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Habit and Diabetes Self-Management in Adolescents with Type 1 Diabetes

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Management of Type 1 diabetes in adolescence is challenging and requires engagement in repeated and complex daily tasks to avoid both immediate and long-term health complications (Chiang et al., 2018). Over 75% of adolescents with Type 1 diabetes do not meet clinical guidelines for glycemic levels (Wood et al., 2013). Multiple studies have supported links between better executive self-regulatory skills that support goal-directed behaviors (e.g., executive function, self-control, and emotion regulation) and more optimal adolescent diabetes self-management (Berg et al., 2018; Lansing & Berg, 2014; Lansing et al., 2016; Perez et al., 2017; Suchy et al., 2016). However, there remains a paucity of research examining the role of habit in the context of adolescent Type 1 diabetes management. In particular, research on habitual behavior in adolescent diabetes management has emphasized either behavior frequency (Petry et al., 2000; Raiff & Dallery, 2010; Rash & Petry, 2015; Stanger et al., 2018) or routines (Pierce & Jordan, 2012; Pierce et al., 2019), both of which fail to differentiate repetitive diabetes behaviors that are caregiver- or goal-dependent from those that occur due to habit. Habits are more clearly identified by examining behavioral automaticity, the extent to which a behavior is performed with decreased thresholds for time, attention (effort), conscious awareness, and goal dependence (Moors, 2016). However, it remains unknown whether behavioral automaticity is indeed related to more optimal self-management for adolescents with Type 1 diabetes.

Greater behavioral automaticity for diabetes self-management may support engagement in goal-directed diabetes tasks in daily life. A diabetes self-management behavior can be performed with varying degrees of automaticity on a continuum from nonautomatic (i.e., goal-dependent, inefficient, conscious, and slow from initiation through execution) to fully automatic (i.e., uncontrolled, efficient, unconscious, and fast from initiation through execution; Gardner et al., 2012). These core features of automaticity are independent, allowing for even complex diabetes self-management tasks that require some time, attention, consciousness, or goal-dependence to occur with a degree of automaticity (Moors, 2016). For example, simple diabetes management tasks might be performed to completion with high levels of automaticity (e.g., blood glucose check), while more complex diabetes management tasks (e.g., insulin dosing) might be initiated automatically, through stimulus-intention pairing, and then maintained through executive goal-directed processes (Moors et al., 2017).

Across multiple health domains, behavioral automaticity is key for increased goal-directed health behavior engagement. For example, greater behavioral automaticity for exercising is associated with increased frequency of exercise, as well as more stability in patterns of engagement in exercise (i.e., at the same time of day and in the same locations; Galla & Duckworth, 2015). Greater behavioral automaticity for taking medications also predicts better self-management in adults with Type 1 diabetes (Phillips et al., 2016) and hypertension (Durand et al., 2018; Phillips et al., 2013), as well as nebulizer use in patients with cystic fibrosis (Hoo et al., 2019). The study of behavioral automaticity in

the context of Type 1 diabetes self-management has exclusively occurred within samples of young adults with Type 1 diabetes. Young adults with Type 1 diabetes describe automaticity in performance of checking glucose, dosing insulin, eating a meal, and initiating exercise and experience increased automaticity following an occupational therapy lifestyle intervention (Hanna & Hansen, 2020; Pyatak et al., 2018). These findings suggest that adolescent with Type 1 diabetes might also benefit from increased behavioral automaticity for diabetes self-management tasks.

More specifically, in the context of Type 1 diabetes management in adolescence, behavioral automaticity may reduce the cognitive resource burden required to complete burdensome self-management tasks and increase persistence of behaviors despite the complex demands of adolescents' daily life (Bolman et al., 2011; Farrell et al., 2004; Helgeson et al., 2010; Schwabe & Wolf, 2009). For example, for an adolescent recently diagnosed with Type 1 diabetes, in order to check their blood glucose levels prior to eating dinner out with friends, the adolescent might have to engage executive functions to pause, remember, and plan a new set of actions for that task, and intentionally engage in that task to completion. Over time, with rehearsal and consistent repetition and reinforcement, initiation, and completion of this task may begin to occur more automatically when cued by the presence of a dinner meal and in spite of other competing goals or stressors. Thus, it is theorized that increased behavioral automaticity for diabetes self-management would be associated with more optimal daily self-management and decreased executive self-regulatory failures for glucose monitoring, as well as more optimal daily glycemic levels in adolescents with Type 1 diabetes.

