THE RELATIONSHIP AMONG EXECUTIVE FUNCTIONING, HEALTH-RELATED QUALITY OF LIFE, AND GLYCEMIC CONTROL IN PEDIATRIC TYPE 1 DIABETES

A Dissertation

by

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ABSTRACT

The purpose of this study was to examine the relationship between glycemic control, executive functioning, and health-related quality of life in pediatric type 1 diabetes, as well as the impact of sex and age on these variables. Adolescents (N = 191) ages 12 to 18, both male and female, and their caregivers were asked to complete the Pediatric Quality of Life (generic form), the Comprehensive Executive Functioning Inventory, and to provide demographic and medical history information. Recent HbA1c, the number of diabetic ketoacidosis episodes, the number of hospitalizations, and a history of ketones, seizures, and hypoglycemia were obtained from the participant's medical record to assess glycemic control.

Results indicated that executive functioning was a significant predictor of the variance of self-report health-related quality of life. When glycemic control was added to the model, executive functioning also significantly predicted parent-report health-related quality of life. Additionally, glycemic control, executive functioning, and health-related quality of life were found to significantly covary with one another. Moreover, there were significant negative correlations between HbA1c, number of DKA episodes, number of hospitalizations in the past 6 months, number of hospitalizations since diagnosis and executive functioning. Regarding glycemic control and quality of life, there were significant negative correlations between HbA1c, number of DKA episodes, hospitalizations in the past 6 months, and hospitalizations since diagnosis with health-related quality of life scales. Finally, there were significant positive correlations between all executive functioning scales and all health-related quality of life scales. Of note, child's current age did not predict nor was it significantly associated with glycemic control or executive functioning. Child's sex had small significant associations with number of

hospitalizations and emotion regulation, but did not predict executive functioning or glycemic control. Results demonstrate the importance of considering executive functioning when evaluating and treating glycemic control and health-related quality of life in pediatric type 1 diabetes.

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CHAPTER I

INTRODUCTION

As advances in medicine become common practice, chronic illnesses are no longer an automatic death sentence. Due to earlier detection and more effective treatments, millions of adults and children in the United States live with chronic illnesses. Research indicates that chronic illness can cause significant stress and can lead to emotional, behavioral, and social problems (Dantzer, Swendsen, Maurice-Tison, & Salamon, 2003; Kakleas, Kandyla, Karayianni, & Karavanaki, 2009; Puri, Sapra, & Jain, 2013). As a result, health-related quality of life (HRQoL) has become an important area of research and clinical practice. HRQoL is the degree to which a medical condition impacts an individual's physical, emotional, social, and mental functioning (Varni & Limbers, 2009). Measuring HRQoL can provide clinicians with a picture of an individual's functioning, as well as provide targets for prevention and intervention on the individual and global level. Moreover, the United States government made monitoring and increasing HRQoL a public health goal with the *Healthy People 2000, 2010,* and *2020* initiatives (Office of Disease Prevention and Health Promotion, 2015).

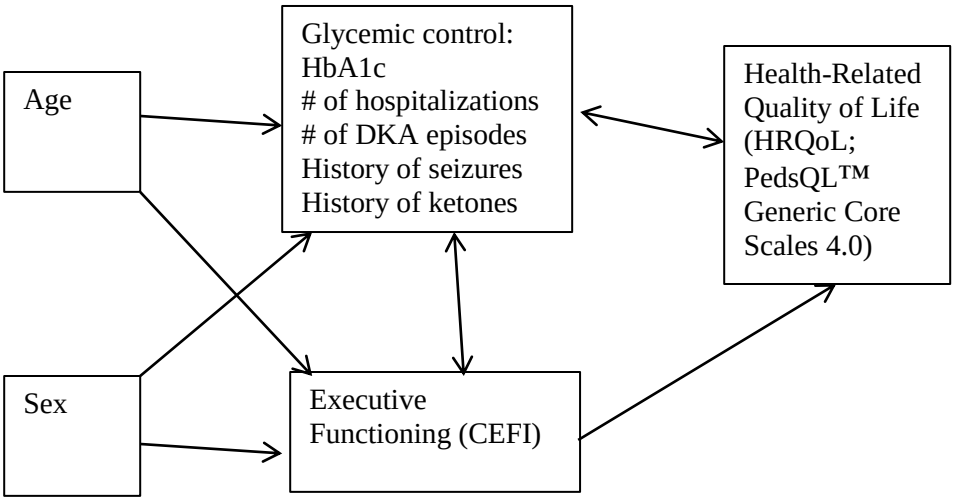
One of the most common chronic illnesses is type 1 and type 2 diabetes (Centers for Disease Control, 2014). Diabetes management is critical to optimal physical and mental functioning, while poor glycemic control can result in organ failure, seizures, and death (Centers for Disease Control, 2014). Furthermore, research indicates that executive functioning is impaired in individuals with type 1 diabetes who have worse glycemic control (Galliot, 2008). Executive functioning includes a variety of cognitive processes that aid in decision-making and goal-directed behavior, such as attention, working memory, planning, and self-regulation (Galliot, 2008). On the other hand, optimal executive functioning contributes to better treatment

adherence and disease management in those with chronic illnesses, including diabetes (Galliot, 2008). Although research indicates that greater treatment adherence and symptom management is associated with better HRQoL in those with type 1 diabetes, the interplay between executive functioning, HRQoL, and glycemic control has not been investigated.

Purpose of the Study

The purpose of this study is to add to what is known about HRQoL and pediatric type 1 diabetes in relation to health outcomes and executive functioning. Poor glycemic control in individuals with type 1 diabetes can negatively impact HRQoL and executive functioning. In turn, deficits in executive functioning can decrease glycemic control and treatment adherence in those with type 1 diabetes. Little is known about the relationship between HRQoL and executive functioning. The interrelationship between these three global variables or specific components within these broader domains has not yet been explored. To address this significant gap in the empirical literature, this study will examine the relationship between executive functioning, glycemic control, and HRQoL in adolescents with type 1 diabetes. Assessing the relationship between these factors can aid in the identification of areas for prevention and intervention that can improve medical outcomes for children and adolescents with type 1 diabetes. The hypothesized model (Figure 1) examines the relationship between age, gender, executive functioning, glycemic control, and HRQoL in youth with type 1 diabetes.

Figure 1. Hypothesized model.



Notes. Hba1c = glycated hemoglobin; DKA = diabetic ketoacidosis; CEFI = Comprehensive Executive Function Inventory; HRQoL = health-related quality of life; PedsQL= Pediatric Quality of Life Inventory

Research Questions

1. Does age predict glycemic control?
    - Based on previous research, it is hypothesized older age will predict worse glycemic control (higher HbA1c, more hospitalizations, more episodes of diabetic ketoacidosis (DKA), and more seizures) due to the increased responsibility for diabetes management in adolescence.
2. Is age correlated with executive functioning?

- Research indicates executive functioning improves with age. It is hypothesized age will significantly correlate with executive functioning, with older age associated with better executive functioning.

3. Does the child's sex predict glycemic control?
    - Previous research suggests females have worse glycemic control in pediatric diabetes; as a result, it is hypothesized female sex will predict worse glycemic control (higher HbA1c, more hospitalizations, more episodes of DKA, more seizures).
4. Does the child's sex predict executive functioning?
    - Based on previous findings, it is hypothesized that male sex will be associated with more executive functioning difficulties (lower scores on the CEFI).
5. Is executive functioning correlated with glycemic control?
    - It is hypothesized that executive functioning (Full Scale score from the CEFI) will negatively correlate with glycemic control (higher HbA1c levels), greater numbers of hospitalizations, greater number of DKA episodes, and history of seizures based on previous research.
    - It is hypothesized that the CEFI subscales will correlate with glycemic control; with greater deficits associated with poorer glycemic control (higher HbA1c levels), greater number of hospitalizations, greater number of DKA episodes, and history of seizures based on previous research findings.
6. Does executive functioning predict HRQoL?

- It is hypothesized executive functioning as measured by the Full Scale score on the CEFI predicts HRQoL (Total Scale Score, Physical Health Summary Score, and Psychosocial Health Summary Score).

7. Does glycemic control correlate with HRQoL?
    - It is hypothesized that there will be a significant direct correlation between HbA1c, number of hospitalizations, number of DKA episodes, history of seizures, and HRQoL. Lower HbA1c levels (better glycemic control) are hypothesized to negatively correlate with higher health-related quality of life (Total Scale Score, Physical Health Summary Score, and Psychosocial Health Summary Score). Higher numbers of hospitalizations, higher numbers of DKA episodes, and a history of seizures are hypothesized to negatively correlate with higher health-related quality of life (Total Scale Score, Physical Health Summary Score, and Psychosocial Health Summary Score).
8. Is the hypothesized model a good fit for the data?
    - It is hypothesized that in the proposed model executive functioning will predict HRQoL and covary with glycemic control. It is also hypothesized that glycemic control covary with HRQoL.

Definition of Terms

HbA1c: Glycated hemoglobin or HbA1c is generally used as a measure of an individual's average blood sugar levels over a period of weeks or months. Unlike blood glucose levels, HbA1c provides insight into blood sugar trends over longer periods of time. Individuals with

diabetes frequently have their HbA1c measured to gauge their level of diabetes control. HbA1c is also commonly referred to as A1c.

Quality of Life: Quality of life refers to the general well-being and welfare of an individual, a group of people, or a society. Quality of life can be measured by examining the wealth, employment, environment, physical health, mental health, education, leisure time, and social connectedness of an individual, group, or society.

Health Related Quality of Life: Health-related quality of life or HRQoL measures the degree to which a chronic illness, health condition, or disease impacts the physical, psychological, cognitive, and social functioning of the effected individual.

Executive Function: Executive functioning refers to a system of cognitive processes that aid in goal directed behaviors. Executive functioning processes include attention, inhibition, self-regulation, organization, working memory, planning, mental flexibility, self-monitoring, and initiation of tasks. Executive functioning is associated with the prefrontal cortex and develops throughout childhood and into early adulthood.

CHAPTER II

LITERATURE REVIEW

Type 1 Diabetes

One of the most common chronic illnesses is diabetes. In America, an estimated 9.3% of the population, or 29.1 million people, have type 1 or type 2 diabetes, while approximately 208,000 children under the age of 20 are currently diagnosed with either type 1 or type 2 diabetes (Centers for Disease Control, 2014). Furthermore, approximately 1.25 million American adults and children have type 1 diabetes, with an estimated 18,436 children were diagnosed with type 1 diabetes from 2008 to 2009 (Centers for Disease Control, 2014). Type 1 diabetes, which is commonly referred to as juvenile-onset diabetes, is generally diagnosed in childhood or adolescence (Craig et al., 2014). Type 1 diabetes is an incurable autoimmune disorder that occurs when the immune system destroys beta cells in the pancreas, which leads to deficits in insulin production and a build-up of glucose in the bloodstream. Insulin is an essential hormone that signals cells to absorb sugar for fuel and helps maintain blood sugar levels (Craig et al., 2014). Blood sugar levels that are too low (hypoglycemic episode) or too high (hyperglycemic episode) have been implicated in several long-term medical complications, increased emergency room visits, increased medical costs, and even death. On the other hand, better glycemic control has been found to reduce the risks for these negative effects (Wysocki et al., 2008). In order to maintain good glycemic control, individuals with type 1 diabetes must monitor their blood sugar levels throughout the day, administer insulin via injection or a pump, maintain a healthy diet, and engage in exercise. The management of type 1 diabetes can be time consuming, painful, and complicated, which often makes metabolic control difficult. Establishing glycemic control is

generally the main goal for those with type 1 diabetes and is essential to optimal physical, psychological, and cognitive functioning.

Type 1 diabetes can contribute to a number of medical, cognitive, and psychological difficulties. Potential negative health outcomes associated with type 1 diabetes include renal failure, cardiovascular issues, nerve damage, kidney damage, blindness, limb amputation, and seizures (Craig et al., 2014). In 2011, 21.9% of adults with type 1 or type 2 diabetes also had coronary heart disease, while 9.1% had experienced a stroke (Centers for Disease Control, 2014). Diabetes is currently the main cause of kidney failure, adult onset blindness, and lower limb amputations and has been found to lower life expectancy by up to fifteen years. Furthermore, in 2010, type 1 and type 2 diabetes was the seventh leading cause of death in the United States, which may be an underrepresentation. Finally, it is estimated that in 2012, the economic cost for diagnosed diabetes in the United States was $245 billion (Centers for Disease Control, 2014). Overall, diabetes can take a serious and potentially deadly toll on an individual's health and can result in increased hospitalizations, greater medical costs, and a plethora of medical problems.

Additionally, type 1 diabetes has been found to be associated with neurological deficits, such as lower grey matter volumes in the cerebellum, temporal-occipital cortex, and thalamus, as well as cerebral edema, and neuronal damage in the hippocampus and other brain areas (Arbeleaz, Semenkovich, & Hershey, 2013; Bjorgaas, 2012; Mauras et al., 2015). Furthermore, cognitive deficits in intelligence, memory, processing speed, visuospatial abilities, psychomotor efficiency, and verbal skills have been found to be associated with type 1 diabetes to varying degrees (Biessels, Deary, & Ryan, 2008; Bjorgaas, 2012). Impaired cognitive functioning in individuals with type 1 diabetes is associated with poorer glycemic control, vascular complications, and earlier onset of the disease (Awad, Gagnon, & Messier, 2004; Biessels et al.,

2008; Parent, Wodrich, & Hasan, 2009). Moreover, individuals with type 1 diabetes may be particularly sensitive to cognitive impairments due to glycemic instability during childhood when brain structures are forming, and later in life when neurodegeneration occurs (Biessels et al., 2008). These cognitive deficits may contribute to the academic difficulties and lower school achievement often found in youth with type 1 diabetes (Dahlquist, & Kallen, 2007; Hannonen et al., 2012; Hannonen et al., 2010). More specifically, studies have demonstrated that youth with type 1 diabetes have significantly lower grades compared to non-diabetic peers (Dalquist & Kallen, 2007; Meo et al., 2013). Moreover, one study found that youth with type 1 diabetes attained lower levels of education over time compared to non-diabetic controls (Wennick, Hallstrom, Lindgren, & Bolin, 2011). Due to problems in diabetes management, it may be that those with type 1 diabetes have difficulties staying in school, are absent more often, and thus, their academic achievement suffers (Hannonen et al., 2012). The cognitive and academic deficits associated with type 1 diabetes make these domains a necessary point for monitoring, prevention, and intervention.

