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Executive Cognitive Functions and Behavioral Control differentially predict HbA1c in Type 1 Diabetes across emerging adulthood

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Abstract

Objectives: To examine contributions of two aspects of executive functioning (executive cognitive functions and behavioral control) to changes in diabetes management across emerging adulthood.

Methods: 247 high school seniors with type 1 diabetes were assessed at baseline and followed for three years. The baseline assessment battery included performance-based measures of executive cognitive functions, behavioral control, IQ estimate (IQ-est), and psychomotor speed; self-report of adherence to diabetes regimen; and glycated hemoglobin (HbA1c) assay kits as a reflection of glycemic control.

Results: Linear and quadratic growth curve models were used to simultaneously examine baseline performance on four cognitive variables (executive cognitive functions, behavioral control, IQ, and psychomotor speed) as predictors of indices of diabetes management (HbA1c and adherence) across four time points. Additionally, general linear regressions examined relative contributions of each cognitive variable at individual timepoints. Results showed that higher behavioral control at baseline was related to lower (better) HbA1c levels across all four time points. In contrast, executive cognitive functions at baseline were related to HbA1c trajectories, accounting for increasingly more HbA1c variance over time with increasing transition to

independence. IQ-est was not related to HbA1c levels or changes over time, but accounted instead for HbA1c variance at baseline (while teens were still living at home), above and beyond all other variables. Cognition was unrelated to adherence.

Conclusions: Different aspects of cognition play a different role in diabetes management at different time points during emerging adulthood years.

Keywords

Executive functioning; cognition; intelligence; chronic illness; adolescence; adherence

Type 1 Diabetes (T1D) is a chronic illness in which the pancreas stops producing insulin (American Diabetes Association, 2019). Management of T1D is complex and requires multiple daily adherence behaviors to keep blood glucose levels close to the normal range (e.g., checking blood glucose, counting carbohydrates, calculating and administering insulin, maintaining healthy diet and exercise; Hood, Peterson, Rohan, & Drotar, 2009). The degree to which blood glucose range is maintained across a period of approximately three months is reflected in glycolated hemoglobin (HbA1c), with lower numbers reflecting more optimal control. In childhood and adolescence, better adherence and lower HbA1c are associated with greater parental involvement (Berg et al., 2017). However, as adolescents transition into emerging adulthood, parental involvement declines with concomitant increases in HbA1c (King, Berg, Butner, Butler, & Wiebe, 2014; Majumder, Cogen, & Monaghan, 2017), making this time period an important focus of research.

Because the T1D regimen is quite complex, it is not surprising that cognitive capacity, most notably executive functioning (EF), plays a role in adherence to T1D regimen and in maintenance of lower HbA1c (Berg et al., 2018; Duke & Harris, 2014; Goethals et al., 2018; McNally, Rohan, Pendley, Delamater, & Drotar, 2010; Suchy et al., 2017, 2016). EF is a complex construct, thought to be comprised of several subdomains (Lezak, Howieson, Bigler, & Tranel, 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Stuss, 2011; Suchy, 2015), although no single model of EF has been universally adopted (Suchy, 2009, 2015) and none have been consistently replicated in factor-analytic studies (Karr et al., 2018). Nevertheless, it is generally accepted that EF is comprised of (a) *cognitive* control processes (sometimes referred to as "executive cognitive functions"), which are responsible for higher-order abilities such as planning, reasoning, and problem-solving (Köstering, Leonhart, Stahl, Weiller, & Kaller, 2016; Swanson & Fung, 2016; Van Hoeck, Watson, & Barbey, 2015); and (b) *behavioral* control processes (closely related to the concept of "self- or behavioral regulation"), responsible for impulse control, initiation and maintenance of adaptive actions over time, and selection of adaptive actions under competing emotionally-salient contingencies (Panwar et al., 2014; Steinberg, 2005; Suchy, 2015). Such a dissociation between processes responsible for cognitive versus behavioral control has also been evidenced in research on T1D management. Specifically, Miller et al. (2013) reported that behavioral regulation (measured via the self-report measure BRIEF; Guy, Isquith, & Gioia, 2004) increased across early adolescence along with increases in adherence to T1D regimen, whereas no such associations were seen for self-reported cognitive control at that age.

One possible explanation for the lack of an association between T1D management and cognitive control during adolescence may be that parents provide ample scaffolding for prospective planning and problem-solving toward higher adherence. Given that cognitive control is related to intelligence (Friedman et al., 2006), and intelligence is partly heritable (Plomin & Deary, 2015), there may be a considerable overlap between parents' and teens' executive cognitive functions, which renders the teens' cognitive control somewhat superfluous for managing T1D. However, parents have limited control over how well their teens follow through *behaviorally*, especially when away from home during the day. This relative lack of parental control makes the teens' own behavioral control a key aspect of T1D management. Once teens transition to adulthood and receive less scaffolding from their parents, their T1D management may become increasingly dependent not only on their behavioral control, but on their cognitive control as well. Consistent with this notion, we have previously found that teens' IQ (which relates to cognitive control; Friedman et al., 2006) was more important than EF performance (comprised of a combination of cognitive and behavioral control measures) in predicting HbA1c among high school seniors living at home with their parents (Suchy et al., 2016). In contrast, after teens graduated from high school and became more independent, changes in their HbA1c values were predicted by EF performance beyond IQ. Specifically, we found that (a) the teens' ability to make adaptive *behavioral* choices predicted, beyond IQ, changes in HbA1c from baseline to one-year follow-up (Suchy et al., 2017), and (b) the teen's performance on an EF composite comprised of both *cognitive* and *behavioral* components predicted, beyond IQ, changes in HbA1c (though, surprisingly, *not* changes in self-reported adherence) two years later (Berg et al., 2018).

