FEATURE ARTICLE

Associations of Executive Function With Diabetes Management and Glycemic Control in Adolescents With Type 1 Diabetes

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AIMS | The aims of this study were to assess domains of executive function in relation to diabetes management and glycemic control in adolescents with type 1 diabetes and to compare adolescent self-report and parent proxy-report of adolescent executive function.

METHODS | Adolescents with type 1 diabetes ($N = 169$, 46% female, age 15.9 ± 1.3 years) and their parents completed self-report and parent proxy-report versions of the Behavior Rating Inventory of Executive Function (BRIEF).

RESULTS | Self-report and parent proxy-report BRIEF *T* scores were moderately to strongly correlated; parent proxy scores were significantly higher than self-report scores. Executive function problems (Global Executive Composite *T* score ≥60) occurred in 9% of adolescents by self-report and 26% by parent proxy-report. For almost all Metacognition Index scales, elevated (*T* score ≥60) parent proxy scores were associated with lower adherence, lower adolescent diabetes self-efficacy, and more parent involvement in diabetes management. Elevated scores on several Metacognition Index scales were associated with less pump use (Plan/Organize by self-report, Initiate by parent proxy-report, and Monitor by parent proxy-report) and higher A1C (Plan/Organize by self-report and parent proxy-report and Organization of Materials by parent proxy-report). The only significant associations for the Behavioral Regulation Index scales occurred for adherence (by parent proxy-report) and diabetes self-efficacy (by self-report and parent-report).

CONCLUSION | Adolescents with type 1 diabetes who have problems with metacognition may need additional support for diabetes self-management.

Executive function refers to a set of cognitive processes involving emotion regulation and goal-directed, problem-solving behaviors such as planning, organization, attention, initiation, inhibition, and working memory (1,2). Development of executive function begins in early childhood and continues throughout adolescence and into young adulthood (3). Adolescence is also a time of increasing independence from parents and family. For adolescents with type 1 diabetes, responsibility for daily diabetes management shifts from parents to adolescents. Diabetes management is multifaceted and involves checking glucose levels, estimating carbohydrate intake, determining insulin doses, and administering insulin, while considering factors such as exercise and acute illnesses. Suboptimal executive function can create additional challenges to diabetes self-care in adolescents (4). Previous studies in adolescents with type 1 diabetes have found that poorer executive function is associated with poorer diabetes management adherence and higher A1C (5–9).

The Behavior Rating Inventory of Executive Function (BRIEF) (10) has been used frequently in research settings to assess executive function of children and adolescents with type 1 diabetes. The BRIEF provides a parent proxy-report of adolescent executive function (a teacher version also available). The BRIEF-Self-Report (BRIEF-SR) is a companion self-report version, validated in youth aged 11–18 years (11). The BRIEF-Parent (86 items) and BRIEF-SR (80 items) are composed of eight clinical scales measuring specific aspects of executive function, two summary indices (the Behavioral Regulation Index [BRI] and the Metacognition Index [MI]), and an overall score (Global Executive Composite [GEC]).

Although the BRIEF has been widely used in adolescents with type 1 diabetes, many of these studies have reported *T* scores for only the GEC or selected scales (5,12,13). The clinical scales provide a detailed assessment about specific areas of executive function problems that may create

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difficulties with diabetes management for adolescents. The BRI scales measure a person's abilities to appropriately inhibit thoughts and actions, shift attention between tasks or topics, solve problems in a flexible manner, and modulate emotional responses. Adolescents with type 1 diabetes who have problems with behavioral regulation may have difficulty stopping an activity to check a glucose level or administer insulin. They may also become extremely frustrated or exhibit overly emotional reactions to out-of-range glucose levels.

The MI scales measure an individuals' abilities in areas such as planning and initiating an activity, generating problem-solving strategies, holding information in working memory, and maintaining organization in their environment. Adolescents with type 1 diabetes who have problems with metacognition may have difficulties keeping track of supplies or gathering the information needed to calculate an insulin dose. They may also have difficulties troubleshooting problems with insulin pumps or continuous glucose monitoring (CGM) systems.

In this study, we aimed to assess whether specific domains of executive function (BRIEF clinical scales) have differing relationships with various aspects of diabetes management and glycemic control. We also sought to provide detailed descriptive data (mean and SD of *T* scores) for the GEC, BRI, MI, and all clinical scales for the BRIEF-Parent and BRIEF-SR in a contemporary sample of adolescents with type 1 diabetes. Few studies in adolescents with type 1 diabetes have used both the BRIEF-Parent and the BRIEF-SR (9,14). Because BRIEF-SR scores are generally lower than BRIEF-Parent scores (11), it is difficult to compare data across multiple studies using different raters (i.e., adolescent self-report in one study vs. parent proxy-report in another study). The report of BRIEF-Parent and BRIEF-SR data from a single sample provides a valuable source for comparison by researchers using the BRIEF-Parent and/or BRIEF-SR in other samples of adolescents with type 1 diabetes or other chronic health conditions.

