argument, children were given a three minute recovery before the second baseline was obtained. Finally, children completed a star-tracing task (Lafayette Instrument Company), which involved tracing a star that was visible only through a mirror. Once the tasks were completed, children listened to a 3 min conflict resolution to the interadult argument for ethical purposes and the electrodes were removed. Mean level responses during the three-minute period of each condition were obtained to derive SCL during each pertinent condition: Initial baseline, argument, second baseline, and the star-tracing condition. Analyses included the initial baseline SCL and second baseline SCL for a more thorough assessment of baseline SCL.

Measures

Demographic Variables—Mothers completed the Hollingshead Index (Hollingshead, 1975), which was used to calculate SES. They also reported on children's age, gender, and ethnicity.

Delinquency—Mothers reported on children's problem behaviors using the Personality Inventory for Children-II (PIC2; Lachar & Gruber, 2001). Under-controlled problem behaviors were examined via an overall scale of Delinquency, which is composed of three subscales that assess Antisocial Behavior (13 items), Dyscontrol (17 items), and Noncompliance (17 items). For the PIC2, test-retest reliability, interrater reliability, and discriminant and construct validity have been demonstrated (Wirt, Lachar, Klinedinst, & Seat, 1990). Further, the Delinquency scale has been found to correlate highly with teacher, clinician, and self-report assessments of similar behaviors (Lachar & Gruber, 2001). Although the PIC2 has an Externalizing Behaviors composite that aggregates the Delinquency and an Attention Problems scale, only the former is pertinent to our study because it has been linked with SCL. In the current sample, the internal consistency for the scale was .96. At T1, fifteen children in the sample (5%) were within the borderline or clinical range of externalizing behavior problems according to their mother (i.e., T scores ≥ 60); at T2 and T3, sixteen and fourteen children in the sample (6% and 5%) were within that range, respectively.

Anger and Aggression—Via interview, children completed the Trauma Symptoms Checklist for Children (TSCC; Briere, 1996), which assesses numerous symptom domains related to children's reactions to non-specified traumatic events. Children rated their angry/aggressive thoughts, feelings, and behaviors on a scale ranging from 0 (never) to 3 (almost all of the time). The scale is composed of nine items (e.g., wanting to yell at or hurt other people, getting into fights, feeling mad, arguing too much). The reliability coefficient with the current sample was $\alpha = .82$. The TSCC has high internal consistency with normal and clinical samples, and is significantly correlated with other commonly used measures in this area (Lanktree & Briere, 1995).

Analysis Plan

To determine the developmental trajectories across 3 years in children's baseline SCL and task SCL (during the laboratory argument and star tracing tasks), a series of multiple domain growth models was fitted to the data. The well-established data analytic technique of multiple domain growth modeling (Keiley, 2007; Keiley, Bates, Dodge, & Pettit, 2000; Keiley, Martin, Liu, & Dolbin-MacNab, 2005; Singer & Willett, 2003) allows for the investigation of the developmental trajectories in several domains simultaneously; therefore, growth in any one domain is controlled in the analyses for growth in the other domains. Specifically, in examining growth in the 4 domains of SNS functioning together in one model [(basal SCL at the beginning of the session, resting SCL between the two stressors, task SCL in response to the normative social stressor (argument), and task SCL in response to the problem-solving challenge (star-tracing)], we can establish average or prototypical trajectories in one of these domains that will have taken into account development in all of the other domains. Thus, children's responses to the lab challenges take into account resting levels of SCL. In addition, we control for the concomitant changes in SES and parent-reported puberty by including growth models for those domains as well, removing yet another set of possible confounds in examining change in SCL

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functioning. Controlling for potential confounds affords more rigor in the testing of our models. In other words, in our series of multiple domain growth models we take into account development of 4 domains of SCL, controlling change in each domain of SCL for change in the others as well as change in puberty and SES.

In all models, time was centered at year 1 of the 3-year study. Thus, the metric of time used in the growth models was 0, 1, and 2. The individual growth model ("within person" or "level-1" model) that best represented the change in these domains was estimated as a linear model. Because we only had 3 time points, a quadratic model was not tested (Singer & Willett, 2003). The level-1 growth model for all of the domains contained two individual growth parameters: (1) an intercept parameter representing initial status, and (2) a slope parameter representing rate of change. Each child's intercept and slope terms were then estimated for growth in each domain.

All models were fit using Mplus Version 5, which allows for the inclusion of respondents with missing data by using full information maximum likelihood (FIML) estimation (Muthén & Muthén, 1998), drawing on the theory in Little and Rubin (1987). In FIML estimation with missing data, observations are sorted into missing data patterns, and each parameter is estimated using all available data for that particular parameter. Mplus estimates a covariance matrix from raw data and a coverage matrix that describes the extent of missing data. The coverage matrix indicated that the percentage of missing data ranged from 8% (T1) to 31% (T3) for the SCL variables, 7% to 10% for the predictors used at T1 (child-reported anger, mother-reported delinquency), 4% (T1) to 25% (T3) for SES, 5% (T1) to 38% (T3) for parent-reported puberty. No differences were found on available demographic, predictor, or outcome variables between respondents who were missing data and those who were not.

For each of the 4 domains of children's SCL, an unconditional growth model (with no predictors of intercept and slope) was fit to the data. After assessing model fit, we tested whether the between-person variation in the growth parameters for each domain was related to variation in the predictors: child sex, race, child-reported anger/aggression at T1, and mother-reported delinquency at T1. As predictors were added to the unconditional model, one at a time, the significance of that predictor's effect on the growth parameters was determined by fitting a reduced model and conducting the appropriate $\Delta\chi^2$ test. A reduced model is formulated by constraining the parameters from the predictor to the growth parameters to zero (Keiley et al., 2005; Singer & Willett, 2003). All two- and three-way interactions were tested and those that did not aid in improving model fit were excluded (Keiley et al., 2005). Thus, our approach was to trim the non-significant interactions to create the most parsimonious model, and only significant interactions are reported.

