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Delay Discounting and Parental Monitoring in Adolescents with Poorly Controlled Type 1 Diabetes

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Abstract

In a sample of adolescents with poorly controlled type 1 diabetes, this study examined if delay discounting, the extent to which individuals prefer immediate over delayed rewards, was associated with severity of non-adherence and poor glycemic control, and if parental monitoring of diabetes management moderated those associations. Sixty-one adolescents ($M_{\text{age}}=15.08_{\text{years}}$, $SD=1.43$) with poorly controlled type 1 diabetes completed a delayed discounting task and an HbA1c blood test. Adherence was assessed via self-monitoring of blood glucose (SMBG) data from adolescents' glucometers. Parents completed a parental monitoring questionnaire. Greater delay discounting was associated with higher HbA1c, but not SMBG. Direct parent observation of diabetes tasks, but not indirect parental monitoring, moderated the link between greater delay discounting and higher HbA1c, with higher direct parent observation buffering the link between greater discounting and poorer glycemic control. Delay discounting may be a target for future interventions to improve HbA1c in youth with type 1 diabetes.

Keywords

Delay Discounting; Parental Monitoring; Type 1 Diabetes; Adolescents; Glycemic Control

For adolescents with type 1 diabetes, preventing long-term health consequences requires intensive insulin therapy, which goes beyond limiting the immediate risks of hypo and hyperglycemia to broadly target the normalization of daily blood glucose levels (Diabetes Control and Complications Trial Research Group, 1993). This treatment regimen requires youth to check their blood glucose levels via finger sticks at least four times per day as well

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Compliance with Ethical Standards.

Conflict of Interest: Amy Hughes Lansing declares that she has no conflict of interest. Catherine Stanger declares that she has no conflict of interest. Rebecca Crochiere declares that she has no conflict of interest. Ann Carracher declares that she has no conflict of interest. Alan Budney declares that he has no conflict of interest.

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 individual participants included in the study.

as dose insulin throughout the day. The insulin dosing process is complex with insulin amounts adjusted to account for both planned meals (via carbohydrate counting) and hyperglycemia (Atkinson, Eisenbarth, & Michels, 2014). Further, the effectiveness of insulin dosing regimens can also be inconsistent, varying from day-to-day in response to changes in physical activity, stress, sleep and illness (American Diabetes Association, 2003). Unfortunately, over 70% of adolescents with type 1 diabetes fail to meet clinical guidelines for glycemic control (HbA1c $\geq 7.5\%$), with increasing age, a longer time since diagnosis of diabetes, and use of multiple daily insulin injections rather than a sub-cutaneous insulin pump linked with poorer glycemic control (Gerstl et al., 2008; Sherr et al., 2016; Wood et al., 2013).

While there are many individual and psychosocial factors that have been linked with problematic management of type 1 diabetes in youth, there has been little research examining the behavioral economics of diabetes management. One focus of behavioral economics research in health psychology has been studying how individuals vary in terms of how much they prefer an immediate reward compared to a later reward, a phenomenon referred to as delay discounting (Green, Fry, & Myerson, 1994). Delay discounting tasks derive these temporal decision-making patterns from individuals' responses on a series of dichotomous choices between either a smaller, more immediate reward (usually monetary) or a larger, but delayed, reward (Madden & Johnson, 2009; Odum, 2011). Delay discounting patterns have been linked with fronto-limbic neural activation related to reward valuation and cognitive control during health behavior decision-making (Ballard & Knutson, 2009; Peters & Buchel, 2011; Stanger et al., 2013) and associated with myriad health behaviors and outcomes. For example, greater discounting of delayed rewards has been associated with increased substance use, abuse, and dependence (Bickel & Johnson, 2003; Johnson, Bickel, & Baker, 2007). Higher discounting of delayed rewards has also been associated with lower likelihood of eating breakfast, using sunscreen and wearing a seat belt, and greater likelihood of engaging in risky sexual behavior (Daugherty & Brase, 2010). Moreover, patterns of delay discounting might also be modifiable, with recent studies showing that cognitive training resulted in decreases in the discounting of future rewards (Bickel, Yi, Landes, Hill, & Baxter, 2011; Peters & Büchel, 2010; Stein et al., 2016). Thus, delay discounting, if associated with type 1 diabetes outcomes, may be a modifiable cognitive factor to target in interventions to improve adherence and glycemic control.