Research Design and Methods

Participants

Study participants were 169 adolescents with type 1 diabetes and 168 parents/guardians (hereafter referred to as parents) of the adolescents. One parent was excluded from analyses because of too many missing responses on the measure of executive function. The participants were enrolled in a longitudinal study aimed at improving self-care and glycemic outcomes in adolescents with type 1 diabetes; results from the entire study have been previously published (15).

Participants in the current report agreed to participate in an ancillary nonintervention study involving assessment of adolescent executive function. The primary aim of the ancillary study was to assess the relationship between executive function and diabetes management and glycemic control in adolescents with type 1 diabetes. The ancillary study was conducted at one of the two sites involved in the longitudinal study. All of the site's participants agreed to participate in the ancillary study.

Data were collected from January 2015 to March 2016. Eligibility criteria for the main study included: age 13–17 years, type 1 diabetes duration ≥6 months, daily insulin dose ≥0.5 units/kg, A1C 6.5–11.0%, fluency in English (for completion of surveys), clinical care at the study site, no significant developmental or cognitive disorder that would prevent full study participation, and no significant mental illness (i.e., major psychiatric disorder or inpatient psychiatric admission in the previous 6 months). The institutional review board at the Joslin Diabetes Center approved the ancillary study protocol, and adolescents/parents provided written informed assent/consent before completing any study procedures.

Executive Function Data

The BRIEF-Parent and BRIEF-SR were used to assess adolescents' executive function (10,11). Parents completed the 86-item BRIEF-Parent form, which has been validated in parents of youth aged 5–18 years. Adolescents completed the 80-item BRIEF-SR, which has been validated in youth aged 11–18 years. Each item on the BRIEF-Parent and BRIEF-SR describes a behavior for which the respondent rates the degree to which it has been a problem in the past 6 months by selecting the rating "never," "sometimes," or "often." Examples include "I have problems getting started on my own" and "I react more strongly to situations than my friends." The BRIEF-Parent and BRIEF-SR are each composed of eight clinical scales assessing specific aspects of executive function: Emotional Control, Inhibit, Shift, Monitor, Organization of Materials, Plan/Organize, Initiate (BRIEF-Parent only), Task Completion (BRIEF-SR only), and Working Memory. The clinical scales are summarized in the BRI and MI, and overall executive function is represented by the GEC, which includes all clinical scales.

The BRIEF-Parent and BRIEF-SR were completed on paper, and trained research staff double data-entered responses into the BRIEF Software Portfolio (PAR, Inc.), which calculates age- and sex-adjusted *T* scores for the GEC, BRI, MI, and clinical scales. *T* scores can range from 30 to 100, with a mean of 50 and an SD of 10. Higher *T* scores indicate poorer executive function. *T* scores ≥60 are considered mildly elevated, and those ≥65 are considered clinically elevated.

Two parents scored at the cutoff score on the BRIEF validity scales—one on the Inconsistency Scale and the other on the Negativity Scale. After careful review of both parents' responses, neither was determined to be invalid; therefore, both were retained in the data set. None of the adolescents scored at or above the cutoff score on the validity scales.

Medical, Diabetes, and Demographic Data

Medical and diabetes treatment information was collected by parent/adolescent interview and medical record review on the same day the BRIEF-Parent and BRIEF-SR were completed. Demographic data (e.g., race/ethnicity and parental education level) were obtained from a survey completed by parents. Diagnosis of attention deficit/hyperactivity disorder (ADHD) was obtained from parent/adolescent reports. A1C was measured by immunoturbidimetric methodology using the Roche Cobas Integra assay (reference range 4.0–6.0%; Roche Diagnostics, Indianapolis, IN). Adolescents and parents also completed the following surveys on tablet computers using REDCap software (16).

Diabetes Management Questionnaire

The Diabetes Management Questionnaire (17) measures adherence to diabetes care tasks over the past month. Adolescents and parents completed parallel versions of the survey. The survey has 20 items (e.g., "How often did you or your parent/guardian check your blood sugar before physical activity?"), answered on a five-point Likert scale with answers ranging from "almost never" to "almost always." Total scores range from 0 to 100, with higher scores indicating better adherence. In the study sample, the Cronbach α was 0.84 for adolescents and 0.82 for parents.

Diabetes Management Self-Efficacy Survey

The Diabetes Management Self-Efficacy Survey (18) measures an adolescent's confidence in completing diabetes management tasks in that moment (i.e., "right now"). Adolescents and parents completed parallel versions of the survey; adolescents rated their own diabetes self-efficacy, and parents rated their child's diabetes self-efficacy. The survey has 16 items (e.g., "I am sure that I can remember to inject or bolus my insulin before eating"), answered on a five-point Likert scale with answers ranging from "disagree a lot" to "agree a lot." Total scores range from 0 to 100, with higher scores indicating higher diabetes self-efficacy. In the study sample, the Cronbach α was 0.90 for adolescents and 0.94 for parents.

