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Executive Functioning, Daily Self-Regulation, and Diabetes Management while Transitioning into Emerging Adulthood

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Abstract

Background Executive functioning (EF) predicts better Type 1 diabetes (T1D) management in the high-risk years after high school, but the daily self-regulation processes involved are unclear.

Purpose To examine whether EF is associated with daily self-regulation that minimizes one's exposure or buffers adverse reactions to daily diabetes problems, and to determine whether these patterns become stronger during the transition out of high school.

Methods A measurement burst design with convenience sampling was used. Seniors in high school with T1D (N = 207; 66% female) completed self-report (i.e., Behavioral Rating Inventory of Executive Functioning) and performance measures of EF (i.e., Delis-Kaplan Executive Function System). A 14-day daily diary assessing self-regulation failures, diabetes problems, affect, and indicators of diabetes management was completed at baseline and 1 year later.

Results Correlations and multilevel modeling were conducted. Lower self-reported EF problems were associated with lower average levels of daily self-regulation failures, and these variables were associated with fewer daily diabetes problems. In contrast, better EF performance was unrelated to average daily self-regulation failures, and was unexpectedly associated with more frequent diabetes problems in year 2. Equally across years, on days participants reported lower than their average levels of daily self-regulation failures, they had fewer diabetes problems, regardless of EF. On days with lower than average diabetes problems, participants reported better diabetes management indicators. EF generally did not buffer daily associations in either year.

Conclusions Regardless of EF, promoting daily self-regulation may prevent diabetes problems and promote T1D management in daily life at this high-risk transitional time.

Lay Summary

Type 1 diabetes (T1D) requires daily self-regulation (e.g., remembering to check blood glucose; regulating emotions, thoughts, and behaviors when diabetes problems arise). These processes draw on executive function (EF) abilities, which may be challenged after high school, when youth experience many life transitions while managing diabetes more independently from parents. The study examined how EF is associated with daily diabetes management as youth transition out of high school. Seniors in high school with T1D completed measures of EF and two 14-day daily diaries, one in the senior year and one the following year. Each evening, participants completed an online survey reporting on self-regulation failures (e.g., forgetting to test blood glucose), diabetes problems, and diabetes management over the past 24 hr. Those with better self-reported EF had lower self-regulation failures and fewer diabetes problems on average. On days with lower self-regulation failures, participants had fewer diabetes problems. On days with fewer diabetes problems, participants reported lower negative emotions, higher confidence in diabetes management, and better self-care behaviors and blood glucose levels. These daily associations occurred regardless of EF. Providing youth with training in self-regulation to prevent daily diabetes problems may promote T1D management during this high-risk transition.

Keywords Emerging adulthood · Diabetes self-management · Executive functioning · Self-regulation · Daily diary · Type 1 diabetes

Introduction

Type 1 diabetes (T1D) management is a challenging daily self-regulation task, particularly during late adolescence and early emerging adulthood [1]. Individuals with T1D must coordinate complex behaviors throughout the day (e.g., check blood glucose [BG] levels, count carbohydrates, adjust insulin dosing) to keep BG levels close to the normal range. This requires ongoing self-regulation such as developing plans and remembering to complete diabetes management tasks in daily life to prevent the occurrence of diabetes-related problems. Individuals must also regulate emotions, cognitions, and behaviors to normalize BG levels as diabetes problems arise.

Self-regulation may be challenged in early emerging adulthood (ages 18–25 years), when youth experience numerous life transitions while managing T1D more independently (e.g., transitioning out of high school and into other school or work environments, developing a network of support for diabetes care beyond parents, transferring from pediatric to adult care) [2]. This developmental period is a time of risk, with many showing low self-management behaviors and their highest (i.e., poorest) BG levels in the initial years after high school [3]. Understanding factors that underlie these patterns is crucial because elevated BG levels are associated with serious microvascular complications [4].

Executive functioning (EF) may facilitate the type of self-regulation that could foster better T1D management in early emerging adulthood [5]. EF comprises a set of neurocognitive processes that allow one to plan, select, initiate, and maintain behaviors that are beneficial for long-term functioning, and to adapt through effective problem-solving when unexpected challenges arise [6]. Most studies of EF and T1D management have utilized self- or parent-reports of EF problems, but some have measured objective EF performance. These measures are not commensurate. Self-reported EF problems are believed to capture how low EF may be revealed in daily life, while performance measures capture EF capacity in a controlled setting [7–9]. These measures show somewhat different associations with T1D management. Greater self- or parent-reported problems with EF have been associated with lower self-management behaviors and/or higher BG both concurrently [10–12] and across adolescence [13, 14]. EF performance, however, has been less consistently associated with self-management behaviors and BG levels [15]. In the present sample, higher self-reported problems in EF were associated with lower self-management behaviors and higher BG levels concurrently, while EF performance was not. In contrast, only EF performance predicted slower deterioration in BG levels over the subsequent 3 years [7].

Few studies have examined how EF may facilitate T1D management in daily life. The present study examined how EF was associated with two aspects of daily self-regulation and T1D management: (a) one's *exposure* to daily diabetes problems and (b) one's cognitive, behavioral, and affective *reactions* when such problems occur. Daily diabetes problems refer to the ongoing hassles, burdens, and stress of managing T1D in daily life [16, 17]. Such problems have been associated with heightened negative affect, lower perceived self-efficacy, lower self-management behaviors, and higher BG levels during adolescence [18–20].

A "reduced exposure" model was initially examined. In this model, it was theorized that better EF would be associated with the experience of fewer daily diabetes problems. Better EF is associated with greater planning for how to achieve diabetes goals in daily life [21] and with fewer lapses in daily self-regulation surrounding T1D management tasks (e.g., less likely to forget or be distracted) [22]. Such daily self-regulation is likely to minimize the occurrence of daily diabetes problems. EF also allows individuals to maintain cognitive control and problem-solve in the moment as one encounters unexpected situations [6]. Thus, EF may also moderate the effects of self-regulation lapses, preventing or limiting them from turning into more problematic situations [21, 23]. Together, such daily self-regulation may allow those with better EF to limit the occurrence of daily diabetes problems.

