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The Relation of Questionnaire and Performance-based Measures of Executive Functioning with Type 1 Diabetes Outcomes among Late Adolescents

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Abstract

Objective—Successfully managing type 1diabetes involves adherence to a complex daily medical regimen, requiring self-regulatory skills that rely on neurocognitive processes known as executive functioning (EF). Adolescents with poorer rated EF abilities display poorer diabetes outcomes. The purpose of this study was to examine the relationship of EF questionnaire and performance measures with adherence and glycemic control, after controlling for IQ and general questionnaire response style.

Methods—Adolescents with type 1 diabetes (M age=17.74, SD=.38 years) and their mothers (N = 196) completed a self/mother-report questionnaire assessing adolescents' ratings of EF abilities (BRIEF). Adolescents also completed performance-based tests of EF (D-KEFS) and and intellectual functioning (WAIS-IV Vocabulary). Adherence was indexed via 2 self-report inventories and the number of daily blood glucose checks, and glycemic control via HbA1c obtained from assay kits.

Results—Self/mother-reports of EF ability were associated with self/mother-reported adherence. Both questionnaire and performance-based measures of EF were associated with glycemic control. However, once IQ was taken into consideration, performance-based EF was no longer associated with glycemic control, IQ independently shared variance with glycemic control.

Conclusions—Our findings suggest that self-reports of EF may be useful in identifying late adolescents who need assistance in managing diabetes in daily life. The finding that performance-based EF measures were not related to glycemic control independent of underlying intellectual capacity raises questions about the specific role of EF in diabetes outcomes.

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Adherence to the complex regimen of type 1 diabetes outcomes involves execution of a range of behaviors (e.g., blood glucose testing, calculating insulin dose) that need to be performed correctly several times each day in the context of other daily challenges (Hood, Peterson, Rohan, & Drotar, 2009). Failure to execute these tasks can result in poor glycemic control, typically measured by glycated hemoglobin (HbA1c). Higher HbA1c has been associated with risk of long-term micro- and macro-vascular complications that impact brain health and cognition (Ambler, Fairchild, Craig, & Cameron, 2006). The risk for poor glycemic control increases as adolescents transition into adulthood and more independently manage their health condition. With this increasing independence, diabetes outcomes may rely more on self-regulation, which refers to one's capacity to manage one's thoughts, feelings, and behaviors toward successful achievement of adaptive goals (Tangney, Baumeister, & Boone, 2004).

From a cognitive neuroscience standpoint, self-regulation relies largely on neurocognitive processes that are collectively known as executive functioning (EF). These processes allow one to make choices and to engage in purposeful, goal-directed, future-oriented behavior (Lezak, Howieson, Bigler, & Tranel, 2013; Suchy, 2009, 2015). Although no single globally accepted definition of EF exists (Suchy, 2009, 2015), it is generally agreed that EF is multifaceted and includes planning and reasoning, organization and problem solving, multitasking, and the ability to control impulses and to follow-through with plans (Lezak et al, 2013; Suchy, 2009, 2015). These higher order processes are in turn supported by more elemental cognitive abilities including initiation and inhibition, set maintenance and working memory, cognitive flexibility and cognitive control, and self-monitoring (for a review see Suchy, 2009, 2015).

As recently reviewed by Duke and Harris (2014), several studies have demonstrated the importance of EF (assessed via self- or parent-reports) in teens' and young adults' diabetes outcomes, as reflected in adherence self-report and glycemic control. However, what is not known from these studies is whether EF as assessed via performance-based measures is also involved in diabetes outcomes. This question is important because questionnaire ratings and performance-based measures of EF may not necessarily measure the same construct. Indeed, results of a recent meta-analysis (Toplak, West, & Stanovich, 2013) indicated a minimal relationship (r=.19) between questionnaire ratings and performance-based measures of EF across 20 studies (both adult and child samples). Nevertheless, some research has demonstrated an association between performance-based measures of EF and glycemic control (Ohmann, Popow, Rami, Konig, Blaas, Fliri, & Schober, 2010). Therefore, the present study examines whether *both* questionnaires (i.e., self-report and mother-report) *and* behavioral (i.e., performance-based) measures of EF relate to diabetes outcomes (as reflected in *both* adherence *and* glycemic control). This question is important from a theoretical standpoint, as it will help clarify the underpinning of the self-regulation construct that relates to diabetes outcomes, as well as from a clinical standpoint, as it will answer the question of whether questionnaires and performance-based measures of EF can be used interchangeably.

Importantly, it is well understood that when assessing EF behaviorally, performance on EF tests needs to be considered in the context of general intellectual functioning, as is typical in

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clinical neuropsychological research and practice (Friedman et al., 2006;Lezak et al., 2013). This is because one's underlying intellectual capacity is almost always intrinsically reflected in performance on any cognitive measures, as IQ reflects (among other things) non-specific, general factors such as motivation to do well, familiarity with test-taking, or the ability to comprehend and follow test instructions (Lezak et al., 2013). Without the consideration of these general processes, it is an open question as to whether EF specifically relates to diabetes outcomes or whether other cognitive variables may be explaining variance both in diabetes outcomes and in EF. In fact, studies have indicated that those with higher general IQ may have better glycemic control (Ross, Frier, Kelnar, & Deary, 2001), and that changes in HbA1c associated with higher IQ may be due to, in part, better self-regulation (Berg, Hughes et al., 2014). Consistent with these considerations, Duke and Harris (2014) recently called for controlling for such processes when examining the relationship between diabetes outcomes and EF, whether assessing EF behaviorally or via self-report. Therefore, in addition to examining the zero order associations among glycemic control, adherence, and EF, we also examined those relationships after statistically controlling for IQ.