Diabetes Family Responsibility Questionnaire

The Diabetes Family Responsibility Questionnaire (19) measures parental involvement in diabetes management tasks over the past month. Adolescents and parents completed parallel versions of the survey. The survey has 19 items (e.g., "Giving insulin injections or boluses [pump]"), for which adolescents and parents each rated who had primary responsibility for carrying out that diabetes task, with answer options of "child," "equal," and "parent." Total scores range from 0 to 100, with higher scores indicating more parental involvement. In the study sample, the Cronbach α was 0.80 for adolescents and 0.85 for parents.

Statistical Analyses

Statistical analyses were performed with SAS, v. 9.4 (SAS Institute, Cary, NC). BRIEF-SR and BRIEF-Parent *T* scores were compared using paired *t* tests and Pearson correlations (20). For both the BRIEF-SR and BRIEF-Parent, we calculated the percentage of adolescents with at least mild problems (*T* score ≥60) and the percentage with clinically significant problems (*T* score ≥65) in executive function. McNemar's test was used to assess agreement between elevated scores on the BRIEF-SR and BRIEF-Parent. Fisher exact, *t*, and χ^2 tests were used to examine associations between demographic and diabetes characteristics and executive function problems (*T* score ≥60). Because mild problems with executive function may affect diabetes management, we used the cutoff score of 60, which has been used in previous reports (21), for these analyses. Because of the number of comparisons, $P < 0.01$ was considered statistically significant.

Results

Participant Characteristics

Participant characteristics and diabetes survey scores for the 169 adolescents (46% female) and 168 parents (83% mothers) are shown in Table 1. The mean age was 15.9 ± 1.3 years, and the mean diabetes duration was 8.4 ± 3.7 years. The sample was relatively homogeneous: 88% were non-Hispanic White, 72% had a parent with at least a college degree, and 67% were using an insulin pump. The mean A1C was 8.5 ± 1.2%, and only 16% had an A1C <7.5%. Fourteen percent self-reported a diagnosis of ADHD. Adolescents' and parents' reports of diabetes adherence were similar (Table 1). Adolescents' ratings of diabetes self-efficacy were significantly higher than those of parents ($P < 0.0001$), and adolescents reported significantly less

TABLE 1 Participant Characteristics

Characteristic	Mean ± SD or %
Age, years	15.9 ± 1.3
Female sex	46
Non-Hispanic White race	88
Parent education	
Less than college degree	28
College degree	33
Graduate school degree	39
ADHD	14
Diabetes duration, years	8.4 ± 3.7
Daily insulin dose, units/kg	0.97 ± 0.28
Insulin pump use	67
Blood glucose monitoring frequency, times/day	4.5 ± 2.1
CGM use	21
A1C, %	8.5 ± 1.2
Diabetes adherence	
Adolescent report	68 ± 15
Parent report	68 ± 14
Diabetes self-efficacy	
Adolescent report	82 ± 16
Parent report	72 ± 22
Diabetes parent involvement	
Adolescent report	36 ± 13
Parent report	44 ± 14

parental involvement in diabetes management than did parents (P <0.0001).

BRIEF-SR and BRIEF-Parent Scores

BRIEF-Parent T scores were significantly higher than BRIEF-SR scores for the GEC, BRI, MI, and all clinical scales (all P <0.0001) (Table 2). Nonetheless, BRIEF-SR and BRIEF-Parent scores were moderately to strongly correlated on the GEC (R = 0.62), BRI (R = 0.61), MI (R = 0.59), and clinical scales (R = 0.47–0.60) (all P <0.0001).

The percentages of elevated BRIEF-SR and BRIEF-Parent scores are shown in Table 3. Four percent of adolescents had clinically significant executive function problems (GEC ≥65) by BRIEF-SR, compared with 16% by BRIEF-Parent (P <0.0001). Nine percent of adolescents had at least mild executive function problems (GEC ≥60) by BRIEF-SR, compared with 26% by BRIEF-Parent (P <0.0001). The percentage of adolescents with T scores ≥60 on the BRI, MI, and clinical scales ranged from 5 to 17% on the BRIEF-SR and 15–35% on the BRIEF-Parent. Scores on the GEC, BRI, MI, and clinical scales were more likely to be elevated (≥60) by parent proxy-report than by adolescent self-report (P <0.0001 for GEC, MI, Working Memory, Plan/Organize, and Organization of Materials; P = 0.0002 for BRI; P = 0.0003 for Shift and Emotional Control; and P = 0.003 for Inhibit).