The aim of the current study was to examine the associations between perceived behavioral automaticity for diabetes self-management tasks, perceived frequency of performance of diabetes self-management tasks, and perceived executive self-regulatory failures in daily glucose checking, as well as daily glycemic levels and variability in adolescents with Type 1 diabetes. It was hypothesized that increased behavioral automaticity for Type 1 diabetes self-management would be associated cross-sectionally with increased self-management and prospectively predict decreased executive self-regulation failures in daily glucose checking, increased daily self-management, and lower mean and variability in daily blood glucose levels.

Method

Participants

Participants in this study included 79 adolescents who attended diabetes camps in the Western United States during the summer of 2019. Participants were considered eligible if they were between the ages of 13 and 17, had a diagnosis of Type 1 diabetes, spoke English, and had access to WiFi after the camp ended, in order to complete daily diary surveys. The majority of the participants self-identified as female (61%), and just over half identified as White non-Hispanic/Latino (54%), with the remaining participants self-identifying as Mixed (23%), Black/African American (8%), White Hispanic/Latino (5%), Asian (3%), American Indian/Alaskan Native (1%), and other (6%). The mean age of participants was 15.16 years ($SD = 1.18$), with an age range of 13 to 17, median of 15.09, and IQR of 1.82. Average age of diagnosis of Type 1 diabetes was 7.34 years ($SD = 3.45$; range = 1–14 years old). A large majority of participants used a continuous glucose monitor (CGM) sensor (86%) and a pump (87%).

Procedure

Ethics approval was received from the University Institutional Review Board at Marquette University. This study used baseline data collected at the camp, including self-report measures of behavioral automaticity for diabetes self-management and perceived performance of self-management tasks. Prior to the start of camp, parents of eligible participants were emailed by the camp coordinators and study investigators to provide information about the study. Within the email, parents were instructed to complete the electronic permission/consent form, if interested. Parents of eligible participants were also offered the option to provide in-person consent when dropping their children off at camp. After consent was acquired, adolescents were provided information about the study and provided assent, if interested. In order to minimize potential effects of camp (e.g., reduced stress and consistent monitoring by camp officials) and gather an accurate representation of baseline functioning, baseline measures were completed on an iPad in a quiet room within the first 2 days of camp. After returning home and returning to school, 1 to 3 months later, participants were asked to complete a 7-day daily diary on their phone or computer at the end of each evening before bedtime. Participants were sent a reminder if they did not complete the diary by an agreed upon time (typically corresponding to the individual's bedtime). The daily diary included self-report of performance of self-management tasks, failures in executive self-regulation around blood glucose checking, and blood glucose levels. Participants were not asked to modify their level of self-management during the daily diary period. Only 50 participants attempted the diary and a subset of those participants ($n = 42$) completed at least five of the seven the diaries. The participants who completed the diary did not significantly differ from those who did not complete the diary on baseline measures of behavioral automaticity, age, gender, or time since diagnosis of diabetes ($ps > .05$). However, adolescents who completed the diary ($M = 3.39$; $SD = .56$) reported greater baseline self-management than those adolescents who did not ($M = 3.12$; $SD = .51$; $p = .029$). Having a CGM was also related to completion of the daily diary ($p = .001$). The primary reasons for noncompletion of the daily diary phase of the study were loss to follow-up and participants no longer having enough time or interest. At each study time point (baseline and daily diary) participants were entered in a drawing to win a \$25 gift card.

Measures

Behavioral Automaticity for Diabetes Self-Management

The Self-Report Behavioral Automaticity Index (SRBAI; Gardner et al., 2012) is a well-validated self-report measure of behavioral automaticity. The SRBAI was developed to assess a variety of health behaviors by validating a set of psychometrically sound question stems that can be answered for multiple behaviors (e.g., Burns, 2020; Durand et al., 2018; Hoo et al., 2019). Health behaviors previously assessed in the chronic illness context on the SRBAI include exercise (Galla & Duckworth, 2015), medication taking (Burns et al., 2019; Durand et al., 2018), and nebulizer use (Hoo et al., 2019) as well as glucose checking and insulin dosing (Pyatak et al., 2018). The SRBAI consists of four item stems: “<<behavior>> is something I do automatically”; “<<behavior>> is something I do without having to consciously remember”; “<<behavior>> is something I do without thinking”; and “<<behavior>> is something I start doing before I realize I'm doing it.” Each stem is then rated on a seven-point scale (1 = *strongly disagree*, 7 = *strongly agree*).