Taken together, findings suggest (a) differential associations of cognitive versus behavioral control with T1D management, and (b) changes in the nature of these associations over time. In other words, different aspects of EF might relate to HbA1c and adherence at different time points during emerging adulthood (i.e., ages 18–25 years). However, this question has not been tested directly. Specifically, cognitive versus behavioral components of EF performance have not been pitted against each other in a single analysis, nor has their influence been examined simultaneously across multiple time points.

The purpose of this study was to test the notion that different aspects of EF contribute to HbA1c and to T1D regimen adherence differentially at different time points of transition from adolescence to emerging adulthood. To that end, we simultaneously examined two aspects of EF (executive cognitive functions versus behavioral control, assessed during the senior year of high school) as predictors of current and future HbA1c and adherence, measured at four yearly time points. Furthermore, because prior research has suggested that HbA1c increases up to the age of 19 and then begins to decline (Miller et. al, 2015), we examined EF as a predictor of both linear and curvilinear HbA1c and adherence trajectories from baseline to 3-year follow-up. Lastly, to better isolate discrete aspects of the EF construct, we examined if EF processes predicted HbA1c and adherence beyond IQ and lower-order processes that are not executive but are necessary for performance of EF tests (e.g., processing speed, visual scanning, etc.). We hypothesized that behavioral control would be necessary for HbA1c and adherence at all four time points, whereas cognitive

control would become increasingly important, as over time young adults tend to manage their illness more independently from their parents.

Method

Participants.

High-school seniors with T1D were recruited from outpatient pediatric endocrinology clinics in two southwestern U.S. cities for a longitudinal multi-site study investigating the transition from adolescence into emerging adulthood. Youth were eligible if they carried T1D diagnosis for at least one year (*M* time since diagnosis = 7.35 years, *SD* =3.88; 94% having diabetes 2 years or more), had English as their primary language, were in their final year of high school, lived with a parent or parent figure at baseline (68.4% lived at home with both, 27.1% with one biological parent; 4.5% with adoptive parents or grandparents), would have regular contact with parents over the subsequent two years, and had no condition that would prohibit study completion (e.g., severe intellectual disability, blindness). Adolescents who dropped out of high school were eligible if they met all other criteria. Of the qualifying 507 individuals approached, 301 (59%) agreed to participate. Of those who initially agreed, 247 (82%) enrolled in the study. Reasons for not participating included lack of interest (33%) or being too busy (34%); 20% declined to provide a reason. At one site, the Institutional Review Board (IRB) permitted comparison of those who did versus did not participate. Participants did not differ from nonparticipants in HbA1c values, disease duration, gender, or usage of insulin pump (*ps* > .05). However, participants were slightly younger (*M* (*SD*) = 17.77 (.43) vs. 17.91 (.48) years, t(203) = 2.27, *p* = .02) and more likely to be Hispanic (21% vs. 11%, X^2 (1) = 3.88, *p* = .049) than nonparticipants. Consistent with the participating clinics, 75.2% of the full sample (N = 247) identified as non-Hispanic White, 14.2% as Hispanic, 4.8% as African American, and the remainder as Asian/Pacific Islander, American Indian, or more than one race. Patients were 17.76 years old on average (*SD* = 0.39) at baseline and 60% were female. Participants were assessed at baseline (Time 1), and at annual intervals one (Time 2), two (Time 3), and three years later (Time 4). At Times 2, 3, and 4 samples were 216, 211, and 179, respectively. The most common reason for withdrawing from the study or for skipping one of the yearly assessments was that participants were too busy. Mean disease duration at baseline ranged from 1.09 to 17.98 years (M=7.35. SD=3.94), with 19.6% considered early onset (prior to age 7). Illness duration was largely unrelated to other dependent and independent variables (Table 1). While at baseline 100% of participants lived at home, this decreased to 51%, 46.8%, and 47.7% for times 2, 3, and 4, respectively.

Procedure

This study was approved by the University of Utah and Southwestern University IRBs. Parents and adolescents provided consent or assent; teens provided consent after they turned 18. At baseline, participants completed all cognitive measures, an HbA1c assay, and received instructions for completing annual online surveys (including self-report of adherence). Because extreme hyper- and hypoglycemia can affect cognitive performance, blood glucose levels were checked prior to completing cognitive performance measures. If levels were outside the range of 75 to 400 mg/dl, participants took steps to normalize blood

glucose; testing was rescheduled for one participant who could not bring blood glucose into range. Blood glucose levels in the testing session were unrelated to cognition (r values < .13, all p values > .11). Teens were paid $50 for the first two and $75 for the last two annual assessments.

Measures

Executive Functions.—To assess EF, we administered (1) the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) battery, (2) the Conners' Continuous Performance Test (CPT-2; Conners, 2000), and (3) the Iowa Gambling Task (IGT; Bechara, 2007), which together generated 10 scores: Letter-Number Sequencing Condition completion time (D-KEFS Trail Making Test); Inhibition and Inhibition/ Switching completion times (D-KEFS Color-Word Interference Test); Letter and Category Conditions correct responses (D-KEFS Verbal Fluency Test); the total correct response from the three conditions for the D-KEFS Design Fluency Test; the total number of selections from the "advantageous" decks on the IGT; and an arithmetic mean of 8 indices of inattention on the CPT-2. All scores were age-corrected scaled scores or age-corrected T-scores, per respective test manuals.