A "reduced reactivity" model was also examined. In this model, it was theorized that EF may provide a foundation for individuals to better regulate emotions, cognitions, and behaviors on days when diabetes problems occur [6]. Higher EF-related constructs have been associated with lower negative emotional reactions to daily stress [19, 24], and higher confidence in one's ability to complete health-behaviors when encountering barriers [25]. EF has also been related to a greater ability to accomplish health behavior intentions [26] and to remain task-focused in the face of daily hassles [24]. Such patterns suggest that those with greater EF may be less reactive to diabetes problems as they occur. That is, EF may buffer associations between daily diabetes problems and adverse indicators such as negative affect, lower self-efficacy, and lower T1D self-management.

Emerging adulthood may create new challenges for these self-regulatory processes as young people face normative stressful transitions while managing T1D more independently from parents [2, 17]. Longitudinal studies revealed that EF was a stronger predictor of BG when parents were less involved in T1D during late adolescence [14] and early emerging adulthood [27]. We expected EF would be especially important as young people transition to greater independence in the year after high school, when they need to manage T1D while facing new daily social contexts (e.g., work, school, living situation) away from parents.

In summary, the present study examined how self-reported EF problems and EF performance related to the daily self-regulation needed to facilitate T1D self-management as young people transition from the senior year in high school into early emerging adulthood. Aim 1 examined whether EF was associated with daily self-regulatory processes that may minimize the experience of daily diabetes problems. We hypothesized that EF would be associated with lower daily self-regulation failures, and that both EF and lower self-regulation failures would be associated with fewer same day diabetes problems. We further hypothesized that EF may moderate the associations of daily self-regulation with daily diabetes problems, such that those with better EF would experience fewer diabetes problems even on days they had more self-regulation failures. Aim 2 examined whether EF was associated with better daily regulation of emotion (i.e., negative affect), cognition (i.e., self-efficacy), and behavior (i.e., self-management behaviors), all of which are necessary to maintain or normalize BG as diabetes problems arise. We hypothesized that on days with more diabetes problems, participants would display higher negative affect, lower self-efficacy, lower self-management behaviors, and higher BG. We also hypothesized that EF would buffer these associations, expecting those with better EF to display less adverse indicators on days with more diabetes problems. Aim 3 examined whether EF associations became stronger across the year after high school.

Method

Participants

High school seniors with T1D were recruited for a longitudinal study with a measurement burst design [28] to examine how self-regulation was associated with T1D management across the transition into emerging adulthood. Using convenience sampling, participants were recruited in clinic or by mail and phone from pediatric endocrinology clinics in two southwestern U.S.

cities. Late adolescents were eligible to participate if they had been diagnosed with T1D for at least one year, had English as their primary language, were in their final year of high school, lived with a parent, were able to have regular contact with parents over the subsequent 2 years, and had no condition to prohibit study completion (e.g., blindness). Of the qualifying 507 individuals, 247 (47%) completed baseline assessments. Reasons for not participating included being too busy (34%) and lack of interest (33%); 20% declined to give a reason. At one site, the Institutional Review Board (IRB) permitted medical record reviews for those who declined. Participants and nonparticipants did not differ on HbA1c, illness duration, gender, or pump status, but participants were more likely to be Hispanic (21% vs. 11%), χ^2 (1) = 3.88, p = .049.

Procedure

The study was approved by the relevant IRBs. Participants were enrolled and completed daily diary data between 2011 and 2014, and thus were not affected by COVID-19. In year 1, procedures involved an initial in-person session where participants provided informed consent or assent; assented adolescents were consented when they reached age 18. Participants also completed performance-based cognitive measures, received instructions for completing online surveys and daily diaries, and completed an HbA1c assay. Because extreme BG levels can affect cognitive performance [5], participants checked their BG prior to cognitive testing; participants completed testing if their BG levels were between 75 and 400 mg/dL. Participants who scored outside this range took steps to address the problem (e.g., eat a snack) and BG was retested every 15 min until in range. BG levels in the testing session were unrelated to performance measures of EF and IQ (r values < 0.13, p values >. 11).

Following the in-person session, participants received an email link to a confidential online survey with instructions to complete the survey individually. Surveys assessed self-reported EF problems at baseline, as well as variables relevant to the broader study. After the survey, a 14-day diary protocol began. At the end of each day, participants received a secure electronic link to a brief survey. Phone call or text message reminders were sent if they had not completed the diary by 9 PM. The 14-day diary and HbA1c assay were repeated in year 2. Participants received $50 for the online survey and HbA1c test and $5 for each daily diary.

Instruments

Cognitive measures

EF performance.

The Delis-Kaplan Executive Function System battery (D-KEFS) [29] was used. Four subtests were completed to measure EF: Trail Making (Number Letter Sequencing completion time); Color-Word Interference (Inhibition and Inhibition/Switching completion times); and Verbal (Letter and Category correct responses) and Design Fluencies (number of correct responses for 3 conditions). The mean of the resulting eight norm-based age-corrected scaled scores was computed to create an EF composite score per manual procedures [29]. Reliability in the full sample was α = 0.84. Given the hierarchical structure of cognition [30], psychomotor speed was also measured using Motor Speed from Trail Making. Psychomotor speed was covaried in all EF performance analyses to isolate EF from lower-order component processes known to confound EF test performance [5, 12].

Self-reported EF problems.

Adolescents completed the widely used Behavior Rating Inventory of Executive Functioning—Self-Report (BRIEF) to assess problems with EF in daily life [31]. Example items include "I forget to hand in my homework even when it's completed" and "I have trouble finishing tasks." Participants rated each of 80 items on a 3-point scale (0 = *never* to 2 = *often*) to indicate the frequency of each problem in the past 6 months. Items were combined into a global EF composite score following manual procedures. Higher scores reflected greater self-reported EF problems or lower EF (α = 0.96).

Estimated IQ.

During cognitive testing, participants completed the Vocabulary subtest of the Wechsler Adult Intelligence Scale—Fourth Edition to estimate crystallized IQ (split-half reliability = 0.93) [32]. This subtest is a highly reliable estimate of crystallized verbal IQ and Full Scale IQ [30, 32]. This was used as a covariate in all analyses because IQ underlies many daily activities and is associated with both self-report and performance measures of EF [6].