Finally, research indicates those with type 1 diabetes are at an increased risk for poorer psychological outcomes, such as increased rates of depression and anxiety (Dantzer et al., 2003). Grey, Whittemore, and Tamborlane (2002), found that youth with type 1 or type 2 diabetes were approximately two to three times more likely to be diagnosed with depression than those without diabetes. A study conducted by Goldney, Philips, Fisher, and Wilson (2004) with 3,010 youth aged 15 and younger with and without type 1 diabetes yielded prevalence of depression in those with diabetes as 24% as opposed to 17% in non-diabetic youth. In a ten-year longitudinal study, Kovacs, Goldston, Obrosky, and Bonar (1997) found that almost half of the youth with pediatric type 1 diabetes developed a psychological disorder, with 27.5% of participants developing

depression. Depression has been linked to a plethora of negative consequences, such as poor social outcomes, poor school performance, and the need for greater medical or psychological treatment. Not only is depression harmful and costly in itself, but internalizing disorders also have been found to be associated with adherence problems to diabetes regimens, poor glycemic control, increased hospitalizations, and greater risk for mortality (Delamater, 2009; Hood et al., 2011). Therefore, treating the depression and other comorbid psychological disorders present in individuals with type 1 diabetes is not only essential for psychosocial development, but also for health outcomes and cost management. Although type 1 diabetes is not often associated with behavioral disorders, research indicates that behavioral problems contribute to poor diabetes control in adolescents (Northam et al., 2005). This association may be due to the underlying deficits in inhibition, planning, and attention associated with poor glycemic control and externalizing disorders.

Health-Related Quality of Life and Diabetes

Health-related quality of life has become an emerging field of study in pediatrics and health research (Polonsky, 2000; Varni & Limbers, 2009). Health-related quality of life (HRQoL) is the "extent to which a disease or medical condition impacts upon the daily physical, emotional, and contextual well-being of an individual" (Cameron, 2003, p.132). In other words, health should not be examined solely through the lens of whether or not an illness or disease is present, but also by physical, psychological, mental, and social functioning (Rubin & Peyrot, 1999). Current measures of HRQoL examine global and disease-specific domains, in order to understand the general and specific impacts of illness (Rubin & Peyrot, 1999; Varni & Limbers, 2009). For example, diabetes-specific quality of life (DSQoL) measures provide more detailed information on issues related to treatment adherence and on disease-specific burdens and

symptoms (Lawrence et al., 2012; Varni & Limbers, 2009). It is essential that practitioners utilize both global and disease-specific measures of HRQoL to tap into various elements associated with general illness and specific illnesses in order to improve patient care and the field of knowledge (Rubin & Peyrot, 1999; Varni & Limbers, 2009).

Research indicates that childhood chronic illnesses can have a significant negative impact on a child's HRQoL (Delamater et al., 2001; Hood, Rausch, & Dolan, 2011; Nardi et al., 2008). The added stress, responsibility, and isolation associated with chronic illness can exacerbate the developmental and psychosocial adjustment problems children already face while growing up (Polonsky, 2000). More specifically, it has been found that children and teens with type 1 diabetes experience lower life satisfaction, lower health perception, lower levels of generic HRQoL, and greater incidences of depression and anxiety than peers without diabetes (Faulkner, 2003; Goldney et al., 2004; Hood, Rausch, & Dolan, 2011; Kalyva, Malakonaki, Eiser, & Mamoulakis, 2010; Nardi et al., 2008; Sundber, Sand, & Forsander, 2014). Poorer quality of life is associated with adherence problems to diabetes regimens, poor glycemic control, increased hospitalizations, and poor coping strategies (Delamater, 2009; Graue et al., 2004; Hood et al., 2011; Penckofer et al., 2012). On the other hand, good glycemic control has been found to be associated with better quality of life in most studies (Hoey et al., 2001; Reid et al., 2013). Quality of life and glycemic control may have a reciprocal relationship whereby when one area worsens so does the other. Kalyva, Malakonaki, and Mamoulakis (2011) found that later age of onset of diabetes, less hyperglycemic episodes, lower HbA1c, older age, and being male were associated with better diabetes-specific and general HRQoL. Moreover, in a study of 325 children with type 1 diabetes and their parents, fear of a hypoglycemic episode was found to be associated with lower quality of life (Johnson, Cooper, Davis, & Jones, 2013), which sheds light

on a possible point for intervention. These studies highlight the importance of examining quality of life as it relates to the patient's medical and psychological functioning. Due to the substantial impact HRQoL can have on diabetes management and health outcomes, it is imperative that clinicians measure and monitor patient quality of life. Clinicians should attempt to obtain parent and child reports when feasible because gaining perspectives from multiple informants can provide a clearer picture of child functioning (Eiser & Varni, 2013). Overall, data gathered from HRQoL measures can aid in the creation and modification of interventions and treatments that are more effective, targeted, feasible, and can aid in alleviating functional impairments in the patient's daily life.

Age differences in HRQoL in pediatric type 1 diabetes

Furthermore, as children develop into adolescents and begin to take greater responsibility for their diabetes management, it is particularly important to monitor quality of life. In general, adolescents tend to report more symptoms of depression and anxiety compared to children in both diabetic and healthy populations (Hanberger, Ludvigsson, & Nordfeldt, 2009; Hoey et al, 2001; Nardi et al., 2008; Wagner et al., 2005). For example, Nardi et al. (2008) studied 70 youth with type 1 diabetes ranging in age from 6 to 18. Results indicated that prior to adolescence, children with type 1 diabetes did not report lower quality of life, more feelings of social isolation, or more behavioral or psychological problems. As children developed into adolescents, there was a significant increase in parent and self-reported symptoms of psychological and behavioral problems, such as depression, anxiety, and defiance. Moreover, depressive and anxiety symptoms were found to contribute to lower quality of life (Nardi et al., 2008). Wagner et al. (2005) also found that in 68 children and adolescents with type 1 diabetes, younger children reported better HRQol and that adolescents reported more symptoms of

depression and anxiety. Adolescence may be a key time to monitor quality of life due to the bodily changes that occur, as well as the new identities and responsibilities that are being explored. Finally, the transition from parent to youth management of diabetes can contribute to an increase in diabetes-specific family conflict, which has been shown to decrease HRQoL (Laffel et al., 2003; Reid et al., 2013) and worsen glycemic control (Rohan et al., 2014). Targeting this transitional period and the communication between parents and youth may have positive outcomes for diabetes management and HRQoL in this population.

Sex differences in HRQoL in pediatric type 1 diabetes

Research indicates sex may also contribute to self and parent-reported HRQoL in pediatric type 1 diabetes. In a study by Lawrence et al. (2012), female sex was negatively associated with HRQoL, while Hanberger, Ludvigsson, and Nordfeldt (2009) found females with type 1 diabetes and their parents reported lower HRQoL than males in both childhood and adolescence. Additionally, in a study conducted by Hilliard et al. (2013), male sex predicated improvements in HRQoL over 1 year, while Kalyva et al. (2011) reported better HRQoL and diabetes-specific HRQoL for adolescent males compared to adolescent females. Moreover, research by Naughton et al. (2014) indicates HRQoL improves over time in males with pediatric type 1 diabetes, but remains the same or decreases for females with pediatric type 1 diabetes. Sex differences in parent and self-reported HRQoL in youth with type 1 diabetes may be explained by girls experiencing psychological adjustment problems at an earlier age and the higher rates of depression and anxiety in females with or without diabetes (Faulkner, 2003; Hanberger, Ludvigsson, and Nordfeldt, 2009; Hoey et al., 2001). Due to the significant connection between psychological functioning and HRQoL, as well as sex-related differences in

HRQoL and emotional adjustment, female youth with type 1 diabetes may need extra monitoring and support.

Glycemic Control

Metabolic or glycemic control involves keeping blood glucose levels as close to normal as possible through diet, exercise, medication, and insulin among other strategies (American Diabetes Association, 2013). Glycemic control is generally the main goal of diabetes management because fluctuations in blood sugar levels may contribute to serious health complication and even death (American College of Endocrinology, 2002; Hannonen et al., 2003; Juarez et al., 2012; Rewers et al., 2014). Generally, glycemic stability is measured by Hemoglobin A1c or HbA1c or A1c, which provides an average of blood glucose levels over a period of time (American Diabetes Association, 2013; American College of Endocrinology, 2002; Rewers et al., 2014). An optimal glycemic level is defined as an HbA1c level less than 7% (58 mmol/mol) for children and adolescents (American Diabetes Association, 2010; Rewers et al., 2014). Glycemic instability can result in hypoglycemia, hyperglycemia, or DKA. Hypoglycemia occurs when blood sugars are lower than normal levels, while hyperglycemia is when blood sugar levels are higher than normal levels (Rewers et al., 2014). Severe hypoglycemia can result in seizures, loss of consciousness, and even death (Mayo Clinic, 2012). On the other hand, complications associated with hyperglycemia include cardiovascular disease, nerve damage, kidney damage, retina damage, and joint problems. (Mayo Clinic, 2015). If hyperglycemia is present over an extended period of time, DKA can occur. DKA is when the body breaks down fat for energy, which results in the production of toxic acids or ketones. Untreated DKA can result in a diabetic coma and death (Mayo Clinic, 2015). In conclusion,

unchecked glycemic variation in type 1 diabetes can have devastating physical and medical consequences.

Glycemic control and HRQoL

The instability and consequential physical ailments associated with glycemic variability in diabetes can also impact HRQoL and diabetes-specific quality of life (DSQoL; Ayano-Takahara et al., 2015; Penckofer et al., 2012; Tahirovic et al., 2012). Glycemic instability in adolescents with type 1 diabetes is associated with lower physical and mental health, greater burden associated with diabetes, less self-efficacy, and a more negative viewpoint on diabetes and their ability to adhere to treatment (Viklund & Ortqvist, 2014). In a study conducted by Lawes, Franklin, and Farmer (2014), researchers examined the HbA1c trajectories of 155 youth with type 1 diabetes for six months after diagnosis and found glycemic instability to be association with negative psychosocial factors, such as a major stressful life event or a diagnosis of a mental illness. Moreover, Lawrence et al. (2012) found that lower QoL is associated with depressive symptoms and more glycemic instability. In a longitudinal study conducted over an average of 23.5 years, 1,441 participants with type 1 diabetes, ranging in age from 13 to 65, were examined (Jacobson et al., 2013). Researchers found that poor metabolic control, medical complications associated with diabetes (i.e., severe hypoglycemia, incontinence, erectile dysfunction, blindness), and depressive symptoms decreased HRQoL. Furthermore, in a study conducted by Hood et al. (2014), researchers found that among 1,307 youth with type 1 diabetes, the first six years after diagnosis was a time of great glycemic instability. Lower DSQoL predicted worse glycemic control over time, but generic QoL did not, while participants who viewed diabetes as a negative impacting factor on their daily life, social life, and academic functioning were more likely to have higher A1c levels over time. Additionally, specific facets

of DSQoL such as disease management and psychosocial functioning have been found to differentiate between those who have poor or stable glycemic control. Ingerski, Laffel, Drotar, Repaske, and Hood (2010) examined the glycemic levels and DSQoL of 261 youth with type 1 diabetes. Results indicated that that DSQoL and glycemic levels were negatively correlated, with higher DSQoL scores being associated with lower A1c. Moreover, family functioning and depression were found to contribute to glycemic control and DSQoL.

Conversely, research indicates that there is a significant association between improvements in HbA1c and improvements in psychological facets of QoL in adults with type 1 diabetes (Lau, Qureshi, & Scott, 2004). Abbatecola et al. (2014) found that in older adults with diabetes, improvements in glycemic control over time correlated with an increase in reported DSQoL. Furthermore, Weinger and Jacobson (2001) delivered an intensive diabetes education intervention to 55 adults with type 1 diabetes. Results indicated that improvements in glycemic control were associated with an increase in satisfaction with diabetes treatment, a facet of DSQoL and a factor that may contribute to treatment adherence. This study highlights the potential utility of educational interventions in diabetes care for reducing glycemic instability and improving QoL. Overall, glycemic control appears to have a significant impact on both generic QoL and DSQoL and vice versa.

Glycemic control and executive functioning

Glycemic instability has also been found to contribute to impairments in cognitive functioning (Kinga & Szamoskozi, 2014). Throughout childhood, the brain develops and requires massive amounts of energy. As a result, the developing brain may be more sensitive to glycemic fluctuations, such as those that occur in type 1 diabetes (Arbelaez, Semenkovich, & Hershey, 2013). Furthermore, these neurological irregularities may negatively impact cognitive

functioning in youth with type 1 diabetes (McCrimmon, Ryan, & Frier, 2012). For example, frequency of hyperglycemia was found to be associated with deficits in executive functioning, learning, memory, and overall intelligence in children with type 1 diabetes when compared to healthy controls (Cato et al., 2014). Furthermore, Patino-Fernandez et al. (2010) found that in preschool age children with type 1 diabetes, poor glycemic control was associated with lower cognitive abilities in general, including slower fine motor speed and lower receptive language. In another study, deficits in verbal intelligence were influenced by episodes of hyperglycemia, while problems with spatial intelligence and long-term recall were associated with hypoglycemia (Pernatie et al., 2008). Hyperglycemia also has been linked to deficits in long-term spatial memory (Malone et al., 2008), as well as learning and memory consolidation (Northam et al., 1999; Nylander et al., 2012). Severe recurrent episodes of hypoglycemia also have been implicated in studies examining visuospatial functioning and motor speed (Desrocher & Rover, 2004; Lin et al., 2010), as well as phonological processing and short-term memory (Hannonen et al., 2003; Lin et al., 2010). Additionally, during acute hypoglycemia, deficits in verbal memory, visual memory, working memory, delayed memory, visual-motor ability, and visual-spatial skills have been observed (Kodl & Seaquist, 2008). Although acute hypoglycemia may be more fleeting, it may negatively impact the acquisition of academic skills in younger children if it occurs at school (Kodl & Seaquist, 2008).