The ten scores were submitted to an exploratory factor analysis with Varimax rotation, yielding two theoretically cogent factors. Factor 1 (41.5% variance) included all verbal and design fluency scores (factor loadings ranged from .551 to .809) and was interpreted as "Executive Cognitive Functions," based on the fact that both verbal and design fluencies require reasoning and problem-solving and depend heavily on higher order cognitive processes such as goal-directed retrieval of information and mental flexibility, which are recognized aspects of executive cognitive functions (Suchy, 2015). Factor 2 (12.1 % variance) included IGT[1], CPT-2, the two Color-Word Interference scores, and the Letter-Number Sequencing score (factor loadings ranged from .556 to .677), and was interpreted as "Behavioral Control," given that these tasks do not require reasoning and problem-solving and rely heavily on behavioral response selection, inhibition of prepotent or emotionally attractive responses, and initiation and maintenance of responses (Suchy, 2015).

Lower Order Cognitive Processes.—To assess lower-order processes needed for performance of the above EF tasks (e.g., graphomotor speed, verbal speed, visual scanning, sequencing), we used six tasks included in the D-KEFS battery for the purpose of controlling for lower-order processes, including Word Reading and Color Naming from the Color-Word Interference Test, and Visual Scanning, Letter Sequencing, Number Sequencing, and Motor Speed from the Trail Making Test. As we did previously (Franchow & Suchy, 2017; Franchow & Suchy, 2015; Suchy et al., 2016), we created a Psychomotor Speed composite by computing the mean of age-corrected scaled scores (based on test manual). Cronbach's α in this sample was .816.

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[1]The IGT is a task of emotional decision making. The performance of the task is not associated with the type of deliberative decision-making processes that are related to executive cognitive functions, but rather with sensitivity to punishing and rewarding incentives as well as the ability to learn the associations between physiologic (somatic) outcomes and behaviors (Bechara, Damasio, Tranel, & Damasio, 1997).

General IQ.—IQ estimate (IQ-est) was generated using the Vocabulary subtest from the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS; Wechsler, 2008). This subtest correlates .91 to .92 with verbal IQ and .79 to .81 with Full Scale IQ in the present age group. Reported split-half reliability for the Vocabulary subtest for ages 16 to 19 in the normative sample is .93. Norm-based age-corrected scaled scores were used in analyses.

HbA1c.—Glycated hemoglobin (HbA_{1c}) was obtained at each time point using HbA1c mail-in kits[2] (provided and processed by CoreMedica Laboratories, accredited by the College of American Pathologists; www.coremedica.net). HbA1c reflects average levels of blood glucose over the preceding 3–4 months, with lower scores indicating better blood glucose levels. At baseline, the kit was completed by the teen after receiving instructions from a trained research assistant who observed test completion. This approach was chosen over obtaining HbA1c from medical records to ensure that the HbA1c measurement at baseline occurred on the day of cognitive testing for all participants, and to obtain HbA1c values from participants at follow-ups, even if they were not routinely seeing a health care provider.

Adherence.—Participants completed a revised 7-item version of the Self Care Inventory (SCI; La Greca, 1990) to assess adherence to the diabetes regimen. With the assistance of a certified diabetes educator and a pediatric endocrinologist, items from the SCI that reflected current recommendations for daily diabetes behaviors were selected. Participants rated how well they followed recommendations for each behavior on a scale from 1 = "never did it" to 5 = "always did as recommended, without fail." Scores were averaged to reflect participants' adherence over the past month, such that higher scores indicate better adherence. In this sample Cronbach's α across the four time points ranged from .77 to .83).

Analytic Plan

As indicated in Participant section, between 72% and 87% of initially-enrolled participants participated in follow-ups 2 to 4. To account for missing data, we generated ten datasets through multiple imputation (MI) (Graham, Young, & Penny, 2009), estimating missing data both for participants missing a variable at a particular time point and for individuals missing an entire time point (for individuals who remained in the study but skipped one of the four assessments). The MI procedure included variables beyond those used in present analyses to help ensure an adequate missing-at-random model.

As a preliminary analysis, we generated zero-order correlations among all dependent and independent variables and potential covariates. To examine cognitive and behavioral aspects of EF simultaneously, we initially constructed a linear and a quadratic growth curve model of the four measures of HbA1c and adherence over time in Mplus v8 using maximum likelihood with the Yuan & Bentler adjustment for non-normality. We then examined whether the cognitive and behavioral aspects of EF uniquely predicted the intercept and the slopes of HbA1c and adherence. Lastly, we followed up with four general linear regressions

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[2]The A1c kits are quite stable (i.e., have a long shelf-life) and our protocols were designed to ensure that the kits would be processed in a timely fashion and would provide valid readings. Expiration dates were always checked prior to recording a reading; no kits were processed passed expiration date.

using the HbA1c and adherence values at each of the four time points individually as the dependent variables and the cognitive variables as predictors. In these analyses, we examined the unique and overlapping variance contributions of each predictor by employing hierarchical variable entry.

Results

Preliminary Analyses

Zero order correlations and descriptive statistics presented in Table 1 show that all cognitive variables correlated with HbA1c at all four time points. Also, consistent with the notion of positive manifold (i.e., better cognition in one area tends to be related to better cognition in another area; Spearman, 1904), all cognitive variables evidenced small to moderate associations with each other, demonstrating the need to control for IQ-est and lower-order processes to isolate the EF construct. Of note, as previously reported by others (Friedman et al., 2006), stronger association was seen between IQ-est and Executive Cognitive Functions as compared to IQ-est and Behavioral Control (R^2 =.19, $p<.001$). Lastly, adherence did not correlate with any of the cognitive variables, with the exception of a small correlation between IQ-est and adherence at time 4.