Using the SRBAI, behavioral automaticity for four diabetes self-management responsibilities was indexed: (a) checking or reviewing blood glucose prior to eating, (b) counting carbohydrates prior to eating, (c) checking or reviewing blood glucose levels upon waking up, and (d) adjusting insulin after a meal or after an out-of-range blood glucose reading. The four tasks selected for the SRBAI in this study were driven by theory and confirmed in pilot testing prior to this study, the latter of which found limited convergent validity of automaticity of additional common diabetes tasks (i.e., checking blood glucose when it is low/high, administering insulin premeal, and reviewing blood glucose log) and self-management. The selected behaviors cover the three primary daily diabetes treatment responsibilities: glucose checking before eating, counting carbohydrates prior to eating, and adjusting insulin after a meal or an out-of-range blood glucose reading. In addition, given emerging work on the importance of morning routines for daily diabetes self-management (Thompson, 2014), an item was included to assess glucose checking upon waking up in the morning. Automaticity for each diabetes self-management task was calculated by averaging the scores of the four item stems for that task, with higher scores indicating greater automaticity of the corresponding task. These scores are referenced as the automaticity for diabetes self-management scales. Overall automaticity was calculated by averaging the scores for all four task scales, with higher average scores indicating greater overall automaticity.

Consistent with previous research using the SRBAI, the SRBAI measure of the four diabetes tasks exhibited sound internal consistency and a unitary factor structure. All of the task scales ($.88 < \alpha < .92$) and the full scale ($\alpha = .91$) demonstrated high internal consistency. Exploratory factor analysis of the task scales with a direct oblim rotation (given expected covariation across scales) and a loading cut off of .4 and Eigenvalue cut off of 1 suggested a unitary factor structure. A single factor was extracted with loadings ranging from .68 (counting carbohydrates prior to eating) to .79 (checking or reviewing blood glucose prior to eating) for each task scale, suggesting use of the full-scale score to summarize automaticity for diabetes self-management is reasonable and appropriate.

Perceived Self-Management

The Self-Care Inventory—Revised (SCI-R; Weinger et al., 2005) assesses perceived completion of self-care management behaviors for diabetes as recommended by a health care provider and was completed by all participants. The measure consists of 15 self-report items that participants rate on a 5-point scale (1 = *never do it*, 5 = *always do this as recommended without fail*) with higher scores indicating greater frequency of that behavior. The measure is scored by averaging the item scores and then converting that average score to a 0- to 100-point scale, where a higher score indicates more optimal self-management. Weinger et al. (2005) found the SCI-R has high internal consistency ($\alpha = .87$), and similar reliability was found in this sample ($\alpha = .71$).

In the subsample that completed the daily diary, daily self-management was assessed using a brief, six-item version of the SCI-R. The six-item version used within the current study has been previously validated for assessment of self-management in the daily diary context (Baucom et al., 2015) in lieu of the full 15-item scale. This scale indexes the extent to which participants completed six diabetes-specific behaviors that day as recommended by health care providers: checking or reviewing blood glucose, administering correct dosage of insulin at the correct time, adjusting insulin for out-of-range blood glucose levels, having accessible quick-acting sugar for low blood glucose levels, eating the

correct foods or counting all carbohydrates, and using pump or continuous glucose monitor correctly. Items were rated on a 5-point scale (1 = *did not do it at all* to 5 = *did it exactly as recommended*), and an average daily self-management score was computed indexing self-management across all diary days. Higher mean scores indicated more optimal self-management. The six-item version of the SCI-R has been found to have high internal consistency (Baucom et al., 2015) and an internal consistency of .96 was found in the present sample.

Daily Self-Regulation Failures in Glucose Checking

During the daily diary portion of the study, participants completed a validated measure of failures of executive self-regulation as they relate to glucose checking (Berg et al., 2014). The measure has participants report the extent to which the goal-directed process of blood glucose checking was disrupted in daily life (for example, “I was so involved in doing something else I was enjoying that I didn’t stop to test my blood glucose when I was supposed to”; “Each time I was about to test my blood glucose, I got distracted by something else”; “I was in a bad mood today and didn’t really care about testing my blood glucose”). The eight-item measure was scored on 5-point scale (1 = *strongly disagree* to 5 = *strongly agree*), with higher scores indicating greater self-regulatory failures around glucose checking within that day. For the current study, an average daily self-regulation failures score was computed indexing individual differences in self-regulatory failures in glucose checking across all diary days. The scale has been used in prior daily diary studies (Berg et al., 2014) as well as the present study ($\alpha = .98$).