Results

The estimated means, standard deviations, and correlations for all model observed variables are shown in Table 1. Note that SCL tended to increase on average throughout the session at each point of assessment. Additional preliminary analyses indicated that, on average, each of the two laboratory tasks elicited significant increases in SCL from the baseline preceding each lab challenge at all time points; because SCL tended to increase throughout the session, testing change in SCL to task from the baseline preceding each task (i.e., baseline 1 for the argument, and baseline 2 for the star-tracing task) was deemed desirable in examining SCL reactivity. Specifically, at T1, children demonstrated significant increases in SCL during the argument [$t(234) = 10.02$, $p < .001$] and star-tracing [$t(234) = 10.45$, $p < .001$] tasks in comparison to the baseline preceding each task. Similarly, at T2, significant increases in children's SCL during the argument [$t(204) = 7.50$, $p < .001$], and star-tracing [$t(204) = 7.08$, $p < .001$] tasks were observed. At T3, children demonstrated significant SCL increases during both the argument

[$t(175) = 5.37$, $p < .001$], and star-tracing [$t(175) = 10.24$, $p < .001$] challenges. Thus, on average, children tended to exhibit significant increases in SCL in response to either the argument or star-tracing tasks during all three time periods (see Table 1 for means and *SD*s).

The fit statistics and delta chi-square tests conducted in model-building are presented in Table 2. The estimated slope and intercept parameters of the final fitted model are in Table 3. Singer and Willett (2003) suggest that a focus on the R^2 statistics and the residual variances should be used, when possible, to quantify the "correspondence between the fitted model and sample data" (p. 47) in multilevel modeling for change. Thus we are including those in Table 2 and Table 3.

The parameter estimates from the unconditional model indicate that baseline 1 SCL (5.00**) and baseline 2 SCL (7.59**) are significantly different from zero at intercept (Time 1), but those for baseline 2 SCL are elevated over those for baseline 1 SCL. In both domains of SCL there are significant decreases in these trajectories over time (−0.31~ for baseline 1; -.63** for baseline 2). The parameter estimates from this same model for the intercepts of task SCL also are different from zero (6.85** for argument; 8.79** for star-tracing), but those for the star task are higher than those for the argument. The slopes for the two task SCL domains also show significant decreases over time (−0.56** for argument; −0.71** for star-tracing). These unconditional trajectories are illustrated in Figure 1. These trajectories indicate that children evidence higher levels of SCL during the star tracing-task than the argument task, but there is a significant decrease in children's SCL during the tasks with increasing development.

The final fitted model with our predictors of child sex, race, self-reported anger/aggression, and mother-reported delinquency indicated that a large proportion of the variance was predicted in the intercepts and slopes of the domains of interest. In most growth models, we are often able to predict variance in intercepts; the assumption being that many of the factors that are related to the difference in levels of behavior evidenced at intercept have come prior to that time - childhood, adolescence, earlier in adulthood (Keiley et al., 2005). We commonly do not predict very much variance in slopes. However, with the present data, we predicted almost 35% to 40% of the variance in the intercepts of growth in baseline SCL and task SCL during the two tasks. In addition, we also predicted a very large amount of the variance in the slopes – 19% to 22%.

The effects of the predictors in the final fitted model (Table 3) on the growth parameters in the 4 domains of SCL, controlling for changes in SES and puberty, can best be illustrated by using the well-established procedure of constructing prototypical plots (Singer & Willett, 2003). To use this procedure we begin by "identifying a prototypical individual distinguished by particular predictor values" (Singer & Willett, 2003, p. 60). We do this by selecting meaningful values of the predictors to substitute into the fitted final model, obtaining the estimated value for the outcome (two baseline SCL measures, and task SCL during the two challenges), and plotting those trajectories. This provides trajectories that would be typical for individuals in the population with those characteristics. In other words, the sample was not divided into groups to illustrate the findings; we are presenting the fitted "true" or "population" trajectories of SCL in children similar to those in our sample. The meaningful values we chose for our plots of prototypical individuals were 0 or 1 for sex, 0 or 1 for race, 1 ½ *SD* above and below the mean for child-reported anger/aggression (0, 13), and 1 ½ *SD* above and below the mean for mother-reported delinquency (0, 11).

To present trajectories of SCL responses as a function of the Race x Sex interaction effect depicted in Table 2, we present figures of prototypical EA and AA boys' (Figure 2a) and girls' (Figure 2b) responses to the lab baseline and task conditions over this age period (8 – 10). EA boys have baseline SCL and task SCL trajectories that begin at a higher level at age

8 and show decreases over time. On the other hand, AA boys begin their trajectories of SCL responses at age 8 at both a lower level, and tend to have more shallow negative slopes, than their EA counterparts (Figure 2a).

Although it is not customary to test the significance of slopes to examine whether each varied from zero in growth curve modeling, and we acknowledge that this is not necessary (Singer & Willett, 2003), we assessed whether the slopes in Figure 2a were significantly different from zero. Given the novelty of our research questions pertinent to changes in children's SCL over time as a function of child sex and race, and the importance of ascertaining developmental trajectories of SCL and the nature of change in these trajectories, we deemed it important to assess the significance of the simple slopes. Whereas the significant interaction effect between child sex and race indicates that the slopes representing these variables are significantly different from each other, testing the simple slopes allows us to assess statistically significant change (e.g., decline, increase) in the slope over time. In relation to slopes in Figure 2a, all simple slopes for EA boys (i.e., for Baseline 1, Argument, Baseline 2, and Star-Tracing) were significantly different from zero at $p < .001$, except Baseline 1, which was significant at $p < .01$. However, none of the simple slopes for AA boys were significantly different from zero. Thus, EA but not AA boys showed a significant decline in SCL over development.

A different pattern emerged for girls (Figure 2b). In comparison to EA girls, AA girls showed a significantly lower level of SNS arousal across all four SCL domains examined at age 8. Testing of the simple slopes indicated that trajectories of SCL responding did not exhibit significant growth over time for either AA or EA girls, and no slope was significantly different from zero.