On the other hand, Musen et al. (2008) studied 249 adolescents with diabetes who were monitored for 6 years. Participants were not found to have a decline in cognitive function over this time period. Furthermore, Ly et al., (2011) in a 16-year longitudinal study did not find any significant differences on general intelligence or memory between youth with type 1 diabetes and a matched control group. There were, however, observed differences between groups on

tasks of executive functioning that included set shifting, concept formation, and problem solving, with youth with diabetes performing worse. Moreover, although Ohmann et al. (2010) did not find any cognitive differences between adolescents with type 1 diabetes and controls, there were significant differences between groups in cognitive flexibility, planning, and concept formation. Across several studies, hypoglycemia has been implicated as a factor associated with deficits in attention, working memory, planning, and problem-solving (Asvold, Sand, Hestad, & Bjorgaas, 2010; Bjorgaas, Gimse, Vik, & Sand, 1997; Cato et al., 2014; Graveling, Deary, & Frier, 2013; Hannonen, Tupola, Ahonen, & Riikonen, 2003; Lin et al., 2010; Ly et al., 2011; Rovet & Alvarez, 1997; Rovet & Ehrlich, 1999; Ryan et al., 1990; Sommerfield, Deary, McAulay, & Frier, 2003; Strudwick et al., 2005). Furthermore, hyperglycemia and DKA are also associated with deficits in attention and working memory (Cameron et al., 2014; Cato et al., 2014; Lin et al., 2010; Shehata & Eltayeb, 2010). Overall, glycemic instability can have an aversive impact on cognitive functioning and executive functioning in particular.

Age differences in glycemic control in pediatric type 1 diabetes

Research indicates age of diagnosis can impact glycemic control in pediatric type 1 diabetes, as well as age factors can affect HbA1c throughout the lifespan (Forga et al., 2013). Diagnosis at a later age is related to poorer glycemic outcomes, while diagnosis of type 1 diabetes at a younger age is associated with better controlled HbA1c. Additionally, youth with an onset of type 1 diabetes in adolescence demonstrate poorer metabolic control compared to those diagnosed in childhood (Forga et al., 2013; Levine et al., 2001). Earlier diagnosis may be related to better adjustment and knowledge about diabetes management. On the other hand, some research has found that longer duration of diabetes is associated with worse glycemic control (Craig et al., 2002). In a study examining 2,180 children and adolescents with type 1

diabetes, researchers found higher HbA1c was significantly correlated with longer duration of diabetes, female gender, and adolescence (Hanberger, Samuelsson, Lindblad, and Ludvigsson, 2008).

As children move into adolescence, research also indicates HbA1c often worsens. Adolescent have higher incidents of DKA, hypoglycemia, and diabetes-related hospitalizations compared to adults (Acerini, Williams, & Dunger, 2001; Forga et al., 2013, Levine et al., 2001). Declines in glycemic control in adolescence may be due to the important hormonal and physiological changes that occur (Acerini et al., 2001), as well as the increased responsibility for diabetes management in adolescence (Lawes, Franklin, & Farmer, 2014). Moreover, psychosocial distress has been found to be correlated with poorer glycemic control and type 1 diabetes outcomes (Viklund & Ortqvist, 2014). As adolescents are more likely to experience higher rates of psychosocial distress and mental health issues, this may play a role in their increased risk for poorer glycemic control (Lawes et al., 2014; Lawrence et al., 2012).

Sex differences in glycemic control in pediatric type 1 diabetes

Sex of the individual has been implicated as potential factor impacting HbA1c, metabolic control, and type 1 diabetes-related health outcomes. Across studies, being female is associated with higher A1c (Hanberger et al., 2008). In a study of 8,020 youth with type 1 diabetes, researchers reported girls on average had higher HbA1c at diagnosis and at follow-up compared to males (Hanberger, Akesson, and Samuelsson, 2013). Another study also found that female adolescents with type 1 diabetes had higher initial HbA1c at diagnosis and over time, compared to adolescent males with type 1 diabetes, up until young adulthood (Samuelsson et al., 2016). Rohan et al. (2013) found that sex was a significant factor in glycemic control over a 3-year period, with female youth with type 1 diabetes more likely to be at a higher risk for future

diabetes-related complications. Additionally, Elsamahy, Elhenawy, and Altayeb (2017) concluded female youth with type 1 diabetes had worse HbA1c over 4 years and required higher insulin dosages 8 and 10 years after diagnosis compared to males with type 1 diabetes. Sex differences in glycemic control may be due to hormonal and psychosocial differences between males and females that impact HbA1c (Lawrence et al., 2012).

Executive Functioning, Type 1 Diabetes, and Glycemic Control

Executive function is a term that subsumes a variety of abilities that reflect cognitive processes such as attention, organization, working memory, reasoning, task flexibility, planning, behavioral and emotional self-regulation, and problem solving (Galliot, 2008; McNally, Rohan, Shroff-Pendley, Delamater, & Drotar, 2010). Executive functioning develops as children age and is associated with the prefrontal cortex. Optimal executive functioning produces self-regulation and persistence, as well as better decision-making, school performance, mental health, and relationships outcomes (Galliot, 2008). Furthermore, research indicates that executive functioning oftentimes plays a substantial role in treatment adherence, glycemic control, and diabetes management (McNally et al., 2010; Rasmussen, Ward, Jenkins, King, & Dunning, 2010; Smith, Kugler, Lewin, Duke, & Storch, 2014), especially when treatment regimens are more intense or require multiple steps (Graziano et al., 2011; Nguyen et al., 2010; Primozic, Tavcar, Avbelj, Zvezdana-Dernovsek, & Ravnik Oblak, 2011; Smith et al., 2014). The management of diabetes often includes dietary restrictions, frequent blood glucose monitoring, and insulin administration (Bagner, Williams, Geffken, Silverstein, & Storch, 2007). These tasks require the patient to employ behavioral self-regulation, attention, working memory, planning, and problem solving in order to achieve optimal treatment. Bagner et al. (2007) explored the relationship between parent ratings of child executive functioning and the child's adherence to

diabetes regimens. Results indicated that in 130 youth with type 1 diabetes, executive functioning predicted diabetes treatment adherence. Furthermore, McNally et al. (2010) researched 235 children with type 1 diabetes and their self and parent ratings of executive functioning, diabetes treatment adherence, and glycemic control. Researchers found that executive functioning facets, such as planning, problem solving, organization, self-regulation, and working memory, contributed to better treatment adherence and metabolic control (McNally et al., 2010). Finally, in a study by Smith et al. (2014), adherence to diabetes regimens moderated the relation between executive functioning and glycemic control. Due to the cognitive requirements associated with diabetes management, executive functions are essential to treatment adherence and should be tracked over time. A summary of the research is included in Table 1.

Table 1

EF and Type 1 Diabetes

Study	**Participants (Sample size, Age range)**	**EF Components Considered**	**Summary Findings**
Metabolic Control and EF Components			
Asvold, Sand, Hestad, & Bjorgaas, 2010	N = 56 Ages 6-10	Problem Solving	Severe hypoglycemia associated with deficits in problem solving.
Bagner et al., 2007	N = 130 Ages 8-19 (M = 12.7)	Behavior Regulation and Metacognition (BRIEF)	Executive function predicted better diabetes regimen adherence.
Berg et al., 2014	N = 110 Mean Age = 17.78	Self-Control, Behavioral Inhibition, and Attention	Self-regulation associated with better treatment adherence.
Bjorgaas, Gimse, Vik, & Sand, 1997	N = 28 Ages 8-16 (M = 12.9)	Attention	Association between hypoglycemic episodes and deficits in attention.

Table 1 continued

Study	Participants (Sample size, Age range)	EF Components Considered	Summary Findings
Metabolic Control and EF Components			
Brands et al., 2005	N = 99 studies	Attention, Cognitive Flexibility	Patients with type 1 diabetes demonstrate deficits in cognitive flexibility.
Brismar et al., 2007	N = 150 Ages 22-56 (M = 26.6)	Attention, Working Memory, and Planning	Diabetes onset and duration were associated with deficits in attention and working memory. Number of hypoglycemic episodes was not significantly associated with impairments.
Cameron et al., 2014	N = 95 Ages 6-18 (M = 11.52)	Working Memory and Attention	DKA and its related cerebral changes in the frontal, temporal, and parietal regions were associated with lower attention and working memory.
Caruso et al., 2014	N = 85 Ages 6-16 (M = 11.5)	Behavior Regulation, Metacognition	Children with type 1 diabetes presented more difficulties with emotion regulation compared to healthy controls.
Cato et al., 2014	N = 216 Ages 4-10 (M = 7)	Attention	Deficits in attention associated with a history of DKA and severe hypoglycemia.
Gaudieri, Chen, Greer, & Holmes, 2008	N = 2,144 (19 studies) Mean Age = 12.55	Attention	Children with type 1 diabetes demonstrated lower performance on measures of attention compared to healthy controls.
Glasgow et al., 2007	N = 506 Ages 21-75 (M = 57.8)	Problem Solving and Self-Management	Problem solving was associated with A1c levels.
Graveling, Deary, & Frier, 2013	N = 32 Ages 25-35 (M = 29.9)	Cognitive Flexibility, Planning, and Problem-Solving	Acute hypoglycemia impaired performance on tasks of executive functioning.
Graziano et al., 2011	N = 109 Ages 12-18 (M = 15.23)	Self-regulation, Emotion Regulation	For boys, emotion regulation deficits were associated with worse treatment adherence and worse glycemic control.
Hannonen, Tupola, Ahonen, & Riikonen, 2003	N = 31 Ages 5.6-11.11 (M = 9.4)	Attention, Planning, Working Memory, and Problem Solving	A history of severe hypoglycemia was associated with poorer performance on attention and working memory tasks.

Table 1 continued

Study	Participants (Sample size, Age range)	EF Components Considered	Summary Findings
Metabolic Control and EF Components			
Hill-Briggs & Gemmell, 2007	N = 52 studies	Problem Solving	Evidence of an association between problem solving and HbA1c levels.
Hughes, Berg, & Wiebe, 2012	N = 137 Ages 10-14 (M = 13.48)	Emotion regulation, Self-Control	Deficits in self-control and emotion regulation were associated with poorer HbA1c.
King et al., 2010	N = 463 Mean Age = 60	Problem Solving and Self-Management	Problem solving associated with management of diabetes.
Lin et al., 2010	N = 181 Mean Age = 21	Working Memory and Attention	Youth with type 1 diabetes performed worse than controls on measures of working memory and sustained and divided attention. Poor working memory associated with hyperglycemia and hypoglycemia.
Ly et al., 2011	N = 67 Mean Age = 19.2	Planning, Problem Solving, Cognitive Flexiblity	Hypoglycemia associated with deficits in planning.
McNally et al., 2010	N = 235 Ages 9-12 (M = 10.54)	Global Executive Composite (BRIEF)	Executive functioning was associated with treatment and adherence. High levels of EF related to better adherence. Adherence related to glycemic control.
Miller et al., 2012	N = 239 Ages 9-11 (M = 10.54)	Self-Management, Behavior Regulation	Self-management did not predict changes in HbA1c over time.
Northam et al., 2001	N = 174 Ages 3-11	Self-Monitoring, Attention, Planning	Attention and planning were poorer in youth with diabetes.
Nguyen et al., 2010	N = 95 Ages 60-90 (M = 72.2)	Attention and Working Memory	Poor glycemic control was associated with deficits in EF.
Primozic et al., 2011	N = 98 Ages 40-80 (M = 63.74)	Attention, Planning, Problem Solving, and Working Memory	Better self-diabetes management associated with planning and problem-solving.
Rasmussen et al., 2011	N = 20 Ages 18-38	Planning and Problem Solving	Planning strategies were associated with greater glycemic stability.

Table 1 continued

Study	Participants (Sample size, Age range)	EF Components Considered	Summary Findings
Metabolic Control and EF Components			
Rohan et al., 2011	N = 239 Ages 9-11 (M = 10.54)	Self-regulation	Deficits in self-regulation associated with poorer glycemic control.
Rovet & Alvarez, 1997	N = 103 Ages 9.3-18.3 (M = 13.5)	Attention, Planning, and Cognitive Flexibility	Youth with diabetes and a history of seizures from hypoglycemia had deficits in focusing attention and inhibition, but not set shifting or sustained attention. Higher glucose levels were associated with deficits in inhibition.
Rovet & Ehrlich, 1999	N = 16 Ages 9.4-17.7 (M = 12.1)	Attention	Hypoglycemic induced seizures associated with deficits in attention.
Ryan et al., 1990	N = 11 Ages 11-18 (M = 14.4)	Planning, Problem Solving, Attention, and Cognitive Flexibility	Mild hypoglycemia associated with impaired performance on planning, problem solving, and attention tasks.
Shehata & Eltayeb, 2010	N = 80 Mean Age = 10.7	Working Memory	DKA associated with deficits in working memory.
Smith et al., 2014	N = 72 Ages 8-18 (M = 13.6)	Global Executive Composite (BRIEF)	Adherence mediated the relationship between EF and glycemic control in youth with better adherence.
Sommerfield, Deary, McAulay, & Frier, 2003	N = 16 Ages 20-38.2 (M = 28.5)	Working Memory	Acute moderate hypoglycemia impaired performance on tasks of working memory.
Strudwick et al., 2005	N = 84 Ages 6-15 (M = 10.3)	Attention and Working Memory	Severe hypoglycemia was not associated with deficits in working memory or attention.
Toobert & Glasgow, 1990	N = 126 Ages 40-88 (M = 60.8)	Problem Solving	Problem solving associated with self-care and diabetes management.
Viklund & Ortqvist, 2014	N = 199 Mean Age = 14.7	Problem Solving	Problem solving ability predicted glycemic control.
Wysocki et al., 2003	N = 142 Ages 6-15 (M = 11.6)	Planning and Attention	Severe hypoglycemia was not associated with deficits in planning or attention.