Daily Blood Glucose Levels

During the daily diary portion of the study, participants self-reported their daily blood glucose levels. Self-report of blood glucose levels, in lieu of meter downloads, has been supported in prior daily diary studies examining both mean and standard deviations in daily blood glucose (Berg et al., 2014; Lansing et al., 2016). No significant differences have been found between self-report and meter download data (Herzer & Hood, 2010; McGrady et al., 2009), or in a recent study that analyzed the same dataset as used in the current study (Benjamin, 2021). At the end of each day, participants who manually checked their blood glucose levels were asked to report all blood glucose levels from that day (up to six values) and provide a timestamp for each value. Participants with a CGM monitor were asked to report their blood glucose levels from six time points (i.e., 6:00am, 9:00 a.m., 12:00 p.m., 3:00 p.m., 6:00 p.m., 9:00 p.m.) to allow for collection of an equivalent number of data points between CGM and non-CGM users. The range of daily blood glucose readings provided by participants was 1 to 6 ($M = 5.62$; $SD = 1.13$). CGM users were also asked to upload their blood glucose data to Tidepool and only $n = 22$ completed those uploads. Where CGM data was available, it was used in daily blood glucose calculations. Otherwise, self-report data was used. Both average (MBG) and standard deviations (SDBG) of daily blood glucose levels across all days were calculated.

Analysis Plan

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) for Windows. First, Pearson correlations and t-tests were used to examine cross-sectional associations of automaticity for diabetes self-management with overall self-management and demographic factors (e.g., CGM status, time since diagnosis, gender, and race/ethnicity). Second, in the smaller subsample that completed the daily diary, Person correlations were conducted to examine prospective

associations between automaticity for diabetes self-management, average daily self-management, average daily self-regulatory failures in glucose checking, and average daily MBG and SDBG. Third, where significant prospective bivariate associations were found, multiple linear regression analyses were conducted to examine if increased automaticity for diabetes self-management predicted those outcomes (i.e., self-management, self-regulatory failures in glucose checking, and MBG) above and beyond CGM status and time since diagnosis. Consistent with prior studies (e.g., Berg et al., 2018; Wiebe et al., 2018), CGM status and time since diagnosis were selected as covariates in the regressions to account for the unique context of diabetes management with a CGM and the longer learning history for those with an earlier age of Type 1 diabetes diagnosis that might contribute to greater formation of automaticity for diabetes self-management.

Results

First, bivariate associations were examined for automaticity for diabetes self-management, overall self-management, and demographic factors including age, gender, time since diagnosis, and race/ethnicity. Greater automaticity for all four task scales were associated with increased self-management cross-sectionally (checking or reviewing blood glucose levels prior to eating, $r = .45, p < .001$; counting carbohydrates prior to eating, $r = .53, p < .001$; checking or reviewing blood glucose levels upon waking up, $r = .45, p < .001$; and, adjusting insulin, $r = .41, p < .001$). Also, greater overall automaticity for diabetes self-management was associated with overall greater self-management ($r = .62, p < .001$). T-tests indicated greater automaticity for diabetes self-management was reported by adolescents who used a CGM (CGM use: $M = 4.44; SD = 1.11$; no CGM use: $M = 3.54; SD = 1.45$; $t(76) = -2.39, p = .019$). However, no differences in automaticity for diabetes self-management were found for different genders or between white non-Hispanic persons and persons of color or of Hispanic ethnicity ($ps > .05$).

Second, in the subsample that completed the daily diary, prospective bivariate associations were examined for automaticity for diabetes self-management, average daily self-management, average daily self-regulatory failures in glucose checking, and average daily MBG and SDBG (see Table 1). Greater automaticity for checking or reviewing blood glucose levels prior to eating and greater automaticity for counting carbohydrates prior to eating were associated with higher average daily self-management ($r = .55, p < .001$; $r = .47, p = .002$, respectively) and fewer average daily self-regulatory failures in glucose checking ($r = -.51, p < .001$; $r = -.44, p = .003$, respectively). Greater automaticity for checking or reviewing blood glucose levels upon waking up and greater automaticity for adjusting insulin were associated with greater average self-management ($r = .38, p = .012$; $r = .47, p = .002$, respectively) but not average daily self-regulation failures in glucose checking ($ps > .05$). Greater overall automaticity for diabetes self-management was associated with greater average daily self-management ($r = .62, p < .001$), fewer average daily self-regulation failures in glucose checking ($r = -.38, p = .012$), and lower average daily MBG ($r = -.35, p = .022$). Greater automaticity for checking or reviewing blood glucose levels prior to eating was associated with lower average daily MBG ($r = -.34, p = .026$). Last, automaticity for diabetes self-management was not related to average daily SDBG ($ps > .05$).