As shown in Table 3, both child-reported anger/aggression and mother-reported delinquency were significant predictors of the intercepts and slopes of the various SCL parameters. Figure 3a presents the SCL responses of prototypical children, with either lower or higher levels of self-reported anger/aggression, over this age period (8–10). Children with lower levels of anger/aggression showed lower levels of SNS arousal across all four SCL domains examined at age 8, in comparison to their counterparts with higher levels of anger/aggression. Furthermore, children higher or lower in anger/aggression showed different slopes over time. As shown in Figure 3a, children with lower levels of anger/aggression have baseline SCL and task SCL trajectories that are shallow and do not change much over time; all the simple slopes were not significantly different from zero. Conversely, children with higher levels of anger/aggression at age 8 have steep negative slopes for SCL responses across all baseline and experimental conditions as they age. Testing of the simple slopes representing prototypical children with high anger/aggression slopes indicated that they were all significantly different from zero at $p < .001$, with the one exception of Baseline 1, which was significant at $p < .01$. Taken together, findings indicate that children low on anger/aggression experience no change in SCL over time while those with high anger/aggression or delinquency experience significant decreases in SCL over development.

Trajectories of SCL responses for children with higher and lower levels of mother-reported delinquency are very similar to those reported earlier based on child-reported anger/aggression (see Figure 2b). Specifically, delinquency was a significant predictor of the intercepts and slopes of children's SCL responses across the laboratory session (see Table 3). Further, prototypical children with lower levels of delinquency at age 8, have baseline SCL and task SCL trajectories that are shallow over time and begin at a lower level at age 8 than the corresponding trajectories for children with higher levels of delinquency. Testing of simple slopes for children lower on delinquency yielded no significant results, indicating no significant change in SCL trajectories over time. Conversely, children with higher delinquency scores at age 8 have trajectories of baseline SCL and task SCL that decrease significantly over time.

Testing the significance of the simple slopes for children high in delinquency illustrated that all slopes were significantly different from zero at $p < .001$, with the exception of Baseline 2, which was significant at $p < .01$.

Discussion

Addressing an open scientific question, trajectories of children's baseline SCL and task SCL were examined across middle and late childhood through growth modeling. Findings from the unconditional model indicated that all SCL domains examined were significantly different from zero at intercept (Time 1), and that there were significant decreases in the slopes of these trajectories over the three waves of assessment. Further, findings demonstrate varying trajectories of SCL over time based on the child's externalizing behavior problems, race, and sex. Knowledge of developmental trajectories of SCL is of importance for a better understanding of developmental psychopathology processes, especially in the context of the increasing knowledge base documenting relations between SCL and externalizing problems, and the scarcity of information regarding either trajectories of SCL or whether individual differences predict these trajectories in childhood.

Children with higher levels of either delinquency (mother-reported) or anger/aggression (child-reported), had higher levels of baseline SCL and task SCL at age 8 than children with lower behavior problems. Further, while trajectories of baseline SCL and task SCL showed significant decreases over time for children with higher levels of externalizing behavior problems, these trajectories remained stable and shallow over time for those with lower levels of such problems. These patterns result in very similar levels of baseline SCL and task SCL for children with higher or lower levels of either delinquency or anger/aggression at T3. Consistency in findings across child- and mother-reports of behavior problems lends confidence in the observed baseline SCL and task SCL trajectory patterns.

Literature findings tend to be supportive of the underarousal hypothesis with adolescents and adults in that individuals with delinquency and conduct disorders or psychopathic traits tend to exhibit lower levels of electrodermal arousal during resting and reactivity conditions (Lorber, 2004). However, with samples that are composed of children, both boys and girls, or non-clinical in nature, findings have been mixed, with some supportive of a positive association between SCL and externalizing behaviors (El-Sheikh, 2005; Hubbard et al., 2002). Contrasting results may be partially reconciled by considering that these studies involved moderation effects with environmental characteristics (e.g., El-Sheikh, 2005) or a certain type of aggression (i.e., reactive aggression controlling for proactive aggression; Hubbard et al., 2002). Moreover, in the context of our findings, these contrasting results may also be reconciled partially through addressing important next questions in this area of inquiry: Whether intercepts and slopes of SCL for children with higher externalizing behavior problems at age 8 would continue to decline through adolescence and adulthood, and whether they would continue to remain stable for those with lower externalizing problems. Answers to these questions would likely shed much light on the inverse pattern of associations between externalizing behavior and SCL responses for children versus older adolescents and adults. The findings of the current study have significant implications for the study of psychophysiological characteristics associated with developmental psychopathology processes. Children higher in externalizing problems may have higher levels of SCL as early as age 8, yet show gradual decline in SCL over development, eventually resembling the underarousal found in adults with antisocial or psychopathic characteristics. We hope that future investigations would extend the study of SCL trajectories over childhood and adolescence to address this important developmental issue.

There are several propositions regarding the relation between SNS functioning and externalizing symptoms, and their development over time, including fearlessness and sensation seeking (e.g., Raine, 1993; 2002). It is plausible that SNS underarousal may be one mechanism that may cause a child not to fear threatening situations or consequences of negative actions, or to even seek out these situations in order to stimulate a chronically underaroused ANS. Beauchaine (2001) and Beauchaine and colleagues (2007) proposed a conceptual framework that integrates theory of motivation for approach and avoidance (Gray, 1987a; 1987b) with Polyvagal theory (Porges, 2007). In this framework, it is hypothesized that externalizing behaviors are related hierarchically to ANS functioning. They proposed that externalizing behaviors may be predicted by a pattern of psychophysiological functioning that includes low levels of inhibition and low sensitivity to punishment, which may be indexed by baseline SCL and task SCL during challenges (Gray, 1987a, 1987b; Fowles, 1980, 1988). The declining levels of SCL over three periods of assessments for children with behavior problems at age 8 suggest that these children develop lower levels of BIS functioning over time. Conversely, the stability in SCL observed over time for children with lower levels of behavior problems may suggest more normative functioning of the BIS and continuity in SNS activity over development.