We expected to replicate prior findings that teen- or parent-reports of EF are related to adherence (Bagner et al., 2007; Berg et al., 2014) and that performance-based measures of EF and IQ are related to HbA1c (Ohmann et al., 2010; Ross et al., 2001). Additionally, we examined the unique contributions of teen- or parent-reports of EF and performance-based measures of EF to diabetes outcomes when pitted against each other in a single regression. Given the small overlap between questionnaires and performance-based measures of EF (Toplak et al., 2013), we did not have specific predictions such *unique* contributions.

Method

Participants

Participants included 196 high school seniors with type 1 diabetes (70 male and 126 female, M age = 17.74, SD= 0.38 years, range 16.9 to 18.7) who completed baseline assessments as part of a larger 2-year longitudinal study examining individual and social factors in how late adolescents transition into emerging adulthood. Participants were recruited during a visit to their outpatient pediatric endocrinology clinic in 2 southwestern cities, and were eligible if they had been diagnosed with type 1 diabetes for at least one year (M = 7.52 years, SD =3.86), spoke English as their primary language, were in their last year of high school, lived with a parent (71.9% lived at home with both parents, 27.6% with one parent), would have regular contact with parents over the subsequent 2 years, and had no condition that would prohibit study completion (e.g., severe intellectual disability, blindness, etc.).

Participants were recruited in-person by a research assistant in clinic, or by mail and phone. Of the qualifying 507 individuals approached, 301 (59%) agreed to participate. Of those, 202 mother-teen dyads completed surveys, diaries, and performance testing. Reasons for not participating included being too busy (34%), lack of interest (33%), and 20% declined to give a reason. Five dyads were excluded due to an invalid pattern of responding on the BRIEF (3 mothers, 2 teens) and 1 due to extreme attentional limitations evident during testing.

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Consistent with the patient population at participating clinics, the sample (N = 196) was 87.7% non-Hispanic White, 14.1% Hispanic, 6.1% African American, 1.2% Asian/Pacific Islander, and 0.06% American Indian. Parent education was reported with 14.8% and 21.4% of mothers and fathers, respectively, having no more than a high school education, 43.4% and 28.0% as having some college or a vocational degree, and 40.8% and 45.4% as having a bachelor's degree or higher. Forty-seven percent of adolescents used an insulin pump.

Procedure

The study was approved by the appropriate Institutional Review Boards, with parents providing informed consent and teens providing consent or assent. Teens completed performance-based measures of EF in lab and received instructions for a subsequent on-line survey measuring self-report of self-regulation skills, EF, and adherence[1]. Teens and mothers had the option to complete surveys at home or in the lab; all but one opted to complete them at home; 98% of the dyads resided in the same household. Teens completed daily diaries for 2 subsequent weeks, including their daily glucometer readings. Teens were paid $50 for lab procedures and the online survey, and $5 for each diary completion; mothers were paid $15 for completing a parent version of the online survey.

Measures

Adherence—Adolescents' adherence to the diabetes regimen was measured in 3 ways. Teens and mothers reported on the Diabetes Behavior Rating Scale (DBRS), a 37-item scale that assesses multiple behaviors required for diabetes outcomes, as well as components of problem solving that are relevant to diabetes outcomes. It correlates highly with more time-intensive interview measures (Iannotti et al., 2006). In the present study, the scale had good reliability (teen and mother α = .836 and .835, respectively, for teens using insulin pump, and .861 and .843, respectively, for teens not using a pump). Higher scores on this measure reflect better ADH. Teens and mothers also completed 7-items from the Self-Care Inventory (SCI), an index that performs well compared to more extensive measures of adherence (Lewin et al., 2009). Prior to the study, SCI items were reviewed by a diabetes educator and pediatric endocrinologist to identify crucial management behaviors, and revised as needed to capture contemporary standards for daily diabetes behaviors. In the present study, the scale had good reliability (teen α = .80, mother α = .86). Higher scores on this measure reflect better ADH. Finally, teens also recorded each blood glucose reading taken off their glucometer at the end of each day over the subsequent 2 weeks, and the total number of blood glucose checks reported each day was analyzed.

Using these 3 indices (SCI, DBRS, and mean number of daily glucometer readings), we created 2 z-scaled factor scores, one each for teen and mother. The factor loadings ranged from .678 to .871, and from .642 to .875, for teens' and mothers' scores. These scores are

[1]Because extreme hyper- and hypoglycemia can affect cognitive performance (Desrocher & Rovet, 2004; Weinger & Jacobson, 1998), blood glucose levels were checked prior to completing performance-based measures. If blood glucose levels were outside the range of 75 to 400, participants took steps to normalize blood glucose (e.g., get a snack; bolus); if blood glucose could not be brought in range within an hour, the testing session was rescheduled. Blood glucose levels were unrelated to all performance-based measures (all r values <.13, all p values>.11) indicating that these procedures were effective at limiting the contribution of current blood glucose to performance during cognitive testing.

