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Executive Functions in Girls with and without Childhood ADHD Followed Through Emerging Adulthood: Developmental Trajectories

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Abstract

Objective: Utilizing an all-female sample, we examined trajectories of executive functioning (EF) performance from childhood through emerging adulthood—and their prediction of key emerging-adult outcomes.

Method: 140 girls carefully diagnosed with ADHD and 88 matched comparison girls were administered EF measurements assessing global EF, response inhibition, and verbal working memory during childhood (mean age = 9.5 years), adolescence (mean age = 14.1 years), the earliest years of adulthood (mean age = 19.6 years), and the end of emerging adulthood (mean age = 25.6 years). Retention rates were excellent. Hierarchical linear modeling was used to estimate growth curves for each EF measure. The linear EF slopes were then used to explore how changes in EF interacted with each participant's persistence/remission of ADHD over time to influence behavioral, emotional, and academic impairment in emerging adulthood.

Results: Although all women experienced absolute improvements in EF performance across time, women with histories of ADHD consistently lagged behind comparison women, even if their ADHD symptoms had remitted by early adulthood. However, EF performance over time did not significantly influence the link between ADHD status and (a) maternal reports of associated behavioral and emotional impairment or (b) objective measures of academic achievement.

Conclusions: These findings indicate that EF deficits should be considered when developing and implementing treatments for ADHD through emerging adulthood. Future research should be aimed at understanding the mechanisms behind these observed trajectory differences.

Keywords

Attention-deficit/hyperactivity disorder (ADHD); Gender; Growth Curve Modeling; Executive Functioning; Developmental Trajectories

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Children with attention-deficit/hyperactivity disorder (ADHD) typically experience declines in symptoms as they age (e.g., Kessler et al., 2006). However, as young adults, nearly all continue to show impairments across multiple domains, including school, work, and social settings (Barkley, 2015; Biederman et al., 2006; Hinshaw, 2018; Hinshaw & Scheffler, 2014). Neuropsychological deficits—particularly those related to executive functioning (EF)—are believed to play a central role with regard to ADHD symptoms and related functional impairments (e.g., Brown, 2013). Yet, little research examines the trajectories of EF in individuals with a history of ADHD beyond late adolescence, particularly for females. Our purpose is to examine the extent to which girls with ADHD continue to experience EF deficits by emerging adulthood (i.e., ages 23–29), compared to their peers without childhood ADHD. We also examine the relation between these EF trajectories and the young women's (a) externalizing and internalizing behaviors and (b) academic achievement in emerging adulthood. Understanding trajectories of EF from childhood to emerging adulthood and their effects on early-adult outcomes could aid both basic research on cognitive functioning throughout the lifespan and development of age-appropriate treatments.

EFs are broadly defined as self-regulatory cognitive processes—such as planning, inhibition, organization, set shifting, working memory, and problem solving—that help individuals attain future-oriented goals (Pennington & Ozonoff, 1996). Individuals typically experience significant growth in EFs throughout childhood and adolescence. This growth corresponds with maturational processes, such as normative neuronal pruning and increased myelination, which enhance connectivity in the frontal lobes—particularly in the prefrontal cortex (PFC) and its intricate web of interconnections with other regions (Jurado & Rosselli, 2007). Such maturational changes continue until the mid-20s, when EF performance normatively peaks as the final refinement of the frontal lobes occurs at that age span (De Luca et al., 2003).

ADHD and Areas of the Brain Implicated in Executive Functioning

Children with ADHD present with a number of structural and functional disparities in the frontal areas of the brain, providing empirical support for the association between executive functioning and ADHD. For example, they show reduced thickness, reduced volume, and atypical symmetry in the prefrontal cortex and other brain regions thought to have a role in EFs, such as the parietotemporal region, the basal ganglia, and the cerebellum (for reviews see Ahmad & Hinshaw, 2015; Gilliam et al., 2011; Krain & Castellanos, 2006; Shaw et al, 2006). These disparities correspond with the abnormal functional connectivity observed in children with ADHD during EF tasks of inhibition control and working memory (McCarthy, Skokaukas, & Fordl, 2014). Yet debate persists over whether these disparities represent a divergence from normal development or a maturational lag, whereby the brain development of individuals with ADHD eventually catches up to that of their peers (El-Sayed, Larsson, Persson, Santosh, & Rydelius, 2003). At least some individuals with ADHD experience a maturational lag, but such research has largely been focused on structural features and connectivity networks—and the "catch up' is not always complete (e.g., Shaw et al., 2007; Sripada, Kessler, & Angstadt, 2014). Overall, an ADHD-related divergence vs. lag regarding EF performance is still an open question.

ADHD and Associated Executive Functioning Deficits

Several meta-analyses, spanning numerous investigations, have found significant differences in EF performance between ADHD participants and controls. In particular, ADHD participants have displayed consistent weaknesses in tasks that index response inhibition, vigilance, working memory, and planning, even when adjusting for IQ, academic achievement, and symptoms of other disorders (Patros et al., 2015; Pennington & Ozonoff, 1996; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Not every individual with ADHD displays EF deficits, but most with ADHD experience some type of EF weakness (Willcutt et al., 2005).

Although improvements in EF performance (in terms of raw scores) appear in those with ADHD as they age, EF deficits often persist beyond childhood. For example, when compared to peers, children with ADHD consistently demonstrate poor EF performance in both childhood and adolescence (Biederman et al., 2007; Hinshaw, Carte, Fan, Jassy, & Owens, 2007; Seidman, Biederman, Monuteaux, Valera, Doyle, & Faraone, 2005). ADHD-related EF deficits in early adulthood have been found in in all-male sample (e.g., Biederman et al., 2006). Likewise, in a previous investigation of the Berkeley Girls with ADHD Longitudinal Study (BGALS) sample, which is also used in our current study, girls with ADHD displayed EF deficits beyond childhood and into the earliest years of adulthood (mean age 19.6; Miller, Ho, & Hinshaw, 2012). Yet research exploring EF deficits in ADHD even further into adulthood for women is limited. Such work is important because, as noted above, studies of normative populations have found that EF peaks into the mid-twenties (De Luca et al., 2003), yet no research on whether this peak is observed in women with a history of ADHD appears to exist.

It is also important to clarify whether the empirically observed trajectories of EF deficits into emerging adulthood found in mostly male samples are parallel in female samples, given that sex differences appear to exist in brain maturation. For example, frontal lobe volume tends to peak earlier in girls than in boys—and girls demonstrate different patterns of cerebral organization than boys (see Mahone & Wodka, 2008, for a review). In addition, sex differences in EF performance have been found in both normative samples and children with ADHD (Mahone & Wodka, 2008). In general, when directly compared to each other, girls and boys with ADHD demonstrate the same deficits on a wide variety of tasks indexing response inhibition, working memory, and planning (Seidman et al., 2005). However, girls with ADHD, compared to other age-matched girls, demonstrate greater impairment across multiple EF domains than in male ADHD vs. comparison contrasts (Mahone & Wodka, 2008). Greater impairment may be more evident in girls during childhood and adolescence because of sex differences in the timing of brain maturation noted above. And, there is a lack of research examining whether or not girls with ADHD continue to display greater EF impairment than their peers beyond late adolescence.