Daily diary measures

Daily self-regulation failures.

Self-regulation failures were assessed with eight items involving cognitive, behavioral, and emotional control failures surrounding BG checking [22]. We focused on BG checking because this behavior is central to normalizing BG levels. Items such as "Each time I was about to test my BG, I got distracted by something else" were rated using a *strongly disagree* (1) to *strongly agree* (5) scale. Reliability was calculated via Hierarchical Linear Modeling (HLM) random intercept models, with time and item as nested levels (α = 0.98 and 0.92 at years 1 and 2). Average daily scores were analyzed.

Frequency of daily diabetes problems.

Participants completed a checklist of five diabetes problems (e.g., feeling bad because of diabetes, dealing with low/high BG) derived from coding open-ended descriptions of mother- and adolescent-reported stressful diabetes events [16]. The frequency of daily diabetes problems was obtained by summing the number of diabetes problems endorsed each day.

Daily negative affect.

Negative affect over the past 24 hr was measured with 9 items, 3 each reflecting depressed mood, anxious mood, and anger [33]. Items were rated on a *not at all* (1) to *extremely* (5) scale. Average scores were analyzed (α = 0.88, accounting for time via HLM).

Daily diabetes self-efficacy.

Daily self-efficacy tapped participants' beliefs in their ability to complete T1D management tasks in daily life. The item "How confident were you in your ability to manage diabetes in the past 24 hours?" was rated using a *not at all* (1) to *extremely* (5) scale [34]. Higher values indicate higher diabetes self-efficacy.

Daily BG checks and levels.

Participants reported each BG reading recorded on their glucometer at the end of each day. The number of BG checks was analyzed as a second index of daily adherence [35], and the average BG level each day was calculated. Average daily BG level was 188.17 (SD = 60.94) and 184.72 (SD = 51.83) mg/dL in years 1 and 2, respectively. Because these values exceed the 180 mg/dL level considered to be hyperglycemic [36], higher values were interpreted as poorer BG.

Analysis Plan

Across all included variables, most cases had complete data (year 1 = 76.51%; year 2 = 76.29%). We accounted for missing data by generating 10 datasets through multiple imputation (MI) [37]. The imputation procedure included variables beyond the current analyses to ensure an adequate "missing-at-random" model. The MI procedure for the survey data was conducted in SPSS v 25 [38]; the multilevel MI procedure for the diary data was conducted separately in Mplus7 [39]. In both procedures, missing data were imputed at the level of the variable (i.e., scale scores) rather than the item. Coefficients were pooled automatically within SPSS, following standard univariate pooling.

Aim 1 (i.e., EF associations with fewer daily self-regulation failures and diabetes problems) was initially analyzed by computing correlations between EF and an individual's average report of daily self-regulation failures aggregated across the 2-week diary period; correlations were computed separately by year. Given the nested structure of the data (i.e., days were nested within participants repeatedly across years), multilevel models were conducted to estimate within- and between-person effects of self-regulation failures and EF predicting daily diabetes problems [40]. At Level 1 (within-person), we examined whether day-to-day fluctuations in self-regulation failures were associated with day-to-day fluctuations in diabetes problems. At Level 2 (between-person), we added on the intercept average daily self-regulation failures aggregated across each diary as well as EF to examine whether these between-person differences were associated with diabetes problems. We then tested for the cross-level interaction to determine whether EF moderated the daily associations between self-regulation failures and diabetes problems. Finally, we included year as a repeated factor to discern whether these associations differed across the transition year out of high school (Aim 3). Daily self-regulation (i.e., Level 1) was mean centered within-person within year, indicating a person's daily fluctuations from his or her own mean across the 14 days. The mean of daily self-regulation failures (i.e., Level 2) was computed as each person's average self-regulation across the 14 days within year, and was grand mean centered separately for each year. EF, which was measured only in year 1, was grand mean centered. Year was effect coded as −1 (year 1) and 1 (year 2).

Separate analyses were conducted for self-reported EF problems and EF performance measures. Covariates were placed on the intercept, and included variables that are often associated with T1D management or that may confound EF effects (i.e., sex, pump status, IQ and, for EF performance, processing speed). Equations to illustrate these analyses are reported in Supplement Material 1.

A parallel set of multilevel models was used to examine Aim 2 (i.e., EF buffers associations between daily diabetes problems and adverse daily indicators of emotion, cognition, behavior, and BG). That is, the analyses reported above were repeated, but with daily diabetes problems as the Level 1 predictor, daily indicators of diabetes management as the Level 1 outcome, and mean daily problems and EF as Level 2 predictors.

Finally, because frequency of both diabetes problems and BG checks were count data, we also analyzed these outcomes using Poisson multilevel regressions. With one exception, coefficients across the two multilevel modeling approaches were consistent in terms of direction and significance of effects (see Supplement Material 2).

Results

At baseline, 236 participants provided survey and valid cognitive data. These participants had a mean HbA1c of 8.27% (*SD* = 1.62), a mean illness duration of 7.34 years (*SD* = 3.88), and 43% were on an insulin pump; 62% were female; 75% identified as non-Hispanic White, 14% as Hispanic, and 5% as African American; 60% and 52% of their mothers and fathers had less than a Bachelor's degree, 33% and 26% had a Bachelor's degree, and 8% and 22% had more than a Bachelor's degree. The present study analyzed data from the 207 participants who completed a daily diary protocol in year 1 and year 2. These 207 participants did not differ from the 29 who did not complete both daily diaries on age, ethnicity, pump status, self-reported EF problems or EF performance (p values > .238). However, they had lower HbA1c at baseline, $t(228) = 2.434$, $p = .016$, and were more likely to be female, χ^2 (1, N = 236) = 10.882, $p = .001$. Adolescents in this n = 207 sample were 66% female, had an average age of 17.78 (*SD* = 0.40) years, and a mean HbA1c of 8.17% (*SD* = 1.64) at baseline. All participants lived in their parental home in year 1; 50% remained living at home, while 50% moved out of their parental home in year 2. Adolescents completed an average of 11.22 diaries (*SD* = 3.59) in year 1 and 11.04 diaries (*SD* = 3.75) in year 2. Participants experienced diabetes problems on most days, reporting at least one diabetes problem on 67% of days (*SD* = 29) in year 1, and 63% of days (*SD* = 35) in year 2. An average of 1.20 (*SD* = 0.81) and 1.12 (*SD* = 0.85) problems per day were reported in years 1 and 2, respectively.