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referred to below as ADH-self and ADH-mom, respectively. Higher values indicate better adherence.

Glycemic control—Glycemic control was indexed using glycated hemoglobin (HbA1c) obtained on the day of cognitive testing with use of in-lab test kits (acquired from and processed by CoreMedica Laboratories, accredited by the College of American Pathologists; www.coremedica.net), rather than physician office visit data, to ensure that HbA1c measurement occurred on the day of testing and that the time elapsed between HbA1c measures and cognitive testing was uniform across participants. The test kit was completed by the adolescent after receiving oral and written instructions from a trained research assistant who then observed the completion of the test. This measure was highly correlated with HbA1c obtained from point of care assays in medical records ($r = .74$, $p < .001$)[2]. One participant had missing test kit data.

Executive Functions—Questionnaires—Teens completed the Behavior Rating Inventory of Executive Functioning-Self-Report (BRIEF-SR; 80 items), while mothers completed the parent-report companion inventory of teen functioning. This widely-used measure inquired about a range of *problems* with EF (e.g., I don't plan ahead for future activities) in daily life. Participants rated each item on a 3-point scale (0 = never to 2 = often) to indicate the frequency of each problem over the past 6 months. Items were combined into a global executive composite score, with excellent reliability in this sample (teen $\alpha = 0.95$; mother $\alpha = 0.97$). The measures are normed for adolescents between 5 and 18 years of age (Guy, Isquith, & Gioia, 2004). Age and gender corrected T-scores (per manual) were used in analyses. The variables for self- and mother-reports are referred to below as the "EF-self" and "EF-mom," respectively, with higher scores on this measure reflecting greater EF problems.

Executive Functions—Performance-Based Assessment—During the in-person laboratory session, teens completed 4 subtests from the Delis-Kaplan Executive Function System battery (D-KEFS; Delis, Kaplan, & Kramer, 2001). Within these subtests, we used those conditions that reflected multiple widely-recognized components of EF: Trail Making (Number Letter Sequencing completion time), reflecting set-maintenance, cognitive flexibility, and working memory; Color-Word Interference (Inhibition and Inhibition/Switching completion times), reflecting response inhibition, and cognitive flexibility and control; and Verbal (Letter and Category correct responses) and Design Fluencies (number of correct responses for 3 conditions), reflecting initiation, self-monitoring, and set maintenance. We used the mean of 8 norm-based age-corrected scaled scores (Delis et al., 2001) to generate a single EF composite score (α=.84). Higher scores on this measure indicate better performance.

Cognition is organized in a hierarchical fashion (Lezak et al., 2013; Stuss & Alexander, 2000); therefore, higher-order processes (such as EF) are confounded by lower-order processes (such as the ability to perceive a stimulus, or the speed at which a response is

[2]We tested whether HbA1c values derived from patient medical records yielded different results than HbA1c home test kits. Results were unchanged.

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generated). To address this issue, the D-KEFS battery contains tasks that are specifically designed to control for these confounds. We included 6 of these tasks in our study (i.e., Color Naming and Word Reading from the Color-Word Interference Test, and Visual Scanning, Number Sequencing, Letter Sequencing, and Motor Speed from the Trail Making Test). We used the mean of the resulting 6 norm-based age-corrected scaled scores (Delis et al., 2001) to create a nonexecutive component composite score (α=.83). To remove the component process variance from the EF composite (i.e., to unconfound them), we computed an unstandardized residual for the EF composite after controlling for the nonexecutive component composite. This residual, referred to as "EF-perform," was used in analyses. Higher values indicate better performance.

Covariates—Because IQ contributes to performance on most cognitive tests, including EF (Friedman et al., 2006; Lezak et al., 2013), it is standard in neuropsychological research to control for IQ to ensure that any observed effects can truly be attributed to the specific construct of interest (Eastvold, Suchy, & Strassberg, 2011; Faja & Dawson, 2014). Thus, we used estimated IQ as a covariate in follow-up analyses. To generate an IQ estimate, we assessed the teens' performance on the Vocabulary subtest of the Wechsler Adult Intelligence Scale-4th Edition (WAIS-IV; Wechsler, 2008) during the in-person laboratory session. This subtest measures word knowledge, and is well known as a highly reliable estimate of crystallized verbal IQ as well as overall Full Scale IQ (FSIQ; Lezak et al., 2013; Wechsler, 2008), correlating .92 with verbal IQ and .78 with FSIQ (Wechsler 2008). We purposefully used a measure of crystallized, rather than fluid, IQ, as crystallized IQ is neurocognitively distinguishable from EF, whereas fluid IQ overlaps with EF (Richland & Burchinal, 2013; Roca et al., 2010). Split-half reliability for the Vocabulary subtest for ages 16 to 19 is excellent at .93 (Wechsler, 2008). Norm-based age-corrected scaled scores (Wechsler, 2008) were used in analyses. Higher scores reflect better performance. We refer to this score as "IQ-est" below.