However, there is conflicting evidence regarding the possible links between delay discounting and behaviors relevant to type 1 diabetes management such as medication adherence and eating behaviors. Studies examining adherence to hypertension and high cholesterol medications have produced mixed results with regards to delay discounting, with one study finding a small but significant association between delay discounting patterns and adherence (Chapman, 2003). In youth with type 1 diabetes, adherence encompasses the set of health-promoting behaviors that are critical for good diabetes outcomes, which are not limited to daily medication adherence. For example, although not caused by obesity, type 1 diabetes management in youth does require decision-making at meal times (i.e., to ensure proper blood glucose checking, carbohydrate counting and insulin dosing) and dysregulated eating behaviors have been linked to poorer glycemic control (Merwin et al., 2014; Young et al., 2013). Research examining eating behaviors and obesity have also found links between

greater discounting of future rewards and consumption of more calories and higher weight (Epstein, Salvy, Carr, Dearing, & Bickel, 2010; Rollins, Dearing, & Epstein, 2010; Weller, Cook, Avsar, & Cox, 2008). These findings are also consistent with research linking decreased delay discounting with greater engagement in health-promoting behaviors (Daugherty & Brase, 2010). Adherence, then, is the primary health-promoting behavior process that is most likely to be linked with delay discounting. Thus, it was theorized that greater delay discounting may be associated with both greater severity of non-adherence and poorer glycemic control among adolescents with poorly controlled type 1 diabetes.

At the same time, adolescents with type 1 diabetes manage this chronic illness within a family system, and parental monitoring of diabetes management may buffer risks associated with greater delay discounting on severity of non-adherence and also poor glycemic control (Modi et al., 2012). Parental monitoring of diabetes management is a multifaceted process in adolescence that includes not only direct parent observation of diabetes management tasks, but also the flow of information between the parent and youth through both youth disclosure and parent solicitation of information about daily diabetes management tasks (Ellis, Templin, et al., 2008). The latter indirect parental monitoring aspects, youth disclosure and parent solicitation, are critical to consider in adolescence as youth begin to spend more time away from the home and complete fewer diabetes management behaviors in the presence of a parent. Research finds that higher parental monitoring (direct and indirect) is linked with increased self-efficacy for diabetes management as well as better adherence and glycemic control across adolescence, even after accounting for parent-youth relationship quality (Berg et al., 2008, 2011, 2016; King et al., 2012; Osborn, Berg, Hughes, Pham, & Wiebe, 2013). For example, on days in which parents have greater knowledge of their teen's diabetes management, teens evidence higher levels of adherence and lower mean daily blood glucose levels (Berg et al., 2016).

One unexamined mechanism by which parental monitoring might facilitate better adherence and glycemic control is that parental monitoring might buffer the association between greater youth delay discounting and poor diabetes outcomes. For example, direct parent observation of diabetes tasks may provide external support to compensate for an adolescent's tendency to choose the immediate reinforcers of non-adherence (e.g., continuing a social or pleasurable activity) over the delayed reward of adherence, experiencing better long-term health. In addition, greater youth disclosure and parent solicitation might increase opportunities for parents to gain knowledge of and correct for the greater frequency of missed blood glucose checks and insulin adjustments in youth with greater delay discounting. Accordingly, it was hypothesized that parental monitoring, both via direct and indirect processes, would moderate the link between delay discounting and the severity of non-adherence and poor glycemic control.

This study examined whether delay discounting and the interaction of delay discounting and parental monitoring were associated with severity of non-adherence and poorer glycemic control in a sample of adolescents with poorly controlled type 1 diabetes. An objective indicator of adherence, frequency of self-monitoring of blood glucose (SMBG), was examined. First, it was hypothesized that greater delay discounting would be associated with lower frequency of SMBG and worse glycemic control (HbA1c). Second, it was

hypothesized that the three facets of parental monitoring, direct parent observation of diabetes tasks, youth disclosure about diabetes, and parent solicitation of information about diabetes from the youth, would each moderate the association of delay discounting with severity of non-adherence and poor glycemic control. Specifically, it was hypothesized that adolescents with lower direct parent observation, youth disclosure, or parent solicitation and greater delay discounting would have the greatest impairments in adherence and glycemic control, while those adolescents with greater delay discounting but higher levels of direct parent observation, youth disclosure, or parent solicitation would show less impairment in adherence and glycemic control. Also, it was hypothesized that regardless of level of direct parent observation, youth disclosure, or parent solicitation, adolescents with lower delay discounting would have similar (and smaller) impairments in adherence and glycemic control.