Table 1. Pearson Correlations of Key Study Variables

Variables	<i>M (SD)</i>	1	2	3	4	5	6	7	8
1. Automaticity for diabetes self-management -overall	4.32 (1.20)	—							
2. Automaticity for checking blood glucose prior to eating	4.04 (1.58)	.78*	—						
3. Automaticity for counting carbohydrates prior to eating	4.36 (1.72)	.71*	.38**	—					
4. Automaticity for checking blood glucose levels upon waking up	4.22 (1.65)	.74*	.59*	.22	—				
5. Automaticity for adjusting insulin	4.56 (1.53)	.74*	.35**	.50*	.39*	—			
6. Average daily diabetes self-management	4.14 (.57)	.62*	.55*	.47**	.38*	.47**	—		
7. Average daily self-regulation failures in glucose checking	2.04 (.94)	-.38*	-.51**	-.44**	-.12	-.07	-.35**	—	
8. Mean blood glucose levels	183.51 (44.90)	-.35*	-.34*	-.27	-.24	-.20	-.19	.35*	—
9. Standard deviations of blood glucose levels	64.38 (19.59)	-.13	-.12	-.17	-.05	-.05	-.08	.16	.73*

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2. Association of Automaticity for Diabetes Self-Management With Diabetes Self-Management

DV: Average daily diabetes self-management	<i>F</i>	<i>df</i>	<i>R</i> ²	β	<i>p</i>	95% CI
Automaticity for:	5.62	3, 38	.31		.003	
Checking blood glucose prior to eating				.20	<.001	[.10, .30]
CGM status				<.03	.95	[-1.06, 1.00]
Time since diagnosis				.01	.70	[-.04, .06]
Automaticity for:	3.82	3, 38	.23		.02	
Counting carbohydrates prior to eating				.16	.00	[.06, .26]
CGM status				-.18	.73	[-1.25, .89]
time since diagnosis				-.01	.62	[-.06, .04]
Automaticity for:	2.46	3, 38	.16		.08	
Checking blood glucose levels upon waking up				.14	.02	[.03, .26]
CGM status				-.38	.49	[-1.49, .73]
Time since diagnosis				-.01	.70	[-.06, .04]
Automaticity for:	3.79	3, 38	.23		.02	
Adjusting insulin after a meal or after an out of range reading				.16	.003	[.06, .27]
CGM status				-.13	.81	[-1.21, .95]
Time since diagnosis				-.02	.51	[-.06, .03]
Overall automaticity for diabetes self-management	8.09	3, 38	.39		<.001	
Full scale				.29	<.001	[.17, .42]
CGM status				-.04	.94	[-1.00, .92]
Time since diagnosis				-.00	.97	[-.04, .04]

Table 3 Association of Automaticity for Diabetes Self-Management With Self-Regulation Failures in Glucose Checking

DV: Average daily self-regulation failures in glucose checking	<i>F</i>	<i>df</i>	<i>R</i> ²	<i>β</i>	<i>p</i>	95% CI
Automaticity for:	5.22	3, 38	.29		.004	
Checking blood glucose prior to eating				-.26	.003	[-.43, -.09]
CGM status				-.02	.978	[-1.74, 1.70]
Time since diagnosis				.05	.180	[-.03, .13]
Automaticity for:	4.98	3, 38	.29		.005	
Counting carbohydrates prior to eating				-.24	.004	[-.39, -.08]
CGM status				.14	.869	[-1.58, 1.86]
time since diagnosis				.08	.041	[.00, .15]
Automaticity for:	1.66	3, 38	.12		.193	
Checking blood glucose levels upon waking up				-.05	.613	[-.25, .15]
CGM status				.45	.632	[-1.44, 2.34]
Time since diagnosis				.08	.052	[-.00, .17]
Automaticity for:	1.60	3, 38	.11		.205	
Adjusting insulin after a meal or after an out of range reading				-.03	.734	[-.21, .15]
CGM status				.41	.671	[-1.51, 2.32]
Time since diagnosis				.09	.045	[.00, .17]
Overall automaticity for diabetes self-management	3.51	3, 38	.22		.024	
Full scale				-.26	.028	[-.50, -.03]
CGM status				.14	.877	[-1.66, 1.94]
Time since diagnosis				.07	.075	[-.01, .15]

Note. CGM = continuous glucose monitor.

Third, in the subsample of adolescents that completed the daily diary and where significant prospective bivariate associations were found (i.e., self-management, self-regulation failures in glucose checking, and MBG), regression analyses were conducted to examine whether greater automaticity for diabetes self-management continued to predict these average daily outcomes, when controlling for CGM use and time since diagnosis. Greater automaticity for checking or reviewing blood glucose levels prior to eating ($b = .20, t(38) = 3.95, p < .001$), greater automaticity for counting carbohydrates prior to eating ($b = .16, t(38) = 3.21, p = .003$), greater automaticity for checking or reviewing blood glucose levels upon waking up ($b = .14, t(38) = 2.52, p = .016$) and greater automaticity for adjusting insulin ($b = .16, t(38) = 3.21, p = .003$) significantly and positively predicted more optimal average daily self-management (see Table 2). Greater overall automaticity also significantly and positively predicted more optimal average daily self-management ($b = .29, t(38) = 4.78, p < .001$). Use of a CGM and time since diagnosis did not predict self-management ($ps > .05$).