Neither elevated BRIEF-SR T scores nor elevated BRIEF-Parent T scores on the GEC, BRI, or MI were significantly associated with adolescent sex, age, age at diabetes diagnosis, or diabetes duration. Racial/ethnic minorities were more likely to have BRI T scores ≥60 on the BRIEF-Parent compared with non-Hispanic White adolescents (45 vs. 15%, P = 0.003). Adolescents with self-reported ADHD were more likely than adolescents without ADHD to have GEC T scores ≥60 on the BRIEF-Parent (71 vs. 18%, P <0.0001) and MI T scores ≥60 on both the BRIEF-SR (29 vs. 7%, P = 0.004) and BRIEF-Parent (79 vs. 18%, P <0.0001).

We examined the level of concordance between BRIEF-SR and BRIEF-Parent reports of executive function problems. Concordance was defined as both BRIEF-SR and BRIEF-Parent <60 or both ≥60. Discordance was defined as BRIEF-SR <60 and BRIEF-Parent ≥60 or BRIEF-SR ≥60 and BRIEF-Parent <60. Concordance between BRIEF-SR and BRIEF-Parent T scores was 81% on the GEC, 85% on the BRI (80–85% on BRI clinical scales), and 78% on the MI (70–79% on MI clinical scales) (Figure 1). Discordance resulting from an elevated BRIEF-Parent score without an elevated BRIEF-SR score was 18% on the GEC, 13% on the BRI (12–16% on BRI clinical scales), and 20% on the MI (19–27% on MI clinical scales). Discordance resulting from an elevated BRIEF-SR score without an elevated BRIEF-Parent score was low, ranging from 1 to 4% on the GEC, BRI, MI, and clinical scales.

Associations Between Elevated (≥60) BRIEF-SR and BRIEF-Parent T Scores and Diabetes Characteristics

GEC, BRI, and MI

Elevated BRIEF-SR scores on the GEC and BRI were associated with lower self-reports of diabetes self-efficacy (GEC P = 0.008, BRI P = 0.007). There were no other significant associations between elevations on the BRIEF-SR GEC, BRI, and MI and diabetes characteristics. Problems with executive function by parent proxy-report were associated with several diabetes characteristics (Table 4). Elevated BRIEF-Parent scores on the GEC, BRI, and/or MI were associated with lower rates of insulin pump use (GEC P = 0.001, BRI P = 0.0005, MI P = 0.0008), higher A1C (GEC P = 0.008, BRI P = 0.002, MI P = 0.005), lower parent-reported adherence (GEC, BRI, and MI P <0.0001), lower parent-reported adolescent diabetes self-efficacy (GEC P = 0.0008, MI P <0.0001), and more parent-reported parental involvement

TABLE 2 *T* Scores by Adolescent Self-Report (BRIEF-SR) and Parent Proxy-Report (BRIEF-Parent)

Survey Component	BRIEF-SR (*N* = 169)	BRIEF-Parent (*N* = 168)	Difference (95% CI)*	Correlation Coefficient (*R*)*
GEC	45.09 ± 10.41	52.68 ± 11.37	7.68 (6.22–9.13)	0.62
BRI	44.24 ± 9.82	50.57 ± 10.38	6.40 (5.04–7.76)	0.61
Inhibit	44.22 ± 9.04	48.70 ± 8.92	4.52 (3.23–5.80)	0.56
Shift	45.36 ± 10.14	51.32 ± 11.41	6.06 (4.49–7.63)	0.55
Emotional Control	47.17 ± 10.50	51.51 ± 10.94	4.40 (2.89–5.91)	0.57
Monitor†	43.66 ± 8.22	–	–	–
MI	46.45 ± 10.65	53.74 ± 11.60	7.38 (5.85–8.91)	0.59
Initiate	–	53.00 ± 11.71	–	–
Working Memory	46.07 ± 9.99	54.36 ± 12.67	8.33 (6.74–9.92)	0.60
Plan/Organize	46.10 ± 9.93	52.70 ± 11.07	6.65 (5.00–8.31)	0.47
Organization of Materials	47.87 ± 10.01	54.48 ± 10.85	6.76 (5.14–8.37)	0.48
Task Completion	48.16 ± 10.53	–	–	–
Monitor†	–	50.89 ± 10.73	–	–

Data are mean ± SD. *All $P < 0.0001$. †The Monitor scale is part of the BRI in the BRIEF-SR and part of the MI in the BRIEF-Parent.

in diabetes management (GEC $P = 0.0002$, BRI $P = 0.003$, MI $P < 0.0001$).