Another crucial issue regarding EF performance during this developmental period relates to the symptomatic persistence of ADHD. Although estimates vary depending on informants and methods used, about 40–50% of individuals with childhood ADHD continue to meet full criteria in early adulthood (Sibley, Mitchell, & Becker, 2016). In female samples, about 41–

44% of women diagnosed with childhood ADHD continue to meet full criteria in early adulthood (Babinski, et al., 2011; Guelzow, Loya, Hinshaw, 2017). A systemic review of 18 studies investigating EFs and ADHD persistence found that early EF performance and its development over time does not differ in those with persistent ADHD compared to those no longer meeting criteria in early adulthood (van Lieshout, Luman, Buitelaar, Rommelse, & Oosterlaan, 2013). However, differences were found in how these groups compared to controls—with persisters demonstrating more pronounced differences than desisters. Furthermore, the vast majority of studies reviewed (over 80%) featured males as participants, and the sole study with an all-female sample (i.e., Mick et al., 2011) explored only how EF performance assessed at one point (and not its development over time) predicted ADHD persistence.

Effort of Executive Functioning on Emergent Adult Outcomes

Individuals with ADHD are prone to a number of poor academic, occupational, and clinical outcomes in emerging adulthood (Barkley, 2015; Hinshaw & Scheffler, 2014). Indeed, in a previous investigation of the BGALS sample, women with persistent ADHD symptoms from childhood to adulthood (i.e., persisters) consistently demonstrated more externalizing, internalizing, and depressive symptoms and more academic impairment in early adulthood than their peers without a history of ADHD (Owens, Zalecki, Gillette, & Hinshaw, 2017). Those who had ADHD in childhood but who no longer met criteria in early adulthood (i.e., desisters) demonstrated fewer impairments. However, they still demonstrated more externalizing symptoms and academic impairment than their peers without a history of ADHD. In the current study, we expand on these findings by exploring a possible link between the trajectory of the young women's EF performance (from childhood to emerging adulthood) and such early adult impairments.

Research in both clinical and community samples supports the link between EFs and multiple domains of impairment, including poor academic achievement (Best, Miller, & Naglieri, 2011), depressive and anxiety symptoms (Han et al., 2016; Micco et al., 2009), and behavioral problems (e.g., aggression and substance use; Martel et al., 2007; Nigg et al., 2006). In general, it has been posited that EF deficits can hamper academic performance by affecting an individual's ability to (a) retain essential information in working memory; (b) ignore irrelevant, distracting information; (c) perform necessary mental operations; and (d) switch from inefficient strategies to efficient ones to increase the odds of succeeding (Best et al., 2011). EFs are also likely to support mental health by promoting emotional self-regulation and enabling individuals to problem solve, inhibit inappropriate impulses, and adapt appropriate coping strategies (Micco et al, 2009; Ogilvie, Stewart, Chan, & Shum, 2011).

Present Study and Hypotheses

Overall, we aim to expand previous research by examining whether girls with ADHD continue to demonstrate EF impairments by their mid-twenties—and investigating how these longitudinal changes may influence their behavioral, emotional, and academic functioning in emerging adulthood. We focus on three aspects of EF that have consistently distinguished

ADHD individuals from their peers: global EF, response inhibition, and working memory (e.g., Patros et al., 2015; Willcutt et.al, 2005). In particular, response inhibition (RI) helps suppress irrelevant (and potentially impairing) behavioral responses; working memory (WM) provides a cognitive workspace in which information can be temporarily stored and maintained; and global EF integrates working memory and response inhibition with other aspects of EF—such as planning, attention to detail, and organization—to accomplish goal-directed behavior (Nigg, 2017; Sami, Carte, Hinshaw, & Zupan, 2003).

We explore the trajectories of global EF, RI, and WM (specifically verbal working memory) from childhood (ages 6–12 years) to adolescence (12–17 years), the earliest years of adulthood (17–23 years), and emerging adulthood (23–29 years). Consistent with past research, we predict that young women with histories of ADHD will continue to demonstrate deficits in global EF, as well as RI and verbal WM, through emerging adulthood. Furthermore, based on past research (Miller, Loya, & Hinshaw, 2013), we predict that the ADHD sample will demonstrate higher rates of improvement than those without ADHD. Even so, their performance will remain lower than that of the comparison sample. We also examine the role of persistent vs. desistent ADHD in this regard, predicting that women with persistent ADHD will demonstrate impairment on more aspects of EF than desisters or comparison participants—and that desisters will demonstrate a more rapid improvement in EF than their counterparts with persistent ADHD. Finally, given clear links between (a) EF performance and (b) clinical and behavioral outcomes of individuals across the developmental spectrum, we predict that those young women with the least improvement in EF performance from childhood to emerging adulthood (i.e., those who have the shallowest linear slopes) will display more behavioral and academic impairments than those with greater improvements. In addition, because poor EF may accentuate the functional impairments already experienced by individuals with ADHD, we also expect the associations between young women's EF trajectories and emerging-adult outcomes to be stronger for those with ADHD than those without. Finally, we predict those with persistent ADHD will demonstrate the strongest associations between EF performance over time and behavioral and academic functioning by the end of emerging adulthood.

Method

Overview

Data were drawn from a longitudinal study of elementary-school-aged girls carefully diagnosed with or without ADHD. Initial data were collected during three summer enrichment programs that took place from 1997 to 1999. Each summer, a new cohort of girls with ADHD participated in a five-week program that offered a combination of classroom, art, drama, and playground activities, along with a comparison sample of girls without ADHD (who were matched in terms of age and ethnicity). Girls and their families underwent a thorough assessment battery pertaining to ADHD status as well as comorbidities, impairments, and functioning in academic, social, and cognitive domains. All evaluations at all waves were conducted during a period in which girls with prior medication histories were not receiving stimulant medication. Well-trained graduate students and bachelor's level research assistants administered the evaluations under the close supervision

of a licensed clinical psychologist. The assessors were unaware of the diagnostic status of the participants.

The families were invited to participate in 5-year, 10-year and 16-year follow-up studies after their initial participation. Participants completed a thorough evaluation, spanning two half-days at our lab/clinic (occasionally, telephone interviews or home visits were performed). Data were gathered from participants and from informants (particularly parents, even if the young adults were no longer living at home). Hinshaw, Owens, Sami, and Fargeon (2006) and Hinshaw et al. (2007) provides full information about the baseline data and follow-up evaluations.