Methods

Participants

Participants for this study included sixty-one adolescents recruited from two clinical sites affiliated with a children's hospital. Over half (57%) of participants were male, with a mean age of 15.08 years ($SD=1.43$). Two-thirds of participants (66%) used an insulin pump and the average duration of diabetes was 6.20 years ($SD=3.54$). The sample was almost entirely (98%) White and largely from the middle class (*MSES* Hollingshead 9-point (1 to 9) Scale = 5.4, $SD = 2.49$). Participating primary caregivers were majority (91%) females. All adolescents were recruited to participate in a randomized controlled trial of an intervention targeting non-adherence in adolescents with poor glycemic control, and this study utilizes data collected at intake prior to randomization. Inclusion criteria were: adolescents ages 13–17, type 1 diabetes diagnosis more than 18 months prior, average glycosylated hemoglobin percentage 8% for the past 6 months and the most recent 8%, and broadband internet at home (to allow participation in web-delivered treatment). Exclusion criteria included pregnancy and severe medical or psychiatric illness. Of those eligible for the study ($n=115$), 53% agreed to participate, and of those who chose not to participate, the majority (94%) reported their reason for not participating as either a lack of interest or time. This study was conducted in compliance with the college's Institutional Review Board.

Procedures

Intake assessments were conducted in the pediatric endocrinology department or a study office centrally located in the region. The study was explained to parents and adolescents, and parental/guardian consent and adolescent assent were obtained for all participants. Adolescents completed a battery of questionnaires and assessments including the delay discounting task, and at that time there was also collection of a blood glycosylated hemoglobin test and glucometer downloads. The participating primary caregiver completed surveys, including a measure of parental monitoring.

Measures

Delay Discounting—A delay discounting task was administered using a computerized program that asked participants to make choice decisions between smaller, immediate

monetary rewards and larger, delayed monetary rewards (Johnson & Bickel, 2002). Monetary rewards are a common way to assess delay discounting patterns across diverse populations, given that money is typically a universally rewarding stimulus. The task presents adolescents with two choice buttons: the left button for a smaller immediate reward, which read “\$ (money amount) right now” and the right button for a larger delayed reward, which read “\$ (money amount) in (delay).” Adolescents then were asked to make a choice between the smaller sum of money available now and the larger sum of money available after a delay. The larger delayed reward was \$1,000 (Mellis, Woodford, Stein, & Bickel, 2017). The delay periods were 1 day, 1 week, 1 month, and 6 months. Delays were always presented in increasing order. At each delay, six trials were administered, with the smaller immediate reward amount varied on each trial. The starting value of the smaller, immediate reward was always 50% of the larger, delayed reward, i.e., \$500. On subsequent trials, the smaller, immediate reward adjusted up or down by 50% depending on the subject’s choice. Specifically, if an adolescent picked the smaller, immediate reward, then the smaller, immediate reward on the subsequent trial decreased by 50%. If an adolescent picked the larger, delayed reward, then the smaller, immediate reward on the subsequent trial increased by 50%. There was a 1 second delay after the new value was presented before a new choice was selected.

Delay discounting rate was estimated using Mazur’s (1978) hyperbolic equation, $V_d = V/(1 + kD)$. V_d represents the discounted value of some reward V as a function of the delay (D in days) prior to the receipt of the reward, and k represents the estimated rate at which delayed rewards are discounted. Higher k values indicate greater discounting, i.e., favoring a smaller, immediate reward, and lower k values indicate less discounting, i.e. favoring larger delayed rewards. An indifference point, which is the value of the immediate reward that is considered as attractive as the alternative delayed reward, was calculated for each delayed reward magnitude at each delay. Those indifference points were then fit to the hyperbolic model of delay discounting rate (k). Distributions of k ’s tend to be highly positively skewed, so logarithm transformations using the natural logarithm ($\ln$) of k were performed to create a normal-like distribution. All analyses used these transformed values, where more negative values indicate less discounting of delayed rewards and less negative (closer to zero) values indicate greater discounting of delay rewards.

The delay discounting rate ($\ln k$) for each participant was examined for orderliness (i.e., non-systematic variance) using a previously published algorithm (Johnson & Bickel, 2008). Of the 61 participants, only 2 participants were excluded from analyses due to non-systematic variance in their responses on the delay discounting task. These 2 participants did not differ from the rest of the sample on HbA1c ($t(59) = -.68, p = .50$). The $\ln k$ of youth in this study ($M \ln k = -4.56$, see Table 1) was similar to average discounting rates found in other samples of adolescents (Duckworth & Seligman, 2005; Stanger et al., 2012). In addition, research on this task in adolescents has shown good test-retest reliability during both middle and late adolescence (Anokhin, Golosheykin, & Mulligan, 2015).