Additionally, because questionnaire measures typically assess not only the constructs of interest, but also, inadvertently, general temperamental styles as well as general response styles (e.g., a general tendency to respond affirmatively to questionnaire statements), we also used teens' and mothers' reports about the teens' general temperamental tendencies as a covariate. For this purpose, teens and mothers completed the Behavioral Inhibition Scale (BIS; 7 items) and Behavioral Activation Scale (BAS; 13 items), measuring general motivational tendencies to avoid punishments or to pursue rewards, respectively (Carver & White, 1994). Items were rated on a scale from 1 (very true for me/my teen) to 4 (very false for me/my teen). Separate sums of scores were generated for BIS and BAS items, with good reliability in this sample (α = 0.80 and 0.82 for teen and mother report of BIS, and .81 and .85 for teen and mother report of BAS, respectively). For convenience, the 2 scores are referred to jointly as BIS/BAS-self and BIS/BAS-mom below, except for cases when BIS and BAS yielded different results.

Data Analysis

Across all the included variables, 63% of cases had complete data; however, the missingness was relatively small for any individual, and diffuse with missing a single value as the modal

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pattern. The majority of missing data was due to participants failing to respond to all questionnaire items. To account for missing data, we generated five datasets through multiple imputation (MI; Graham, 2009). The imputation procedure included variables beyond the presented analyses to help ensure an adequate 'missing at random' model. Across all analyses, the lowest efficiency was .922, suggesting adequate recovery of the missing data.

Principal analyses consisted of a series of hierarchical regressions using glycemic control, ADH-self and AHD-mom as dependent variables, and EF-self, EF-mom, EF-perform as independent variables. After completing principal analyses, we conducted follow-up analyses in which we tested whether variables that contributed to the initial regression models continued to account for variance after controlling for IQ-est and the BIS/BAS. Lastly, we conducted supplementary analyses in which we controlled for illness duration as a potential confound. All analyses were also repeated using insulin pump status as a covariate, which, although related to HbA1c, did not change any of the results reported below, and thus is not reported separately.

Results

Preliminary Analyses

Descriptive statistics and zero order correlations among the dependent and independent variables and the covariates can be found in Table 1. All normed performances were squarely in the average range relative to norms (Delis et al., 2001; Guy et al., 2004; Wechsler, 2008). HbA1c was significantly correlated with all dependent variables (consistent with prior research; Bagner et al., 2007; McNally et al., 2010). Additionally, whereas ADH-self was associated only with self-report of EF, ADH-mom was associated both with self-reported EF and with IQ-est. Lastly, as would be expected, EF-perform and IQ-est were correlated with each other.

Link between EF and Diabetes outcomes

Associations with adherence—To determine whether adherence is more strongly associated with teen/parent report vs. performance of EF, we conducted a series of hierarchical regressions, using adherence scores for teen and mother (i.e., ADH-self and ADH-mom) separately as dependent variables. When using ADH-self as the dependent variable, we used EF-self as the independent variable on step 1, and EF-perform as an independent variable on step 2. We then reversed the order of variable entry to allow for computation of unique and overlapping variances. As seen in Table 2 (under "Teen," italicized R^2_{change} values), EF-self accounted for 18% of unique variance in ADH-self (R^2_{change} , i.e., partial correlation), whereas EF-perform accounted for virtually no unique variance. When both variables were entered simultaneously (i.e., in a non-hierarchical fashion), the results once again showed that EF-self ($B=-0.040$, $t=6.30$, $p<.001$) was significantly associated with ADH-self, whereas EF-perform was not ($p=.355$).

Next, for mothers' report, we repeated the above set of analyses, substituting ADH-self with ADH-mom as the dependent variable, and EF-self with EF-mom as the independent

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variables. Similar to the teen results from the hierarchical regressions, EF-mom emerged as the primary correlate, accounting for 17% of unique variance in ADH-mom, whereas EF-perform accounted for virtually no variance. See Table 2, columns under "Mother," italicized R^2_{change} values. When both variables were entered simultaneously (i.e., in a non-hierarchical fashion), the results once again showed that EF-mom ($B = -0.04$, $t=6.21$, $p<.001$) was a significant correlate of ADH-mom, whereas EF-perform was not ($p=.25$).

Associations with HbA1c—To determine whether HbA1c was more strongly associated with questionnaire vs. performance-based measures of EF, we repeated the same series of hierarchical regressions using HbA1c (in place of ADH) as the dependent variable. In contrast to the hierarchical results for ADH-self, both EF-perform and EF-self emerged as significant correlates of HbA1c. Specifically, as can be seen in Table 2 (columns under "Teen," rows corresponding to "HbA1c"), both EF-self and EF-perform accounted for variance in HbA1c (2% and 4%, respectively, with 1% of variance overlapping). Italicized R^2_{change} values in Table 2 reflect unique variance. When both variables were entered simultaneously (i.e., in a non-hierarchical fashion), the results once again showed that both EF-self ($B=.022$, $t=2.21$, $p=.027$) and EF-perform ($B= -.241$, $t=2.96$, $p=.003$) were significant correlates of HbA1c.