Participants—The original sample consisted of 140 girls rigorously diagnosed with childhood ADHD (M age = 9.6) and 88 comparison girls (mean age = 9.4) at baseline (Wave 1). The sample was ethnically diverse (53% White, 27% African American, 11% Latina, and 9% Asian American). Exclusion criteria included an IQ lower than 70, overt neurological damage, psychosis, or pervasive developmental disorder, and medical conditions that permitted participation in the summer camp. Full data from the childhood phase of this investigation can be found in Hinshaw (2002). Of the original 228 families, 209 (92%) participated in the 5-year follow-up (Wave 2; mean age = 14.1); see Hinshaw et al. (2006) and Hinshaw et al. (2007) for neuropsychological data. Next, 216 (95%) participated in the 10-year follow-up study (designated as Wave 3: mean age = 19.6); see Miller et al. (2012) for information on neuropsychological performance. Finally, 211 (93%) participated in the 16-year follow-up (designated as Wave 4; mean age = 25.6; see Owens et al, 2017). Extensive tracking procedures were utilized to maintain high retention rates of the sample over this longitudinal interval.

Measures

Executive Functioning

EF measures were selected for (a) their prior validation and evidence for revealing brain-based correlates (at the time of measure selection, in the 1990s), and (b) past research evidence that they differentiated individuals with ADHD from those without. These measures were administered at all four waves.

Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944).—The ROCF was used to assess global EF. In this task, the individual is asked to copy and draw a complex figure composed of 64 segments. An error proportion score (EPS)—derived by dividing the number of errors by the total number of segments drawn—was used to index the participants' efficiency in drawing the figure. The EPS goes beyond merely assessing the presence or absence of figure elements, as it also appraises whether a participant misplaces, rotates, or perseverates on each element of the figure. Because it emphasizes the efficiency of drawn segments, the EPS taps various EF processes, including planning, response inhibition, attention, and organization (Sami, Carte, Hinshaw, and Zupan, 2003). Only the copy condition of the ROCF (i.e., immediate drawing, with the figure present) was used in the analyses, because (surprisingly) it was the only condition that differentiated ADHD from comparison status at baseline (see Sami et al., 2003). Indeed, the EPS has shown large

effects in terms of differentiating ADHD from comparison participants at earlier data waves. This task was administered at Wave 1, Wave 3, and Wave 4 (see below for the parallel measure administered at Wave 2); thus, it was considered to be time-varying in the growth curve modeling analyses. Higher scores (meaning more errors) indicate greater EF impairment. In terms of inter-scorer agreement, intraclass correlations between the pairs of the three primary scorers for the EPS at Wave 1 ranged from .91 to .94 (based on 84–195 drawings completed across rater pairs); the intraclass correlation at Wave 3 between the two primary scorers was .91 on a sample of 70 drawings; and at Wave 4, it was .94 between similar pairs for 79 drawings. This index has shown excellent psychometric properties in subsequent research (e.g., Hinshaw, 2002; Hinshaw et al., 2007; Miller et al., 2012)

Taylor Complex Figure Test (TCFT; Taylor, 1969).—The TCFT was administered at Wave 2 as a parallel test for the ROCF, to prevent possible practice effects. It measures the same constructs as the ROCF and is considered to be the only major alternative to the ROCF in test-retest situations (Helmes, 2000). We switched back to the ROCF for Waves 3 and 4. As with the ROCF, only the copy condition of the TCFT was used in the current analyses, and a parallel EPS indexed participants' efficiency in drawing the figure. The intraclass correlation between pairs of three scorers ranged from .77 to .94 (mean = .84) in a subsample of 60 drawings.

Conners' Continuous Performance Task (CPT; Conners, 1995).—The CPT was used to assess attentional processing and response inhibition. The task requires participants to press the spacebar when all target letters (except the letter "X") appear on the screen. Simultaneously, participants are instructed to refrain from pressing the spacebar when the "X" appears on the screen. The 14-minute task consists of trials presented in six blocks, during which the stimulus is presented for 250 ms (with interstimulus intervals of 1, 2, and 4 secs). Only the percentages of commission errors (indicative of response inhibition) were used in the analyses. There was not enough variance in the percentages of omission errors (indicative of sustained attention) to compute estimates (for example, at Wave 4, 40% of the participants made no errors and 75% of participants made fewer than 1% omission errors). Higher percentages of commission errors were indicative of poorer inhibitory executive functioning; this variable was utilized as a time-varying variable in the growth curve modeling analyses.

WISC-III Digit Span (Wechsler, 1991).—The Digit Span was used to assess verbal working memory. During this task, participants are asked to recall digit sequence of increasing length in original (Digits Forward) and reverse order (Digits Backwards). The raw scores of these tasks (i.e., Digits Forward and Backwards) were combined, so that lower scores indicated greater working memory impairment, and were utilized as a time varying variable. The WISC-III is a well-established, psychometrically sound measure, with the Digit Span subtest having an internal consistency of .85 and test-retest reliability of .75 (Wechsler, 1991).

Measures of Adult Outcome

Core measures emanating from various sources (parent- and self-report; objective testing) indexed the young women's emerging-adult behavioral and academic outcomes (Wave 4).

Self-reported externalizing and internalizing behaviors.—The sample self-reported on their externalizing and internalizing behaviors, using the Adult Self-Report (ASR), a frequently utilized 126-item measure that has well-established internal consistency, test-retest reliability, and validity (Achenbach & Rescorla, 2003). For adults, Cronbach's alphas for the broad-band internalizing and the externalizing scales = .93 and .89, respectively (one week test-retest reliabilities = .89 and .91). The ASR metric is a 3-point scale (0 = *not true*; 2 = *very true or often true*). We converted raw scores to T-scores using age and sex norms.

Parent-reported externalizing and internalizing behaviors.—Parent-reported externalizing and internalizing behaviors were measured using the Adult Behavior Checklist (ABCL). For a majority of cases (86.8%), the young woman's mother completed this measure. The ABCL is a 126-item measure that parallels the ASR and, likewise, has well-established internal consistency, test-retest reliability, and validity (Achenbach & Rescorla, 2003). The Cronbach's alphas for the broad-band internalizing and the externalizing scales = .92 and .93, respectively, for the behavior of the target adult as reported by the parent (one week test-retest reliabilities = .80 and .92). Parents rated items assessing their child's behavior using the same 3-point scale (0 = *not true*; 2 = *very true or often true*) as the ASR; raw scores were converted to T-scores using age and sex norms. In the present sample, the cross- informant correlation between the ASR and ABCL was .43 for the internalizing scale and .44 for the externalizing scale.