Parent Monitoring of Diabetes Care—To assess parental monitoring of diabetes care parents completed the Revised Parental Monitoring of Diabetes Care questionnaire (Ellis et al., 2012). This 27 item scale includes three subscales: direct parent observation (8 items),

youth disclosure (6 items), and parent solicitation (of information from youth; 4 items). All items were answered on a 5-point likert scale with parents reporting how frequently they completed certain monitoring tasks. Example items include, “How often did you look at the readings in your child’s blood glucose meter?” (direct parent observation), “If your child missed an insulin dose, how often would he/she tell you without you asking?” (youth disclosure), and “How often did you ask your child if they tested his/her blood glucose” (parent solicitation). An average across items on each subscale was used for analyses. Higher scores indicate greater levels of parental monitoring. This full scale has been previously validated in a sample of adolescents with type 1 diabetes (Ellis et al., 2012) with good reliability ($\alpha = .91$) and the measure showed good reliability in this sample ($\alpha = .88$). In addition, each subscale evidenced good reliability: direct parent observation $\alpha = .82$, youth disclosure $\alpha = .91$, and parent solicitation $\alpha = .82$. The average levels of direct parent observation ($M = 3.87$) and youth disclosure ($M=2.16$) in this sample were similar to average levels found in the validation study for this measure, while the average levels of parent solicitation ($M=4.31$) were elevated by 1.5 points compared to the validation study.

Self-monitoring of Blood Glucose—To assess frequency of SMBG, data were downloaded from participants’ blood glucose meters at the intake assessment. All data from 14 days prior to each assessment point was recorded, including times and results of blood glucose checks. The number of blood glucose checks on each of those 14 days was counted and then an average frequency of daily blood glucose checks was calculated.

Glycemic control—Glycosylated hemoglobin percentage (HbA1c) from a blood draw during the intake was used as the measure of glycemic control. Although participants were recruited from two clinic locations, all blood samples were analyzed in the same laboratory.

Analyses

Analyses were conducted using SPSS v.23. Pearson correlation analyses were conducted to assess the bivariate association between delay discounting rates, parental monitoring (all three facets), frequency of SMBG, and HbA1c. There were no missing data for any of the measures. The association of delay discounting and the interaction of delay discounting and parental monitoring with SMBG and HbA1c were examined through multiple linear regressions. Analogous models were used for all three facets of parental monitoring. Use of an insulin pump and time since diagnosis were included as covariates in each model due to theorized associations between these indicators and the key outcomes of SMBG and HbA1c. Also, age was included as a covariate to control for the association of decreases in adherence and glycemic control as well as delay discounting with older age in adolescence (King, Berg, Butner, Butler, & Wiebe, 2014; Steinberg et al., 2009). For each outcome (SMBG and HbA1c) analogous regression models were examined with delay discounting and the covariates entered on the first step, the parental monitoring variable entered on the second step, and the interaction of parental monitoring variable and delay discounting on the third step. The significance of the full model, change in variance predicted at each step, and regression coefficients for each predictor were examined. For significant interactions, the interaction was visualized and simple slopes analyses were conducted to assess if the slopes of the association between delay discounting and outcomes (SMBG or HbA1c) were

different from zero at both lower (1 SD below mean level) and higher (1SD above mean level) levels of that parental monitoring variable.

Results

Descriptive statistics for each key variable and correlations among those variables are provided in Table 1. A significant bivariate association was found between greater delay discounting and higher HbA1c ($r=.39, p=.002$), but not between delay discounting and SMBG ($r=-.20, p=.14$) or any facet of parental monitoring (direct parent observation: $r=-.02, p=.91$; youth disclosure: $r=-.10, p=.44$; parent solicitation: $r=.20, p=.14$). There were also significant associations between greater SMBG and greater parental monitoring (direct parent observation: $r=.49, p<.001$; youth disclosure: $r=.40, p=.002$; parent solicitation: $r=.34, p=.01$) as well as greater SMBG and lower HbA1c ($r=-.45, p<.001$) and greater direct parent observation and lower HbA1c ($r=-.26, p=.05$).