Next, for mothers' report, we repeated the above set of analyses, substituting EF-self with EF-mom. Similar to the teen results, both EF-mom and EF-perform accounted for significant unique variance in HbA1c (11% and 4%, respectively), and again when entered simultaneously, both EF-mom ($B=.047$, $t=4.87$, $p<.001$) and EF-perform ($B=-.220$, $t=2.83$, $p=.005$) emerged as significant correlates of HbA1c. See Table 2 (columns under "Mother," rows corresponding to "HbA1c," italicized R^2_{change} values for unique variance).

Controlling for IQ and response style—Next, to determine whether the above-identified relationships could be explained by IQ-est or general temperamental tendencies/questionnaire response style, we conducted another set of analyses, using in turn ADH-self, ADH-mom, and HbA1c as the dependent variables, and IQ-est and BIS/BAS (self or mom, as relevant, see Table 3) as covariates on Step 1. Step 2 included all previously identified significant correlates, as seen in Table 3 in the column labeled "IV" (for "independent variable").

With respect to ADH, as can be seen from Table 3, IQ-est and BIS/BAS together accounted for significant variance in ADH-mom, but *not* ADH-self. Regardless, EF questionnaires entered on Step 2 continued to contribute additional unique variance above and beyond IQ-est and BIS/BAS, for both ADH-self (23% of variance) and ADH-mom (17%). See italicized R^2_{change} values in Table 3. When examining the coefficients for these same 3 independent variables in a simple linear (i.e., non-hierarchical) regression, similar findings emerged: Using ADH-self as the dependent variable, neither BIS/BAS-self nor IQ-est emerged as significant correlates (all p values >.19), with EF-self emerging as the only significant correlate ($B= -.042$, $t=6.53$, $p<.001$); and using ADH-mom as the dependent variable, EF-mom emerged as the primary correlate; $B= -.041$, $t=6.45$, $p<.001$), with both IQ-est ($B=.051$, $t=2.44$, $p=.015$) and BIS-mom ($B=-.036$, $t=2.24$, $p=.025$) also contributing to the model. Together, these findings suggest that whereas teens' intellectual abilities

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(assessed behaviorally) and temperamental/response style do not contribute to their own self-report of ADH, they do contribute to mothers' report of ADH.

With respect to glycemic control, as can be seen from Table 3, IQ-est and BIS/BAS (entered on step 1 as a covariate) accounted for a significant amount (10%; see R^2_{change} value in the table) of variance in HbA1c. Additionally, EF variables that significantly contributed to the model in the principal analyses (as reported in Table 2) were entered on Step 2, and together accounted for variance above and beyond the covariates (11%; italicized R^2_{change} value in Table 3). Examination of individual coefficients in a simple linear (i.e., non-hierarchical) regression model revealed that IQ-est (B=−.091, t=2.57, p=.010) and EF-mom (B=.042, t=3.79, p<.001) contributed significantly to the model, with EF-perform and BIS-self showing a trend (p=.083 and .073, respectively). The remaining variables (EF-self, BIS/BAS-mom, and BAS-self) failed to contribute to the model (all p values >.16). Together, these results suggest that glycemic control is related to IQ and to mothers' judgements of adherence, but only mildly at best to performance on behavioral measures of EF once IQ is controlled. In other words, the association between performance-based EF measures and glycemic control (reported in Table 2) was largely explained by IQ.

The impact of glycemic control on cognition

To address whether poor self-regulation capacity is a result, rather than a cause, of poor glucose management, we examined whether illness duration (expected to be associated with greater "wear and tear" on the neuroanatomic substrates of self-regulation and cognition; Ferguson et al., 2005) was accounting for the findings presented in Table 3 for HbA1c. To that end, we conducted a linear regression, using HbA1c as the criterion variable and illness duration, IQ-est, EF-perform, and mothers' and teens' reports of EF, ADH, and BIS/BAS as independent variables. The results once again showed that although illness duration contributed significantly to the model (B=.052, t=2.00, p=.046), IQ-est (B= −.093, t=2.67, p=.008) and EF-mom (B=.041, t=3.71, p<.001) continued to be significant correlates of HbA1c. The remaining variables failed to contribute significantly to the model.

Discussion

This study yielded several key findings: (1) questionnaire ratings of EF, but *not* performance-based measures of EF, were associated with a largely questionnaire-based index of ADH, whereas (2) *both* performance-based measures of EF *and* questionnaire ratings of EF were associated with HbA1c. (3) Once IQ was taken into consideration, performance-based EF did not exhibit an association with HbA1c; instead, IQ contributed independently to HbA1c.