Greater overall automaticity for checking or reviewing blood glucose levels prior to eating ($b = -.26, t(38) = -3.13, p = .003$) and greater automaticity for counting carbohydrates prior to eating ($b = -.24, t(38) = -3.02, p = .004$), which were the only two task scales to share bivariate associations with self-regulation failures, significantly and positively predicted fewer average self-regulation failures in daily glucose checking (see Table 3). In only the automaticity for counting carbohydrates before eating model, did longer time since diagnosis share a significant association with self-regulation failures, where longer time since diagnoses predicted more frequent average daily self-regulation failures in glucose checking ($b = .09, t(38) = 2.07, p = .045$). CGM use did not predict average daily self-regulation failures in glucose checking in all three models ($ps > .05$).

As documented in Table 4, greater overall automaticity continued to significantly predict lower average daily MBG ($b = -10.94, t(38) = -2.13, p = .040$). However, greater automaticity for checking or reviewing blood glucose levels prior to eating, which was the only task scale to share a bivariate association with MBG, did not continue to prospectively predict average daily MBG ($p > .05$). In all MBG models, except the automaticity for checking or reviewing blood glucose levels prior to eating model, longer time since diagnosis also shared a significant association with MBG, where longer time since diagnosis predicted greater average MBG. CGM use did not predict average daily MBG in any of the models ($ps > .05$).

Table 4 Association of Automaticity for Diabetes Self-Management With M Blood Glucose Levels

DV: Average daily mean blood glucose levels	F	df	R ²	β	p	95% CI
Automaticity for:	3.08	3, 38	.20		.039	
Checking blood glucose prior to eating				-7.04	.091	[-15.27, 1.18]
CGM status				-29.16	.476	[-1.74, 1.70]
Time since diagnosis				3.42	.085	[-.49, 7.32]
Automaticity for:	3.16	3, 38	.20		.036	
Counting carbohydrates prior to eating				-6.53	.081	[-13.91, .85]
CGM status				-25.18	.534	[-106.33, 55.97]
Time since diagnosis				4.34	.022	[.66, 8.02]
Automaticity for:	2.57	3, 38	.17		.069	
Checking blood glucose levels upon waking up				-5.34	.203	[-13.68, 3.00]
CGM status				-17.29	.672	[-99.42, 64.84]
Time since diagnosis				4.20	.031	[.41, 7.98]
Automaticity for:	2.60	3, 38	.17		.066	
Adjusting insulin after a meal or after an out of range reading				-5.16	.192	[-13.02, 2.70]
CGM status				-24.82	.548	[-107.75, 58.12]
Time since diagnosis				4.48	.020	[.74, 8.23]
Overall automaticity for diabetes self-management	3.66	3, 38	.22		.021	
Full scale				-10.94	.040	[-21.35, -.52]
CGM status				-29.61	.460	[-109.89, 50.66]
Time since diagnosis				3.83	.042	[.15, 7.51]

Note. CGM = continuous glucose monitor.

Discussion

This study examined the associations of behavioral automaticity for diabetes self-management with average daily self-management and self-regulation failures in blood glucose checking as well as average daily glycemic levels in a sample of adolescents with Type 1 diabetes. Partially consistent with our hypotheses, greater automaticity across multiple diabetes tasks was cross-sectionally and prospectively associated with more optimal self-management, and prospectively associated with fewer daily self-regulation failures in glucose monitoring and lower daily average blood glucose levels, but not standard deviations of blood glucose levels. With the exception of the association between automaticity for checking or reviewing blood glucose levels prior to eating and average daily blood glucose levels, these significant associations occurred above and beyond CGM use and time since diagnosis. These findings are consistent with research showing that health behaviors that are more automatic (i.e., have lower thresholds for time, attention, conscious awareness, and goal-dependence) are also more likely maintained across days and reduce executive self-regulatory demands (Bolman et al., 2011). It is likely that adolescents with Type 1 diabetes who reported greater automaticity for diabetes self-management could initiate common diabetes tasks with decreased demands for time, attention, goal-dependence, and conscious awareness.