Reduced Exposure Model: EF and the Occurrence of Daily Diabetes Problems

Bivariate correlations examined associations of EF with aggregated mean scores for daily self-regulation failures in years 1 and 2. Consistent with expectations, individuals with more self-reported EF problems (i.e., higher BRIEF) reported higher self-regulation failures on average across each of the 2-week diary periods ($r_{\text{year 1}} = 0.315$, $p < .001$; $r_{\text{year 2}} = 0.232$, $p = .001$). In contrast, better EF performance was unrelated to average daily self-regulation failures at each time point ($r_{\text{year 1}} = -0.009$, $p = .897$; $r_{\text{year 2}} = 0.039$, $p = .589$).

Multilevel models displayed in Table 1 revealed both between- and within-person associations of daily self-regulation with diabetes problems. At the between-person level (see row for mean daily self-regulation failures), those with lower mean daily self-regulation failures reported fewer daily diabetes problems on average across the 2-week diary. At the within-person level (see row for daily self-regulation failures), on days when individuals reported lower than their average level of daily self-regulation failures, they reported fewer diabetes problems. These associations were not moderated by EF or by year.

Table 1 Multilevel Models Predicting Daily Diabetes Problems from EF and Daily Self-Regulation Failures across Years

Predictor	Self-reported EF problems (BRIEF) as measure of EF	EF performance as measure of EF
	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value
Intercept	1.209 (0.061)**** t = 19.873, p < .001	1.207 (0.061)**** t = 19.649, p < .001
Mean daily self-regulation failures (BP)	0.272 (0.034)**** t = 8.104, p < .001	0.296 (0.033)**** t = 8.912, p < .001
Daily self-regulation failures (WP)	0.371 (0.033)**** t = 11.352, p < .001	0.368 (0.033)**** t = 11.282, p < .001
EF	0.011 (0.004)*** t = 3.010, p = .003	0.059 (0.035) t = 1.689, p = .096
Year	−0.120 (0.024)**** t = −5.032, p < .001	−0.126 (0.024)**** t = −5.283, p < .001
Daily self-regulation failures × EF	−0.002 (0.003) t = −0.744, p = .457	0.012 (0.018) t = 0.696, p = .487
Daily self-regulation failures × year	−0.015 (0.051) t = −0.289, p = .772	−0.014 (0.050) t = −0.278, p = .781
EF × year	−0.006 (0.002)**+ t = −2.651, p = .008	0.038 (0.012)*** t = 3.133, p = .002
Daily self-regulation failures × EF × year	0.003 (0.005) t = 0.660, p = .510	0.023 (0.029) t = 0.819, p = .413

Note. EF = Executive functioning; BRIEF = Behavior Rating Inventory of Executive Functioning (higher scores indicate more self-reported EF problems or lower EF); Mean daily self-regulation failures refers to average daily self-regulation failures aggregated across the 14-day diary within year; BP = between-person effects of daily self-regulation failures; WP = within-person effects of daily self-regulation failures; Covariates (not shown) included pump status, gender, IQ and for EF Performance analyses psychomotor speed; Year was effect coded as year 1 = −1 and year 2 = 1; ****p < .001; ***p < .005; **p < .01; *p < .05; +The self-reported EF problems X year effect was not significant when data were analyzed using Poisson multilevel modeling (see Supplement Material 2).

It is notable that EF interacted with year to predict diabetes problems. Predicted means were computed for EF scores one standard deviation above and below the mean (see Fig. 1). Those with better self-reported EF (i.e., lower EF problems) had fewer diabetes problems, an association that was strongest in year 1. In contrast, those with better EF performance reported *more* diabetes problems, and this association was strongest in year 2. The finding that EF performance was associated with more daily diabetes problems in year 2 was unexpected. We considered that this may have occurred if individuals with better EF performance were more likely to move away from their parental home in the year after high school, potentially creating a more stressful T1D management context. To explore this possibility, we examined whether individuals who remained living at home (50%) versus moved away from parents in the year after high school (50%) differed on EF performance and daily diabetes problems. Individuals who moved away from home in year 2 did have better baseline EF performance (t = 5.67, p < .001), and reported more frequent diabetes problems on average compared to those who did not (t = 2.301, p = .019). However, the interaction between EF performance and year remained significant when change in residential status was covaried (t = 3.170, p = .002).

Reactivity Model: EF and Daily Associations of Diabetes Problems with Adverse Indicators

Tables 2 and 3 display results of the multilevel analyses examining EF as a moderator of associations between daily diabetes problems and daily indicators of diabetes management. There was a between-person effect for mean daily diabetes problems, indicating that those who experienced more diabetes problems on average across the 2-week diaries also reported more negative affect, lower self-efficacy, lower adherence behaviors, more frequent BG checking, and higher BG levels on average (see rows for mean daily diabetes problems). Above and beyond these average effects, there were also within-person associations between daily diabetes problems and daily indicators (see rows for daily diabetes problems). As individuals moved from a day with lower to a day with higher than their average number of diabetes problems, they displayed higher negative affect, lower self-efficacy, lower self-management behaviors, and higher BG levels. Participants also reported more frequent BG checking, suggesting they increased efforts to check BG levels on days with more diabetes problems.

There was limited evidence to suggest that EF buffered these daily associations of diabetes problems with adverse diabetes management indicators. The only interaction between self-reported EF and daily diabetes problems occurred for analyses of negative affect (Table 2). Predicted means for scores ±1 SD from the mean on EF and daily diabetes problems are displayed in Fig. 2. Consistent with a buffering role for EF, individuals who self-reported lower EF problems (i.e., better EF) displayed a weaker association between more frequent daily diabetes problems and heightened daily negative affect than those who self-reported higher EF problems. EF performance and year did not moderate any associations between daily diabetes problems and daily adverse indicators (Table 3).