Table 1 continued

Study	Participants (Sample size, Age range)	EF Components Considered	Summary Findings
EF Components and HRQoL			
Brown & Landgraf, 2010	N = 3,683 Ages 18-55	Executive function	Improvements in EF functioning were correlated with increases in HRQoL in adults with ADHD.
Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010	N = 135 Ages 65-75 (M = 69.6)	Planning, Working Memory, and Set Shifting	Set shifting and working memory were associated with health-related quality of life in older women.
de Vries & Geurts, 2015	N = 196 Ages 8-12 (M = 10.2)	Emotion Regulation, Working Memory, Planning, and Organization	Lower QoL was associated with deficits in executive functioning in children with autism.
Grech et al., 2015	N = 107 Ages 26-74 (M = 48.8)	Problem Solving, Decision Making, Planning, Working Memory, Cognitive Flexibility, Inhibition, and Attention	Poorer performance on tasks of working memory and cognitive flexibility predicted higher levels of stress and lower physical quality of life in adults with multiple sclerosis.
Jaser et al., 2012	N = 327 Ages 11-14 (M = 12.3)	Self-Management	In youth with type 1 diabetes, self-management mediated the relationship between coping and QoL and coping and glycemic control.
Krpan, Levine, Stuss, & Dawson, 2007	N = 36 Mean Age = 33.8	Problem Solving, Working Memory, Cognitive Flexibility, and Inhibition	In adults with a traumatic brain injury, better EF was associated with better coping.
Laffond et al., 2011	N = 29 Ages 1-15 (M = 7.10	Behavior Regulation, Metacognition, Global Executive Composite (BRIEF)	Symptoms of depression, EF deficits, and lower quality of life were significantly correlated with each other in children with a benign tumor.
Neal et al., 2015	N = 151 Ages 13-16 (	Global Executive Composite (BRIEF)	Deficits in EF were associated with poorer psychosocial health in adolescents with cyanotic congenital heart disease.

Table 1 continued

Study	Participants (Sample size, Age range)	EF Components Considered	Summary Findings
EF Components and HRQoL			
Sherman, Slick, & Eyrl, 2006	N = 121 Mean Age = 11.9	Global Executive Composite (BRIEF)	Clinically significant executive dysfunction related to lower HRQoL in children with epilepsy.

Notes: EF = executive functioning; HRQoL = health-related quality of life; QoL = quality of life; HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; BRIEF = Behavior Rating Inventory of Executive Function

Although diabetes treatment adherence, management, and glycemic control may be impacted by executive functions, glycemic control also appears to influence executive functioning. Executive functioning requires large amounts of glucose to operate properly (Galliot, 2008). Variations in glycemic control, such as a hypo- or hyperglycemic event, appear to have a negative impact on executive functioning (Bade-White & Obrzut, 2009; Cato et al., 2014; Graveling, Deary, & Frier, 2013). Specifically, executive functioning operations such as working memory, attention, decision-making, planning, and mental flexibility have been determined to be especially vulnerable to the deleterious effects of hypoglycemic episodes (Bade-White & Obrzut, 2009; Rovet & Alvarez, 1997). Further, extreme glycemic fluctuations in childhood and adolescence may have an even greater impact on executive functioning due to the sensitivity of the developing brain (Arbelaez, Semenkovich, & Hershey, 2013; Bade-White & Obrzut, 2009; Biessels, Deary, & Ryan, 2008; Bjorgaas, 2012; Brismar et al., 2007; Gaudieri, Chen, Greer, & Holmes, 2008). Because of the potential negative consequences of glycemic fluctuations on executive functioning, it is imperative that blood glucose levels are monitored to prevent cognitive impairment. Most of the current research on executive functioning in pediatric

type 1 diabetes focuses on attention, working memory, self-regulation, and problem solving or planning.

Attention in pediatric type 1 diabetes

Attention is the ability to selectively focus on a stimuli or aspect of information, while ignoring other information. Attention is often conceptualized as being composed of three components: alerting, orienting, and executive attention (Anderson, 2010; Geva, Zivan, Warsha, & Olchik, 2013). Alerting is the ability to maintain a state of sensitivity or vigilance to incoming stimuli and information, while orienting is the ability to select necessary or relevant sensory information (Visintin et al., 2015). Moreover, executive attention is the ability to detect and resolve conflicting information or the ability to inhibit competing stimuli (Visintin et al., 2015). Research indicates that attention is often suboptimal in those with pediatric type 1 diabetes (Bade-White & Obrzut, 2009; Northam et al., 2005). For example, Rovet and Alvarez (1997) studied 103 youth with type 1 diabetes in comparison to 100 healthy controls on measures of intelligence and attention. Participants with type 1 diabetes demonstrated deficits in orienting, while children with early-onset diabetes performed worse on orienting tasks than those with later-onset diabetes. Moreover, children with type 1 diabetes and a history of seizures performed significantly worse on tasks that required alerting and executive attention than those youth with type 1 diabetes without a history of seizures. These results indicate not only differences in attentional capabilities between youth with and without type 1 diabetes, but also different attentional deficits based on age of onset for type 1 diabetes and a history of seizures.

Moreover, research has found an association between hypoglycemic episodes, age of onset, and deficits in attention. Hannonen, Tupola, Ahonen, and Riikonen (2003) compared youth with type 1 diabetes and a history of severe hypoglycemia to children with type 1 diabetes

without a history of severe hypoglycemic and to healthy controls. Although results were not statistically significant due to the small sample size, group differences were found on measures of attention, with youth with type 1 diabetes performing worse on tasks that measured attention. Furthermore, results indicated that youth with type 1 diabetes and severe hypoglycemic performed worse on cognitive and attention tasks than youth with type 1 diabetes without severe hypoglycemia. Additionally, Bjorgaas, Gimse, Vik, and Sand (1997) examined cognitive and attentional differences between youth with type 1 diabetes with and without episodes of severe hypoglycemia and healthy controls. Results indicated an association between early onset of type 1 diabetes, severe hypoglycemic episodes, and attentional deficits. Finally, in a meta-analysis that examined fifteen studies and included 2,144 children with type 1 diabetes and 751 controls, results indicated that children with type 1 diabetes demonstrated performance deficits on tasks of attention (Gaudieri, Chen, Greer, & Holmes, 2008) with earlier onset diabetes (i.e., before age 7) associated with greater deficits in attention.

Longitudinal research also has elucidated some of the effects of pediatric diabetes on attention. Lin, Northam, Rankins, Werther, and Cameron (2010) examined youth with type 1 diabetes and healthy controls over 12 years. Researchers found that children with early-onset diabetes performed worse on tasks of sustained and divided attention compared to those with later onset diabetes and healthy controls. Interestingly, frequency of hyper- and hypoglycemic episodes were not found to be associated with performance on tasks of attention. In a seven-year longitudinal study, 16 children with type 1 diabetes were evaluated on various neurocognitive measures (Rovet & Ehrlich, 1999). Participants with early-onset diabetes (before age 5) scored significantly lower on continuous attention performance tasks and youth with diabetes and a history of seizures had lower scores on sustained attention tasks. Finally, in a study that

examined neurocognitive functioning in youth with type 1 diabetes and severe hypoglycemia over 18 months, results indicated that severe hypoglycemia was not associated with decreases in attention (Wysocki et al., 2003). Although contrary to findings from other studies, the Wysocki et al. (2003) study may lend support to the theory that it is an interplay of factors (i.e., age of onset, hypoglycemic episodes, seizures, and so on) that affect attention, rather than one factor alone. Overall, these studies highlight the detrimental impact that pediatric type 1 diabetes can have on attention; however, more longitudinal studies need to be conducted to elucidate how the interplay of diabetic complications and factors that affect attention over time.

Working memory in pediatric type 1 diabetes

Working memory is the ability to hold and manipulate information for a short period of time and is essential for learning and problem solving (Sommerfield, Deary, McAulay, & Frier, 2003). Significant deficits in working memory have been found in youth and adults with type 1 diabetes (Hannonen et al., 2003). In a study that examined the cognitive performance of 105 youth with type 1 diabetes and 75 healthy controls, researchers found that youth with type 1 diabetes performed worse on working memory tasks compared to non-diabetic controls (Lin et al., 2010). Moreover, poorer performance on tasks of working memory was associated with hypoglycemic episodes (Lin et al., 2010; Sommerfield et al., 2003). More specifically, neuroimaging research indicated that severe hypoglycemia might cause synaptic and neuronal damage in the hippocampus, an area that is thought to contribute to working memory (Hershey et al., 2010; Schwartz, Wasserman, Powell, & Axelrad, 2014; Yamada et al., 2004). Furthermore, Hershey et al. (2010), found that in youth with type 1 diabetes, hippocampal volumes were enlarged and associated with hypoglycemic episodes. Larger hippocampal volumes may indicate a compensatory response to hypoglycemic episodes, and have been found in children with autism

and attention-deficit/hyperactivity disorder, disorders that are also prone to deficits in executive functioning (Hershey et al., 2010). On the other hand, Strudwick et al. (2005), found that seizures or coma as a result of severe hypoglycemia in youth with pediatric type 1 diabetes were not associated with working memory deficits.

In contrast, hyperglycemic episodes have been linked to working memory deficits (Lin et al., 2010) and neuroanatomical differences in the cerebellum and medial pre-frontal cortex (Marzelli et al., 2014). The cerebellum, particularly the superior-posterior cerebellum, and the pre-frontal cortex have been implicated in working memory, which may explain why neuroanatomical discrepancies in these areas may manifest as deficits in working memory (Marzelli et al., 2014). Finally, DKA also has been found to be associated with significant performance deficits in working memory (Schwartz et al., 2014; Shehata & Eltayeb, 2010). DKA occurs when the body produces high levels of blood acids or ketones, due to an inability to produce insulin, which results in the breakdown of fat for fuel (Mayo Clinic, 2012). Cameron et al. (2014), found that in youth with type 1 diabetes and DKA, white matter volume in the frontal lobe was enlarged due to cerebral edema. Furthermore, this enlargement in the frontal lobe was associated with deficits in working memory, which is not surprising since this brain area is often associated with a variety of executive functions. Overall, an array of potential side effects of pediatric type 1 diabetes, such as hypo- and hyperglycemic episodes, as well as DKA, have been implicated in suboptimal working memory.

Self-regulation in pediatric type 1 diabetes

Self-regulation involves the capacity to monitor and control emotions, thoughts, and behaviors and is often associated with inhibitory-control (Anderson, 2010). Self-regulation is imperative to emotional and behavioral regulation, as well as planning, academic success, and

the maintenance of social relationships (Graziano et al., 2011; McNally et al., 2010; Schilling, Grey, & Knafl, 2002). Berg et al. (2014) found that in 110 youth with type 1 diabetes, self-regulation skills were associated with diabetes regimen adherence. In fact, fluctuations in self-regulation across days predicted the degree to which youth adhered to treatment. Additionally, Rohan et al. (2011) found that youth with type 1 diabetes displayed distinct patterns of self-management that contributed to glycemic control. More specifically, higher levels of self-management were associated with better HbA1c levels.

On the other hand, children with type 1 diabetes have been found to have significantly higher deficits in emotional control and behavioral regulation compared to non-diabetic peers (Caruso et al., 2014). For example, Hughes, Berg, and Wiebe (2012) found that in adolescents with type 1 diabetes, problems with emotional processing, and low self-control, there was more glycemic instability. Furthermore, research indicates that emotion regulation deficits are associated with poor treatment adherence and glycemic control in boys with type 1 diabetes, but not girls (Graziano et al., 2011). This sex difference may be due to the fact that in general, boys exhibit more executive functioning deficits than girls, so this facet is less likely to impact adherence in females (Graziano et al., 2011). Results of the Northam et al. (2001) study demonstrated decreases in self-monitoring ability six years after diagnosis for youth with type 1 diabetes. On the other hand, Miller et al. (2012), found that emotional regulation improved over a two-year period in adolescents with type 1 diabetes, which was associated with better self-management and diabetes treatment adherence. Surprisingly, Miller et al. (2012), found that neither executive functioning overall nor self-management specifically predicted glycemic control, but better self-regulation was associated with better metabolic control. These disparate findings may be due to different measurements or definition of emotional, behavioral, or self-

regulation. Furthermore, executive function abilities, such as self and emotional-regulation develop through young adulthood; therefore, improvements in self-management as children age are not inconsistent with normal development. Comparisons between youth with and without type 1 diabetes on measures of self-regulation may shed more light on the divergent findings in the current literature. Finally, it also should be noted that research indicates that self-regulation leads to better glycemic control and treatment adherence (Bagner et al., 2007; Hughes, Berg, & Wiebe, 2012; McNally et al., 2010; Rohan et al., 2011). Overall, the current literature supports the need for more research into how pediatric type 1 diabetes affects the development and maintenance of self-regulation, especially as this particular ability has implications for treatment adherence and quality of life.

Problem-solving and planning in pediatric type 1 diabetes

The ability to problem-solve involves analysis of a problem or pattern, the weighing of various choices, the effective selection and implementation of a solution, and the evaluation of the chosen solution (Anderson, 2010; Rustad et al., 2013; Wysocki et al., 2008). Problem solving has been found to be associated with academic, occupational, and social success (Wysocki et al., 2008). Planning is often considered an element of problem solving and involves the integration of information to achieve a goal or solve a problem. Furthermore, planning and problem solving have been found to be significantly impaired in children with type 1 diabetes (Brands, Biessels, De Haan, Kappelle, & Kessels, 2005; Northam et al., 2001). In a 16-year longitudinal study, Asvold, Sand, Hestad, and Bjorgaas (2010) found that participants with type 1 diabetes did significantly worse on tasks of problem solving compared to non-diabetic controls and these deficits were correlated with more incidents of severe hypoglycemia. Moreover, in a meta-analysis conducted by Brands et al. (2005), researchers found a decreased ability to

problem solve in novel situations in those with type 1 diabetes, while Viklund and Ortqvist (2014) found that problem-solving ability helped in predicting variation in HbA1c stability in youth with type 1 diabetes. Furthermore, induced hypoglycemia in children results in poorer performance on tasks related to planning and decision-making (Ryan et al., 1990), while severe hypoglycemia has been implicated in problem-solving deficits (Bjorgaas, 2012). Additionally, episodes of hypoglycemia and seizures at a younger age appear to more significantly affect planning (Asvold et al., 2010; Ly, Anderson, McNamara, Davis, & Jones, 2011). Enlargements found in the frontal lobe of youth with type 1 diabetes due to DKA also may be related to deficits in planning and problem solving (Cameron et al., 2014). Finally, problem solving and planning have been found to contribute to better management of diabetes and adherence to treatment in some studies (Glasgow et al., 2007; King et al., 2010; McNally et al., 2010); Toobert & Glasgow, 1990), but not others (Hill-Briggs & Gemmell, 2007; Miller et al., 2012). In conclusion, research on the problem solving and planning abilities of youth with type 1 diabetes is sparse. Future research is needed in these areas, as deficits in problem solving and planning can have detrimental effects on treatment adherence, especially when children transition into adolescence and begin to take responsibility for diabetes management (Bagner et al., 2007).