Self-reported depression.—The young women's self-reported depressive symptoms were measured via the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996). This measure comprises 21 items and is used to assess the presence of depressive symptoms including negative mood, interpersonal problems, and negative self-esteem. Participants rate the presence of each symptom during the past two weeks on a 4-point scale ("0" = absence of a symptom; "3" = presence of an extreme form of a symptom). The test-retest reliability and internal consistency of the CDI have been well-established: internal consistency = .92 in outpatient populations and .93 in college age students; test–retest reliability averages .93 (Beck et al., 1996).

Wechsler Individual Achievement Test, 2nd Edition (WIAT-II; Weschler 1992).—On this individually administered test, the Word Reading subtest measures sight-reading ability of known words and the Math Reasoning subtest indexes understanding of numbers, consumer math concepts, geometric measurement, and basic graphs in order to solve multi-step word problems. The WIAT-II is considered a psychometrically sound assessment of academic achievement, with both internal consistency and test-retest reliability estimates above .85 for most subtests (Wechsler, 1992). Standard scores (normed based on the participants' age and grade) from both the Word Reading subtest and Math Reasoning subtest were used as a measure of academic functioning at Wave 4, with higher scores indicating higher achievement.

Demographic Variables

The young women's diagnostic status at baseline (i.e., Wave 1) was determined by scores on the Swanson, Nolan, and Pelham Questionnaire (SNAP) and the National Institute of Mental Health Diagnostic Interview Schedule for Children Version IV (DISC-IV; see Hinshaw (2002) for details regarding the procedures]). This variable was dummy coded: those with childhood ADHD were coded as 1 and those in the comparison group were coded as 0. The young women's age in years was also collected at each assessment. Baseline family annual income and maternal education (as reported by the primary parent) were collected at baseline as well as the young women's ethnic background.

The young women's ADHD persistence vs. remission status was determined based on their diagnostic status at Wave 3 and Wave 4, which was established using the SNAP and DISC-IV (using a norm-based cutoff of either four inattentive or four hyperactive-impulsive symptoms). Women who met criteria for ADHD at baseline were classified into three groups: (1) women who no longer met criteria at both Wave 3 and 4 were considered desisters, (2) women who continued to meet criteria at both Wave 3 and 4 were considered persisters, and (3) women who no longer met criteria at either Wave 3 *or* 4 were considered partials (i.e., they partially desisted or partially persisted; see Owens et al. (2017) for more information on the remission status groups).

Statistical Analyses

All statistical analyses were performed using STATA version 14. The repeated, prospective design resulted in a two-level hierarchical structure, with each wave of data collection nested within participants. After examining descriptive statistics and correlations among the variables, we conducted t-tests and one-way ANOVAs to assess group differences with respect to the EF measures at all waves. Then, via hierarchical linear modeling, we calculated growth curves to model the average change of EF over time (i.e., the participants' ages at each assessment), each participant's change in EF, and predictors (i.e., baseline ADHD status) that may account for individual differences in change over time. All data available were utilized. Maximum likelihood estimation (MLE), considered a common and well-established estimation method (Garson, 2013), was used to derive the estimates of the growth curve models.

These analyses involved four steps: First, for an unconditional growth model, we investigated individual and group-level EF performance as a function of time (i.e., participant age) and without predictors. Both intercepts and slopes were allowed to vary, as individual variability was expected to be high. Second, given the expected nature of EFs (i.e., that EF performance, parallel to frontal cortical development, would generally improve throughout childhood and adolescence before peaking and plateauing in early adulthood), we considered a non-linear trajectory of EF and investigated adding polynomial terms to the model. Third, we added predictors (i.e., ADHD baseline diagnostic status) of variance in the growth curve slope and intercept of each EF measure. Finally, we examined cross-level interaction terms between participants' age and childhood diagnostic status to investigate possible differences in EF trajectories between those with childhood ADHD and those without. We repeated these analyses for each measure of EF: ROCF (global measure of EF),

CPT commission errors (indicative of RI), and Digit Span (Verbal WM). We then repeated all analyses to examine ADHD persistence/remission status as a predictor of the variance in the slope and intercept of each EF measure. We also investigated possible differences in EF trajectories among persisters, desisters, partials, and comparison women without childhood ADHD by adding cross-level interaction terms between the participants' age and their ADHD remission status for each EF measure.

Finally, to test effects of EF performance over time on behavioral, emotional, and academic impairments during emerging adulthood, sample-level estimates from the final growth curve models were used to estimate an individual slope and intercept for each woman's EF trajectory. Hierarchical multiple regression was then used to explore the relation between a young woman's slope and her emerging adult behavioral and academic impairment measures (i.e., the steepness of a slope was examined as a predictor of emerging adult impairment). At Step 1, we entered childhood diagnostic status (ADHD vs. comparison, dummy coded), plus maternal education and family income as covariates. The individual-level slopes from the previous growth curve model were entered as predictors at Step 2. At Step 3, we entered two-way interactions between these slopes and childhood ADHD status, to examine possible diagnostic group differences in the association between EF trajectories and emerging-adult impairments. We repeated these analyses for each of the emerging-adult impairment measures (self-reported externalizing, parent-reported externalizing, self-reported internalizing, parent-reported internalizing, self-reported depression, and objective Reading/Math scores), yielding seven hierarchical regression models. A second set of hierarchical multiple regressions was performed with the women's ADHD persistence/remission status (instead of childhood diagnostic status) entered at Step 1. We utilized the Benjamini-Hochberg (BH) procedure after each set of hierarchical multiple regressions for each emerging adult outcome variable to protect against Type I error by controlling for a false discovery rate (What Works Clearinghouse, 2008).

Results

Descriptive Statistics

Table 1 presents scores for the ADHD and comparison samples regarding demographic variables. The groups were statistically indistinguishable with respect to age, family income, and maternal education. However, a chi-square test did reveal a significant difference in the ethnic composition of the groups, χ^2 (4, N = 201) = 9.298, p <.05, with a higher percentage of Asian American girls in the comparison group. With the exception of self-reported internalizing problems, the young women with ADHD demonstrated poorer behavioral, emotional, and academic achievement outcomes than the comparison sample on all measures. See Table S1 in the supplementary materials for intercorrelations between the EF measures from each wave and Tables S2 and S3 for group comparisons of executive function across all four waves. In general, young women with childhood ADHD, when compared to their typically developing peers, had worse scores on all EF measures across all waves with the exception of Wave 1 CPT commission scores (RI). Persisters had far worse scores than comparison women on all EF measures across all waves with the exception of Wave 1 CPT commission scores. Desisters demonstrated the same pattern of worse EF scores, yet with

the additional exception of Wave 2 CPT commission scores. Partial remitters had worse scores than comparison women only on DS raw scores at Waves 2, 3, and 4. Persisters, desisters, and partial remitters did not differ significantly from one another on any measure at any wave.