Our findings that automaticity for diabetes self-management was unrelated to average daily MBG or average daily SDBG, with the exception of the bivariate association between automaticity for checking or reviewing blood glucose levels prior to eating and MBG, and overall automaticity prospectively predicting MBG, suggest that increased automaticity for the routine diabetes tasks indexed within the current study may not consistently translate into more optimal glycemic levels and variation. While only overall automaticity was linked to MBG, above and beyond CGM use and time since diagnosis, there were small to medium effect sizes of the relationships between automaticity for each individual diabetes task and average daily MBG in our smaller daily diary sample. Given these effect sizes and that Type 1 error cannot be ruled out, it is hypothesized that the contribution of automaticity for diabetes self-management to glycemic levels might be nuanced and interconnected with executive cognitive functions that undergird deliberative, complex problem solving, planning, and goal valuation. Study of this habit-goal interface has historically partitioned automaticity as relating only to purely automatic, stimulus driven simple acts, that is, habits (Gardner et al., 2012; Phillips et al., 2013). However, Moors (2016) argues that automaticity is not only the domain of purely stimulus-driven behaviors and further research is needed on the continuum of automaticity. In the diabetes context, this continuum might include the alarm of your CGM may cause you to automatically grab your receiver (phone), which activates a goal of staying in-range that prioritizes the allocation of executive functions to the continued act of eating a carbohydrate snack to treat hypoglycemia or dosing insulin in preparation for a meal. It is likely that the association of automaticity for diabetes-self management with glycemic levels requires measurement of automaticity in a way that includes broader features of these interactions with goal-dependent behaviors that are initiated with automaticity. Unfortunately, the SRBAI, does not index the goal-dependence of tasks, so this remains an area for future research.

Similarly, it may be that the most critical health behaviors for automaticity are those that initiate chains of more complex behaviors. For example, the finding that only overall automaticity was associated with MBG suggests that having a greater repertoire of behaviors that occur more

automatically to initiate diabetes behavior chains may be key for glucose regulation. In addition, the SRBAI in this study assessed automaticity for adjusting insulin after a meal or an out-of-range reading, but not automaticity for dosing insulin prior to a meal, which was not associated with self-management in pilot work, despite prior literature showing the strong link between dosing insulin premeal and glycemic control (Slattery et al., 2018). It may be that automaticity of insulin dosing premeal was not associated, as glucose checking or carbohydrate counting instead initiate that behavior chain and are the key behaviors for automaticity. At the same time, more automatically dosing insulin for extra food or later corrections is a unique behavior chain outside of starting a meal, and thus automaticity for this task might remain important. Continued investigation into the associations between automaticity of common diabetes tasks and glycemic control is warranted.

The findings of this study should be considered in the context of some limitations. First, the small size and demographic characteristics of the daily diary subsample limits the conclusions that can be drawn regarding the lack of prospective associations of automaticity for diabetes self-management with glycemic levels. Particularly, our sample was primarily White and, while socioeconomic status (SES) was not assessed in the current study, given that adolescents were required to have access to WiFi and own a tablet, smartphone or computer, it is possible that the sample primarily included adolescents from middle or high SES households. This is consistent with prior studies which suggest that adolescents who report being socioeconomically disadvantaged or self-identify as an ethnic/racial minority group member are less likely to attend diabetes camps (Valenzuela et al., 2020). Nonetheless, the camp which participants attended provides scholarships for any family in need, with up to 66% of campers receiving a full scholarship and up to 25% receiving a partial scholarship; thus, it is possible we had a wide distribution of SES within our sample.

Second, CGM status and baseline levels of self-management were related to diary completion, thus our findings demonstrate an attrition bias and findings might not translate to adolescents who do not have a CGM or who report a low level of baseline self-management. Relatedly, the majority of the sample used CGM and pump technologies. Recent estimates suggest at least 25% of adolescents and young adults use CGM technology, with the rate drastically increasing as new advances in diabetes technology emerge (American Diabetes Association, 2019). Therefore, the findings may not generalize to adolescents who do not use these technologies. Automaticity for diabetes self-management may be even more critical for adolescents not using CGMs or insulin pumps given the increase in tasks required for daily management without a CGM or insulin pump.

Third, data were self-report and further assessment of parent report and objective/experimental measures of automaticity, as well as self-management and blood glucose levels, are needed to clarify the role of automaticity in the daily life of adolescents with Type 1 diabetes. For example, for CGM users, estimates of time-in-range, rather than mean or standard deviations of blood glucose, may provide a more accurate understanding of the association between automaticity and glycemic control. It is notable that a subsample of participants within our study provided CGM downloads ($n = 22$), and those data were included in analyses, where available. Thus, it is less likely that the study findings were driven by method variance alone.