Cognitive and Behavioral Control Predicting HbA1c and Adherence Over Time

In the growth model using HbA1c as the dependent variable, time was centered between the 2nd and 3rd measure to minimize collinearity due to scaling of time. Both a linear (−1.5, −0.5, 0.5, & 1.5) and quadratic (2.25, 0.25, 0.25, 2.25) slope were tested and the residuals for HbA1c were equated over time. Overall the model was a good fit for the data, Average $X^2(df=4, n=233)=7.567$, $SD X^2=2.535$. For the unconditional model, significant parameters were observed on all the growth parameters (see Figure 1) suggesting that, on average, individuals were increasing in HbA1c over time while this increase attenuated as time continued. The variance components for the intercept, linear, and quadratic slopes suggested that these patterns varied substantially across individuals.

Executive Cognitive Functions, Behavioral Control, IQ-est, and Psychomotor Speed were then added to simultaneously predict the intercept, as well as the linear and quadratic slopes (see Table 2 for coefficients). Only Behavioral Control uniquely predicted the intercept of HbA1c, with higher Behavioral Control related to lower HbA1c. Further, only Executive Cognitive Functions related to the linear slope, with better cognitive control related to a slower increase in HbA1c over time. None of the variables tested accounted uniquely for variation in the quadratic slope[3]. Figure 2 shows trajectories at one standard deviation above and below the mean in cognitive and behavioral control scores Table 3 shows norm-referenced scaled scores for each of the four cognitive variables used in analyses.

Using the same growth modeling procedure, we treated adherence (operationalized as the SCI score) as the dependent variable. Both the fixed effect and random effect for the quadratic slope failed to meet conventional significance (fixed=0.000, $p=.994$, variance

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[3]Controlling for disease duration in analyses did not change results.

component=0.199, p=.993). Further, inclusion of Executive Cognitive Functions, Behavioral Control, IQ, and Psychomotor Speed failed to predict the linear slope (though Executive Cognitive Functions and Behavioral Control uniquely predicted the intercept with higher scores corresponding to higher adherence). These results did not change as a function of including or excluding the quadratic slope (nor did Executive Cognitive Functions, Behavioral Control, IQ, and Psychomotor Speed predict the quadratic slope)[3].

Unique Contributions of Cognitive and Behavioral Control to HbA1c at Each Time Point

To examine specific contributions of each cognitive variable to HbA1c at each time point, we further conducted a series of general linear regressions, using HbA1c at each time point as the dependent variables and the four cognitive variables as predictors.

For Time 1, general linear regression model was statistically significant [$F_{4,228}=8.46$, $p = <.001$] and accounted for 13.5% of variance in HbA1c. Behavioral Control ($\beta= -.204$, $p=.009$) and IQ-est ($\beta= -.254$, $p=.001$) emerged as a unique predictor beyond all other variables.

For Time 2, the model was statistically significant [$F_{4,228}=5.56$, $p = <.001$] and accounted for 8.6% of variance in HbA1c. Behavioral Control ($\beta= -.228$, $p=.007$) emerged as the sole unique predictor beyond all other variables.

For Time 3, the model was statistically significant [$F_{4,228}=4.85$, $p =.001$] and accounted for 7.6% of variance in HbA1c. Behavioral Control ($\beta= -.181$, $p=.049$) and Cognitive Control ($\beta= -.191$, $p=.033$) emerged as unique predictors above and beyond all other variables.

For Time 4, the model was statistically significant model [$F_{4,228}=10.44$, $p <.001$] and accounted for 14.7% of variance in HbA1c. Behavioral Control ($\beta= -.257$, $p=.004$) and Cognitive Control ($\beta= -.354$, $p=.002$) again emerged as unique predictors beyond all other variables.

Partitioning of variance is illustrated in Figure 3. As seen, Executive Cognitive Functions emerged with time as a progressively more important unique predictor, whereas Behavioral Control consistently contributed unique variance across time. Importantly, contributions of Executive Cognitive Functions and Behavioral control held above and beyond IQ-est and psychomotor speed, suggesting that the EF construct, not other aspects of cognition, explain the results.

Lastly, the above analyses were *not* conducted with adherence as the dependent variable, given that lack of meaningful associations in the preliminary analyses.

Discussion

The present study examined two components of EF (Executive Cognitive Functions and Behavioral Control) as predictors of HbA1c and adherence over four yearly assessments among young adults with T1D as they transitioned from the senior year of high school into early emerging adulthood. The results showed that Behavioral Control is consistently related

to HbA1c over time, accounting for a small amount of unique variance beyond other cognitive variables. In contrast, Executive Cognitive Functions are related to the *trajectory* of HbA1c values from baseline to Time 4, becoming increasingly more prominent as a correlate of HbA1c with increasing transition to adulthood. Although IQ-est did not significantly factor into changes across time, it is notable that at baseline (i.e., in senior year of high school) it accounted for significant amount of unique variance beyond all the other cognitive variables in a linear regression. The present study contributes to the growing literature on the association between EF and HbA1c among youth with T1D and extends prior findings by demonstrating that different components of EF contribute differentially to HbA1c at different periods of development.

In this study no association was found between the *trajectories* of self-reported adherence and cognition. Emerging adults' reports of adherence did not vary greatly across the 3 years (see also Berg et al., 2018), likely making it difficult to predict the small changes that did occur. Additionally, emerging adults' self-reports of adherence are only modestly related to other metrics of adherence such as blood glucose checks (Berg et al., 2016). Future work utilizing additional metrics of adherence is needed to fully understand the link between EF and trajectories of adherence across time.