Association of Delay Discounting and the Interaction of Direct Parent Observation and Delay Discounting with SMBG

The first set of multiple linear regressions examined the associations of delay discounting, parental monitoring and the interaction of delay discounting and direct parent observation with SMBG, while controlling for use of a pump, length of diagnosis, and teen age (see Table 2). In step 1, delay discounting was entered along with covariates and this full model was significant and explained 19% of the variance in SMBG ($F(4, 53)= 5.75, p=.001$). However, the only significant association with SMBG was for teen age ($b=-.51, p=.02, 95\% \text{ CI } [-.93, -.09]$), suggesting that older teens showed less frequent SMBG. In step 2, direct parent observation was added and the full model remained significant, now explaining 34% of the variance in SMBG ($F(5, 52)= 5.53, p<.001$). Greater direct parent observation was significantly associated with more frequent SMBG ($b= 1.54, p=.001, 95\% \text{ CI } [.67, 2.41]$), explaining an additional 16% of variance in SMBG. There were no other significant associations at this step. Finally, in step 3 the interaction of direct parent observation and delay discounting was entered in the model and again the full model remained significant, explaining 36% of the variance in SMBG ($F(6, 51)= 6.62, p<.001$). Greater direct parent observation continued to be associated with greater SMBG; however, the interaction of delay discounting and direct parent observation was not significantly associated with SMBG ($b=-.21, p=.31, 95\% \text{ CI } [-.61, .20]$). These analyses suggested that less direct parent observation of diabetes tasks, but not greater delay discounting, was associated with higher levels of non-adherence in teens with poorly controlled type 1 diabetes.

Association of Delay Discounting and the Interaction of Direct Parent Observation and Delay Discounting with HbA1c

A second set of multiple linear regressions examined the associations of delay discounting, direct parent observation and the interaction of delay discounting and direct parent observation with HbA1c, while controlling for use of a pump, length of diagnosis, and teen age (see Table 3). In step 1, delay discounting was entered along with covariates and this full model was significant and explained 30% of the variance in HbA1c ($F(4, 53)= 5.75, p=.001$). Higher delay discounting was significantly associated with higher HbA1c ($b=.15, p$

= .01, 95% CI [.04, .26]). Also, use of a pump was associated with lower HbA1c ($b = -.57$, $p = .03$, 95% CI [-1.08, -.06]) suggesting that lower delay discounting and pump use were linked to better glycemic control. In step 2, direct parent observation was added and the full model remained significant, now explaining 35% of the variance in HbA1c ($R^2(5, 52) = 5.53$, $p < .001$). Delay discounting and use of a pump continued to be significantly associated with HbA1c (see Table 3); however, there was not a significant association for direct parent observation ($b = -.32$, $p = .07$, 95% CI [-.66, .02]), suggesting that lower delay discounting, but not direct parent observation was uniquely linked to better glycemic control. Finally, in step 3 the interaction of direct parent observation and delay discounting was entered in the model and again the full model remained significant, explaining 44% of the variance in HbA1c ($R^2(6, 51) = 6.62$, $p < .001$). The interaction was associated with HbA1c ($b = -.21$, $p = .01$, 95% CI [-.36, -.06]), and a significant main effect of greater delay discounting with higher HbA1c remained ($b = .19$, $p = .001$, 95% CI [.09, .29]), suggesting that both the interaction of delay discounting and direct parent observation and lower delay discounting alone were associated with better glycemic control.

The interaction was visualized (see Figure 1) and probed to examine regions of significance and the slopes of the association of delay discounting and HbA1c at both one standard deviation above and below the average levels of direct parent observation. Specifically, youth who were higher in delay discounting, but lower in direct parent observation had the highest HbA1c, while youth who were higher in delay discounting, but also higher in direct parent observation had similar HbA1c to those with lower delay discounting. Simple slopes testing was conducted finding that the association between delay discounting and HbA1c for teens with lower direct parent observation (slope = .34, $p < .001$) was significantly different from zero, while the association between delay discounting and HbA1c for teens with higher direct parent observation (slope = .03, $p = .69$) was not significantly different from zero. More specifically, the association between delay discounting and HbA1c was not significantly different from zero when direct parent observation scores were greater than 2.64 (i.e., between one and two standard deviations below the mean). This suggests that moderate to higher levels of direct parent observation buffered the link between higher delay discounting and higher HbA1c.

Youth Disclosure and Parent Solicitation of Information about Diabetes

Analogous models to those examined with direct parent observation were also examined for the two facets of indirect parental monitoring, youth disclosure and parent solicitation (see Tables 2 and 3). There was no significant interaction between delay discounting and youth disclosure in predicting HbA1c ($b = -.03$, $p = .58$, 95% CI [-.15, .09]) or SMBG ($b = -.002$, $p = .99$, 95% CI [-.30, .30]). Also, there was no significant interaction between delay discounting and parent solicitation in predicting HbA1c ($b = -.05$, $p = .63$, 95% CI [-.25, .15]) or SMBG ($b = -.03$, $p = .91$, 95% CI [-.49, .55]). These findings suggest that unlike direct parent observation, indirect monitoring of diabetes tasks relying on youth report (disclosed or solicited) of diabetes activities did not buffer the association between greater delay discounting and poorer glycemic control. However, like the findings for direct parent observation, after accounting for delay discounting, unique variance in SMBG was explained by both youth disclosure ($b = .92$, $p = .002$, 95% CI [.36, 1.47]) and parent

solicitation ($b = 1.03$, $p = .02$, 95% CI [.21, 1.85]), suggesting that increased indirect parental monitoring was also associated with increased frequency of SMBG in youth with poorly controlled type 1 diabetes.