In addition to the effects of externalizing behavior problems on children's SCL over time, the child's sex and race interacted in the prediction of SCL trajectories. Whereas most growth models do not predict variance in slopes of the domains of interest (Keiley et al., 2005), a large proportion of the variance in both the intercepts and slopes was predicted by our final model, which included race, sex, and externalizing behavior problems. Specifically, almost 35% to 40% of the variance in the intercepts of growth in, and 19% to 22% of the variance in slopes for, baseline SCL and task SCL during the two tasks were predicted by our final model. These findings are supportive of developmental changes in children's SCL response during late childhood and early adolescence and highlight several individual differences that are important predictors of such growth.

The present results indicated higher levels of SCL in boys versus girls but only at T1. Furthermore, higher levels of SCL were observed across the session for European than African American children. Sex-related effects in baseline SCL and SCL reactivity have been reported. Several studies supported higher levels of baseline SCL (El-Sheikh, 2007) and SCL reactivity to stressors (McManis, Bradley, Berg, Cuthbert, & Lang, 2001) in girls in comparisons to boys. Although the literature at large with adults documents higher levels of tonic electrodermal activity in women in comparison to men (Boucsein, 1992), sex-related effects in SCL have not been consistent (Venables & Mitchell, 1996). Observed race-related effects indicating higher levels of SCL in European in comparison to African Americans are consistent with the acknowledged racial differences in baseline SCL, which are thought to be primarily due to the inverse relation between the number of sweat glands and darker skin pigmentation (Boucsein, 1992). However, few studies have examined the role of either sex or race in trajectories of SCL over development. The present findings augment this literature by demonstrating not only direct effects of these individual differences over time, but more importantly that the two variables interact in predicting trajectories of SCL in late childhood. This interaction effect has rarely been examined, and pertinent findings are discussed next.

The effects of the predictors in the final fitted model on the growth parameters in the 4 domains of SCL responses are best illustrated by "identifying a prototypical individual distinguished by particular predictor values" (Singer & Willett, 2003, p. 60). Graphs for prototypical children illustrated that EA boys begin their SCL trajectories at age 8 with higher SCL levels than AA boys, and have significant negative slopes as they age. Conversely, trajectories of SCL responding for AA boys were shallow and did not show significant growth over time. Similar to findings observed for boys, in comparisons to AA girls, EA girls began their trajectories of SCL responding at a higher level at age 8. However, neither AA nor EA girls showed significant change in their SCL responses over development. An important avenue for future research is the examination of factors associated with changes in SCL over time. In other words, why do trajectories of SCL decline at various rates for boys and girls, children from various ethnic/racial backgrounds, and those with higher and lower levels of behavior problems?

Across all three periods of assessments, children's SCL continued to increase throughout each session with lowest levels observed during initial baselines and highest levels found during the star-tracing task. These findings are not surprising and indicate increased arousal throughout the procedures, with no full recovery of SCL during the second baseline when compared to the initial baseline of the session. Interestingly, this increased arousal across the session was observed for all children (e.g., girls and boys, European and African American), and has important implications for the assessment of SCL. We chose a fixed order of procedures and stimuli presentation (Baseline 1, Argument, Baseline 2, and Star-tracing) because we were more interested in individual differences in trajectories of SCL than in comparisons among children's responses during the various lab procedures. However, the findings suggest that several baselines may be needed when investigating SCL reactivity to various challenges, and that counterbalancing the presentation of various stimuli may be desired if one's main interest is in comparing children's responses to various stressors. For our purposes, consistency in findings across the four parameters of SCL examined during each of the three waves of assessment increases confidence in our developmental trajectories results.

Findings need to be interpreted within the study's context and limitations. Children's SCL responses were examined between the average ages of 8 and 10. It is plausible that assessment of children's SCL during other developmental periods may yield a different pattern of findings, and a very important next step is the investigation of children's SCL trajectories over larger developmental periods. We also examined SCL during three time points, which does not allow for the investigation of non-linear trajectories. A more thorough explication of developmental trajectories requires at least four assessments to explore both linear and non-linear effects over time (Duncan, Duncan, & Strycker, 2006; Singer & Willett, 2003). Related to the issue of repeated measures, presenting a resolution to the argument at each time point may have influenced levels of physiological responding at T2 and T3. Nevertheless, on average, children exhibited significant increases in SCL during the argument task across all three waves of assessments. Furthermore, we have examined one electrodermal measure in our study. Future investigations incorporating multiple electrodermal responses (e.g., skin conductance responses), or SNS indices (e.g., Pre-ejection period) are likely to shed further light on understanding trajectories of children's SNS activity over development. In addition, our sample was not a clinical sample and it is possible that a different pattern of effects may be observed for children with more severe behavior problems. Nevertheless, growth in developmental trajectories of SCL over time adds to a scant body of literature and hopefully offers guidance for future directions in this area of inquiry towards a better understanding of relations between developmental processes and ANS functioning.