The present results provide a theoretically cogent account of how cognition relates to HbA1c during this important developmental period. First, during the senior year of high school while all teens were still living at home with parents, HbA1c was, in part, explained by IQ-est. Teens' IQ likely reflects a broad array of factors including the teens' own self-control (Berg et al., 2014), along with the broader family environment and parental involvement. Research also shows that parental education and socioeconomic status (SES) are related to teens' T1D management (Rechenberg, Whittemore, Grey, & Jaser, 2016). Because children's IQ is known to relate to parents' IQ (Plomin & Deary, 2015) and maternal IQ is associated with children's HbA1c beyond SES (Ross et al., 2001), the association between teens' IQ and their HbA1c may be more a reflection of the family environment than of the importance of teens' IQ for their T1D management. This interpretation is particularly likely given that IQ drops out as a predictor once teens graduate from high school and begin to assume more independent lifestyle. Of note, although 100% of the teens lived at home at baseline, nearly half the sample continued to live at home for all three follow-ups, illustrating that living situation is but one aspect of independence. A more thorough assessment of independence beyond living situation was unfortunately not conducted.

Unlike IQ-est, Executive Cognitive Functions were not uniquely predictive of HbA1c while teens still lived at home. This likely reflects that parents provide structure for their teens that may simplify the cognitive demands of diabetes management. Such structure may consist of parents monitoring the teen's glucose checks and food, or by helping them problem-solve around potential obstacles to adherence. However, as young people assume greater independence from their parents and become responsible for organizing their own daily life, Executive Cognitive Functions become progressively more important. Importantly, as is apparent from the trajectories illustrated in Figure 2, Executive Cognitive Functions are *necessary but not sufficient* for diabetes management. To execute intended plans, Behavioral Control is needed.

Behavioral control reflects the capacity to (a) say no to attractive but unwise choices or to avoid giving in to impulses and urges (e.g., avoid consuming unhealthy foods or alcohol), (b) repeatedly and regularly execute daily tasks (e.g., glucose checks), and (c) follow through with intentions and plans (e.g., exercise). In line with the notion that Executive Cognitive Functions are necessary but not sufficient to effectively manage T1D, the present study suggests a fairly stable association between HbA1c and Behavioral Control across all four timepoints. This suggests that individual differences in impulse control, emotional decision making, and the ability to initiate and complete planned tasks relate to how well teens are able to maintain good HbA1c. These results are in line with Steinberg's (Steinberg, 2005) model of the importance of impulse control for the successful execution of adaptive behaviors across this developmental period. In fact, Wiebe et al. (2018) found that individuals who generally planned well for how to achieve diabetes management goals were derailed when others interfered with diabetes management in daily life, but this was primarily true for those with lower EF (measured as a combination of cognitive and behavioral control skills).

The different trajectories of HbA1c predicted by high and low cognitive and behavioral components of EF (see Figure 1) add to a growing literature indicating that individuals vary in their HbA1c across late adolescence and emerging adulthood. Longitudinal studies of HbA1c across emerging adulthood reveal that some individuals increase in HbA1c, whereas others maintain fairly stable levels (Helgeson et al., 2018; Luyckx & Seiffge-Krenke, 2009; Schwandt et al., 2017). A large number of factors have distinguished those with more stable versus worsening HbA1c, including SES, psychological distress (Helgeson et al., 2018), and family climate and teen self-concept (Luyckx & Seiffge-Krenke, 2009). Additionally, teens who leave home are at an increased risk for the development of depressive symptoms, which are themselves associated with poorer HbA1c (Baucom, Turner, Tracy, Berg, & Wiebe, 2018) and with EF weaknesses (Rogers et al., 2004). The present results indicate that those with poorer cognitive and behavioral control are also at risk for exhibiting detrimental HbA1c trajectories across the emerging adult years. Combined weaknesses in both the cognitive and behavioral components of EF may mean that such individuals lack both the cognitive skills to engage in the complex problem-solving required for more independent diabetes management and the impulse control to prevent oneself from engaging in high-risk behaviors (e.g., drinking, skipping blood glucose tests). We should note that, as seen in Table 3, our participants experiencing low cognitive and behavioral control were falling in a category that would be considered low average to mildly impaired (rather than clinically significantly impaired), with the mean values for the low groups falling at about 2/3 of SD below norms (i.e., mean Scaled Scores around 8), with some individuals falling more than 1 SD below norms (i.e., minimum Scaled Scores around 6). It is likely that individuals with clinically significant impairments in cognitive and behavioral components of EF would display even greater deterioration in HbA1c across this high-risk developmental period.

The present findings need to be interpreted in the context of limitations. First, although this study conducted a highly comprehensive assessments of EF, we did not assess all aspects of EF, especially the ability to manage multiple tasks simultaneously (Suchy, 2015). Relatedly, we did not assess prospective memory, which is known to relate to independent daily functioning, including management of complex medication regimens (Avci et al., 2018).

Second, we only assessed EF at baseline, even though aspects of EF continue to mature across this transitional period, and deterioration in HbA1c as well as fluctuations in daily blood glucose may also affect cognition (Gonder-Frederick et al., 2009). In fact, as recently reviewed, those with early T1D onset tend to have poorer cognition including EF, which is attributable to both hypo- and hyperglycemia (Ryan, van Duinkerken, Rosano, 2016). Future research needs to assess these components of EF across time to understand the complex interplay between developmental changes in EF as well as the deleterious impact of dysglycemia on the specific aspects of cognition examined in this study. Third, the majority of teens in the present study had parents with some college education, limiting the generalizability of the results. However, given that EF is negatively affected by low SES (Hackman, Gallop, Evans, & Farah, 2015), the results may be even stronger in a more economically and educationally diverse sample. Fourth, the failure to find an association between adherence and cognition limits our interpretation that cognition affects HbA1c through health behaviors. Adherence behaviors are challenging to measure in the T1D self-management context, and different findings may occur with additional or alternative measures.