Although findings supported that questionnaire measures of EF were associated with both ADH and glycemic control, the results caution researchers from using these questionnaires as evidence of the neurocognitive processes presumed to underlie EF. Specifically, the present study found that performance-based measures of EF were unrelated to questionnaire ratings of ADH, and that IQ, rather than performance-based measures of EF, represented principal cognitive correlates of glycemic control (as reflected in HbA1c). Toplak and colleagues (2013) also suggested that performance-based measures of EF tap into a different

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construct than self-report EF measures, with performance-based measures differentially reflecting the ability to engage in EF processes in the structured laboratory setting, while self-report measures capture the engagement in EF-controlled behaviors in everyday life. Put differently, performance-based measures reflect one's EF potential under ideal circumstances, including one's capacity to reason and problem solve, whereas self-report measures reflect one's perception of whether one actually capitalizes on this potential in daily life. There is also evidence that performance-based measures of EF are more predictive of cognitively-based outcomes such as occupational success (Bowman, 1996; Ready, Stierman, & Paulsen, 2001), whereas self-report measures correlate with certain behaviors such as substance use, risk-taking, and aggression in young adult samples (Bowman, 1996; Ready et al., 2001). Extending this to diabetes outcomes, one could argue that teens who exhibit certain traits, such as greater tendencies to take risks or to overvalue rewards over punishments, may also be less likely to adhere to their diabetes regimens, regardless of their cognitive or EF capacities.

These findings raise interesting questions regarding how different aspects of cognitive capacity, that is, EF and IQ, contribute to diabetes outcomes. With respect to EF, it is well understood that EF is comprised of cognitive control (e.g., working memory, reasoning) on the one hand and behavioral/emotional control (e.g., inhibition of impulses and emotional drives) on the other (Stuss, 2011; Suchy, 2009, 2015). Based on the present findings and other research (Gioia et al., 2009; Rosenthal et al., 2013), it appears that the behavioral/emotional control aspect of EF (which is likely in part responsible for behavioral attempts at ADH) may best be captured by questionnaire ratings (such as on the BRIEF). In contrast, the cognitive control aspect of EF is best reflected in performances on cognitive measures (Lezak et al., 2013). Interestingly, although this performance-based aspect of EF emerged in the present study as a correlate of glycemic control, this relationship was largely explained by IQ. Of course such interpretations need to consider the fact that all results are a function of the employed assessment instruments, and behavioral measures of emotional control were not employed in this study.

It is possible that the relationship of IQ with glycemic control may reflect one's ability to perform adherence tasks without errors. In fact, some aspects of diabetes outcomes have considerable cognitive components, such as accurately noting glucose readings, calculating carbohydrates, and adjusting insulin as needed based on blood glucose values and carbohydrate counts. Furthermore, IQ appears to be related to one's ability to judge the accuracy with which daily tasks are performed (Suchy, Kraybill, & Franchow, 2011), thus facilitating adjustments or improvements in one's adherence behaviors. Similarly, given that an estimate of *verbal* IQ was used in this study, it is also possible that good verbal abilities facilitated better comprehension of complex instructions about diabetes management, or better memory for verbally communicated diabetes-related material. However, non-cognitive explanations can also be offered. For example, there is the possibility that IQ is simply a proxy for other factors, such as socio-economic status (SES; Taylor, Frier, Gold, &Deary, 2003), which itself is an important predictor of diabetes care. For example, children with type 1 diabetes from lower SES households have poorer glycemic control, more hospitalizations, and more hypoglycemic episodes (Drew, Berg, King, Verdant, Butler, Griffiths, & Wiebe, 2011). However, studies investigating the roles of both IQ and factors

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related to SES found that IQ is a unique correlate of health outcomes and disease knowledge. For example, IQ was the strongest correlate of adults' knowledge of diabetes, over and above social class (Taylor, Frier, Gold, & Dreary, 2003), and parental IQ and child's age uniquely related to glycemic control above social class (Ross, Frier, Kelnar, & Deary, 2001). These findings are consistent with theoretical perspectives on the role of IQ in health and longevity (Gottfredson & Dreary, 2004) and, together with our results, suggest that IQ is a fundamental ability in successfully managing type 1 diabetes.

Interestingly, as seen in the correlations in Table 1 and the regressions in Table 3, IQ appeared to play a role in mothers' reports of ADH. These findings suggest the possibility that mothers use what they know about their teens' applied cognitive abilities (e.g., their children's school performance) as proxies for their estimates of ADH. In contrast, teens may report on their *actual* adherence behaviors, rather than on their *capacity* to engage in those behaviors. On the whole, these findings are consistent with prior research showing that ratings in the BRIEF depend on who the rater is (Wochos, Semerjian, & Walsh, 2014). That said, given the association between IQ and glycemic control found in this study and in prior research (discussed above), it is possible that mothers' tendency to use IQ as a proxy when rating their children's behavior may be a good one, as reflected in the fact that IQ and mothers' (not teens'!) ratings of EF are the strongest correlates of glycemic control (Table 3). Of course it is also possible that because teen's EF is still not fully mature, and because self-awareness if often considered to fall under the EF umbrella, teens' awareness of their own EF capacity and their own adherence behaviors may both be equally flawed. From that standpoint, it is not surprising that mothers' judgment of the teens' abilities is more strongly associated with glycemic control.