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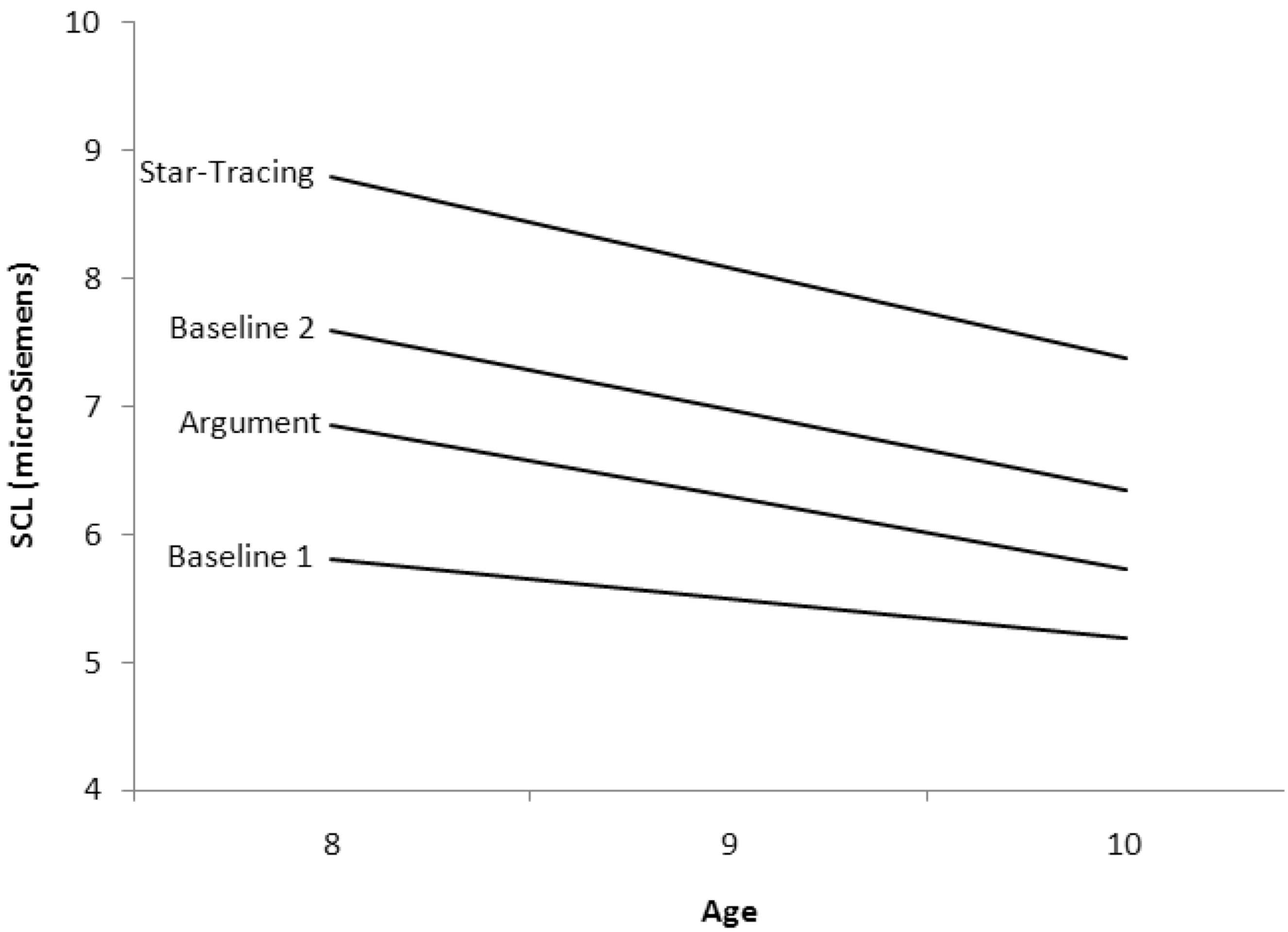

Figure 1.
Unconditional model fitted trajectories for SCL during both baselines (B1, B2) and during the Argument and Star-tracing tasks (N=251).

Figure 2a.

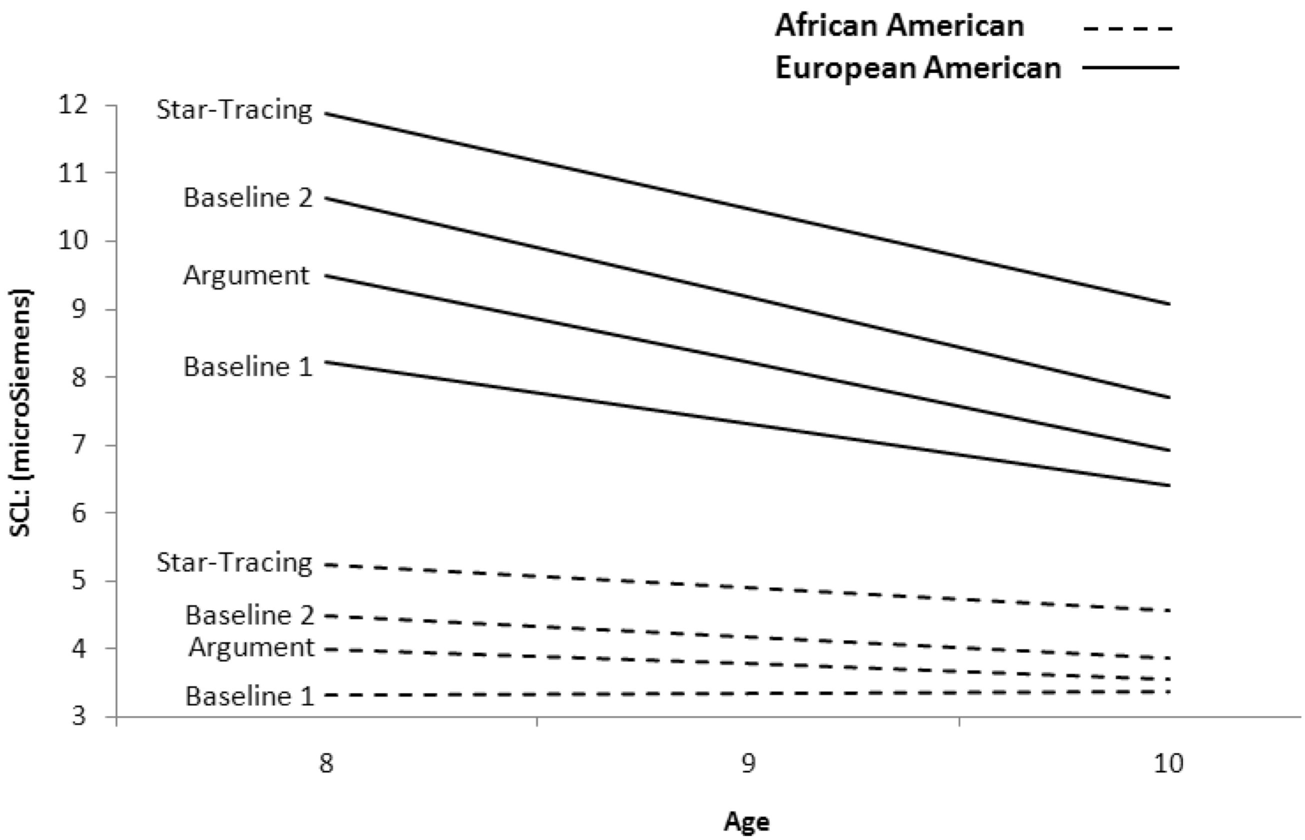
African American
European American
12
11
10
9
8
7
6
5
4
3
SCL: (microSiemens)
Star-Tracing
Baseline 2
Argument
Baseline 1
Star-Tracing
Baseline 2
Argument
Baseline 1
8
9
10
Age

Figure 2b.