The findings of the present study have important implications for promoting T1D management as late adolescents transition into emerging adulthood. Assessment of both cognitive and behavioral aspects of EF in clinical care may be necessary to identify who is in need of additional support and skill-building interventions, including help with identifying the social contexts that pose barriers to T1D management and development of strategies for preventing lapses in diabetes self-management in those situations (e.g., if-then planning; Gollwitzer & Oettingen, 2011). These individuals may also benefit from efforts to identify new social support resources, especially in risky situations away from parents (Wasserman, Hilliard, Schwartz, & Anderson, 2015). Finally, the findings that cognitive control predicts changes in HbA1c across time and becomes increasingly important as emerging adults mature suggest the ongoing need to evaluate EF and to target interventions that compensate for lower cognitive skills (e.g., structured planning, problem-solving skills, etc.).

Lastly, the present findings have implications for neuropsychological practice, as related to the utility of EF assessment for prediction of daily functioning. Specifically, the present findings are consistent with the Contextually Valid Executive Assessment (ConVExA) model, which posits that univariate association between EF and outcomes cannot always be assumed, as this association may be moderated by a variety of contextual factors (Suchy, 2015, pp. 158–159; Suchy, 2019). By identifying the specific contextual factors as they relate to individual patients, tailored predictions can identify who, and under what circumstances, is at particular risk for lapses in functioning.

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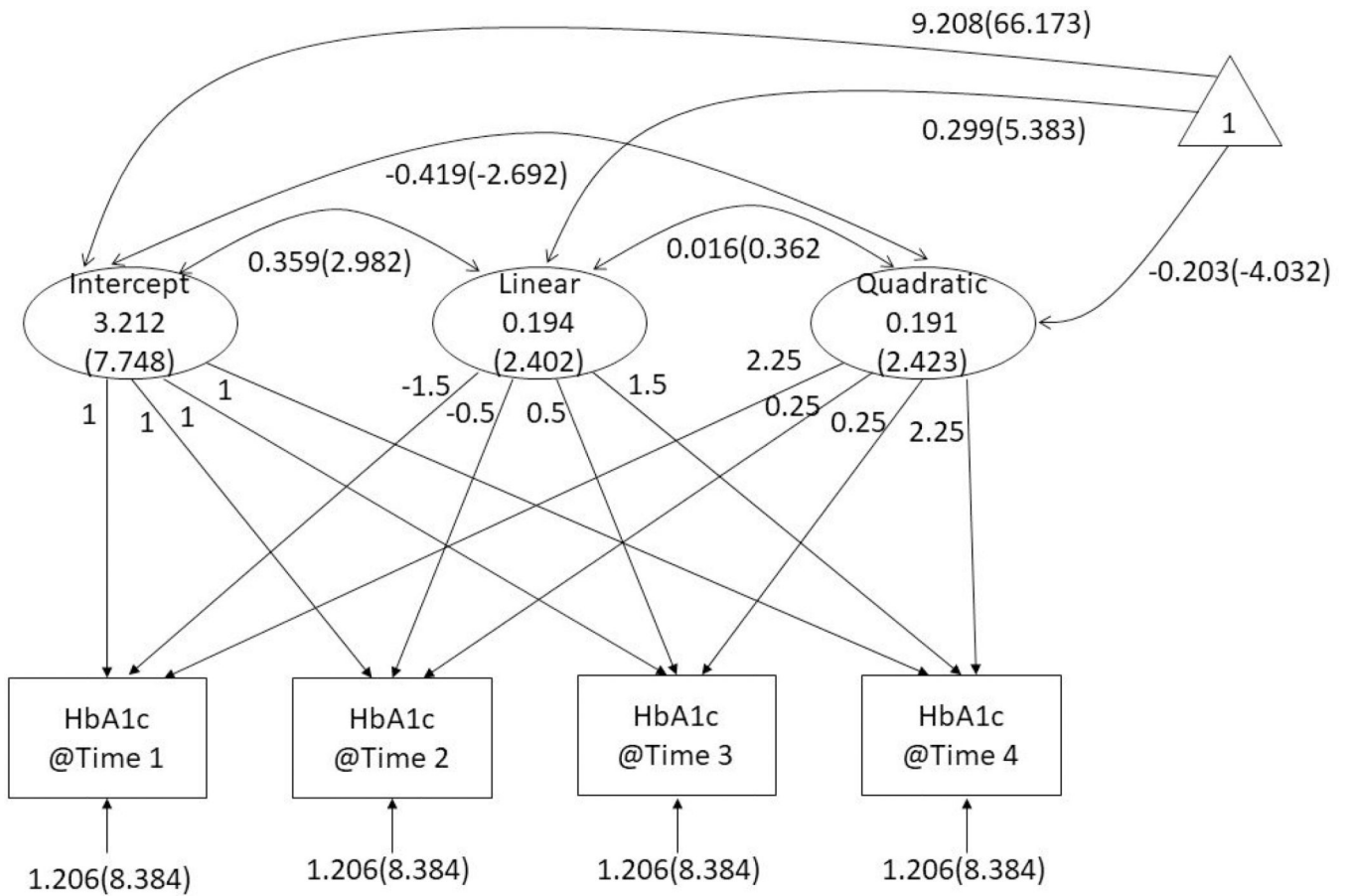
Figure 1.
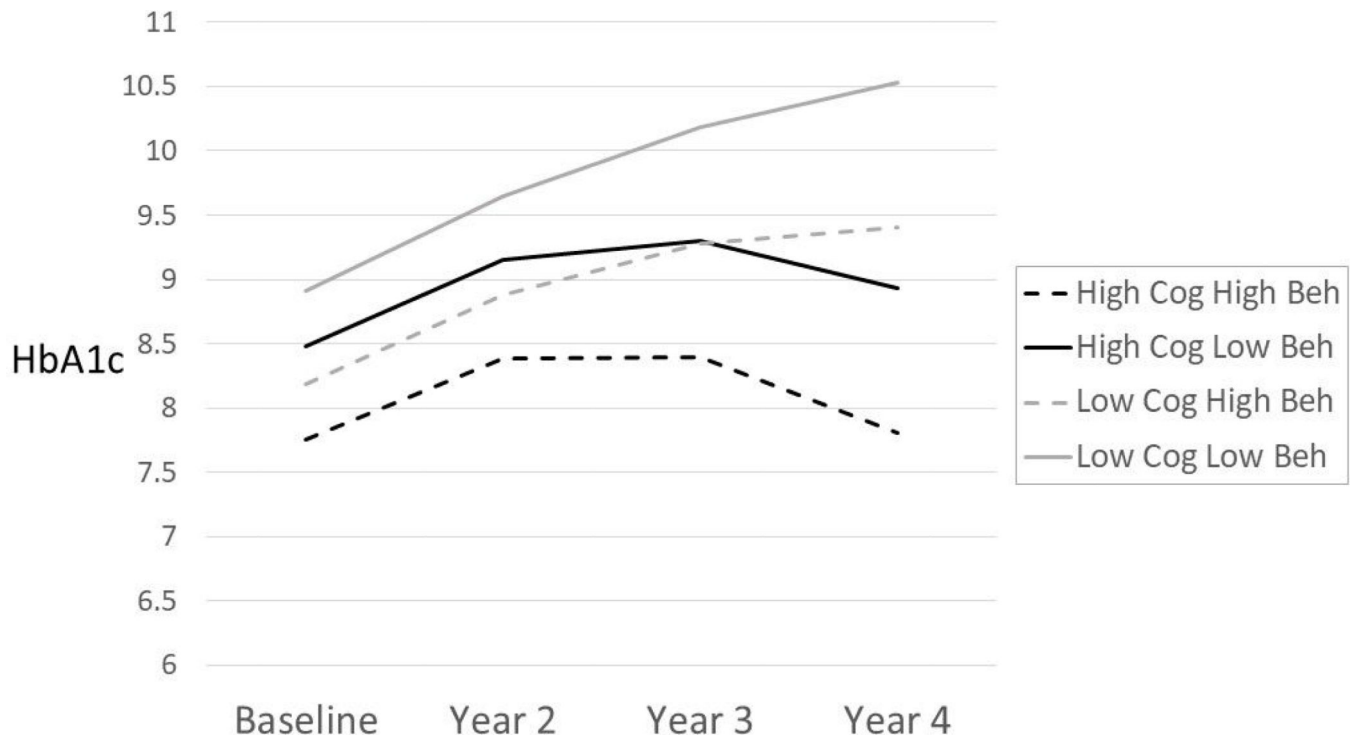The unconditional model significant parameters. N=247.