The results raise important questions about the direction of the association between performance-based cognitive ability and glycemic control, which cannot be directly addressed in the present analyses. Specifically, although our results demonstrated that better cognitive function was associated with better glycemic control, the cross-sectional nature of our results precludes conclusions regarding the causal direction of effects. On the one hand, our results are consistent with a growing literature that views cognitive function as an important resource for managing complex adherence regimens, although most of this research has focused on mother or teen ratings of cognitive function (Bagner et al., 2007; Miller et al., 2012). On the other hand, an equally plausible interpretation is that poor glycemic control places adolescents at risk for cognitive difficulties (Gaudieri, Chen, Greer & Holmes, 2008). A number of studies find that children with type 1 diabetes show somewhat lower intellectual function compared to controls (Gaudieri et al., 2008; Naguib, Kulinskaya, Lomax, & Garralda, 2009) across a number of verbal and visual spatial abilities. Further, both hypo- and hyperglycemia have been associated with poorer cognitive function (Desrocher & Rovet, 2004; Naguib et al., 2009). However, the fact that IQ continued to relate to HbA1c when illness duration was taken into account lends support for the idea that cognitive function is an important resource for good diabetes outcomes. Nevertheless, longitudinal data that allow for testing multiple directions of effects are needed to further address this issue. It is likely that the relationship between cognitive function and diabetes outcomes is a transactional one whereby cognitive function is a resource that can be used to

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support complex regimens needed to maintain glycemic control, and that adequate glycemic control is necessary for optimal cognitive development.

The results of the study should be interpreted in the context of some limitations. First, although we included cognitive measures that tap several cognitive constructs (e.g., vocabulary, numerous metrics of EF), the battery was not comprehensive, and several cognitive domains (e.g., spatial processing, learning and memory, visual integration) related to deficits among children with type 1 diabetes (see Gaudieri et al., 2000; Naguib et al., 2009) were not included. Future research would benefit from a comprehensive assessment of cognitive function performance together with relevant mother and adolescent ratings to further understand which cognitive domains are most predictive of diabetes outcomes. Second, the fact that mother and adolescent ratings of cognitive function and adherence were questionnaire-based means that we cannot rule out common method variance as an explanation for why these measures were more related to ADH than performance-based measures. A multi-method approach to adherence that includes more objective measures such as number of blood glucose checks actually downloaded from glucometers would be beneficial in addressing whether questionnaire-based or performance-based measures are more related to ADH. Third, our sample included late adolescents within a restricted age range, and as such may not generalize to other developmental time periods. For instance, Miller et al. (2012) demonstrated that ratings of executive function may be less related to diabetes outcomes during earlier time periods when parents may be more involved in diabetes management. Fourth, recent research has begun to demonstrate the utility of a diabetes specific measure of EF, the The Diabetes Related Executive Functioning Scale (DREFS; Duke, Raymond, & Harris, 2014) that may represent a more appropriate method for EF ratings in this line of research. Lastly, our sample was predominantly female. Gender distribution was affected by the fact that some males at one of the 2 sites were not eligible for participation owing to their plans to be away from their parents after completing high school, a requirement for the aims of the larger study.

The present findings hold important implications for understanding and promoting diabetes management and outcome in late adolescence. Assessment of executive functions and underlying cognitive skills are often used to identify patients who may need additional structure and support to manage complex medical conditions. The present data suggest that questionnaire measures of EF may be useful to identify late adolescents who need assistance with diabetes adherence, which may become increasingly important as they transition to greater independence in adulthood. In particular, self-report assessments of adherence provide much useful information only to the extent that patients feel comfortable disclosing poor adherence. Reporting general self-regulatory failures on EF questionnaires may be less threatening to patients and thus lead to greater disclosure, thereby allowing providers to “flag” patients who may be at risk. The fact that performance-based EF measures were not related to glycemic control independent of underlying intellectual capacity raises questions about the specific role of EF, but may guide targeted assessments and interventions. For example, IQ screening among patients with type 1 diabetes may be useful to identify those who need enhanced assistance from parents and providers to manage their illness at this vulnerable time of development. Future research should focus on identifying clinically relevant cutting scores.

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Table 1

Means, standard deviations, ranges, and zero-order correlations among dependent and independent variables.

Variable	M (SD)	Range	1	2	3	4	5	6	7	8	9	10	11	12
1. HbA1c	8.16 (1.53)	4.40-11.80	1											
2. Pump Status	.47 (.50)	0-1	−.28**	1										
3. Length Dx	7.52 (3.86)	1.12-17.98	.13	.09	1									
4. ADH-self	.00 (1.00)	−3.03-2.68	−.30**	.01	−.08	1								
5. ADH-mom	.00 (1.00)	−3.31-2.83	−.41**	.10	−.07	.66**	1							
6. EF-self	54.11 (10.65)	31-89	.18*	.05	−.01	−.43**	−.30**	1						
7. EF-mom	54.53 (10.55)	35-91	.35**	.00	.02	−.30**	−.42**	.48**	1					
8. BIS-self	20.50 (4.21)	9-28	−.11	.14	.01	−.03	.01	.27**	.09	1				
9. BAS-self	40.03 (5.07)	27-52	−.06	−.09	−.01	−.03	.04	.07	.05	..07	1			
10. BIS-mom	20.40 (4.13)	7-28	.04	.05	−.06	.02	.06	.14*	.20**	.46**	−.01	1		
11. BAS-mom	40.15 (5.44)	21-52	..03	.01	.04	−.02	−.01	.02	.06	.02	.24**	.11	1	
12. IQ-est	11.53 (3.12)	5-18	−.28**	.23**	−.03	.08	.22**	−.06	−.15*	.10	−.10	−.03	−.01	1
13. EF-Perform	.00 (1.32)	−4.11-3.04	−.23**	.20**	−.04	.11	.12	−.12	−.11	.02	−.04	−.02	.00	.36**