Growth Curve Modeling

See Table S4 in the supplementary materials for details regarding the estimates for the hierarchical linear models exploring the developmental change in each EF measure based on childhood ADHD status. See Table 2 for details regarding the estimates for the hierarchical linear models exploring the developmental change in each EF measure based on the young's women's adult ADHD status.

Developmental Trajectory of ROCF/TCFT.

In the unconditional growth model, the estimated slope for the growth curve across all participants indicated that the EPS decreased over time, from childhood to emerging adulthood, (B = −.01, $p < .001$). Given the pattern based on observed means of the error proportion scores for the ROCF/TCFT across the four waves (see Figure S1a), the appropriateness of a quadratic model was considered. In Model 2, with the quadratic term added, both the linear slope (B = −.05, $p < .001$) and quadratic term (B = .001, $p < .001$) remained significant, suggesting that the young women's EPS decreased over time, with rapid improvements occurring in early childhood and adolescence before plateauing (and even slightly reversing) in early/emerging adulthood. A significant likelihood-ratio test (comparing Model 2 vs. Model 1) provided strong evidence that the quadratic term should be retained: $\Delta\chi^2(1)=127.70$, $p < .001$. In Model 3, Wave 1 diagnostic status was entered as a predictor of the variance around the slope and intercept. The participants with childhood ADHD had error scores that were on average .08 greater (i.e., worse) than those of the young women without childhood ADHD. A significant likelihood-ratio test provided strong evidence that this predictor should be retained: $\Delta\chi^2(1)=40.41$, $p < .001$. In the final model (Model 4; see Table S4), a significant two-way interaction between diagnostic status and time was found (B = −.003, $p < .05$); a significant likelihood-ratio test indicated that the interaction term should be retained: $\Delta\chi^2(1)=4.44$, $p < .05$. Post-hoc analyses suggested that young women with ADHD had steeper decreases in errors (B = −.06, $p < .001$) than did typically developing counterparts (B = −.03, $p < .001$), even though both groups experienced declines over time (see Figure 1).

When these analyses were repeated using ADHD persistence/remission status as a predictor of variance around the slope and intercept (see Table 2), women with childhood ADHD, regardless of their changes in diagnostic status, had larger error proportion scores than comparison women: persisters (B = .10, $p < .001$), desisters (B = .09, $p < .001$), and partial remitters (B = .05, $p < .01$). Partials, on average, had lower (i.e., better) scores than desisters (B = −.04, $p < .05$) and persisters (B = −.05, $p < .01$). No significant differences were found between persisters and desisters (B= −.001, *n.s.*). When interaction terms between persistence/remission status and time were added to the model, a significant two-way interaction was found, suggesting that persisters had a different trajectory than comparisons (B = −.004, $p < .05$). However, no other two-way interactions were significant; a likelihood-

ratio test indicated that the interaction model was marginally significant (vs. the previous model with predictors only: $\Delta\chi^2(3)=6.73$, $p = .08$.

Developmental Trajectory of CPT.

In the unconditional growth model, the estimated slope for the growth curve across all participants indicated that commission error scores decreased over time, from childhood to emerging adulthood, (B = −1.21, $p < .001$). Given the pattern of observed means (see Figure S1b), a quadratic term was considered. In Model 2, with the quadratic term added, both the linear slope (B = −5.48, $p < .001$), and quadratic term (B = .12, $p < .001$) were significant. In conjunction with a plot of the means, this pattern suggests that young women's commission errors followed a similar trajectory as the ROFT/TCFT error proportion scores: decreasing over time, with rapid improvements occurring in early childhood and adolescence before plateauing and even reversing in early/emerging adulthood. A significant likelihood-ratio test comparing this model against the previous provided strong evidence that the quadratic term should be retained: $\Delta\chi^2(1)=46.65$, $p < .001$. When childhood diagnostic status was entered as a predictor in Model 3, results indicated that the young women with childhood ADHD had a commission error proportion that was on average 8.49 points greater (i.e., worse) than those young women without childhood ADHD. A significant likelihood-ratio test provided strong evidence that this predictor should be retained: $\Delta\chi^2(1)=16.42$, $p < .001$. In Model 4, a significant two-way interaction between diagnostic status and time was not found (B = .31, *n.s.*), with a significance likelihood-ratio test indicating that the interaction term should not be retained: $\Delta\chi^2(1)=2.35$, *n.s.* See Table S4 for details regarding the final growth curve model.

When these analyses were repeated using ADHD persistence/remission status as a predictor, results indicated that all women with childhood ADHD (see Table 2), regardless of remission status, had more commission errors than women without childhood ADHD on average: persisters (B = 11.41, $p < .001$), desisters (B = 9.24, $p < .01$), and partial remitters (B = 6.68, $p < .05$). No significant differences were found when persisters, desisters, and partial remitters were compared to one another. When interaction terms between persistence/remission status and time were added to the model, no significant two-way interactions were found.

Developmental Trajectory of Digit Span.

In the unconditional growth model, the estimated slope for the growth curve across all participants indicated that digit span scores increased (i.e., improved) over time, from childhood to emerging adulthood (B = .24, $p < .001$). Given the pattern of the observed means (see Figure S1c), a quadratic term was considered. In Model 2, with the quadratic term added, both the linear slope (B = 1.01, $p < .001$), and quadratic term (B = −.02, $p < .001$) were significant. In conjunction with a plot of the means, we found a parallel trend to those for ROCF/TCFT and CPT commission errors, with rapid improvements occurring in early childhood and adolescence before plateauing in early/emerging adulthood. A subsequent likelihood-ratio test provided strong evidence that the quadratic term should be retained: $\Delta\chi^2(1)=104.78$, $p < .001$. With the addition of childhood diagnostic status as a predictor in Model 3, digit span scores for young women with childhood ADHD were

significantly lower (i.e., 2.26 points worse) than young women without childhood ADHD. A significant likelihood-ratio test provided strong evidence that this predictor should be retained: $\Delta\chi^2(1)=38.97$, $p < .001$. In Model 4, a significant two-way interaction was not found between diagnostic status and time (B = −.009, *n.s.*), with a significant likelihood-ratio test indicating that the interaction term should not be retained: $\Delta\chi^2(1)=.11$, *n.s.* See Table S4 for details regarding the final growth curve model.

When these analyses were repeated using ADHD persistence/remission status as a predictor, results indicated that all women with childhood ADHD (see Table 2), regardless of such status, had lower digit span scores than women without childhood ADHD on average: persisters (B = −2.37, $p < .001$), desisters (B = −2.79 $p < .001$), and partial remitters (B = -2.23, $p < .001$). No significant differences were found when persisters, desisters, and partial remitters were compared to one another. When interaction terms between remission status and time were added to the model, no significant two-way interactions were found.