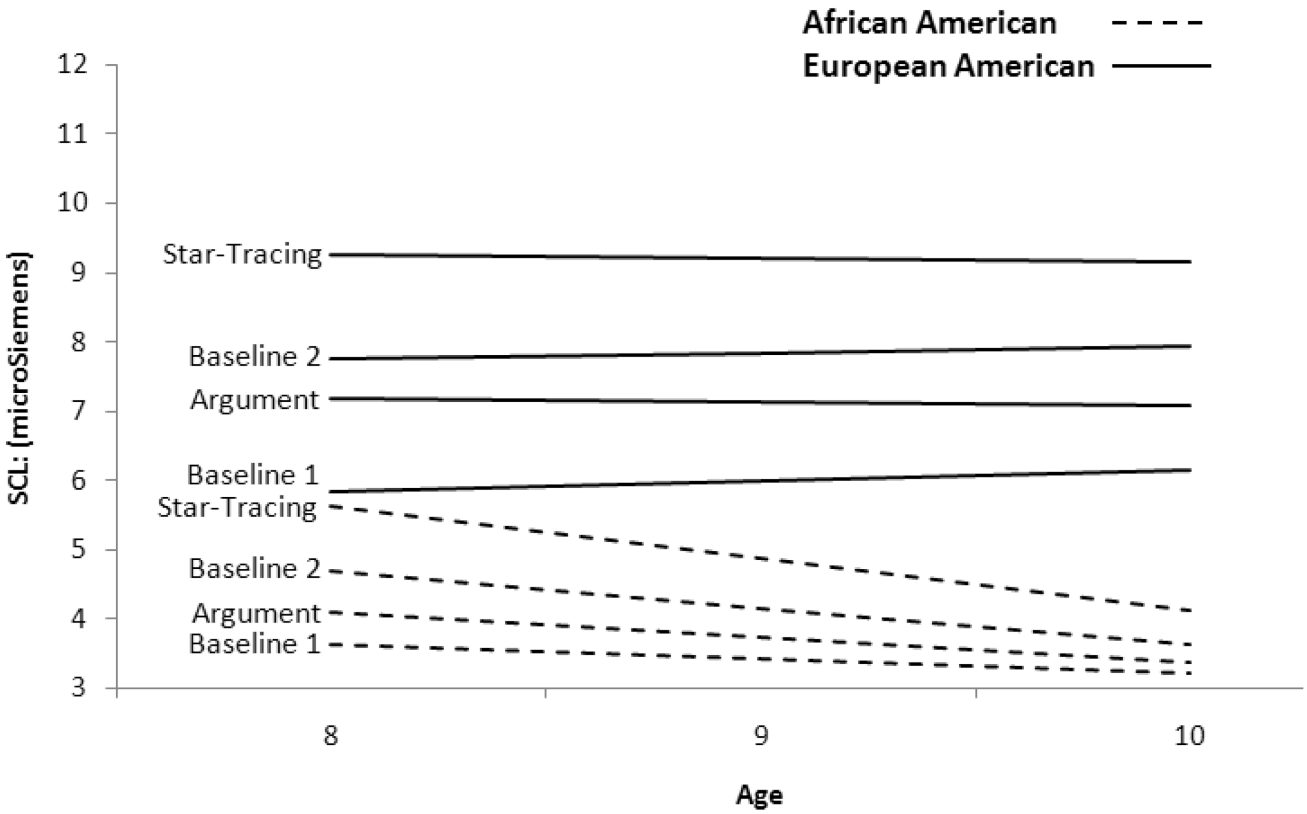

Figure 2.

Figure 2a. Fitted trajectories for SCL-B1, SCL-B2, SCL-Argument, and SCL-Star-tracing for prototypical *boys* of EA and AA race. Analyses controlled for changes in SES and puberty status, and all other model variables were held at their means (N = 251)

Figure 2b. Fitted trajectories for SCL-B1, SCL-B2, SCL-Argument, and SCL-Star-tracing for prototypical *girls* of EA and AA race. Analyses controlled for changes in SES and puberty status, and all other model variables were held at their means (N = 251)