BRI Clinical Scales

Elevated BRIEF-SR scores on the Shift and Emotional Control scales were associated with lower self-reported diabetes self-efficacy (Shift ≥60 vs. <60: 72 ± 19 vs. 84 ± 15, $P = 0.004$; and Emotional Control ≥60 vs. <60: 72 ± 18 vs. 83 ± 15, $P = 0.004$). No other relationships were statistically significant for the BRIEF-SR BRI clinical scales. Elevated BRIEF-Parent scores on the Inhibit, Shift, and Emotional Control scales were associated with lower parent proxy-reported adherence (Inhibit ≥60 vs. <60: 61 ± 13 vs. 69 ± 14, $P = 0.009$; Shift ≥60 vs. <60: 59 ± 13 vs. 70 ± 13, $P < 0.0001$; and Emotional Control ≥60 vs. <60: 59 ± 11 vs. 71 ± 13, $P < 0.0001$). Elevated BRIEF-Parent scores on the Shift scale were also associated with lower parent-reported diabetes self-efficacy (≥60 vs. <60: 62 ± 24 vs. 75 ± 21, $P = 0.001$).

MI Clinical Scales

Elevated BRIEF-SR scores on the Plan/Organize scale were associated with less pump use (≥60 vs. <60: 25 vs. 71%, $P = 0.002$) and higher A1C (≥60 vs. <60: 9.4 ± 1.3 vs. 8.4 ± 1.1%, $P = 0.005$). No other relationships were statistically significant for the BRIEF-SR MI clinical scales. Elevated BRIEF-Parent scores on the MI clinical scales were associated with numerous diabetes management variables (Table 5). Elevated BRIEF-Parent scores on the Initiate ($P = 0.008$) and Monitor ($P = 0.007$) scales were associated

TABLE 3 Percentages of *T* Scores ≥65 and ≥60 by Adolescent Self-Report (BRIEF-SR) and Parent Proxy-Report (BRIEF-Parent)

Survey Component	BRIEF-SR (*N* = 169)		BRIEF-Parent (*N* = 168)	
	T Score ≥65	*T* Score ≥60	*T* Score ≥65	*T* Score ≥60
GEC	4	9	16	26
BRI	4	8	12	18
Inhibit	4	7	7	15
Shift	6	11	17	23
Emotional Control	7	10	14	22
Monitor*	3	5	–	–
MI	7	10	18	27
Initiate	–	–	17	25
Working Memory	6	10	19	30
Plan/Organize	5	7	17	24
Organization of Materials	8	11	24	35
Task Completion	8	17	–	–
Monitor*	–	–	14	24

*The Monitor scale is part of the BRI in the BRIEF-SR and part of the MI in the BRIEF-Parent.

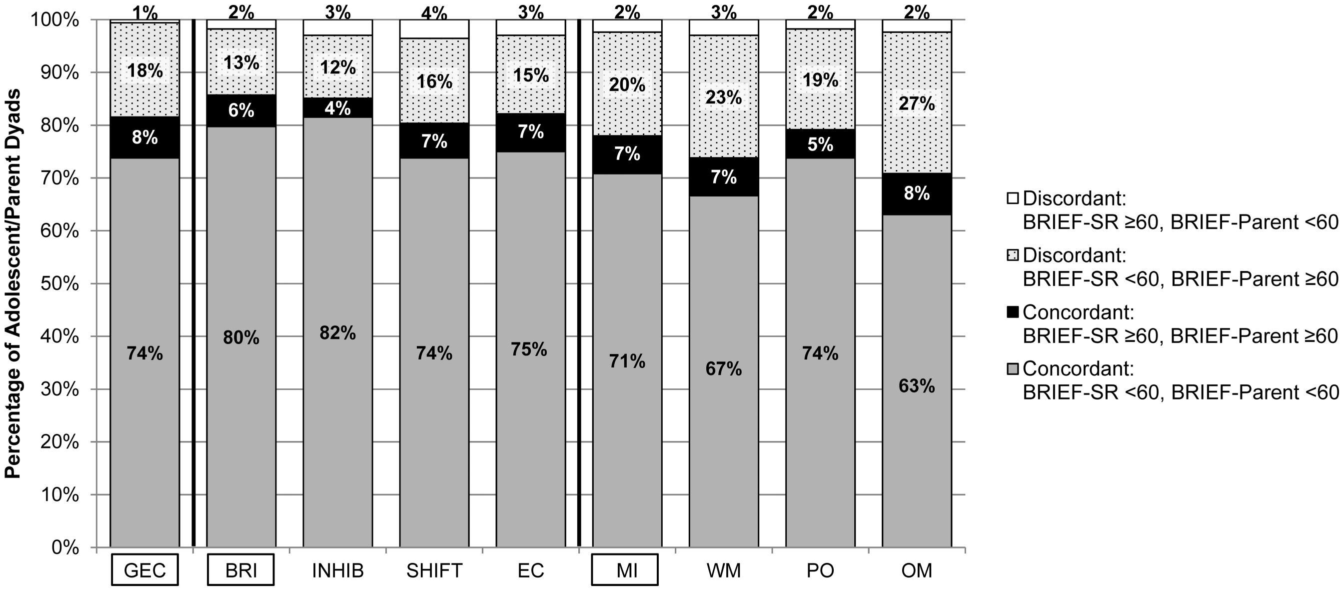

FIGURE 1 Concordance/discordance in adolescent executive function problems by adolescent self-report (BRIEF-SR) and parent proxy-report (BRIEF-Parent). *T* scores ≥60 indicate at least mild executive function problems. EC, Emotional Control; INHIB, Inhibit; OM, Organization of Materials; PO, Plan/Organize; WM, Working Memory.