Emerging Adult Outcomes Predicted by EF Trajectories and Childhood ADHD

See Table S5 in supplementary material for details regarding the regression models.

Trajectory of ROCF/TCFT Error.

The trajectory (i.e., slope) of ROCF/TCFT performance was not predictive of any emerging-adult outcomes. Likewise, no two-way interactions between the trajectory and diagnostic status were found.

Trajectory of CPT Error.

Similarly, the trajectory of CPT performance was not predictive of any of the emerging adult outcomes, and no two-way interactions between the trajectory and diagnostic status were found.

Trajectory of Digit Span Raw Score.

The trajectory of digit span performance was predictive of self-reported externalizing symptoms ($\beta = .17$, $p < .05$), explaining a significant proportion of the variance in these symptoms, $R^2 = .11$, $F(4, 200) = 6.20$, $p < .001$. Specifically, and surprisingly, steeper increases in digit span performance were associated with *higher* levels of externalizing symptoms. This relation continued to be significant after the BH correction. The trajectory of digit span performance was not predictive of any other emerging adult outcomes. No two-way interactions between the trajectory and diagnostic groups were found.

Emerging Adult Outcomes Predicted by EF Trajectories and ADHD Persistence/Remission

See Tables S6 and S7 in supplementary material for details regarding the regression models.

Trajectory of ROCF/TCFT Error.

The trajectory of ROCF/TCFT error was not predictive of any of the emerging-adult outcomes. However, after the BH correction, differences in the association between externalizing and ROCF/TCFT error over time were found for persisters when compared to

both comparisons ($\beta = -.20$, $p < .05$) and desisters ($\beta = -.28$, $p < .05$). Further analysis revealed that this association was significant for persisters ($\beta = -.36$, $p < .05$) but not desisters ($\beta = .15$, *n.s.)*. As demonstrated in Figure 2, persisters with the smallest improvements in ROCF/TCFT error (or worsening errors in some cases) unexpectedly reported fewer externalizing symptoms at Wave 4.

Trajectory of CPT.

The trajectory of CPT performance was not predictive of any of the emerging adult outcomes, and no two-way interactions were found.

Trajectory of Digit Span.

The trajectory of digit span performance continued to predict self-reported externalizing symptoms ($\beta = .17$, $p < .05$), adjusting for remission status, explaining a significant proportion of the variance in these symptoms, $R^2 = .21$, $F(6, 195) = 8.56$ $p < .001$. That is, steeper increases in digit span performance were associated with *higher* levels of externalizing symptoms. This relation continued to be significant after the BH correction.

Discussion

Developmental Trajectory of EFs in Women with ADHD

As predicted, compared to their typically developing counterparts, girls diagnosed with ADHD in childhood continued to exhibit poor performance on all aspects of EF measured—global executive functioning, inhibitory control, and verbal working memory—through the developmental period of emerging adulthood. This core finding is consistent with previous research in younger and predominately male samples, which has revealed that individuals with ADHD consistently experience more EF deficits than their peers without ADHD (e.g., Willcutt et al., 2005). Furthermore, the overall trajectories for all three aspects of EF followed a quadratic trend, with rapid improvements observed from childhood to adolescence before plateauing (and in some cases slightly reversing) during emerging adulthood. This pattern is also congruent with past research revealing EF plateaus and slight declines in cognitive performance (specifically on tasks requiring processing efficiency and the manipulation or transformation of information) in normative samples of young adults—perhaps related to continual changes in brain structure and connectivity during this period (De Luca et al., 2003; Salthouse, 2013). Crucially, however, although both the ADHD group and comparison groups exhibited improvements in all three aspects of EF beyond childhood, the young women with ADHD consistently lagged behind their counterparts. Because those with ADHD did not catch up to their peers on any aspect of EF tasks at any point of the developmental trajectories observed—and appeared to plateau at the same time as their counterparts—the current findings do not support the idea that individuals with ADHD are experiencing merely a maturational lag (i.e., eventually catching up with their peers with regard to EF). Instead, the deficits were long-lived.

A diagnostic group difference emerged for global EF over time, as measured by the ROCF/TCFT. The young women with ADHD demonstrated steeper improvements than their typically developing peers on this measure of global executive functioning. A plot of this

trajectory (Figure 1) reveals that, from childhood to late adolescence, the young women with childhood ADHD experienced steeper improvements in global EF than their peers before rapidly leveling off, whereas their peers experienced a more gradual increase in global EF performance. Thus, young women with childhood ADHD appear to experience early rapid changes in global EF that bring them closer to (but not at the same level as) their peers' EF performance. Mechanisms underlying such rapid improvements mandate study.

When examining the persistence of the women's ADHD symptoms into emerging adulthood, we noted some interesting findings. Compared to typically developing peers, women with both persistent ADHD and remitted ADHD demonstrated poorer performance on all three aspects of EF at nearly every time point assessed. Furthermore, contrary to our hypotheses, desisters demonstrated the same level of EF impairments as persisters, when compared with the comparison group at each time point. When persisters and desisters were directly compared to each other, there were no significant differences in their absolute EF performance at any time point—and their EF trajectories were not significantly different. Still, this finding is largely consistent with research involving male samples (e.g. van Lieshout et al., 2013), suggesting that adults with ADHD demonstrate continued EF impairments even if their ADHD symptoms remit.

On the other hand, when the rate of EF development in both groups was compared to that of comparison women, persisters (but not desisters) demonstrated steeper improvements in global EF than comparisons. Interestingly, young women whose symptoms had partially remitted (i.e., they did not meet full criteria for ADHD in either late adolescence or emerging adulthood) demonstrated an unexpected pattern of EF performance, particularly regarding verbal working memory. Specifically, they demonstrated better global EF performance than either desisters or persisters across the same period. Overall—and unexpectedly—partial remitters demonstrated the least impairment among the women with childhood ADHD.

As noted in the Introduction, not every individual with ADHD demonstrates EF impairment, leading a number of theorists to propose multiple causal pathways related to ADHD. For example, both cognitive deficits (accompanying EF impairments) and deficits in the motivational/reward circuit have been implicated as separate mechanisms in ADHD (Sonuga-Barke, 2010). Thus, it is possible that deficits in the motivational/reward circuit may play a more central role in the symptoms of partial remitters than do deficits in EF impairments.

Effects of EF Trajectory on the Women's Emerging-Adult Outcomes.