Sex differences in executive functioning

There has been mixed evidence for sex differences in executive functioning. In a study of 2,200 youth, Naglieri and Rojahn (2001) found that females performed better than males on tasks of planning and attention. Behavioral inhibitory control has also been found to be better in females compared to males (Yuan et al., 2008), as well as self-regulation (Coyne, Vaske, Boisvert, & Wright, 2015). On the other hand, other studies have found no significant differences between sexes for attention and memory (Chan, 2001; Solianik, Brazaitis, &

Skurvydas, 2016) or working memory (Hill, Laird, & Robinson, 2014; Teleb & Al Awamleh, 2012). In contrast, some research has indicated that women perform better on verbal working memory tasks, while men perform better on visual-spatial working memory tasks (Harness et al., 2008; Hill et al., 2014). Overall, the literature is not clear on how sex potentially impacts executive functioning.

Age differences in executive functioning

Research indicates executive functioning improves throughout childhood and peaks in the mid to late 20's, which may be due to the development of neural and cognitive networks over time (De Luca et al., 2003). Executive functioning domains develop at different points in childhood and adolescence. For example, attention appears to begin to develop in infancy and throughout early childhood, while cognitive flexibility, goal setting, and information processing grow exponentially up until 12-years-old. Additionally, executive functioning is further refined throughout adolescence and into adulthood (Anderson, 2002; De Luca et al., 2003). Furthermore, Brocki and Bohlin (2004) found that development of executive functioning occurs in three particularly active stages of development: ages 6 to 8, ages 9 to 12, and adolescence. Over time, executive functioning abilities improve with age and development.

Quality of Life and Executive Functioning

Currently, there is very little research examining the connection between executive functioning and quality of life. In a study conducted by Sherman, Slick, and Eyrl (2006), executive dysfunction adversely impacted HRQoL in children with epilepsy, while Neal et al. (2015) found that deficits in executive functioning were associated with poorer psychosocial health in adolescents with cyanotic congenital heart disease. Moreover, de Vries and Geurts (2015) found that children with Autism Spectrum Disorders' (ASD) reported lower quality of

life was associated with deficits in executive functioning. Specifically, parents reported that their child with ASD presented deficits in cognitive flexibility, emotional control, inhibition, working memory, planning, and organization, which contributed to a decreased quality of life in social, emotional, and academic functioning. Laffond et al. (2011) found that in children with craniopharyngioma, or a benign tumor, symptoms of depression, executive functioning deficits, and lower quality of life were significantly correlated with each other. Additionally, in a study that examined executive functioning and coping in adolescents and adults who sustained a traumatic brain injury (TBI), researchers found that better executive functioning was associated with more effective problem solving and coping (Krpan, Levine, Stuss, & Dawson, 2007). Furthermore, research indicates that deficits in executive functions, specifically set shifting and working memory, are associated with lower HRQoL in older women (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010). Finally, self-management has been found to increase quality of life in adolescents with type 1 diabetes (Jaser et al., 2012), while improvements in executive functioning are correlated with increases in HRQoL in adults with attention-deficit/hyperactivity disorder (Brown & Landgraf, 2010). On the other hand, in a study conducted by Grech et al. (2015), researchers did not find a significant association between executive functioning and attention and stress, depression, anxiety, or quality of life in adults with multiple sclerosis; however, poorer performance on tasks of working memory and cognitive flexibility predicted higher levels of stress and lower physical quality of life. Although these studies elucidate the possible relationship between executive functioning and HRQoL, more research is needed to clarify this potential relationship, particularly in pediatric patients with type 1 diabetes.

CHAPTER III

METHODS

The current study used a cross-sectional design to gain information about the relationship between executive functioning, glycemic control, and health-related quality of life in youth with type 1 diabetes. Perspectives on executive functioning and HRQoL were gained using both parent and self-report measures, while glycemic control was measured using data collected from medical records (HbA1c, number of hospitalizations, number of DKA episodes). Power analysis was conducted using the G-power 2 program (2008) before data was collected. An alpha level of .05 and an effect size of .3 for correlational analyses and .15 for regression analysis was used and indicated that 162 participants were needed.

Participants

Participants were recruited from the Endocrinology practice at Children's Medical Center Dallas (n = 191). Children ages 12-18, both male and female, with type 1 diabetes, along with one caregiver (parent or legal guardian) were included in the study. Inclusion criteria included English-language speakers. As for exclusion criteria, participants could not have a known chromosomal disorder or a developmental delay, as this could impact executive functioning or HRQoL and could potentially contribute to an inability to understand self-report materials. Finally, youth diagnosed with non-type 1 diabetes (i.e. type 2 diabetes, steroid induced, and so on) were excluded, as these diagnoses require different medical interventions and may impact executive functioning, health outcomes, and generic and diabetes-specific quality of life. The majority of participants identified as white (60.2%), male (53.4%), and the majority of caregiver participants were mothers (74.3%). The mean age for participants was 14.85. The study sample's demographic characteristics are presented in Table 2.

Table 2

Participant demographic characteristics

Variable	N	%	M (SD)
Age	191		14.85 (1.78)
Gender			
Male	102	53.4	
Female	89	46.6	
Race			
White	115	60.2	
African American	36	18.8	
Hispanic	22	11.5	
Asian or Pacific Islander	4	2.1	
Native American	1	.5	
Other	13	6.8	
Person Reporting			
Mother/Step-mother	142	74.3	
Father/Step-father	24	12.6	
Grandparent	9	4.7	
Other	10	5.2	
Missing	3	1.6	

Procedures

IRB approval was obtained from Texas A&M University, University of Texas Southwestern Medical Center, and by Children's Medical Center (CMC), Dallas. Eligible participants were identified through a search of EPIC (Children's Medical Center Dallas's electronic medical records database) by the medical provider or research staff. Recruitment took place in the waiting room of the Endocrinology clinic by researchers. The study purpose was

explained to potential participants and if they were interested, information on what is involved was provided, with an emphasis on the voluntariness of participation. Participants were given a consent form to review and an opportunity to ask questions; they had as much time as they liked to review the form. Written consent was obtained from the parent or legal guardian and written assent was given by the adolescents.

Participation entailed completion of the questionnaires on quality of life, executive functioning, and demographic information. Questionnaires were completed on an iPad using RedCap. Research staff were available to assist in the completion of forms as needed. In addition, information on medical history and glycemic control (HbA1c) was obtained from medical records. Medical data was collected and recorded by medical staff at the Endocrinology clinic and transferred to the subject's medical chart review on RedCap. The parent and the child/adolescent completed research protocols in the following order: PedsQL™ 4.0 Generic Core Scales, PedsQL™ Family Information Form, and the Comprehensive Executive Function Inventory (CEFI: Naglieri & Goldstein, 2013).

The parent and child completed the questionnaires independently from one another and were discouraged from consulting one another during the completion of the questionnaires. If the child or parent had a question about an item, the item was not interpreted for them but was repeated verbatim. The subject was prompted to answer the item according to what they thought the question meant. If they still had difficulty selecting an answer, they were asked to choose the response that most closely reflected how they felt. If a parent/child asked for an interpretation or score from the responses, they were informed that this was not possible and that their answers would be combined with other participants' answers and analyzed as a group, rather than as individual responses. When questionnaires were returned, the study member checked all items

to ensure that they were answered and that there was not more than one response to the item. When the forms were completed, research staff saved the responses to RedCap. All research protocols were de-identified and assigned an identification number, with the corresponding parent and child forms assigned a matching identification number. After completion of protocols, participants were given a $10 gift card to Target, which was provided by the Endocrinology department at CMC Dallas, and copies of signed consent forms.

Measures

Medical Chart Review Form

At each appointment, the attending research staff completed the medical chart review form. The medical chart review includes the patient's sociodemographic information, medical history, current prescribed medications, age of diagnosis, number of hypo- and hyperglycemic episodes over the last six months, number of hospitalizations related to diabetes, history of DKA, any comorbid diagnoses, and current measure of HbA1c. This measure was developed by Dr. James Varni. A copy is provided in the Appendix.

PedsQL™ Family Information Form

The PedsQL™ Family Information Form assesses demographic information such as the date of birth, gender, race/ethnicity, and parental educational and occupational information. This information will be used to gather demographic data about participants.

PedsQL™ 4.0 Generic Core Scales

The PedsQL™ 4.0 Generic Core Scales (Varni, 1998) is 23-item measure of generic HRQoL that assesses physical, emotional, social, and school functioning in youth that are healthy and chronically ill (Varni & Limbers, 2009). Self-report forms can be used with youth ages 5 to 18 and the parent report for ages 2 to 18; the items for both forms are identical. Raters

report the frequency of problems over the past month using a five-point Likert scale. Higher scores indicate fewer reported problems. The PedsQL™ 4.0 generates a Total Scale Score, a Physical Health Summary Score, and a Psychosocial Health Summary Score. Additionally, four subscales are produced (Physical Functioning, Emotional Functioning, Social Functioning, and School Functioning). The PedsQL™ 4.0 Generic Core Scales have been studied internationally and have acceptable rates of validity and reliability (Hilliard et al., 2013; Varni et al., 2003). The measure has strong internal consistency on both the child and parent reports. Internal consistency ranges from .71 to .88 across scales on the child self-report and from .73 to .89 across scales on the parent proxy-report (Varni et al., 2003). Interrater reliability between parent and youth reports were moderate (ICC = .60) for the Total Scale Score (Varni, Limbers, & Burwinkle, 2007). Moreover, studies have shown that the PedsQL™ 4.0 Generic Core Scales has excellent construct validity, with healthy children reporting significantly less symptoms related to poor health-related quality of life compared to chronically ill children (Varni, Seid, & Kurtin, 2001; Varni, Burwinkle, Seid, & Skarr, 2003). In this study, the variables generated by the PedsQL™ 4.0 Generic Core Scales of interest included the Total Scale Score, Physical Health Summary Score, and the Psychosocial Health Summary Score. The internal consistency of the PedsQL subscales and the Total Scale Score for the dataset were calculated. Both the self-report PedsQL (α = .94) and parent-report PedsQL (α = .91) had high internal consistency, indicating the subscales and total score on the PedsQL consistently measure the same construct.

Based on Varni et al. (2003), the cut-off scores for children with chronic health conditions were as follows; self-report Total Score (69.7, SD = 13.16), self-report Physical Health Summary Score (72.98, SD = 13.88), self-report Psychosocial Health Summary Score (66.03, SD = 14.70), parent-report Total Score (65.4, SD = 15.92), parent-report Physical Health

Summary Score (63.28, SD = 19.98), and parent-report Psychosocial Health Summary Score (64.38, SD = 15.84).

Comprehensive Executive Function Inventory

The Comprehensive Executive Function Inventory (CEFI; Naglieri & Goldstein, 2013) measures parent, teacher, and self-report of executive functioning abilities in children and adolescents. Parent and Teacher report forms assesses youth ranging in age from 5 to 18, while the Self-Report form assesses ages 12 to 18 years old. Each form has 100 questions and uses a 6-point Likert format to determine behavioral frequency. The CEFI produces one Full Scale Score and nine subscales. Obtained scores are compared to a nationally normed sample that was consistent with the 2009 United States census (Naglieri & Goldstein, 2013). Subscales include Attention, Emotion Regulation, Flexibility, Inhibitory Control, Initiation, Organization, Planning, Self-Monitoring, and Working Memory. All forms of the CEFI have strong internal consistency on the Full-Scale score (range = .97 to .99) and interrater reliability was strong between parent raters (corrected r = .88) and between teachers (corrected r = .68). After reporters were administered the CEFI seven to thirty days apart, test-retest reliability coefficients were found to be high (corrected r = .77 to .91) for the Full-Scale score across forms (Naglieri & Goldstein, 2013). In this study, the variables generated by the CEFI that will be examined include the Full-Scale score, Attention, Planning, Self-Monitoring, Inhibitory Control, Emotion Regulation, Flexibility and Working Memory subscales.

The internal consistency of the CEFI subscales and the Full-Scale Score for the dataset were calculated. Both the self-report CEFI (α = .96) and parent-report CEFI (α = .98) had high internal consistency, indicating the subscales and total score on the CEFI consistently measure

the same construct. A summary of the measures used and the corresponding constructs are presented in Table 3.

Table 3

Variables and measures in current study

Construct	Measure/Variables
Demographics	Medical Chart Review Form; PedsQL™ Family Information Form
Diagnostic History	Medical Chart Review Form
HRQoL	PedsQL™ 4.0 Generic Core Scales: Total Scale Score, Physical Health Summary Score, and Psychosocial Health Summary Score (Parent and Self Report)
Glycemic Control	Most recent HbA1c, Number of Hypo- and Hyperglycemic episodes, number of DKA episodes, History of Ketones, History of Diabetes-Related Seizures, and Number of Hospitalizations for Diabetes (Medical Chart Review Form)
Executive Functioning	CEFI: Full-Scale score and subscales (Parent and Self Report)

CHAPTER IV

RESULTS

Initial Data Processing

Initial activity included identifying those protocols that were valid and could be included. Scores that were flagged as "invalid" were not included in the analyses, while scores flagged with "caution" were further examined. Scores that were flagged for "caution" based on great response variability were not included in data analyses, while those flagged due to a tendency to be overly negative or positive were included, as these scores may still reflect true behavior or emotions.

Missing data were examined for frequency and response patterns. Of the 191 participants, 178 (93%) of the participants had all the necessary data; six participants (3%) did not have the parent-report CEFI, but did have the number of DKA episodes; and five participants (3%) did not have any parent-reported measures, but did have the number of DKA episodes. The remaining response patterns had a frequency of 1% or less.