Discussion

The purpose of this study was to examine the association of delay discounting with severity of non-adherence and poor glycemic control in adolescents with poorly controlled type 1 diabetes, and to determine whether parental monitoring moderated those associations. Consistent with hypotheses about glycemic control, greater discounting of delayed rewards was associated with greater severity of poor glycemic control. This finding is consistent with research finding that greater delay discounting is linked with problematic health outcomes such as obesity (Epstein et al., 2010), and findings that individuals with greater delay discounting are less likely to engage in health promoting behaviors despite the long-term benefits for their health (Daugherty & Brase, 2010). Notably, this previous work on delay discounting has also found that these decision-making patterns are malleable and that working memory training, episodic future thinking, and physical activity interventions might serve to decrease discounting rates and increase engagement in health promoting behaviors (Bickel et al., 2011; Sofis, Carrillo, & Jarmolowics, 2017; Stein et al., 2016). Thus, delay discounting may be a novel target for intervention in youth with poorly controlled type 1 diabetes and high delay discounting.

In addition, and also consistent with our hypotheses, direct parent observation moderated the link between delay discounting and HbA1c, supporting the importance of examining health behavior decision making patterns, such as delay discounting, in the context of the family system. One mechanism whereby direct parent observation of diabetes tasks may benefit adolescents with poorly controlled diabetes and greater delay discounting is in compensating for decision making patterns that favor immediate rewards over delayed outcomes, such as future health, including better glycemic control. This recommendation is consistent with literature supporting the importance of parental monitoring of diabetes for good diabetes outcomes both across adolescence and into emerging adulthood (Berg et al., 2008, 2016; King et al., 2012; Osborn et al., 2013). Increasing direct parent observation of diabetes tasks might be an additional modifiable target for improving glycemic control in adolescents with poorly controlled type 1 diabetes who evidence greater delay discounting. Multiple family-based interventions, e.g., Diabetes Behavioral Family Systems Therapy and Multisystemic Therapy, have evidenced benefits for youth adherence and glycemic control (Ellis, Naar-King, et al., 2008; Wysocki et al., 2007). These interventions might be leveraged to facilitate increases in direct parent observation in youth with greater delay discounting, while decreasing family conflict and increasing youth responsibility for disease management across time.

Yet, in contrast to our hypotheses, the findings also suggested that indirect monitoring of diabetes activities occurring while the youth is not with the parent, via either increased youth disclosure or parent solicitation, did not uniquely benefit glycemic control in youth with greater delay discounting (i.e., there was no significant moderation). This finding presents a challenge in the context of interventions to increase parental monitoring, as across time

adolescents spend increasing time away from home, not under the direct supervision of their parent. Research would then benefit from exploring methods to increase direct parent observation of diabetes management without drastically infringing on youth autonomy and increasing family conflict (Hilliard et al., 2012). For example, families might employ other means to provide direct monitoring for youth with high delay discounting and poor glycemic control, such as engaging the school nurse or other school personnel, or using technology-based systems where both youth and parent can simultaneously review the youth's diabetes status (e.g., using a continuous glucose monitor with a companion smartphone or web application that shares data).

With regards to SMBG, the other primary hypothesis that higher delay discounting would be associated with lower frequency of SMBG and that parental monitoring would moderate that association was not supported. Rather, SMBG was associated with each parental monitoring facet, but not delay discounting or the interaction of delay discounting and parental monitoring. While this is consistent with some findings that delay discounting was not associated with hypertension and high cholesterol medication adherence (Chapman, 2003), it is inconsistent with findings that delay discounting is associated with lesser engagement in other health promoting behaviors (Daugherty & Brase, 2010). Of note, daily blood glucose checking is one behavior within a sequence of behaviors and decisions required for optimal diabetes adherence. It may be that adherence behaviors other than SMBG, such as counting carbohydrates, accurate dosing of insulin boluses, and using insulin or carbohydrates to correct hypo and hyperglycemia are more strongly linked with delay discounting. In addition, although not traditionally assessed in adherence measures, dysregulated eating behaviors may be another link between delay discounting and glycemic control. Adolescents with poorly controlled type 1 diabetes who exhibit greater delay discounting may be at greater risk for eating more than planned at meals, requiring additional insulin adjustments, or for dysregulated eating patterns (e.g., late night or all-day eating), that make accurate insulin dosing more challenging (Epstein et al., 2010). The association between delay discounting and these other important diabetes management behaviors warrants investigation.