As in previous studies (e.g., Biederman et al., 2006; Biederman et al., 2012), we found that ADHD status was predictive of emerging-adult behavioral and academic outcomes. However, of the three EF trajectories tested, the trajectory for WM was the only one predictive of behavioral functioning in emerging adulthood. Furthermore, the pattern of results was unexpected, in that steeper improvements in WM were associated with *more* self-reported externalizing symptoms, regardless of ADHD status. Likewise, the trajectory of WM was predictive of behavioral functioning in emerging adulthood even when adjusting for persistence/remission status. An interaction revealed that persisters with the least

improvements in ROCF/TCFT error paradoxically reported the fewest externalizing symptoms by the end of emerging adulthood. These findings are in direct contrast to past research repeatedly linking EF deficits with a higher risk of externalizing in individuals with ADHD (e.g., Martel, Nikolas, & Nigg, 2007). For one thing, it could be that, in the present sample, women were underreporting their externalizing behavior, with slow development of EF adversely affecting awareness of their own behavior. This interpretation would be consistent with past research indicating that individuals with ADHD are poor reporters of their own behavior (e.g. Sibley et al., 2016), suggesting strongly that multiple informants are crucial for diagnosing and understanding externalizing behavior, especially in young women with persistent ADHD.

Overall, contrary to our hypotheses, we did not find substantial evidence suggesting that the development of a young woman's WM, RI, or global EF was indicative of later behavioral or academic outcomes. These findings contradict previous research demonstrating longitudinal links between EFs and both academic and clinical outcomes (e.g. Best et al., 2011; Han et al., 2016). However, past studies have focused on EF at a fixed point in time (i.e., a single time point in early childhood). Indeed, in past research investigating the very sample used in our analysis, links between EF performance and concurrent academic, behavioral, and clinical outcomes were found (e.g., Miller, Nevado-Montenegro, & Hinshaw, 2012) It appears that concurrent EF performance is more predictive of young women's functional outcomes than the development of EF performance over time. Moreover, the apparently paradoxical findings along these lines may be linked to the fact that those participants with the worst initial EF scores showed—partly reflecting regression artifacts—the largest improvements; but it was their initially poor EF skills that actually predicted such higher adult externalizing scores. Finally, there may be links between EF development and other measures of behavioral and academic outcomes (e.g. substance use, self-injurious behavior, GPA, college attendance, and degree completion)—which should be investigated further.

Several limitations should be taken into consideration when interpreting these results. First, because research examining EF in young women with ADHD has been quite limited, we focused on females with ADHD. Given the lack of a male sample, we could not directly investigate sex differences. To date, there is a dearth of studies examining sex differences in the trajectory of EF. Because a number of known sex differences in brain development, structure, and function exist (Mahone &Wodka, 2008), future studies should examine these differences directly. Furthermore, we did not examine the influence of ADHD diagnostic types (now termed "presentations") on EFs (i.e., predominately inattentive, hyperactive-impulsive, or combined). It may be the case that the observed EF trajectories may be different for those with one presentation versus another (or, dimensionally, regarding one symptom dimension vs. the other). Still, past research with the current sample has revealed almost no significant presentation-related differences for any neuropsychological variable (see Hinshaw, 2002 and Hinshaw et al, 2007). We note, as well, that this investigation was limited to global EF, RI, and verbal WM. In addition, we examined academic achievement using only the word reading and math reasoning subtests of the Wechsler Individual Achievement Test. Thus, future studies should aim to explore other aspects of EF (e.g., planning, set shifting, and spatial working memory) and academic achievement (e.g.,

reading comprehension, math fluency, etc.). Finally, it is possible that we did not observe significant links between the EFs trajectories and the young women's adult outcomes because of low power. Future studies should aim to replicate this study in a larger sample size. Overall, despite these limitations, this study features several key strengths—in particular, multi-wave data, a low participant attrition rate, and an ethnically diverse sample—which contribute to the overall validity and generalizability of the findings.

Conclusions and Implications

The current findings contribute to our understanding of how executive functioning develops over time, from childhood to emerging adulthood, for females with ADHD. Despite overall EF improvements over time, young women diagnosed with childhood ADHD consistently experienced EF deficits from childhood through emerging adulthood even if their symptoms remitted. Thus, the development of early interventions targeting EF deficits more broadly should be considered, in order to help lessen the pervasive EF performance gap observed between ADHD and comparison samples. It is also quite possible that interventions should be directed more specifically to impairments in young adults with ADHD than to underlying EF deficits per se. Given the lack of association found between a young women's EF development over time and her behavioral outcomes and academic achievement, a young women's EF performance at a given point in time may be more salient than the trajectory of her EF performance, which may, as noted above, reflect regression artifacts. Future research should aim to understand further individual differences in processes and mechanisms linked to EF impairment—and to functional impairments more generally.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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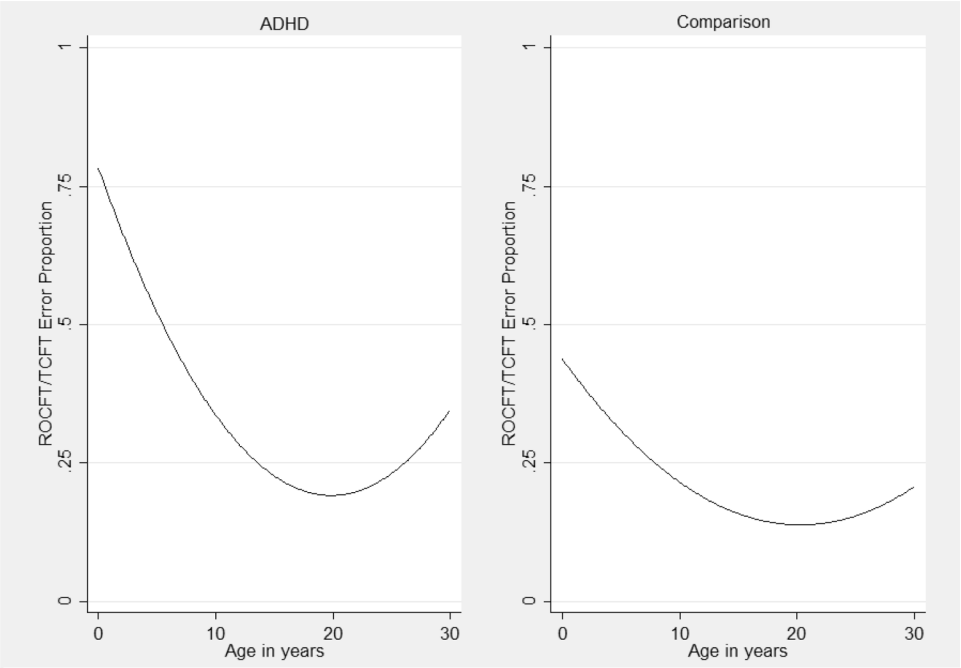

Fig. 1.