with less pump use. Elevated BRIEF-Parent scores on the Initiate scale were also associated with less frequent blood glucose monitoring (P <0.01). Elevated BRIEF-Parent scores on the Plan/Organize (P = 0.003) and Organization of Materials (P = 0.003) scales were associated with higher A1C. On all MI clinical scales, elevated BRIEF-Parent scores were associated with lower parent proxy-reported adherence (P <0.0001 to P = 0.0003) and lower parent-reported diabetes self-efficacy (P <0.0001 to P = 0.003). On all MI clinical scales except Initiate, elevated BRIEF-Parent scores were associated with more parent-reported involvement in diabetes management (P <0.0001 to P = 0.007).

Discussion

Assessment of executive function problems in people with type 1 diabetes is important across the life span, including during adolescence. In this study, we examined adolescent self-reports and parent proxy-reports of adolescent executive function, assessed with the validated BRIEF, and associations with diabetes management characteristics and glycemic control in adolescents with type 1 diabetes. Age- and sex-adjusted self-report and parent proxy-report *T* scores on the individual indices and clinical scales were moderately to strongly correlated. However, parent proxy-report scores were significantly higher than self-report scores. These findings are

TABLE 4 Diabetes Management Characteristics According to Parent Proxy Elevations (≥60) on the GEC, BRI, and MI

Characteristic	GEC			BRI			MI		
	<60 (*N* = 125)	≥60 (*N* = 43)	*P*	<60 (*N* = 137)	≥60 (*N* = 31)	*P*	<60 (*N* = 123)	≥60 (*N* = 45)	*P*
Insulin pump use	74	47	0.001	74	39	0.0005	75	47	0.0008
Blood glucose monitoring frequency, times/day	4.7 ± 2.2	3.9 ± 1.6	0.01	4.7 ± 2.2	3.8 ± 1.6	0.02	4.7 ± 2.2	4.0 ± 1.6	0.02
A1C, %	8.4 ± 1.1	8.9 ± 1.3	0.008	8.4 ± 1.1	9.1 ± 1.4	0.002	8.3 ± 1.0	9.0 ± 1.5	0.005
Diabetes adherence score	70 ± 13	61 ± 13	<0.0001	70 ± 13	59 ± 12	<0.0001	71 ± 13	61 ± 14	<0.0001
Diabetes self-efficacy score	75 ± 21	62 ± 24	0.0008	74 ± 21	63 ± 25	0.01	76 ± 20	59 ± 24	<0.0001
Diabetes parental involvement score	41 ± 13	51 ± 16	0.0002	42 ± 14	51 ± 16	0.003	41 ± 13	52 ± 15	<0.0001

Data are % or mean ± SD.

TABLE 5 Diabetes Management Characteristics According to Parent Proxy Elevations (≥60) on the MI Clinical Scales

Characteristic	Initiate			Working Memory			Plan/Organize			Organization of Materials			Monitor		
	<60 (*N* = 126)	≥60 (*N* = 42)	*P*	<60 (*N* = 117)	≥60 (*N* = 51)	*P*	<60 (*N* = 127)	≥60 (*N* = 41)	*P*	<60 (*N* = 110)	≥60 (*N* = 58)	*P*	<60 (*N* = 127)	≥60 (*N* = 41)	*P*
Insulin pump use	73	50	0.008	74	53	0.01	72	54	0.04	72	59	0.09	73	49	0.007
Blood glucose monitoring frequency, times/day	4.8 ± 2.1	3.8 ± 1.8	<0.01	4.8 ± 2.2	4.0 ± 1.7	0.03	4.7 ± 2.2	3.9 ± 1.7	0.02	4.7 ± 2.2	4.2 ± 1.8	0.10	4.7 ± 2.2	4.0 ± 1.6	0.03
A1C, %	8.4 ± 1.1	8.9 ± 1.4	0.03	8.4 ± 1.1	8.8 ± 1.4	0.04	8.4 ± 1.1	9.0 ± 1.3	0.003	8.3 ± 1.0	8.9 ± 1.4	0.003	8.4 ± 1.0	9.0 ± 1.5	0.02
Diabetes adherence score	71 ± 12	59 ± 15	<0.0001	70 ± 13	62 ± 13	0.0003	71 ± 13	60 ± 14	<0.0001	71 ± 14	63 ± 13	0.0002	70 ± 13	61 ± 13	<0.0001
Diabetes self-efficacy score	75 ± 21	62 ± 22	0.002	77 ± 19	60 ± 24	<0.0001	76 ± 20	58 ± 23	<0.0001	75 ± 20	65 ± 24	0.003	75 ± 20	61 ± 25	0.0005
Diabetes parent involvement score	42 ± 14	48 ± 15	0.02	40 ± 13	52 ± 14	<0.0001	41 ± 14	51 ± 15	0.0004	41 ± 14	48 ± 14	0.007	41 ± 14	50 ± 15	0.0006