Note: N = 196;

ADH-self/mom = Composite score from Self Care Inventory self/mother reports, Diabetes Behavior Rating Scale self/mother reports, and number of daily blood glucose checks reported daily over the course of 2 weeks (higher values reflect better adherence), EF-self/mom = Behavior Rating Inventory of Executive Functioning-Self-Report (BRIEF) self/mother reports (higher values reflect greater EF difficulties), BIS-self/mom = Behavior Inhibition Scale (higher values reflect greater inhibition), BAS-self/mom=Behavior Activation Scale (higher values reflect greater activation), IQ-est = Vocabulary subtest of the Wechsler Adult Intelligence Scale 4th edition (higher values reflect better performance), EF-Perform = Residualized EF Composite controlling for Component Composite (higher values reflect better performance), Pump (higher values reflect better performance), Pump Status coded 1 if on pump and 0 if not on pump.

** $p < .01$;

* $p < .05$

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Table 2

Hierarchical regression results showing the contributions of mother- and self-ratings of EF and EF-performance to adherence (ADH) and glycemic control (HbA1c)

			Teen (DVs: ADH-self, HbA1c)					Mother (DVs: ADH-mom, HbA1c)				
DV	**MOD**	**Step**	**IV/Teen**	R^2_{change}	F_{change}	***Df1,2***	***p***	**IV/Mom**	R^2_{change}	F_{change}	***Df1, 2***	***p***
ADH	1	1	EF-self	0.186	44.38	1, 194	<0.001	EF-mom	0.179	42.22	1, 194	<0.001
		2	EF-perform	*0.004*	0.91	1, 193	0.350	EF-perform	*0.006*	1.36	1, 193	0.250
	2	1	EF-perform	0.012	2.45	1, 194	0.122	EF-perform	0.014	2.85	1, 194	0.094
		2	EF-self	*0.177*	42.29	1, 193	<0.001	EF-mom	*0.170*	40.21	1, 193	<0.001
HbA1c	1	1	EF-self	0.032	6.45	1, 194	0.012	EF-mom	0.120	26.53	1, 194	<0.001
		2	EF-perform	*0.041*	8.54	1, 193	0.004	EF-perform	*0.035*	7.89	1, 193	0.006
	2	1	EF-perform	0.050	10.10	1, 194	0.002	EF-perform	0.050	10.07	1, 194	0.002
		2	EF-self	*0.024*	4.96	1, 193	0.027	EF-mom	*0.105*	24.09	1, 193	<0.001

Note: Model 2, Step 1 predicting HbA1c is identical for Teen and Mother, as there is no difference in EF-perform (the predictor) or HbA1c (the criterion) across the Teen and Mother models. It is presented here for ease of comparison with Step 2. Italicized values reflect unique variance. MOD=Model; ADH-self/mom = Composite score from Self Care Inventory self/mother reports, Diabetes Behavior Rating Scale self/mother reports, and number of daily blood glucose checks reported daily over the course of 2 weeks (higher values reflect better adherence), EF-self/mom = Behavior Rating Inventory of Executive Functioning-Self-Report (BRIEF) self/mother reports (higher values reflect greater EF difficulties), EF-Perform = Residualized Composite of 8 D-KEFS scores after controlling for D-KEFS Component Composite (higher values reflect better performance).

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Table 3

Hierarchical regression results showing the contribution of EF to adherence (ADH) and to glycemic control (HbA1c) after controlling for IQ and Response Style

DV	Step	IV	R^2_{change}	F_{change}	Df1, 2	p
ADH-self	1	IQ-estimate	0.01	0.51	3, 192	.672
		BIS/BAS-self				
	2	EF-self*	*0.23*	44.71	1, 191	<0.001
ADH-mom	1	IQ-estimate*	0.05	3.46	3, 192	0.018
		BIS*/BAS-mom				
	2	EF-mom*	*0.17*	42.85	1, 191	<0.001
HbA1c	1	IQ-estimate*	0.10	4.17	5, 190	0.002
		BIS/BAS-self				
		BIS/BAS-mom				
	2	EF-self	*0.11*	8.94	3, 187	<0.001
		EF-mom*				
		EF-perform				

Note:

ADH-self/mom = Composite score from Self Care Inventory self/mother reports, Diabetes Behavior Rating Scale self/mother reports, and number of daily blood glucose checks reported daily over the course of 2 weeks (higher values reflect better adherence), EF-self/mom = Behavior Rating Inventory of Executive Functioning-Self-Report (BRIEF) self/mother reports (higher values reflect greater EF difficulties), EF-Perform = Residualized Composite of 8 D-KEFS scores after controlling for D-KEFS Component Composite (higher values reflect better performance), BIS-self/mom = Behavior Inhibition Scale (higher values reflect greater inhibition), BAS-self/mom=Behavior Activation Scale (higher values reflect greater activation), IQ-est = Vocabulary subtest of the Wechsler Adult Intelligence Scale 4th edition (higher values reflect better performance).

*Significant predictor in a General Linear Model. Italicized values reflect unique variance.