Figure 3a

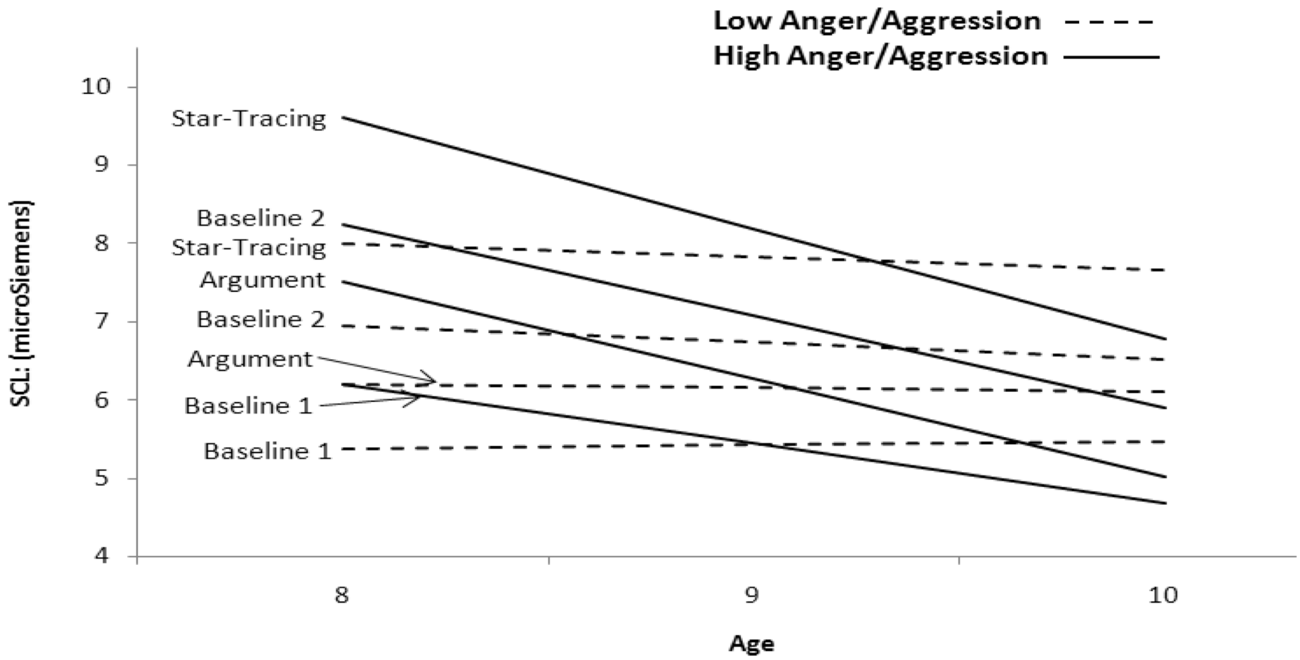
Low Anger/Aggression
High Anger/Aggression
SCL: (microSiemens)
10
9
8
7
6
5
4
Star-Tracing
Baseline 2
Star-Tracing
Argument
Baseline 2
Argument
Baseline 1
Baseline 1
8
9
10
Age

Figure 3b.

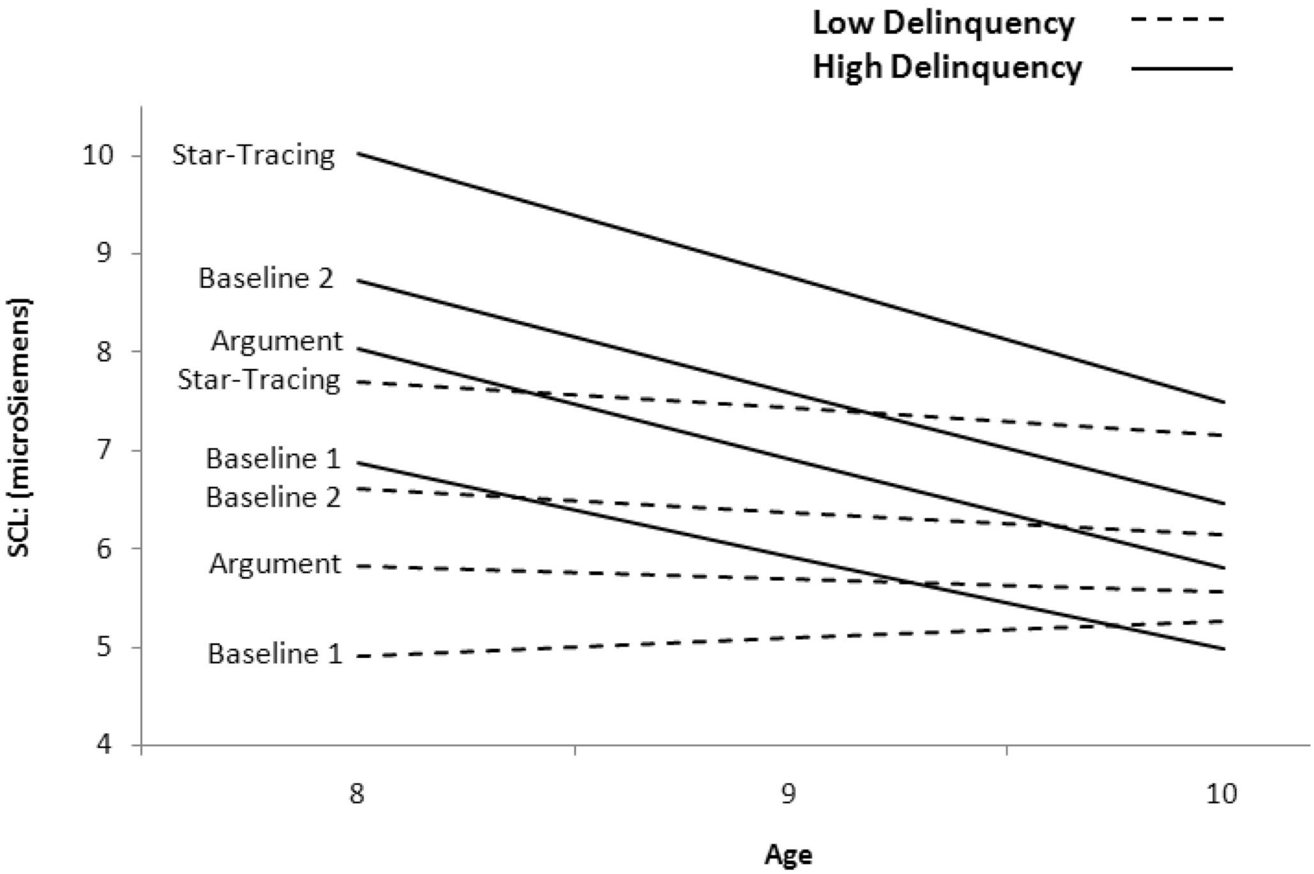

Figure 3.

Figure 3a. Fitted Trajectory for SCL during both baselines (B1, B2) and during the Argument and Star-tracing tasks for prototypical children with higher (13) and lower (0) levels of child reported anger, and all other variables held at their means (N = 251).

Figure 3b. Fitted Trajectory for SCL during both baselines (B1, B2) and during the Argument and Star-tracing tasks for prototypical children with higher (11) and lower (0) levels of mother reported behavior problems, and all other variables held at their means (N = 251).