Seven of the participants were 18-year-olds and did not have a parent or guardian present at the medical appointment; this explains some of the missing parent-report data. The high number of missing data for number of DKA episodes since type 1 diabetes diagnosis (11 participants) was likely in part due to the researcher being unable to find this information in the medical chart. Parent or patient-reported number of DKA episodes since diagnosis was merged with the number of DKA episodes in the medical record, with discrepancies favoring the medical record. A consideration for the frequency of missing CEFI data is the length of the CEFI (100 questions). Many participants reported frustration with the long length of this questionnaire and the time it took to complete.

The missing data were tested for missing completely at random (MCAR) using Little's test (Little, 1988). Results indicated the data were not MCAR and was statistically significant at .01 ($p < .05$). Missing at random (MAR) analyses also were conducted to examine the data. T-tests showed that missing cases were not significantly different than complete cases, indicating that the data are MAR.

Data were tested for normality by examining the skewness and kurtosis of the data distribution. All variables had a skewness with an absolute value of three or less and kurtosis with an absolute value of seven or less, meeting the normality assumptions for structural equation modeling (West, Finch, & Curran, 1995), except for medical variables. Data imputation led to greater skewness and kurtosis for HbA1c, number of hospitalizations since diagnosis, number of hospitalizations in the past six months, and number of DKA episodes. Medical variables no longer met assumptions of normality after imputation, most likely because these variables do not come from a normative sample. As a result, analyses involving HbA1c, number of DKA episodes, hospitalizations since diagnosis, and hospitalizations in the past six months were conducted with the available data. Since normality assumptions were not violated after mean imputation for executive functioning and quality of life variables, mean imputation was used for analyses.

Using the Shapiro-Wilk test of normality, continuous variables that were not normally distributed included HbA1c (p =.95, $\alpha < .001$) number of DKA episodes (p = .60, $\alpha < .001$), number of times the child was hospitalized in the past 6 months (p = .60, $\alpha < .001$), number of times the child has ever been hospitalized (p = .81, $\alpha < .001$), self-report Physical Health Summary Score (p = .89, $\alpha < .001$) self-report Psychosocial Health Summary Score (p = .94, $\alpha < .001$), self-report Total Scale Score (p = .94, $\alpha < .001$), parent-report Physical Health Summary

Score (p = .83, α < .001), parent-report Psychosocial Health Summary Score (p = .94, α < .001), and the parent-report Total Scale Score (p = .93, α < .001), self-report Initiate on the CEFI (p = .01, α < .001), self-report Inhibitory Control (p = .95, α < .001), self-report Organization on the CEFI (p = .93, α < .001), self-report Emotion Regulation on the CEFI (p = .98, α = .03), self-report Flexibility on the CEFI (p = .98, α = .002), parent report Emotion Regulation on the CEFI (p = .98, α = .01), parent-report Flexibility on the CEFI (p = .98, α = .01), parent-report Initiate on the CEFI (p = .98, α = .02), parent-report Organization on the CEFI (p = .98, α = 02), parent report Planning on the CEFI (p = .98, α = .02), parent report Self-Monitoring on the CEFI (p = .98, α = .02), and parent report Working Memory on the CEFI (p = .98, α = .01). As a result, Spearman's rho was used to run correlational analyses and the Satorra-Bentler scaled difference chi-square test was used to account for non-normal data in SEM (Bryant & Satorra, 2012).

Descriptive Data for Sample

The means and standard deviations were calculated for self- and parent-report scales on the CEFI and PedsQL, as well as for health variables. Mean HbA1c was 9.10 (SD = 2.08), mean number of DKA episodes was 1.33 (SD = 2.18), mean number of hospitalizations in the past 6 months was .47 (SD = .88), and mean number of hospitalizations since diagnosis was 1.17 (SD = 1.29). The data is presented in Table 4.

Table 4

Means and standard deviations for glycemic control variables

Variable	Mean	SD
HbA1c	9.10	2.08
Number of DKA Episodes	1.33	2.18

Table 4 continued

Variable	Mean	SD
Hospitalizations Ever	1.17	1.29
Hospitalizations last 6 months	.47	.88

Notes. HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; SD = standard deviation

For CEFI scales, the means and standard deviations are presented in Table 5. Overall, this sample had CEFI means comparable to the normative sample of a mean of 100 and a standard deviation of 15, with means in the average range.

Table 5

Means and standard deviations for self and parent-report CEFI

Subscale/Scale	Mean	SD
SR Initiate	99.37	15.09
SR Organization	96.05	15.98
SR Planning	100.15	15.05
SR Self-Monitoring	100.6	15.08
SR Attention	98.60	15.32
SR Emotion-Regulation	99.39	16.26
SR Flexibility	102.70	16.46
SR Inhibitory Control	101.49	17.04
SR Working Memory	100.14	13.99

Table 5 continued

Subscale/Scale	Mean	SD
SR Full-Scale Score	99.87	14.66
PR Initiate	97.64	12.90
PR Organization	96.98	13.20
PR Planning	97.76	13.64
PR Self-Monitoring	97.90	13.81
PR Attention	97.68	13.82
PR Emotion Regulation	97.63	13.80
PR Flexibility	99.43	14.41
PR Inhibitory Control	99.51	14.08
PR Working Memory	97.52	13.54
PR Full-Scale Score	97.71	13.30

Notes. CEFI = Comprehensive Executive Function Inventory; SR = self-report; PR = parent-report; SD = standard deviation

The means and standard deviations for the self- and parent-report Total Score, Physical Health Summary Score, and Psychosocial Health Summary Score on the PedsQL also were calculated. Cut-off scores for significant impairment are 69.7 for self-report Total, 72.98 for self-report Physical Health Summary, 66.03 for self-report Psychosocial Health Summary, 65.4 for parent-report Total Score, 63.28 for parent-report Physical Health Summary, and 64.35 for parent-report Psychosocial Health Summary (Varni et al., 2003). Compared to the cut-off scores proposed by Varni et al. (2003), the sample means across reporters and PedsQL scales were

above the cut-off score for significant deficits, indicating that means were in the average range (Table 6).

Table 6

Means and standard deviations for self- and parent-report PedsQL

Subscale/Scale	Mean	SD
SR Physical Health Summary	89.95	12.17
SR Psychosocial Health Summary	79.60	13.25
SR Total Score	82.21	12.14
PR Physical Health Summary	86.74	15.09
PR Psychosocial Health Summary	81.49	14.89
PR Total Score	83.33	13.46

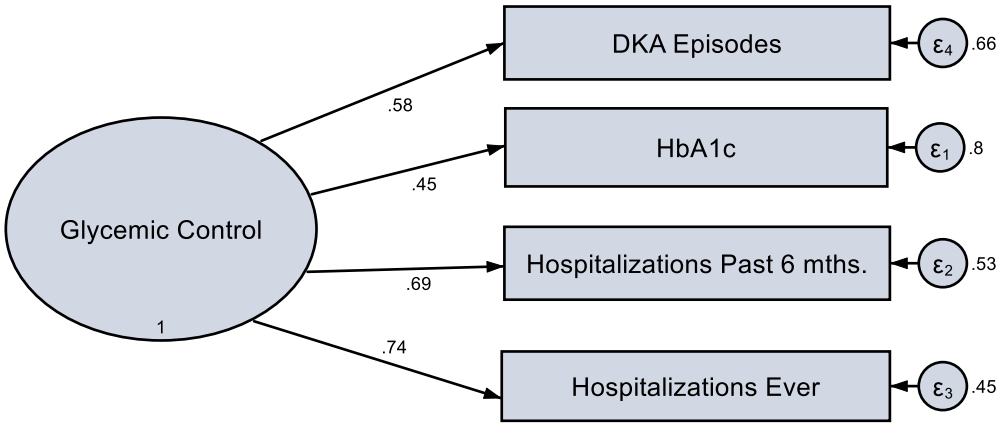
Notes. PedsQL = Pediatric Quality of Life Inventory; SR = self-report; PR = parent-report; SD = standard deviation

Confirmatory Factor Analysis of Glycemic Control

A Confirmatory Factor Analysis (CFA) was conducted on the latent construct of glycemic control, as measured by the observed variables of Hba1c, hospitalization for diabetes in the past six months, hospitalizations since diagnosis, and number of DKA episodes (n = 178). History of seizures and a history of hypoglycemia were removed from the model because of low frequency. A history of ketones was removed from the model due to insignificant factor loading. The CFA showed that the model was a good fit for the data (Figure 2). Using the Satorra-Bentler scaled adjustment, the model chi-square was not significant, $\chi^2(2) = 0.82$ ($p = .66$), while the TLI and CFI were 1.05 and 1.00, respectively. The RMSEA was .00 and the SRMR was .02,

indicating the model is a good fit. The factor loadings range from .45 ($p < .001$) for HbA1c to .74 ($p < .001$) for hospitalizations since diagnosis. Effect sizes ranged from small ($R^2 = .20$) for HbA1c to medium ($R^2 = .55$) for number of hospitalizations since diagnosis. Overall, the model explains 74% of the variance of the latent variable of glycemic control (Table 7).

Figure 2. Common factor model of latent construct of glycemic control.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months

Table 7

Standardized coefficient, standard error, significance level, and effect sizes for CFA model of latent construct of glycemic control

Variable	β	*SE*	*P*	R^2
HbA1c	.45	.09	<.001	.20
Number of DKA episodes	.58	.08	<.001	.34
Number of Hospitalizations ever	.74	.06	<.001	.55

Table 7 continued

Variable	β	*SE*	*P*	R^2
Hospitalizations in past 6 mths.	.69	.08	<.001	.47
Error of HbA1c	.80	.08	--	--
Error of Hospitalizations ever	.45	.10	--	--
Error of Hospitalizations 6 mths.	.53	.11	--	--
Error of Number of DKA Episodes	.66	.10	--	--

Notes. HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; CFA = confirmatory factor analysis; mths. = months; n = 178

Research Question 1. Age and glycemic control

Does current age predict glycemic control? Based on previous research, it was hypothesized older age would predict worse glycemic control (i.e., higher HbA1c, more hospitalizations, and more episodes of DKA) due to the increased responsibility for diabetes management in adolescence. First, the correlation between age and glycemic control was analyzed to see if there was an association using Spearman's rho. There were no significant correlations between age and HbA1c, hospitalizations in the last 6 months, the number of hospitalizations since diagnosis, or the number of DKA episodes (Table 8).

Table 8

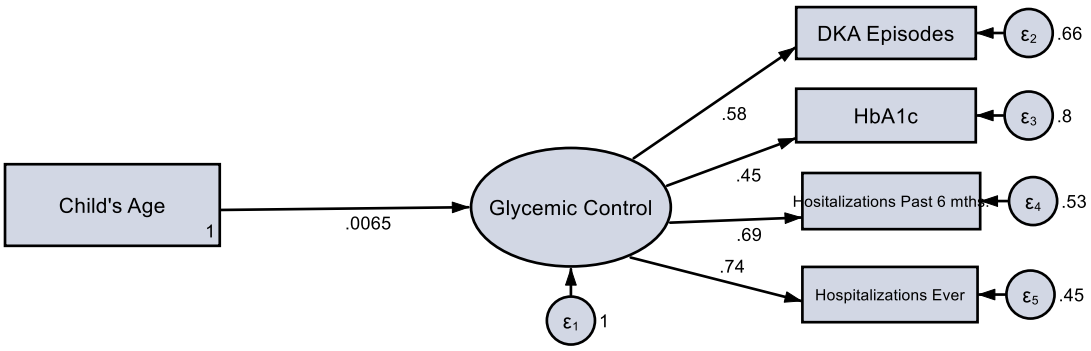
Correlation (r_s) between current age and glycemic control

	Age	
Variable	r_s	*p*
HbA1c	-.02	.39
Number of DKA Episodes	.12	.06
Hospitalizations last 6 months	-.01	.43
Hospitalizations Ever	.07	.18

Notes. HbA1c = glycated hemoglobin; DKA= diabetic ketoacidosis; * $p < .05$, ** $p < .01$ (1-tailed); DKA episodes (n = 180); all other variables (n = 190)

SEM was conducted to examine if age predicts glycemic control. Findings showed that the model was a good fit for the data. The model chi-square with Satorra-Bentler adjustment was not significant, $\chi^2(5) = 4.33$ ($p = .50$), while the TLI and CFI were 1.02 and 1.00, respectively and the RMSEA was .00, indicating good model fit. Age did not significantly predict glycemic control. $\beta(178) = .01$ ($p = .93$) as shown in Figure 3 and Table 9.

Figure 3. Model of child's age predicting glycemic control.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months

Table 9

Standardized coefficient, standard error, significance level, and effect sizes for model of child's age predicting glycemic control

Variable	β	*SE*	*p*	R^2
Child's age → Glycemic Control	.01	.08	.93	.00
HbA1c	.45	.09	<.001	.20
Hospitalization in past 6 mths.	.69	.08	<.001	.47
Number of Hospitalizations Ever	.74	.06	<.001	.55
Number of DKA Episodes	.58	.09	<.001	.34
Error of Glycemic Control	1.00	.01	--	--
Error of HbA1c	.80	.08	--	--
Error of Hospitalizations 6 mths.	.53	.11	--	--

Table 9 continued

Variable	β	*SE*	*p*	R^2
Error of Hospitalizations ever	.45	.09	--	--
Error of Number of DKA Episodes	.66	.10	--	--

Notes. HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; mths. = months; n = 178

Research Question 2. Age and executive functioning

Does age correlate with executive functioning? Research indicates executive functioning improves with age. It was hypothesized age would be associated with executive functioning, with older age correlating with higher CEFI scores. Since the CEFI scores are age-corrected, the association between age and executive functioning could not be directly examined. As a result, age was added as a covariate to the relationship between sex and executive functioning. A MANCOVA was performed to examine age, sex, and self- and parent-report executive functioning. Results are presented in Research Question 4.

Research Question 3. Sex and glycemic control

Using MANOVA, the association between glycemic control and child's sex were examined. Levene's test of equality of equal variances was performed to measure homoscedasticity. Number of DKA episodes (p = .01) and hospitalizations in the past 6 months (p = .01) were significant at $p < .05$, indicating they did not meet the assumption of equal variances. Therefore, the results of the MANOVA for DKA episodes and hospitalizations in the past 6 months are not valid. On the other hand, there was a small but significant association between sex and number of hospitalizations since diagnosis (η^2 = .03, p = .04), with female

gender associated with more hospitalizations since diagnosis. Results indicated no significant relationship between sex and HbA1c (Table 10).