Data are % or mean ± SD.

consistent with limited previous research comparing adolescent self-report and parent proxy-report BRIEF *T* scores in community-based samples (11,22).

Parent proxy-report scores in our sample were similar to parent proxy-report scores in normative samples (22) and other samples of children and adolescents with type 1 diabetes (5,9,12,21). The BRIEF-SR has been used less frequently in clinical research than the BRIEF-Parent, and, thus, there are fewer data for comparison. In a community-based sample of eighth-graders (aged 13–15 years), the mean BRIEF-SR GEC *T* score was 50.46 (22). In a study by Suchy et al. (9) involving a sample of 196 high school seniors with type 1 diabetes with a mean A1C of 8.2 ± 1.5%, the mean BRIEF-SR GEC *T* score was 54.11. Both of these values are higher than the self-reported GEC *T* score in our sample (45.09), likely reflecting the relatively narrow eligibility criteria of our sample with respect to glycemic control, given their agreement to participate in a longitudinal study aimed at improving diabetes self-care and glycemic control.

In our sample, problems with executive function were not associated with sex, age, or diabetes duration. Most of the significant associations between executive function problems and diabetes characteristics were observed for the MI clinical scales. These scales measure a person's abilities in areas such as planning and initiating an activity, generating problem-solving strategies, holding information in working memory, and maintaining organization in their environment. Adolescents with type 1 diabetes who have problems with metacognition may have challenges with diabetes management tasks (e.g., keeping track of supplies and checking glucose levels). They may also have difficulties gathering the information needed to calculate an insulin dose (e.g., glucose level, carbohydrate amount in meal/snack, and planned activity) or troubleshooting problems with diabetes devices such as insulin pumps or CGM systems. Problems with executive function may lead parents to avoid insulin pump use because pump use tends to place more self-care responsibility in adolescents' hands.

The relationships between executive function and adherence and glycemic control in our sample are in line with previous research (6–8). Not all studies have demonstrated a significant relationship between executive function and glycemic control. However, A1C may be related to executive function through the mediating variable of adherence, as demonstrated by McNally et al. (12). Interestingly, some studies have shown significant relationships between executive function and survey-based measures of adherence but not blood glucose monitoring frequency (5,21). In our study, only the BRIEF-Parent Initiate scale was significantly associated with blood glucose monitoring frequency.

Diabetes management is complex and involves not only checking glucose levels, but also estimating carbohydrate intake, determining insulin doses, and administering insulin, while considering factors such as exercise and acute illnesses. Problems with executive function may negatively affect these many areas of diabetes management. For example, in qualitative semistructured interviews with six adolescents who had type 1 diabetes and ADHD, participants reported problems with establishing and maintaining diabetes management routines and reported that they would like family and school personnel to be more involved in helping them with tasks such as interpreting glucose levels and insulin dose calculations (23). Even as diabetes monitoring and treatment technologies become more automated, executive function is still necessary to integrate information, make treatment decisions, maintain supplies, and troubleshoot technology failures.

Our primary aim was to assess associations between diabetes characteristics and specific components of executive function assessed by individual clinical scales. We found stronger associations for the MI scales than for the BRI scales. In contrast, Miller et al. (24) found that poorer behavioral regulation was associated with poorer adherence over 2 years but did not find an association between metacognition and adherence. However, the study participants were younger (baseline ages 9–11 years) than the participants in our study and may have had more parental involvement in diabetes management, which likely helped overcome the impact of metacognitive challenges. In a longitudinal study by Suchy et al. (25), both behavioral and cognitive aspects of executive function were related to glycemic control during the transition to young adulthood. Osipoff et al. (26) also found an association between metacognitive executive function problems, by parent proxy-report, and higher A1C in youth with type 1 diabetes aged 6–18 years.