Discussion

The present study provides evidence that EF is involved in self-regulation to support T1D management in daily life during the high-risk time of late adolescence and early emerging adulthood. Using the conceptual framework of

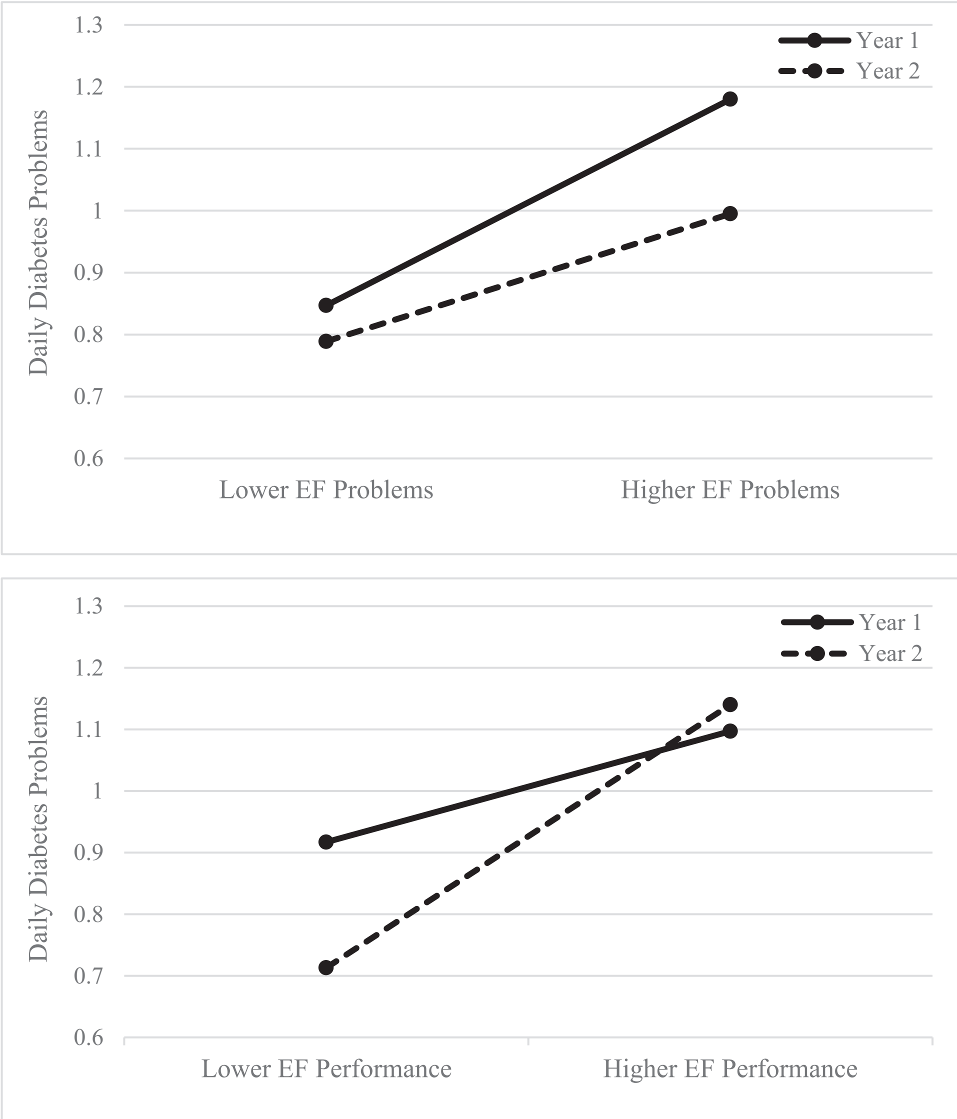

Fig. 1. Predicted Means for the EF × Year Interactions Predicting Average Daily Diabetes Problems. Note. EF = Executive functioning; EF problems = self-reported EF problems on the Behavioral Rating Inventory of Executive Functioning (higher values indicate more EF problems or lower EF); EF performance = objective measure of EF (higher values indicate higher EF); Both panels display predicted means for low and high EF calculated at ±1 SD from the mean; The interaction of self-reported EF problems × year (top panel) was not significant in analyses based on a Poisson multilevel regression (see Supplement Material 2).

"exposure" and "reactivity" models, we explored how EF may be related to daily diabetes problems and T1D management. Findings primarily supported an exposure model in that lower self-reported EF problems were associated with fewer daily diabetes problems. We did not find evidence for a reactivity model as EF generally did not buffer the association of diabetes problems with adverse daily indicators. Importantly, self-report and performance EF measures yielded different findings, consistent with prior reports [7, 8, 12]. These measures appear to tap quite different daily self-regulation processes that need to be better understood to facilitate daily T1D management at this high-risk transition time.

Consistent with expectations, individuals with better self-reported EF (i.e., fewer self-reported EF problems) displayed lower average levels of daily self-regulation failures surrounding BG checking. In addition, better self-reported EF and lower daily self-regulation failures were associated with fewer daily diabetes problems. It is notable that there were both between- and within-person associations linking self-regulation failures to diabetes problems, indicating that even individuals who generally have good self-regulation (i.e., lower average self-regulation failures; lower self-reported EF problems) appeared to be derailed on days with lapses in self-regulation. It was surprising that EF did not moderate these within-person associations, given prior findings that EF-related constructs buffer the adverse effects of daily lapses [19, 21]. The end-of-day diary design may have resulted in a less sensitive assessment of these processes than would be found with more frequent assessments throughout the day. Regardless, findings demonstrate that effective T1D management requires a daily process where *all* individuals need to make real-time decisions to support BG checking within the complexities of daily life.