Table 10

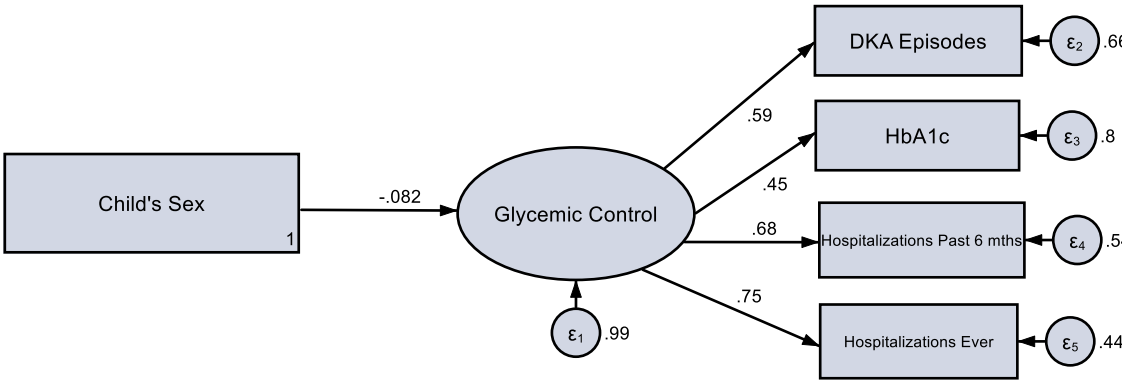
MANOVA (η^2) between child's sex and glycemic control

			Child's Sex	
Variable	η	η^2	*F*	*p*
HbA1c	.11	.01	1.05	.35
# of DKA Episodes	.14	.02	1.68	.19
Hosp. last 6 mths.	.17	.03	2.70	.07
Hospitalizations Ever	.18	.03	3.29	.04*

Notes. HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; Hosp. = hospitalizations; mths. = months; dx = diagnosis; * $p < .05$, ** $p < .01$; DKA episodes (n = 178); all other variables (n = 191)

CFA was conducted to examine if sex predicts glycemic control. The model chi-square with the Satorra-Bentler scaled test was not significant, $\chi^2(5) = 4.09$ ($p = .54$). The TLI and CFI were 1.02 and 1.00, respectively. The RMSEA was .03, which indicates a good model fit. The factor loadings range from .45 ($p < .001$) for the HbA1c variable to .75 ($p < .001$) for the number of hospitalizations since diagnosis. Sex was not a significant predictor of glycemic control $\beta(178) = -.08$ ($p = .38$). Results are shown in Figure 4 and Table 11.

Figure 4. Model examining child's sex predicting glycemic control.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months

Table 11

Standardized coefficient, standard error, significance level, and effect sizes for model of child's sex predicting glycemic control

Variable	β	*SE*	*p*	R^2
Sex → Glycemic Control	-.08	.09	.38	00
HbA1c	.45	.09	<.001	.20
Hospitalization in past 6 mths.	.68	.08	<.001	.46
Hospitalizations Ever	.75	.06	<.001	.56
DKA Episodes	.59	.08	<.001	.34
Error of Glycemic Control	.99	.02	--	--
Error of HbA1c	.80	.08	--	--

Table 11 continued

Variable	β	*SE*	*p*	R^2
Error of Hospitalizations 6 mths.	.54	.11	--	--
Error of Hospitalizations Ever	.44	.09	--	--
Error of DKA Episodes	.66	.10	--	--

Notes. HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; mths. = months; n = 178

Research Question 4. Sex and executive functioning

The relation between sex and executive functioning scales on the CEFI were examined using MANCOVA, with child's age added as a covariate. Levene's test of equality of equal variances was performed to measure homoscedasticity. Self-report Attention (p = .01), Flexibility (p = .02), Initiate (p = .01), Organization (p = .01), and Self-Monitoring (p = .01) were significant at $p < .05$, indicating they did not meet the assumption of equal variances. Child's sex and age were associated with self-report Inhibitory Control, Organization, Planning, and Self-Monitoring, but due to not meeting the standard of homogeneity of variance, only the variable of Inhibitory Control is valid (Table 12). As such, child's sex and age explains some of the self-reported inhibition; however, these effects are small.

Table 12

MANCOVA (η_p^2) between child's sex and self-report CEFI scales with child's age as a covariate

		Child's Sex	
Variable	η_p^2	*F*	*p*
Self-Report Initiate	.13	28.6	<.01**

Table 12 continued

	Child's Sex		
Variable	η_p^2	*F*	*p*
Self-Report Planning	.00	.84	.36
Self-Report Organization	.11	22.57	<.01**
Self-Report Self-Monitoring	.04	7.15	.01**
Self-Report Attention	.01	2.11	.15
Self-Report Emotion Regulation	.01	1.76	.19
Self-Report Flexibility	.00	.83	.36
Self-Report Inhibitory Control	.13	26.82	<.01**
Self-Report Working Memory	.00	38.59	.66
Self-Report Full Scale Score	.01	2.01	.16

Notes. CEFI = Comprehensive Executive Functioning Inventory; * $p < .05$, ** $p < .01$; n = 191

Levene's test of equality of equal variances was performed to measure homoscedasticity of parent-report scales on the CEFI. Parent-report Planning ($p = .02$), Self-Monitoring ($p = .01$), and Full-Scale score ($p = .02$) were significant at $p < .05$, indicating they did not meet the assumption of equal variances. There were no significant differences between child's sex for parent-report executive functioning when age was added as a covariate (Table 13).

Table 13

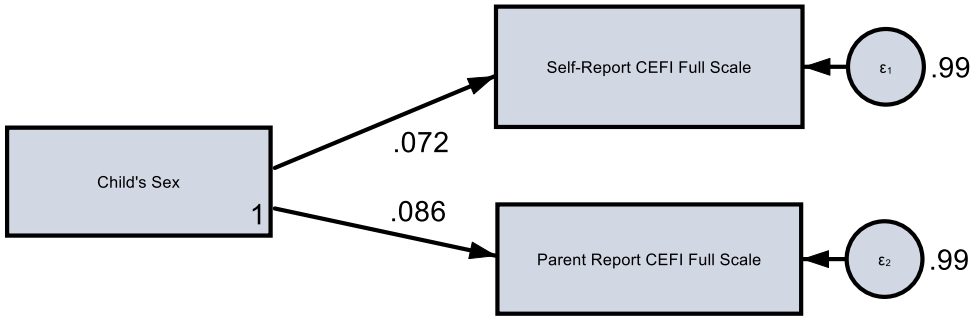
MANCOVA (η_p^2) between child's sex and parent-reported CEFI scales with child's age as a covariate

		Child's Sex	
Variable	η_p^2	*F*	*p*
Parent-Report Initiate	.00	.33	.57
Parent-Report Organization	.00	.50	.48
Parent-Report Planning	.01	1.16	.28
Parent-Report Self-Monitoring	.00	.01	.93
Parent-Report Attention	.00	.42	.52
Parent-Report Emotion Regulation	.01	1.25	.26
Parent-Report Flexibility	.00	.15	.70
Parent-Report Inhibitory Control	.01	1.68	.20
Parent-Report Working Memory	.00	.03	.87
Parent-Report Full Scale Score	.00	.28	.80

*No*tes. CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$; n = 191

A path analysis was conducted to examine if sex predicted executive functioning (Figure 5). Results from the path analysis showed that sex did not significantly predict executive functioning, as reported by the child, $\beta(191) = .07$ ($p = .13$), or the parent report, $\beta(191) = .09$ ($p = .20$; Table 14).

Figure 5. Model examining child's sex predicting parent and self-report Full Scale Score on the CEFI.



Notes. CEFI = Comprehensive Executive Function Inventory

Table 14

Standardized coefficient, standard error, significance level, and effect sizes for model of child's sex predicting parent and self-report Full Scale score on the CEFI

Variable	β	*SE*	*p*	R^2
Sex →SR Full Scale score	.07	.05	.13	.00
Sex →PR Full Scale score	.09	.07	.20	.00
Error of SR Full Scale	.99	.01	--	--
Error of PR Full Scale	.99	.01	--	--

Notes. CEFI = Comprehensive Executive Function Inventory; SR = self-report; PR = parent-report; n = 191

Research Question 5. Executive function and glycemic control

Does executive functioning correlate with glycemic control? It was hypothesized that deficits in executive functioning (Full-Scale score from the CEFI) would correlate with poorer

glycemic control (higher HbA1c levels) based on previous research. To test these hypotheses, a correlation matrix was computed for the CEFI total and subscales and HbA1c for both parent and child ratings using a Spearman's rho one-tailed test (n = 190). Results indicated a significant, but small, negative relationship between HbA1c and self-report Organization, Self-Monitoring, Attention, Emotion Regulation, Inhibitory Control, and the Full-Scale score (see Table 15). In effect as HbA1c levels went down (better glycemic control), executive functioning went up.

Table 15

Correlations (r_s) between HbA1c and self-reported CEFI scales

	HbA1c	
Variable	r_s	*p*
Self-reported Initiate	-.09	.11
Self-reported Organization	-.18**	.01
Self-reported Planning	-.12	.06
Self-reported Self-Monitoring	-.16**	.01
Self-reported Attention	-.15*	.02
Self-reported Emotion Regulation	-.21**	<.01
Self-reported Flexibility	-.07	.16
Self-reported Inhibitory Control	-.17**	.01
Self-reported Working Memory	-.07	.17
Self-reported Full-Scale score	-.17**	.01

Notes. HbA1c = glycated hemoglobin; CEFI = Comprehensive Executive Function Inventory; *p < .05, ** p < .01 (1-tailed); n = 190

Additionally, self-report CEFI scales were examined with number of hospitalizations in the past six months, number of hospitalizations since diagnosis, and number of DKA episodes. There were no significant correlations between number of DKA episodes and self-report executive functioning, as measured by the CEFI (Table 16).

Table 16

Correlations (r_s) between number of DKA episodes and self-reported CEFI scales

	Number of DKA episodes	
	r_s	*p*
Self-reported Initiate	.04	.31
Self-reported Organization	-.06	.20
Self-reported Planning	-.02	.42
Self-reported Self-Monitoring	.02	.38
Self-reported Attention	.02	.40
Self-reported Emotion Regulation	-.07	.19
Self-reported Flexibility	-.01	.48
Self-reported Inhibitory Control	-.02	.41
Self-reported Working Memory	-.06	.23
Self-reported Full-Scale score	-.01	.45

Notes. DKA = diabetic ketoacidosis; CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 180

There were significant negative correlations between the number of hospitalizations since diagnosis and self-report Inhibitory Control and Organization (Table 17). As number of hospitalizations since diagnosis increased, organizational skills and inhibition decreased.

Table 17

Correlations (r_s) between number of hospitalizations since diagnosis and self-reported CEFI scores.

	Number of hospitalizations since diagnosis	
	r_s	*p*
Self-reported Initiate	-.08	.12
Self-reported Organization	-.12*	.05
Self-reported Planning	-.06	.22
Self-reported Self-Monitoring	-.07	.17
Self-reported Attention	-.07	.16
Self-reported Emotion Regulation	-.11	.07
Self-reported Flexibility	.00	.50
Self-reported Inhibitory Control	-.12*	.05
Self-reported Working Memory	-.07	.16
Self-reported Full-Scale score	-.07	.16

Notes. CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

The number of hospitalizations in the past 6 months was not significantly correlated with any self-report CEFI scales (Table 18).

Table 18

Correlations (r_s) between number of hospitalizations in the past 6 months and self-reported CEFI scores

	Number of hospitalizations in past 6 mths.	
	r_s	*p*
Self-reported Initiate	.02	.40
Self-reported Organization	-.11	.07
Self-reported Planning	-.02	.37
Self-reported Self-Monitoring	.01	.43
Self-reported Attention	-.04	.29
Self-reported Emotion Regulation	-.02	.40
Self-reported Flexibility	.01	.44
Self-reported Inhibitory Control	.00	.50
Self-reported Working Memory	-.06	.20
Self-reported Full-Scale score	.01	.45

Notes. CEFI = Comprehensive Executive Function Inventory; mths = months; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

The relationship between parent-report on the CEFI and HbA1c also was analyzed using Spearman's rho. There was a significant, but small, negative correlation between HbA1c and all

parent-reported scales on the CEFI (Table 19). As with self-report, the higher the HbA1c (poorer glycemic control), the lower the executive functioning domain.

Table 19

Correlations (r_s) between HbA1c and parent-reported CEFI scales

	HbA1c	
	r_s	*p*
Parent-reported Initiate	-.18**	.01
Parent-reported Organization	-.15*	.02
Parent-reported Planning	-.22**	.00
Parent-reported Self-Monitoring	-.15*	.02
Parent-reported Attention	-.17*	.01
Parent-reported Emotion Regulation	-.25**	<.01
Parent-reported Flexibility	-.12*	.05
Parent-reported Inhibitory Control	-.19**	<.01
Parent-reported Working Memory	-.16*	.01
Parent-reported Full-Scale score	-.19**	.01

Notes. HbA1c = glycated hemoglobin; CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

Parent-reported CEFI scales also were examined in relation to number of hospitalizations in the past 6 months, the number of hospitalizations since diagnosis, and the number of DKA episodes. There was a significant, negative relationship between number of DKA episodes and

all parent-reported CEFI scales (n = 180; Table 20). As number of DKA episodes increased, executive functioning decreased.

Table 20

Correlations (r_s) between number of DKA episodes and parent-reported CEFI scales

	Number of DKA episodes	
	r_s	*p*
Parent-reported Initiate	-.20*	<.01
Parent-reported Organization	-.15*	.02
Parent-reported Planning	-.21**	<.01
Parent-reported Self-Monitoring	-.23**	<.01
Parent-reported Attention	-.22**	<.01
Parent-reported Emotion Regulation	-.28**	<.01
Parent-reported Flexibility	-.24**	<.01
Parent-reported Inhibitory Control	-.21**	<.01
Parent-reported Working Memory	-.19**	.01
Parent-reported Full-Scale score	-.22**	<.01

Notes. DKA = diabetic ketoacidosis; CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 180

Number of hospitalizations in the past 6 months had small significant negative correlations with all parent-reported executive functioning scales, except for Self-Monitoring

(Table 21). As the number of hospitalizations in the past 6 months increased, parent-reported executive functioning decreased.