These results should be interpreted with consideration of multiple limitations. This sample consisted of almost entirely Caucasian adolescents from largely middle class families; therefore, these results may not generalize to adolescents of other races/ethnicities and socioeconomic statuses. Also, risk for type II error is increased due to the smaller sample size ($n=61$), such that a significant association between delay discounting and SMBG might well be established in a larger sample. These analyses are cross-sectional and do not explore longitudinal associations between delay discounting and later SMBG and poor glycemic control, with future research needed to explore these associations prospectively. Further, due to the inclusion criterion of $HbA1c \leq 8\%$, this study's data contain a floor effect of glycemic control; therefore, these results do not reflect the full spectrum of adolescent glycemic control and these findings should not be generalized to youth with good glycemic control. Additional research is warranted on this topic in larger samples of youth with good and poor control of type 1 diabetes.

These findings also suggest multiple directions for future research and clinical endeavors. Foremost, future research should aim to clarify the associations of delay discounting, and the interaction of parental monitoring and delay discounting, with glycemic control to identify the adherence behavior pathways underlying these associations. Also, as research has suggested that delay discounting is a malleable pattern that may change in response to intervention, research is needed to develop interventions that might effectively target delay discounting in youth with type 1 diabetes to facilitate improvements in glycemic control. In addition, research should also explore how use of technology, such as insulin pumps or continuous glucose monitors, might facilitate parental monitoring in youth with higher discounting rates. Similarly, further work is needed examining how other family processes, such as family conflict or parent-youth relationship quality, might also interrelate with delay discounting and glycemic control.

Finally, these findings suggest some initial clinical implications. For example, increased direct parent observation of diabetes tasks may be an important target for behavioral interventions to improve glycemic control in adolescents who evidence greater delay discounting. These adolescents will likely require more intensive parent involvement in diabetes management throughout adolescence to provide a structured scaffolding in the transition to more independent care into emerging adulthood. This notion may contrast with an emphasis in many clinical pediatric settings on increasing adolescent independence in their disease management; however, research on late adolescents (ages 17 and 18) with diabetes suggests that while on average levels of parental monitoring have decreased, parental monitoring remains a significant predictor of diabetes outcomes (Berg et al., 2016). Evidence of greater delay discounting, i.e., being overly influenced by the present and heavily “discounting” the future, may be useful as a clinical marker of youths who are at high risk for poor type 1 diabetes outcomes in adolescence, requiring more intensive behavioral and family-based interventions and increased social support.

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Figure 1.
The Interaction of Delay Discounting and Direct Parent Observation in Predicting Glycemic Control in Adolescents with Poorly Controlled Type 1 Diabetes.

Table 1

Descriptive Data and Correlations for Key Study Variables

	Mean (SD)	Min/Max	DO	YD	PS	SMBG	HbA1c
Delay Discounting	-4.56 (2.06)	-7.65/-	.21	-.02	-.10	.20	.39**
Direct Parent Observation (DO)	3.87 (.75)	2.13/5.00		.22	.62**	.49**	-.26*
Youth Disclosure (YD)	2.16 (1.06)	1.00/5.00			.10	.40**	-.15
Parent Solicitation (PS)	4.31 (.76)	2.00/5.00				.34*	-.05
SMBG	4.61 (2.43)	0/16					-.45**
HbA1c	9.16 (.96)	8.0/12.7					

* $p < .05$,** $p < .01$

Regression analyses examining the association between Delay Discounting, and the interaction of Delay Discounting and Parental Monitoring with SMBG