In contrast to self-reported EF findings, better EF performance was unrelated to daily self-regulation failures, and predicted *more frequent* daily diabetes problems, especially in the year after high school. Although unexpected, this finding

Table 2 Multilevel Models Predicting Daily Indicators from Self-Reported EF Problems (BRIEF) and Daily Diabetes Problems across Years

Predictor	Daily negative affect	Daily self-efficacy	Daily self-management	Daily blood glucose checks	Daily blood glucose mean
	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value
Intercept	1.655 (0.06)**** $t = 29.920, p < .001$	3.907 (0.07)**** $t = 53.213, p < .001$	4.171 (0.07)**** $t = 61.709, p < .001$	3.491 (0.14)**** $t = 25.321, p < .001$	170.865 (5.34)**** $t = 31.991, p < .001$
Mean daily diabetes problems (BP)	0.130 (0.02)**** $t = 5.256, p < .001$	−0.321 (0.03)**** $t = −10.158, p < .001$	−0.198 (0.03)**** $t = −7.407, p < .001$	0.309 (0.07)**** $t = 4.625, p < .001$	14.545 (2.59)**** $t = 5.622, p < .001$
Daily diabetes problems (WP)	0.079 (0.01)**** $t = 6.439, p < .001$	−0.199 (0.02)**** $t = −12.199, p < .001$	−0.083 (0.01)**** $t = −6.982, p < .001$	0.121 (0.03)**** $t = 4.166, p < .001$	11.009 (1.45)**** $t = 7.600, p < .001$
EF	0.020 (0.00)**** $t = 6.987, p < .001$	−0.014 (0.00)**** $t = −3.716, p < .001$	−0.016 (0.00)**** $t = −4.424, p < .001$	−0.021 (0.01)* $t = −2.102, p = .042$	1.047 (0.27)**** $t = 3.901, p < .001$
Year	−0.013 (0.01) $t = −1.524, p = .127$	−0.050 (0.01)**** $t = −4.727, p < .001$	−0.051 (0.01)**** $t = −5.965, p < .001$	−0.226 (0.04)**** $t = −5.194, p < .001$	−0.180 (0.95) $t = −0.190, p = .849$
Daily diabetes problems × EF	0.003 (0.00)* $t = 2.383, p = .017$	−0.001 (0.00) $t = −0.627, p = .531$	−0.002 (0.00) $t = −1.585, p = .113$	−0.002 (0.00) $t = −0.843, p = .400$	0.126 (0.14) $t = 0.931, p = .352$
Daily diabetes problems × year	0.003 (0.01) $t = 0.242, p = .809$	0.013 (0.01) $t = 0.956, p = .339$	−0.001 (0.01) $t = −0.133, p = .894$	−0.000 (0.05) $t = −0.003, p = .998$	−1.824 (1.25) $t = −1.454, p = .147$
EF × year	−0.003(0.00)**** $t = −4.116, p < .001$	0.001 (0.00) $t = 1.082, p = .279$	0.004 (0.00)**** $t = 4.924, p < .001$	0.015 (0.00)**** $t = 3.552, p < .001$	−0.233 (0.09)* $t = −2.458, p = .015$
Daily diabetes problems × EF × year	0.000 (0.00) $t = 0.011, p = .991$	−0.000 (0.00) $t = −0.016, p = .987$	−0.001 (0.00) $t = −0.787, p = .432$	−0.003 (0.01) $t = −0.497, p = .619$	−0.007 (0.12) $t = −0.063, p = .950$

Note. EF = Executive functioning; BRIEF = Behavior Rating Inventory of Executive Functioning (higher scores indicate more self-reported EF problems or lower EF); Mean daily diabetes problems refers to average daily frequency of diabetes problems aggregated across the 14-day diary within year; BP = between-person effects of diabetes problems; WP = within-person effects of diabetes problems; Covariates (not shown) included pump status, gender, and IQ; Year was effect coded as year 1 = −1 and year 2 = 1; ****$p < .001$; ***$p < .005$; **$p < .01$; *$p < .05$.

Table 3 Multilevel Models Predicting Daily Indicators from EF Performance and Daily Diabetes Problems across Years

Predictor	Daily negative affect	Daily self-efficacy	Daily self-management	Daily blood glucose checks	Daily blood glucose mean
	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value	Estimate (SE) *t*, *p* value
Intercept	1.670 (0.06)**** $t = 28.123, p < .001$	3.904 (0.07)**** $t = 52.465, p < .001$	4.159 (0.07)**** $t = 59.637, p < .001$	3.500 (0.14)**** $t = 25.069, p < .001$	171.461 (5.44)**** $t = 31.491, p < .001$
Mean daily diabetes problems (BP)	0.168 (0.03)**** $t = 6.696, p < .001$	−0.341 (0.03)**** $t = −10.848, p < .001$	−0.234 (0.03)**** $t = -8.722, p < .001$	0.238 (0.07)**** $t = 3.588, p < .001$	16.754 (2.57)**** $t = 6.522, p < .001$
Daily diabetes problems (WP)	0.082 (0.01)**** $t = 6.470, p < .001$	−0.199 (0.02)**** $t = −12.116, p < .001$	−0.083 (0.01)**** $t = −6.834, p < .001$	0.114 (0.03)**** $t = 3.903, p < .001$	11.309 (1.48)**** $t = 7.650, p < .001$
EF	−0.057 (0.03)* $t = −2.166, p = .030$	0.071 (0.03)* $t = 2.176, p = .030$	0.057 (0.03) $t = 1.874, p = .061$	0.072 (0.09) $t = 0.806, p = .429$	−3.437 (2.26) $t = −1.520, p = .129$
Year	−0.011 (0.01) $t = −1.312, p = .190$	−0.051 (0.01)**** $t = −4.798, p < .001$	−0.053 (0.01)**** $t = −6.141, p < .001$	−0.232 (0.04)**** $t = −5.341, p < .001$	−0.080 (0.95) $t = −0.084, p = .933$
Daily diabetes problems × EF	−0.003 (0.01) $t = −0.405, p = .685$	−0.004 (0.01) $t = −0.465, p = .642$	−0.008 (0.01) $t = −1.322, p = .186$	0.001 (0.02) $t = 0.071, p = .943$	−0.851 (0.74) $t = −1.145, p = .253$
Daily diabetes problems × year	0.003 (0.01) $t = 0.278, p = .781$	0.015 (0.01) $t = 1.061, p = .289$	−0.001 (0.01) $t = −0.137, p = .891$	−0.013 (0.05) $t = −0.242, p = .809$	−1.702 (1.29) $t = −1.323, p = .187$
EF × year	0.004 (0.00) $t = 0.964, p = .335$	−0.009 (0.01) $t = −1.643, p = .100$	0.000 (0.00) $t = 0.052, p = .958$	0.064 (0.02)** $t = 2.711, p = .007$	1.171 (0.52)* $t = 2.240, p = .026$
Daily diabetes problems × EF × year	−0.004 (0.01) $t = −0.677, p = .498$	−0.004 (0.01) $t = −0.544, p = .586$	0.002 (0.01) $t = 0.381, p = .703$	0.034 (0.03) $t = 1.216, p = .224$	−0.294 (0.66) $t = −0.446, p = .656$