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Table 1

Estimated means, standard deviations, and correlations among model variables (N=251)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. SCL - B1 T1	-																
2. SCL - Argument T1	.95**	-															
3. SCL - B2 T1	.94**	.96**	-														
4. SCL - Star-tracing T1	.90**	.93**	.95**	--													
5. SCL - B1 T2	.45**	.45**	.42**	.38**	--												
6. SCL - Argument T2	.45**	.44**	.42**	.38**	.96**	--											
7. SCL - B2 T2	.42**	.41**	.40**	.35**	.91**	.96**	--										
8. SCL - Star-tracing T2	.45**	.45**	.44**	.41**	.88**	.91**	.93**	--									
9. SCL - B1 T3	.49**	.43**	.43**	.42**	.47**	.46**	.38**	.41**	--								
10.SCL - Argument T3	.50**	.45**	.45**	.42**	.49**	.49**	.42**	.44**	.97**	--							
11.SCL – B2 T3	.48**	.44**	.45**	.42**	.47**	.48**	.42**	.44**	.94**	.97**	--						
12.SCL - Star-tracing T3	.47**	.44**	.44**	.43**	.51**	.52**	.46**	.50**	.93**	.94**	.98**	--					
13. Child Sex [a]	−.15*	−.16*	−.18**	−.14*	−.09	−.07	−.07	−.08	−.02	.02	.03	.02	--				
14. Race [b]	.37**	.40**	.43**	.41**	.38**	.37**	.39**	.43**	.38**	.40**	.43**	.46**	−.09	--			
15. Child Sex x Race	.03	.05	.02	.06	.08	.12	.11	.13*	.21**	.25**	.26**	.29**	.63**	.52**	--		
16. Behavior Problems T1	.20**	.18**	.17*	.17*	.14*	.18**	.18**	.21**	−.02	.00	.01	.01	.04	.01	.03	--	
17. Anger/Aggression T1	.12	.14*	.13*	.15*	.07	.09	.10	.10	.−.09	−.11	−.07	−.07	−.06	−.01	−.04	.19**	--
M	5.79	6.78	7.46	8.75	5.12	5.82	6.60	7.50	5.35	5.90	6.46	7.52	--	--	--	4.53	5.34
SD	4.48	5.09	5.36	5.77	3.78	4.36	4.85	5.07	4.57	5.15	5.30	5.94	--	--	--	4.44	5.36

Note. T1= Data collected at time 1; T2 = Data collected at time 2; T3 = Data collected at T3.

B1 = Baseline 1; B2 = Baseline 2.

[a]Child Sex coded with 1 for girls and 0 for boys.

[b]Race was code with 1 for European Americans and 0 for African Americans.

*$p < .05$;

** $p < .01$.

Table 2

Fit statistics for the six 7-domain models fit to data and delta-chi square statistics testing for predictor significance ($N = 251$).

Model	χ^2 (df)	$\Delta \chi^2$ (Δ df)	SRMR[a]	RMSEA[b]	Average variance predicted in intercepts (R^2)	Average variance predicted in slopes (R^2)
Unconditional	1264 (112)		.08	.20		
+Child sex	1323 (167)	18* (8)	.09	.17	4.0%	4.9%
+Race	1330 (174)	70*** (8)	.08	.16	27.4%	5.2%
+Sex*Race	1331 (181)	16* (8)	.08	.16	30.1%	9.8%
+Anger/Aggression (CR)	1339 (188)	17* (8)	.08	.16	32.7%	16.8%
+Delinquency (MR)	1356 (195)	18* (8)	.08	.15	36.9%	21.7%

Note.

[a] Standardized root mean square residual

[b] Root mean square error of approximation

CR = Child report; MR = Mother report.

* $p < .05$;

*** $p < .001$

Table 3

Parameter estimates and standard errors (in parentheses) of mean linear growth factors of SCL over 3 years, the effects of child-reported anger/aggression, mother-reported behavior problems, child sex, race, and the interaction of sex and race on these growth factors, the residual variance of the growth factors, and the amount of variance predicted in each growth factor, controlling for the change in SES and puberty (N = 251).

	SCL Baseline 1		SCL during Argument		SCL Baseline 2		SCL during Star-Tracing	
	Intercept	**Slope**	**Intercept**	**Slope**	**Intercept**	**Slope**	**Intercept**	**Slope**
Conditional Mean	2.19** (0.67)	0.81~ (0.44)	2.56** (0.80)	0.68 (0.50)	3.11*** (0.83)	0.45 (0.52)	3.63*** (0.89)	0.57 (0.58)
Predictors								
Child Sex	0.31 (0.81)	−0.24 (0.53)	0.09 (0.96)	−0.14 (0.60)	0.19 (1.00)	−0.22 (0.63)	0.39 (1.08)	−0.41 (0.70)
Race	4.91*** (0.73)	−0.94~ (0.48)	5.50*** (0.86)	−1.06~ (0.55)	6.14*** (0.90)	−1.16s* (0.57)	6.63*** (0.97)	−1.06~ (0.64)
Sex x Race	−2.70** (1.01)	1.32* (0.66)	−2.40* (1.10)	1.36~ (0.76)	−3.08* (1.25)	1.77* (0.79)	−2.99* (1.34)	1.75* (0.88)
Anger/Aggression (CR)	0.06 (0.05)	−0.06* (0.03)	0.10~ (0.06)	−0.09** (0.04)	0.10~ (0.06)	−0.07* (0.04)	0.12* (0.06)	−0.10* (0.04)
Delinquency (MR)	0.18** (0.05)	−0.10** (0.04)	0.20** (0.07)	−0.09* (0.04)	0.19** (0.07)	−0.08~ (0.04)	0.21** (0.07)	−0.09~ (0.05)
Res Variance	8.38***	1.99**	12.26**	2.65**	12.32**	2.58**	13.36**	3.45**
R^2	36.0%	22.5%	34.3%	22.3%	37.7%	22.8%	39.5%	19.1%

Note.

CR = Child report; MR = Mother report.

~ $p < .10$;

* $p < .05$;

** $p < .01$;

*** $p < .001$.