Fourth, baseline data were collected during diabetes camp, in which there is likely improved emotional functioning, extensive peer support, and support and monitoring of glycemic control by camp

counselors and other providers (Weissberg-Benchell & Rychlik, 2017). Therefore, it is possible that baseline functioning may have been skewed and carryover effects of increased diabetes self-management from camp to 1 to 3 months later may have affected daily diary data. Moreover, data from 2011 suggests that only about 30,000 adolescents attend a diabetes camp annually (American Diabetes Association, 2012), thus our sample is likely most representative of a small subsample of adolescents with Type 1 diabetes. It is imperative to determine whether the presence and strength of the relationships found within the current study may generalize outside of adolescents with diabetes that attend a diabetes camp.

Last, while our findings provide support for the use of the SRBAI in understanding automaticity for diabetes self-management in adolescents, further validation of the measure is needed. The strong internal consistency and unitary factor structure of the SRBAI for diabetes self-management, in conjunction with cross-sectional and prospective associations with self-management, disruptions in glucose checking, and average glycemic control suggest that the SRBAI measure may be useful in indexing perceived automaticity for diabetes self-management, and perhaps average blood glucose levels. This is consistent with previous research supporting the validity of the SRBAI for assessing automaticity for health behavior engagement in chronic illness populations (e.g., Durand et al., 2018; Phillips et al., 2016; Pyatak et al., 2018) and extends this work to adolescents with Type 1 diabetes. Yet, more thorough psychometric evaluation (i.e., test-retest reliability, discriminant and predictive validity, confirmatory factor analysis) of the SRBAI for diabetes self-management in a larger sample is warranted. Though not conducted in the current study, such investigation should include an examination of the convergence between automaticity of a specific diabetes task and engagement in the task, rather than overall self-management (for example, whether automaticity for adjusting insulin after a meal or after an out-of-range blood glucose reading is specifically related to the actual performance of insulin blousing, rather than broad engagement in various self-management tasks).

The findings of the study provide preliminary support for the role of behavioral automaticity for diabetes self-management in explaining daily self-management, disruptions in adolescents with Type 1 diabetes, and perhaps MBG, as well as the use of the SRBAI in measuring automaticity for diabetes self-management. Future research should explore the association between automaticity for diabetes self-management and level of diabetes self-management over time, including an examination of within-person associations over time, multiple trajectories of automaticity development that might exist, as well as consideration of the role of neural processes in predicting the strength of this association. Increasing automaticity for diabetes self-management may be helpful in incrementally lowering the cognitive demands required for diabetes management and increasing persistence in diabetes tasks in stressful (Bolman et al., 2011; Schwabe & Wolf, 2009) or less resourced (i.e., limited time or attention) environments, which could, in turn, help decrease diabetes distress and improve health-related quality of life, as well as glycemic outcomes. Interventions specifically targeting automaticity (e.g., Fritz et al., 2017; Pyatak et al., 2018) for diabetes self-management are deserving of further inquiry, including an exploration of the role of stress and automaticity in adolescents' diabetes behavior change.

Finally, automaticity likely develops through three primary learning processes: skill mastery, enhanced stimulus pairing (i.e., to increase stimulus control for intentions and acts), and enhanced goal valuation for goal-directed action (Martiny-Huenger et al., 2017; Moors, 2016). Shifts in required time, attention,

and goal-dependence in response to learning may be mediated by changes in the quality of representation of the act or intention in long term memory and more efficient activation of premotor nodes in daily life (Moors, 2016; Moors et al., 2017). Interventions to increase automaticity for diabetes self-management in adolescents will likely need to include:

1. Skills training to mastery with rehearsal, monitoring and feedback beyond the scope of typical diabetes education and inclusive of the transfer of autonomy for tasks from caregiver to child;
2. Increasing the strength of stimulus-behavior pairing and stimulus-intention pairing through modification of the salience of critical diabetes stimuli and reinforcers (e.g., physiological symptoms of hypo and hyperglycemia) and consistent reinforcement of stimulus pairings; and
3. Enhancing the valuation of diabetes related goals through priming future thinking, modifying reinforcers, and modifying other psychobiological factors that impact valuation (e.g., depression or anxiety).

For example, behavioral interventions, such as contingency management or parent behavioral contracting, might be specifically targeted at increasing automaticity through incentives and behavior chaining (Stanger et al., 2018; Stoeckel & Duke, 2015). In addition, attentional bias training might also be useful in amplifying the salience of cues and incentives to facilitate automaticity in behavioral learning (Kakoschke et al., 2014). Across these intervention modalities, delivery of interventions focused on automaticity for diabetes self-management soon after the diagnosis, during the honeymoon phase, might be particularly helpful in establishing optimal diabetes management across adolescence.

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