Note. EF = Executive functioning; Mean daily diabetes problems refers to average daily frequency of diabetes problems aggregated across the 14-day diary within year; BP = between-person effects of diabetes problems; WP = within-person effects of diabetes problems; Covariates (not shown) included pump status, gender, IQ and psychomotor speed; Year was effect coded as year 1 = −1 and year 2 = 1; ****$p < .001$; ***$p < .005$; **$p < .01$; *$p < .05$.

is not without precedent. Stawski et al. found that individuals with greater fluid cognitive abilities unexpectedly reported more daily stressors, potentially because such individuals have more engaged and busy lives that may generate stress [41]. We explored this possibility with mixed results. Those with better EF performance were more likely to move away from home, and those who moved reported more diabetes problems (in both years). However, the association of EF

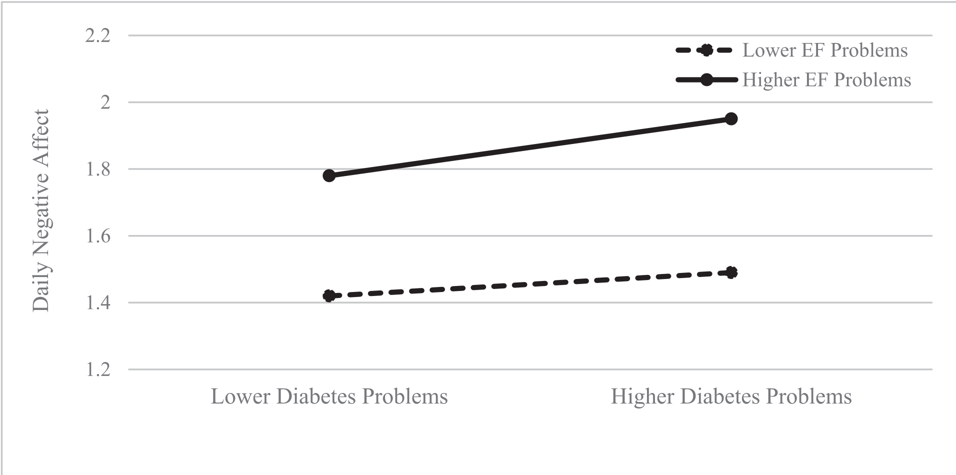

Fig. 2. Predicted Means for Self-reported EF Problems Moderating the Daily Association Between Diabetes Problems and Negative Affect. Note. EF = Executive functioning; EF problems = self-reported EF problems from the Behavioral Rating Inventory of Executive Functioning (higher values indicate more EF problems or lower EF); Predicted means were calculated for scores ±1 SD from the mean for EF and daily diabetes problems.

performance with greater frequency of diabetes problems in year 2 remained when residence status was covaried.

An alternative explanation is that those with better EF performance reported more diabetes problems because they were more aware of, attentive to, and/or disclosing of diabetes problems when such problems occurred. Individuals with better EF-related skills appear more able to recognize their own weaknesses and to provide less inflated self-assessments [42]. Indeed, recent research has shown that better EF performance is associated with more accurate self-report [43]. Thus, those with higher EF performance may have accurately reported diabetes problems, while those with lower EF under-reported diabetes problems. Effective regulation of BG likely requires the ability to recognize and acknowledge diabetes problems as they occur, allowing one to take steps to prevent future escalation or repetition. Such daily self-regulation processes may partially explain prior findings from the present sample that those with higher EF performance had slower increases in BG levels in the years after high school [7].

Although not part of the specific aims, it is also important to consider that the frequency of daily diabetes problems decreased across years. This seems inconsistent with the notion that the transition into emerging adulthood is a time of heightened stress that poses new challenges for managing T1D. The measure of daily diabetes problems did not directly tap into the broader aspects of this stressful transition, where transitioning social contexts have been found to be particularly challenging (e.g., fearing stigma while checking BG in work settings; managing T1D in the presence of unfamiliar peers or in less structured social contexts) [1, 2, 18, 44]. Future research to examine these stressful contexts more directly will be useful to identify the factors that undermine or facilitate a successful emerging adulthood transition. It is notable that the decrease in diabetes problems from year 1 to year 2 appeared to occur primarily among individuals with lower EF at baseline (i.e., lower EF performance, higher self-reported EF problems; see Fig. 1). It is possible that those with lower EF became progressively less aware of and attentive to their diabetes problems as they transitioned into emerging adulthood away from parents. That is, with less scaffolding from parents (e.g., reminders and inquiries about T1D management) and new non-diabetes stressors to navigate, these individuals may have become less concerned about T1D management in ways that are reflected in reports of diabetes problems.

The links between diabetes problems and a host of adverse daily indicators are consistent with the notion that such problems pose challenges for regulating emotion, cognition, and behavior in daily life. Individuals who reported more frequent diabetes problems on average across the 2-week diary also displayed higher average adverse indicators. Further, on days individuals reported greater than their average frequency of diabetes problems, they displayed higher negative affect, lower self-efficacy, lower self-management behaviors, and higher BG levels. Diabetes problems were also associated with more frequent BG checking, an interesting finding in light of suggestions that BG checking is an index of adherence [35]. We interpret this as evidence that individuals increased efforts to regulate BG levels when problems occurred. It is not possible to disentangle causal associations, given that all measures were obtained at end of day. In fact, we believe associations reflect ongoing transactional processes that occur in a dynamic fashion as diabetes problems unfold throughout one's day [45, 46]. For example, mismanagement may contribute to diabetes problems, which undermine affect and self-efficacy even as attempts are made to deal with poor BG levels by increasing BG checking.