Figure 2.
N=247.

"Cog" = Executive Cognitive Functions. "Beh" = Behavioral Control.

The Figure illustrates predicted growth curve of HbA1c at 1 SD above and below of Executive Cognitive Functions and Behavioral Control. As seen in the Figure, best outcomes are seen for individuals who have both good Behavioral Control and good Executive Cognitive Functions, whereas the poorest outcomes are seen for individuals who have weaknesses in both areas. Of note, interaction effects were not tested, as they were not hypothesized.
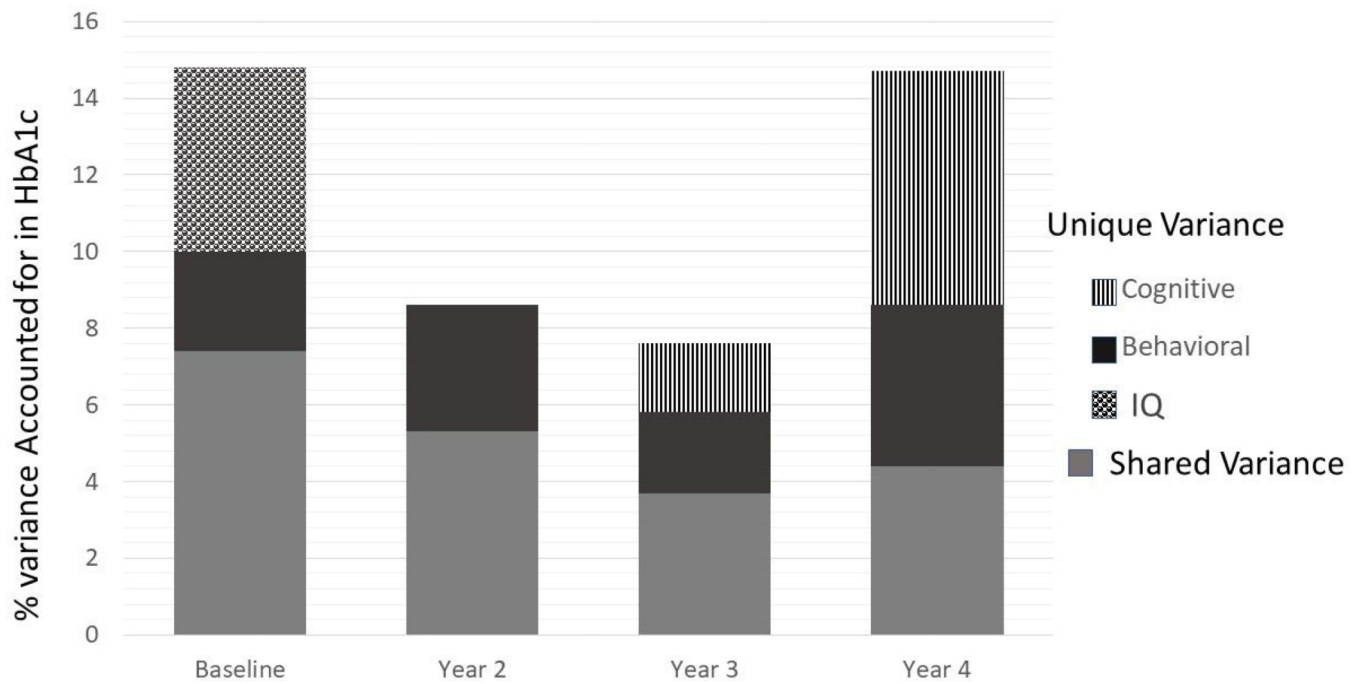
Figure 3.
Percent of unique and overlapping variance accounting for in HbA1c by cognitive variables.
As seen in the figure, IQ, executive cognitive functions, and behavioral control each
contributed unique variance above and beyond the other variables at least at some
timepoints. As would be expected, psychomotor speed did not account for any unique
variance; it was included in the model simply to ensure that executive function scores are not
confounded by lower order cognitive processes that are necessary for performance of most
executive function tasks.