Predicted Trajectory of ROCF/TCFT error proportion scores across age for ADHD and Comparison Women

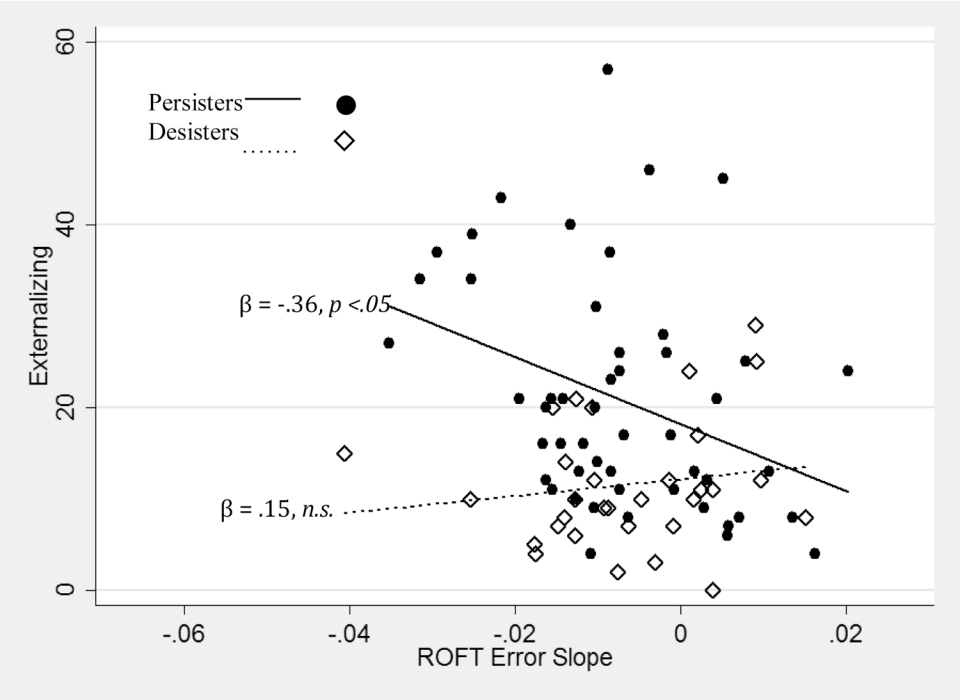

Fig. 2.

Regression of Externalizing on the Trajectory of ROCF/TCFT Error Proportion Scores for Women with Persistent ADHD Symptoms and Women No Longer Meeting Criteria for ADHD

Table 1

Demographic Variables and Emerging Adult Outcomes

	ADHD[a]		Comparison[b]		T-test	Cohen's d
	M	*SD*	*M*	*SD*	*t (df)*	
Demographic Variables						
Age (in years)						
Wave 1	9.64	.14	9.43	.18	−0.89 (226)	−.11
Wave 2	14.26	.15	13.84	.18	−1.79 (207)	−.25
Wave 3	19.62	.15	19.45	.19	−0.74 (215)	−.10
Wave 4	25.64	.16	25.42	.20	−0.85 (209)	−.11
Ethnicity (%)						
European American	60.8		46.9			
African American	22.5		27.2			
Hispanic American	11.7		11.1			
Asian American[c]	4.2		14.8			
Total Annual Family Income (%)	6.47	2.59	6.81	2.37	−.94 (197)	−.14
<$10,000	2.5		5.8			
$10,001 to $20,000	3.7		2.5			
$20,001 to $30,000	6.2		7.6			
$30,001 to $40,000	7.4		6.8			
$40,001 to $50,000	7.4		14.4			
$50,001 to $60,000	12.3		7.6			
$60,001 to $70,000	12.3		11			
$70,001 to $75,000	7.4		6.8			
>$75,000	40.7		36.4			
Maternal Education[e]	4.76	.88	4.98	.95	−1.66 (199)	−.24
Less than 8th grade (%)	0.0		0.0			
Some high school	1.2		0.0			
High school graduate	2.5		4.2			
Some College	30.9		40.8			
College graduate	28.4		30.0			
Advanced or prof. degree	37.0		25.0			
Emerging Adult Outcomes						
Mother-reported Internalizing	58.40	13.13	45.67	10.78	−7.08 (187)**	−1.06
Self-reported Internalizing	21.23	12.84	17.99	13.46	−1.75 (205)	−.24
Mother-reported Externalizing	58.81	10.07	46.20	7.94	−3.24 (187)**	−1.39
Self-reported Externalizing	16.23	10.53	11.61	9.42	−9.28 (205)**	−.46
Self-Reported Depression	9.51	.75	6.33	.87	−5.47 (206)*	−0.76
WIAT Reading Comp	92.90	15.12	105.32	8.37	6.88 (205)**	1.02
WIAT Math Fluency	85.20	17.25	101.93	15.75	7.09 (203)**	1.01

[a] For Wave 1, n=140. For Wave 2, n=127. For Wave 3, n = 131. For Wave 4, n= 126

[b] For Wave 1, n=88. For Wave 2, n=82. For Wave 3, n = 86. For Wave 4, n= 85

[c] The comparison group had a higher % of Asian American girls: $\chi^2(4) = 9.298$, $p < .05$

* $p < .05$.

** $p < .01$.

*** $p < .001$

Table 2

Final Growth Curve Models of EF Performance by Participants' Emerging Adult ADHD Status

	ROCF/TCFT		CPT Commission		Digit Span	
	Est	**(SE)**	**Est**	**(SE)**	**Est**	**(SE)**
Fixed Part						
Age	−.05	(.004)***	−5.79	(.62)***	1.04	(.08)***
Age^2	.001	(.0001)***	.13	(.02)***	−.02	(.002)***
Control v. Desist	.15	(.04)***	9.24	(3.08)**	−2.79	(.54)***
Control v. Partial	.10	(.04)*	6.68	(2.87)**	−2.29	(.52)***
Control v. Persist	.18	(.04)***	11.41	(2.59)*	−2.37	(.46)***
Desist v. Partial	−.05	(.05)	−2.57	(3.56)	.56	(.64)
Desist v. Persist	.04	(.05)	2.17	(3.34)	.43	(.59)
Persist v. Partial	−.09	(.04)	−4.73	(3.14)	.14	(.57)
Age X Control v. Desist	−.003	(.002)				
Age X Control v. Partial	−.002	(.002)				
Age X Control v. Persist	−.004	(.002)*				
Age X Desist v. Partial	.0005	(.002)				
Age X Desist v. Persist	−.001	(.002)				
Age X Persist v. Partial	.0004	(.002)				
Random Part						
Between level						
$\sqrt{\psi 11}$	.16	.01	14.21	3.17	1.74	.43
$\sqrt{\psi 22}$ (Age)	.006	.0008	.49	.26	.07	.03
ρ_{12}	−.91	.02	−.55	.26	.38	.67
Within level						
$\sqrt{\theta}$	.09	.003	15.46	.62	1.98	.07
Log likelihood	112.09		102.46		339.48	

* p < .05.

** p < .01.

*** p<.001.