Table 2

	F	R ²	R ²	B	95% CI
Step 1	3.02 [*]	.19			
Pump				.81	[−.60, 2.21]
Length of Diagnosis				.07	[−.12, .26]
Age				−.51 [*]	[−.93, −.09]
Delay Discounting				−.17	[−.47, .13]
Step 2- Direct Parent Observation (DO)	5.46 ^{**}	.34	.16 ^{**}		
Pump				1.28	[−.02, 2.58]
Length of Diagnosis				.03	[−.14, .20]
Age				−.07	[−.52, .39]
Delay Discounting				−.16	[−.43, .12]
DO				1.54 ^{**}	[.67, 2.41]
Step 3	4.73	.36	.01		
Pump				1.43 [*]	[.10, 2.75]
Length of Diagnosis				.023	[−.14, .20]
Age				−.04	[−.50, .42]
Delay Discounting				−.12	[−.40, .17]
DO				1.61 ^{**}	[.73, 2.50]
Delay Discounting × DO				−.21	[−.61, .20]
Step 2- Youth Disclosure (YD)	5.22 ^{**}	.33	.15 ^{**}		
Pump				−1.05	[−2.25, 2.33]
Length of Diagnosis				.003	[−.09, .18]
Age				−.48 [*]	[−.87, −.10]
Delay Discounting				−.13	[−.41, .15]
YD				.92 ^{**}	[.38, 1.46]

	F	R ²	R ²	B	95% CI
Step 3	4.27**	.33	<.001		
Pump				1.04	[-.28, 2.37]
Length of Diagnosis				.003	[-.17, .18]
Age				-.48*	[-.88, -.09]
Delay Discounting				-.13	[-.43, .16]
YD				.92**	[.36, 1.47]
Delay Discounting × YD				-.002	[-.30, .295]
Step 2- Parent Solicitation (PS)	3.96**	.28	.09*		
Pump				.94	[-.40, 2.28]
Length of Diagnosis				.04	[-.14, .21]
Age				-.37	[-.78, .05]
Delay Discounting				-.25	[-.55, .05]
PS				1.02*	[.22, 1.83]
Step 3	3.24**	.28	<.001		
Pump				.93	[-.45, 2.30]
Length of Diagnosis				.04	[-.15, .22]
Age				-.37	[-.79, .06]
Delay Discounting				-.26	[-.59, .07]
PS				1.03*	[.21, 1.85]
Delay Discounting x PS				.03	[-.49, .55]

*
 $p < .05$,

**
 $p < .01$

Regression analyses examining the association between Delay Discounting, and the interaction of Delay Discounting and Parental Monitoring with HbA1c

Table 3

	F	R ²	R ²	B	95% CI
Step 1	5.75 ^{**}	.30			
Pump				-.57 [*]	[-1.08, -.06]
Length of Diagnosis				-.03	[-.10, .03]
Age				.10	[-.05, .25]
Delay Discounting				.15 [*]	[-.04, .26]
Step 2- Direct Parent Observation (DO)	5.53 ^{**}	.35	.05		
Pump				-.67 [*]	[-1.18, -.16]
Length of Diagnosis				-.02	[-.09, .04]
Age				.01	[-.17, .19]
Delay Discounting				.14 [*]	[-.04, .25]
DO				-.32	[-.66, .02]
Step 3	6.62 ^{**}	.44	.09 ^{**}		
Pump				-.52 [*]	[-1.01, -.04]
Length of Diagnosis				-.02	[-.09, .04]
Age				.04	[-.13, .21]
Delay Discounting				.19 ^{**}	[-.08, .29]
DO				-.24	[-.57, .08]
Delay Discounting × DO				-.21 ^{**}	[-.36, -.06]
Step 2- Youth Disclosure (YD)	4.75 ^{**}	.31	.01		
Pump				-.59 [*]	[-1.11, -.08]
Length of Diagnosis				-.03	[-.10, .04]
Age				.10	[-.06, .25]
Delay Discounting				.14 [*]	[-.03, .25]
YD				-.10	[-.31, .12]

	F	R ²	B	95% CI
Step 3	3.95**	.32		.004
Pump			-.62*	[-1.15, -.10]
Length of Diagnosis			-.02	[-.09, .05]
Age			.11	[-.05, .26]
Delay Discounting			.13*	[-.02, .25]
YD			-.11	[-.33, .11]
Delay Discounting × YD			-.03	[-.15, .09]
Step 2- Parent Solicitation (PS)	4.61**	.31		.01
Pump			-.58*	[-1.10, -.07]
Length of Diagnosis			-.03	[-.10, .04]
Age			.09	[-.07, .25]
Delay Discounting			.15*	[-.04, .27]
PS			-.09	[-.40, .22]
Step 3	3.83**	.31		.003
Pump			-.56*	[-1.09, -.03]
Length of Diagnosis			-.03	[-.10, .04]
Age			.09	[-.07, .25]
Delay Discounting			.17*	[-.04, .29]
PS			-.10	[-.41, .22]
Delay Discounting × PS			-.05	[-.25, .15]

*
p < .05,

**
p < .01