The importance of studying diabetes problems is underscored by findings that EF generally did not buffer links between daily diabetes problems and adverse indicators. That is, once diabetes problems occurred, they tended to be associated with all adverse indicators regardless of one's EF. The only evidence that EF buffered adverse outcomes in the face of diabetes problems was that those with better self-reported EF displayed weaker daily associations between diabetes problems and negative affect. This is consistent with prior studies suggesting EF-related constructs buffer negative emotional reactivity to daily stress [19, 24], and could suggest that findings for self-reported EF reflect both a reduced exposure and a reduced reactivity model. However, this is a single finding out of multiple tests and the pattern did not extend to daily self-management behaviors or BG indicators.

The present study contributes to the literature demonstrating that measures of EF performance and self-reported EF problems are not commensurate. These measures are only modestly correlated, and are believed to tap into different cognitive and behavioral processes [7–9]. It has been argued that the BRIEF measures how EF problems are revealed in real-world settings, with scores likely to be affected not only by characteristics of the individual (e.g., cognition), but also by contextual factors (e.g., support from parents; living in a chaotic home environment). In contrast, EF performance has been argued to reflect underlying neurocognitive capabilities in a constrained and structured context, with scores relatively less confounded by contextual factors. The findings that self-reported EF problems were associated with important aspects of diabetes management in daily life are consistent with these distinctions. More research that includes both self-report and performance measures of EF will be necessary to clarify the distinct and overlapping aspects of the underlying constructs and their implications for diabetes management. Future work should not assume these are alternative measures of the same construct, but should clearly articulate the decision points for specific measures and interpretation of findings in light of measurement differences.

The results need to be interpreted in the context of limitations. First, daily variables were assessed via self-report. Shared method variance may explain some findings such as why self-reported EF was associated with daily self-regulation failures, while EF performance was not. Second, analyses examined concurrent daily processes and causal inferences cannot be made. We focused on within-day (rather than across-day) associations as daily diabetes problems often develop, escalate, and/or are resolved within minutes or hours rather than across days. Alternative approaches such as ecological momentary assessments (EMA) that obtain multiple assessments throughout the day will be necessary to disentangle how shifts in diabetes problems interface with indicators of diabetes management. Third, we examined EF links to daily self-regulation without considering the social context in which T1D management occurs. Prior studies have demonstrated that—among those with higher EF performance and better BG levels (i.e., lower HbA1c)—daily diabetes problems served to coordinate father's involvement in management [46]. Thus, EF may help individuals better regulate their social environment to support T1D management [1], with diabetes problems providing opportunities to solicit and receive support rather than only being stressors to be managed individually. Fourth, we purposively examined a limited age range to understand the specific transition out of high school; findings may not generalize to other ages. Fifth, although EF continues to develop across this transition, EF was measured only at baseline. This may have undermined support for hypotheses that EF effects would become stronger in year 2.

Findings contribute to the growing literature indicating that EF is an important resource for T1D management, and shed light on how EF is revealed in daily life. Self-reported EF problems were associated with higher daily lapses in self-regulation and more daily diabetes problems, all of which were linked to more adverse indicators of daily management. Interventions to provide structures to reduce self-regulation failures may thus promote better T1D management. Implementation intention and proactive coping interventions may facilitate the anticipation and prevention of daily disruptions to management [47], and interventions to facilitate self-regulation and skills to manage social relationships may minimize barriers and build supportive social structures for T1D management [48]. Habit formation interventions may also prove useful to minimize daily lapses by reducing self-regulation demands [49]. Screening for high BRIEF scores may identify those in greatest need for such interventions, although our findings suggest all individuals could benefit from support to prevent the occurrence of daily diabetes problems. Future research involving additional variables (e.g., involvement of others) and alternative designs (e.g., EMA) will be necessary to understand how EF performance is linked to daily management. There is a high need for such research, given that EF performance prospectively predicts better BG management across this high-risk transitional time.

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Compliance of Ethical Standards

Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors Deborah J. Wiebe, Cynthia A. Berg, Ascher K. Munion, Maria D. Ramirez Loyola, Daniel Mello, Jonathan E. Butner, Yana Suchy, Jessica Marino declare that they have no conflict of interest.

Authors' Contributions Deborah J Wiebe, PhD MPH (Conceptualization: Lead; Data curation: Lead; Formal analysis: Lead; Funding acquisition: Lead; Investigation: Lead; Methodology: Lead; Project administration: Equal; Supervision: Lead; Validation: Equal; Writing – original draft: Lead; Writing – review & editing: Lead), Cynthia A Berg, PhD (Conceptualization: Equal; Data curation: Equal; Funding acquisition: Equal; Investigation: Equal; Methodology: Equal; Project administration: Equal; Supervision: Equal; Writing – original draft: Supporting; Writing – review & editing: Supporting), Maria D Ramirez Loyola, MA (Data curation: Supporting; Formal analysis: Supporting; Project administration: Supporting; Validation: Supporting; Writing – original draft: Supporting; Writing – review & editing: Supporting), Daniel Mello, PhD (Data curation: Supporting; Formal analysis: Supporting; Investigation: Supporting; Methodology: Supporting; Project administration: Supporting; Validation: Supporting; Writing – original draft: Supporting; Writing – review & editing: Supporting), Jonathan E Butner, PhD (Conceptualization: Equal; Formal analysis: Lead; Funding acquisition: Supporting; Methodology: Equal; Supervision: Supporting; Writing – review & editing: Supporting), Yana Suchy, PhD (Conceptualization: Equal; Funding acquisition: Supporting; Methodology: Supporting; Writing – original draft: Supporting; Writing – review & editing: Supporting), Jessica Marino, BA (Data curation: Supporting; Project administration: Supporting; Writing – original draft: Supporting; Writing – review & editing: Supporting), and Ascher K Munion, PhD (Data curation: Supporting; Formal analysis: Supporting; Validation: Supporting; Writing – original draft: Supporting; Writing – review & editing: Supporting)

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individuals included in this article.

Transparency statements The study was not formally registered. The analytic plan was not formally pre-registered. The data and the materials are available from the authors and are currently being posted on OSF. There is not analytic code associated with this study.

Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online

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