Although the BRIEF is one of the most commonly used rating scales for assessing executive function, there are limited published data providing scores and rates of elevations for all components of the BRIEF (i.e., the GEC, BRI, MI, and clinical scales) in adolescents with type 1 diabetes. This article adds valuable new information to the scientific literature by providing such detailed descriptive data for both parent proxy-report and adolescent self-report in a contemporary sample of adolescents with type 1 diabetes. In assessments of adolescent functioning, self-report and parent proxy-report scores are often correlated but may differ in magnitude (27). Thus, the perspectives of multiple raters can provide valuable information when using survey-based assessment tools such as the BRIEF. Indeed, a recent review article on executive function in adolescents and young adults with type 1 diabetes recommended that "future studies incorporate both self and caregiver reports in measurement . . . . Inclusion of adolescents' and young adults' perspective in research and clinical care demonstrate values of their voice in medical decision-making" (28).

The percentage of adolescent/parent dyads in which there was discordance resulting from an elevated BRIEF-Parent score without an elevated BRIEF-SR score ranged from 12–27%, with slightly higher levels of discordance on the MI scales than on the BRI scales. One possible explanation for the differences in scores is social desirability bias. Adolescents may underestimate problems, either consciously or unconsciously, whereas parents may be more willing to rate their adolescent's behaviors as occurring "sometimes" or "often" (vs. "never"). Adolescent and parent perceptions regarding frequency may also differ. Adolescents may perceive that forgetting to bring home school assignments once a week is "sometimes," whereas parents may perceive this to be "often."

One limitation of the study is the relative homogeneity of the study sample. The majority of participants were non-Hispanic White, and approximately two-thirds used an insulin pump. Additional research is needed in more diverse samples. Indeed, the observation of higher rates of executive function problems in racial/ethnic minorities by parent proxy-report may reflect type 1 error, highlighting the need for further study in larger samples. Approximately one-fifth of participants were using CGM, and analyses did not reveal any differences in CGM use according to executive function problems; further research regarding associations of executive function problems and CGM use in other samples with more CGM use will be informative.

Another limitation is that we did not check participants' blood glucose at the time of survey completion to ensure no hypoglycemia or hyperglycemia. We also did not collect data from the medical record regarding diagnosis or management of ADHD, although 14% of the sample had ADHD by self-report.

Finally, the study sample was limited to those who met eligibility criteria for the longitudinal study. The sample did not include adolescents with an A1C >11.0%, significant developmental or cognitive disorders, or significant mental illness, as these factors may have affected individuals' ability to fully participate in the longitudinal study. Future research on executive function can include these youth. Studies have shown that chronic hyperglycemia has a detrimental impact on cognitive function in children and adolescents with type 1 diabetes (29), and rates of executive function problems may have been even higher if individuals with an A1C >11.0% were included in the sample.

Although it is likely not practical to implement the BRIEF as a routine screening measure in clinical settings, diabetes health care providers may be aware of potential difficulties with executive function from other sources such as a diagnosis of ADHD, school-based screening tests, or reports from other health care providers. Providers can also ask adolescents and their parents about difficulties with diabetes management that may signal executive function problems.

If providers do have access to the results of screening measures such as the BRIEF that provide information about specific domains of executive function problems, this information can be particularly helpful in targeting specific areas for intervention. At times, adolescents can be referred for specific testing with trained mental health professionals. When there is information to suggest problems with executive function, providers should work with the adolescent, family, and, possibly, school nurse to provide the additional support needed. This strategy may include increasing parental involvement in the adolescent's diabetes self-management, scheduling more frequent clinic appointments, and/or tailoring the diabetes treatment plan to better match the adolescent's understanding and capabilities. Providers can also help to develop strategies to mitigate difficulties with specific aspects of diabetes management (e.g., checking glucose levels and remembering to carry diabetes supplies). Finally, providers should work with the family and school personnel to ensure that the adolescent has appropriate support at school (e.g., a 504 Plan).

In summary, adequate executive function is important for success in daily tasks. As adolescents take on more responsibilities and become more independent in multiple areas of their life (e.g., school, social activities, work, and health care) and prepare for transitions away from the family to college or the workplace and from pediatric to adult health care settings, executive function plays an important role in whether they will be successful in assuming additional responsibilities and navigating such transitions. In this study, we found that problems with executive function, primarily for the MI clinical scales, were associated with poorer adherence and poorer glycemic control. Adolescents with type 1 diabetes who have problems with metacognition may need additional support from parents, other family members, and health care providers to carry out diabetes management tasks. Thus, identification of executive function problems in adolescents with type 1 diabetes is important, since it can provide an area for active intervention. Further research is needed to elucidate the differences in adolescent self-reports and parent proxy-reports of executive function problems using the BRIEF.

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DUALITY OF INTEREST

No potential conflicts of interest relevant to this article were reported.

AUTHOR CONTRIBUTIONS

M.H. performed data analyses and data interpretation and wrote the first draft of the manuscript. L.K.V. designed the study; collected, analyzed, and interpreted data; and participated in the manuscript writing and revision. R.K.S. and Z.G. performed data collection and interpretation. L.M.L. developed the study conception and design, performed data collection and interpretation, and participated in manuscript revisions. L.M.L. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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