Table 1.

Zero order correlations and descriptive statistics for all dependent and independent variables.

	M (SD)	1	2	3	4	5	6	7	8	9	10	11	12
1. Time 1 HbA1c	8.27 (1.65)	1											
2. Time 2 HbA1c	9.14 (2.00)	.487**	1										
3. Time 3 HbA1c	9.23 (2.12)	.518**	.732**	1									
4. Time 4 HbA1c	9.25 (2.27)	.432**	.599**	.689**	1								
5. Time 1 SCI	3.98 (0.60)	-.233**	-.144*	-.150*	-.075	1							
6. Time 2 SCI	3.97 (0.59)	-.106	-.229*	-.120	-.013	.562**	1						
7. Time 3 SCI	3.93 (0.66)	-.268**	-.238**	-.329**	-.181*	.473**	.552**	1					
8. Time 4 SCI	4.01 (0.54)	-.162*	-.219**	-.275**	-.323**	.398**	.453**	.554**	1				
9. ECF	11.71 (2.30)	-.174**	-.213**	-.252**	-.332**	.011	.011	.014	.066	1			
10. BC	10.66 (1.75)	-.236**	-.225**	-.197**	-.178**	.038	.002	.022	.020	.000	1		
11. PS	11.13 (1.63)	-.158*	-.231**	-.235**	-.199**	-.023	-.022	-.063	-.053	.592**	.458**	1	
12. IQ	11.50 (3.28)	-.331**	-.187**	-.159*	-.165*	-.005	-.088	-.042	-.156*	.445**	.254**	.361**	1
13. Duration	7.35 (3.93)	.121	.014	.020	.005	-.162*	-.118	-.048	-.081	-.073	.022	-.026	-.019

Note. N=247

ECF=Executive cognitive function composite; BC= Behavioral control composite; PS=Psychomotor speed composite. Duration= disease duration (years).

Table 2.

Unstandardized coefficients (Z-values) in predicting the Quadratic Growth Model of HbA1c

	Executive Cognitive Functions	Behavioral Control	IQ	Psychomotor Speed	Residual Variance
Intercept	−0.324(−1.686)	−0.414(−2.338) [*]	−0.016(−0.308)	−0.015(−0.127)	2.880(7.377) [*]
Linear	−0.193(−2.486) [*]	−0.067(−1.089)	0.034(1.686)	0.012(0.272)	0.164(1.981) [*]
Quadratic	−0.082(−1.117)	−0.022(−0.330)	−0.026(−1.194)	0.061(1.232)	0.175(2.299) [*]

Note.

[*] $p<.05$; N=247

Table 3.

Means, standard deviations, and ranges for dependent variables by group expressed as norm referenced Scaled Scores

	Executive Cognitive Functions			Behavioral Control		
	Low (n=38)	Middle (n=163)	High (n=32)	Low (n=41)	Middle (n=154)	High (n=38)
Executive Cognitive Functions	8.25 (1.12)	11.87 (1.47)	15.00 (.97)	10.54 (2.95)	11.91 (2.05)	12.08 (2.04)
	6–10.4	8.8–14.8	13–17.6	6–16.4	6–17.6	7.2–16
Behavioral Control	9.28 (2.03)	10.76 (1.52)	10.53 (1.17)	8.09 (1.34)	10.71 (.98)	12.49 (.72)
	5.72–12.9	5.57–14.38	8.3–13.04	5.57–10.82	7.89–12.85	10.92–14.38
IQ-est	9.02 (3.27)	11.70 (3.06)	13.47 (2.56)	10.30 (3.5)	11.55 (3.11)	12.63 (3.29)
	4.11–19	5–19	6–18	4.11–17	5–19	6–19
Psychomotor Speed	9.38 (1.96)	11.34 (1.32)	12.16 (.86)	9.90 (1.84)	11.29 (1.51)	11.84 (.85)
	4.33–12.83	6.33–14.33	10.17–13.67	5.5–13.17	4.33–14.33	10.33–13.83

Note.

N=247

Scaled Score in normative sample M=10, SD=3; "Low"=1 SD or more below the sample mean, "High"=1 SD or more above the sample mean, "Middle" =within ± 1 SD around the sample mean.