Table 21

Correlations (r_s) between parent-reported CEFI scores and number of hospitalizations in the last 6 months

	Hospitalizations in the last 6 months	
	r_s	*p*
Parent-reported Initiate	-.14*	.03
Parent-reported Organization	-.12*	.04
Parent-reported Planning	-.13*	.04
Parent-reported Self-Monitoring	-.09	.12
Parent-reported Attention	-.18**	.01
Parent-reported Emotion Regulation	-.26**	<.01
Parent-reported Flexibility	-.18**	.01
Parent-reported Inhibitory Control	-.18**	.01
Parent-reported Working Memory	-.15*	.02
Parent-reported Full-Scale score	-.17**	.01

Notes. CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

There were also small significant negative Spearman's rho correlations between number of hospitalizations since diagnosis and all parent-reported scales on the CEFI (Table 22). As the

number of hospitalizations since diagnosis increased, parent-reported executive functioning decreased.

Table 22

Correlation (r_s) between parent-reported CEFI scales and number of hospitalizations since diagnosis

	Number of hospitalizations since diagnosis	
	r_s	*p*
Parent-reported Initiate	-.18**	.01
Parent-reported Organization	-.14*	.03
Parent-reported Planning	-.16*	.02
Parent-reported Self-Monitoring	-.17*	.02
Parent-reported Attention	-.19**	.01
Parent-reported Emotion Regulation	-.25**	<.01
Parent-reported Flexibility	-.20**	.01
Parent-reported Inhibitory Control	-.18**	.01
Parent-reported Working Memory	-.21**	.01
Parent-reported Full-Scale score	-.20**	.01

Notes. CEFI = Comprehensive Executive Function Inventory; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

Research Question 6. Executive function and HRQoL

In order to test the hypothesis that executive functioning predicts HRQoL, a Spearman's rho correlational matrix was first created to see if there was a relationship between these

variables (n = 191). For both self-report (Table 23) and parent-report (Table 24) measures, there were positive significant correlations between all three HRQoL variables and all the CEFI scales. As executive functioning increased, HRQoL also increased.

Table 23

Correlations (r_s) between self-report CEFI scales and self-report HRQoL

	Physical		Psychosocial		Total	
	r_s	*p*	r_s	*p*	r_s	*p*
Self-reported Initiate	.34**	<.001	.31**	<.001	.35**	<.001
Self-reported Organization	.34**	<.001	.40**	<.001	.42**	<.001
Self-reported Planning	.30**	<.001	.37**	<.001	.38**	<.001
Self-reported Self-Monitoring	.34**	<.001	.38**	<.001	.40**	<.001
Self-reported Attention	.40**	<.001	.47**	<.001	.49**	<.001
Self-reported Emotion Regulation	.36**	<.001	.47**	<.001	.47**	<.001
Self-reported Flexibility	.30**	<.001	.32**	<.001	.33**	<.001
Self-reported Inhibitory Control	.32**	<.001	.38**	<.001	.38**	<.001
Self-reported Working Memory	.38**	<.001	.50**	<.001	.50**	<.001
Self-reported Full-Scale score	.39**	<.001	.46**	<.001	.48**	<.001

Notes. CEFI = Comprehensive Executive Function Inventory; HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$; n = 191

Table 24

Correlations (r_s) between parent-reported CEFI scales and parent reported HRQoL

	Physical		Psychosocial		Total	
	r_s	*p*	r_s	*p*	r_s	*p*
Parent-reported Initiate	.30**	<.001	.37**	<.001	.40**	<.001
Parent-reported Organization	.24**	<.001	.36**	<.001	.37**	<.001
Parent-reported Planning	.23**	<.001	.38**	<.001	.38**	<.001
Parent-reported Self-Monitoring	.24**	<.001	.38**	<.001	.38**	<.001
Parent-reported Attention	.30**	<.001	.42**	<.001	.43**	<.001
Parent-reported Emotion Reg.	.26**	<.001	.40**	<.001	.40**	<.001
Parent-reported Flexibility	.21**	<.001	.32**	<.001	.34**	<.001
Parent-reported Inhibitory Control	.20**	<.001	.36**	<.001	.34**	<.001
Parent-reported Working Memory	.26**	<.001	.42**	<.001	.41**	<.001
Parent-reported Full-Scale score	.27**	<.001	.42**	<.001	.43**	<.001

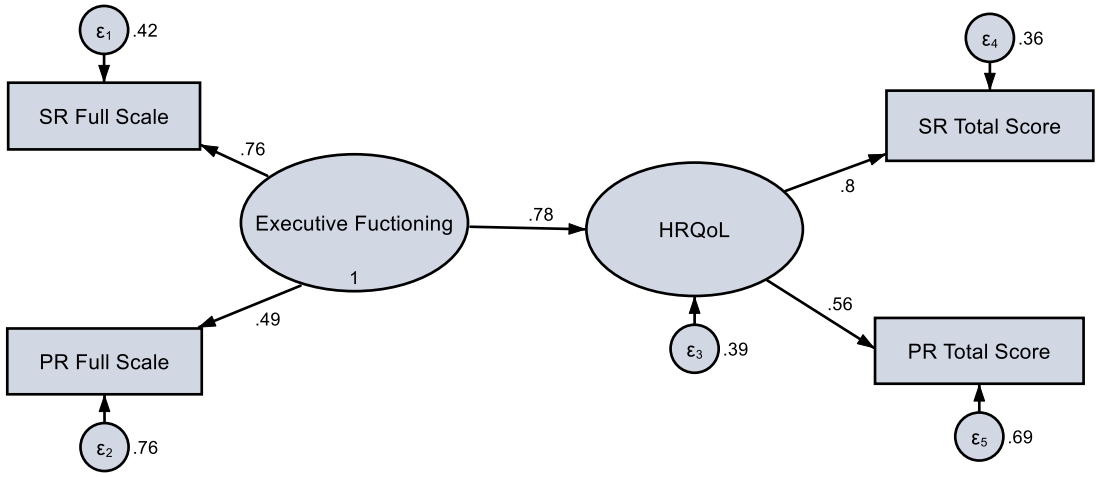
Notes. CEFI = Comprehensive Executive Function Inventory; HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$; n = 191

SEM analysis was conducted to examine if executive functioning, as measured by the Full-Scale scores for child and parent-report CEFIs, predicted HRQoL, as measured by the Total Scale Scores on the parent and self-report PedsQL (Figure 6). The model chi-square using the Satorra-Bentler adjustment was significant, $\chi^2(1) = 14.18$, $p < .01$, indicating the model is not a good fit for the data. The TLI and CFI were .89 and .39, indicating poor model fit, while the RMSEA was .26.

In the model, executive functioning significantly predicted HRQoL, $\beta(191) = .78$, $p < .001$ and had an effect size of $R^2 = .61$ (Table 25). Factor loadings for executive functioning ranged from .76 ($p < .001$) for the self-report CEFI Full Scale score to .49 ($p < .001$) for the parent-report

CEFI Full Scale score. Factor loading for HRQoL ranged from .56 ($p < .001$) for parent-report Total Scale Sore on the PedsQL to .80 ($p < .001$) for the self-report Total Scale Score on the PedsQL. Although this model accounted for 77% of the overall variance, based on the fit indices, this model is not the best fit for the data.

Figure 6. Model of executive functioning predicting HRQoL Total Scale Scores on the PedsQL for parent and self-report.



Notes. HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 25

Standardized coefficient, standard error, significance level, and effect sizes for model of executive functioning predicting HRQoL

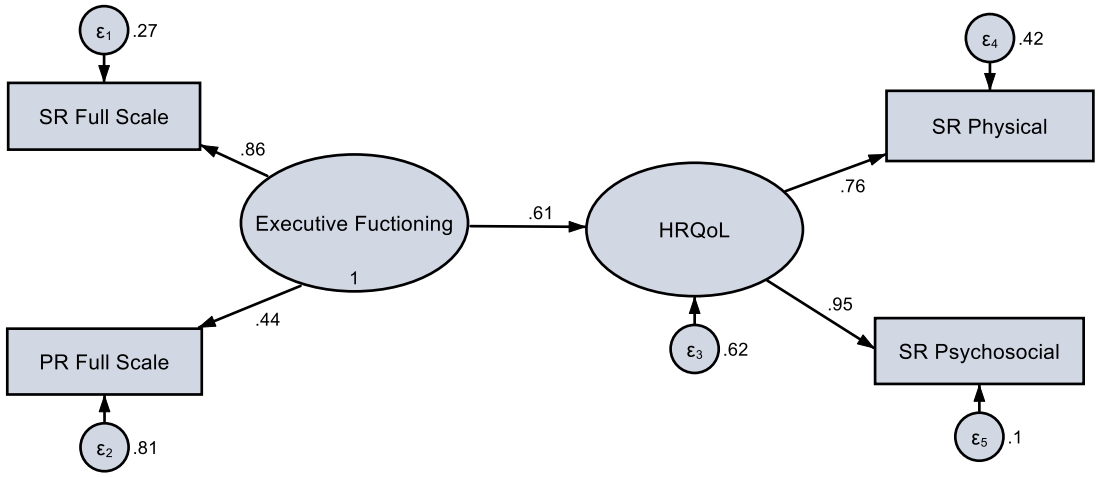
Variable	β	*SE*	*p*	R^2
Executive Functioning → HRQoL	.78	.09	<.001	.61
SR Full-Scale score (CEFI)	.76	.09	<.001	.24
PR Full-Scale Score (CEFI)	.49	.08	<.001	.64
SR Total Score (PedsQL)	.80	.07	<.001	.31
PR Total Score (PedsQL)	.56	.08	<.001	--
Error of HRQoL	.39	.14	--	--
Error of SR Full-Scale	.42	.13	--	--
Error of PR Full-Scale	.76	.08	--	--
Error of SR Total Score	.36	.11	--	--
Error of PR Total Score	.69	.07	--	

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Functioning Inventory; PedsQL = Pediatric Quality of Life Inventory; SR = self-report; PR = parent-report; n = 191

A model examining executive functioning predicting self-report Psychosocial and Physical Health Summary Scores on the PedsQL also was conducted (Figure 7). The model chi-square was not significant, $\chi^2(1) = 1.51$, $p = .22$. The TLI and CFI were .99 and 1.00, respectively. The RMSEA was .05, which indicates a good model fit. Factor loadings for executive functioning ranged from .86 (p <.001) for the self-report CEFI Full-Scale score to .44 (p < .001) for the parent-report CEFI Full-Scale score (Table 26). Factor loadings for self-report HRQoL ranged from .95 (p <.001) for the Psychosocial Health Summary score to .76 (p < .001)

for the Physical Health Summary score. Executive functioning was found to significantly predict self-reported HRQoL β(191) = .61 ($p < .001$) and had a small effect size ($R^2 = .38$). The model accounted for 78% of the overall variance. Increases in executive functioning predicted increases in self-report physical and psychosocial HRQoL.

Figure 7. Model of executive functioning predicting self-report Physical and Psychosocial Health Summary scores.



Notes. HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 26

Standardized coefficient, standard error, significance level, and effect sizes for model of executive functioning predicting self-report physical and psychosocial HRQoL

Variable	β	*SE*	*p*	R^2
Executive Functioning → HRQoL	.61	.09	<.001	.37
SR Full-Scale score (CEFI)	.87	.11	<.001	.76
PR Full-Scale Score (CEFI)	.47	.08	<.001	.18
SR Physical Health Score (PedsQL)	.76	.05	<.001	.57
SR Psychosocial Health Score (PedsQL)	.94	.05	<.001	.89
Error of HRQoL	.63	.11	--	--
Error of SR Full-Scale	.24	.19	--	--
Error of PR Full-Scale	.82	.10	--	--
Error of SR Physical Health Score	.43	.08	--	--
Error of SR Psychosocial Health Score	.11	.10	--	--

Notes. CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; SR = self-report; PR = parent-report; n = 191

Additionally, SEM was conducted to examine the hypothesis that executive functioning, as measured by the parent and self-report CEFI Full Scale scores, predicts parent-reported HRQoL, as measured by the Physical and Psychosocial Health Summary Scores on the PedsQL. The data in this model did not converge, indicating poor model fit. Based on this analysis,

executive functioning may not be a good predictor of parent-report HRQoL. Based on the three models examining executive functioning and HRQoL, the best fit for the data is executive functioning predicting self-report Physical and Psychosocial HRQoL.

Research Question 7. HRQoL and glycemic control

To test the hypothesis that HRQoL and glycemic control are related, two Spearman's rho correlational matrices examining self and parent-reported Psychosocial Health Summary Scores, Physical Health Summary Scores, and Total Scale Scores with HbA1c, number of DKA episodes, number of hospitalizations in the past 6 months, and number of hospitalizations since diagnosis. Results indicated a small significant negative correlation between HbA1c and self-reported Psychosocial Health Summary Score and self-report Total Scale Score. Additionally, there were small significant negative correlations between HbA1c and all parent-reported HRQoL scores (Table 27). As HRQoL increased, HbA1c decreased (better glycemic control), which is consistent with the proposed hypothesis.

Table 27

Correlations (r_s) between HbA1c and HRQoL

	HbA1c	
	r_s	*p*
Self-reported Physical Health	-.08	.15
Self-reported Psychosocial Health	-.14*	.03
Self-reported Total Scale Score	-.14*	.03
Parent-reported Physical Health	-.19**	<.01
Parent-reported Psychosocial Health	-.22**	<.01

Table 27 continued

	HbA1c	
	r_s	p
Parent-reported Total Scale Score	-.23**	<.01

Notes. HbA1c = glycated hemoglobin; HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

The number of DKA episodes was significantly correlated with all self- and parent-report HRQoL scales on the PedsQL (Table 28). As number of DKA episodes increased, self and parent-reported physical health quality of life decreased.

Table 28

Correlations (r_s) between number of DKA episodes and HRQoL

	Number of DKA episodes	
	r_s	p
Self-reported Physical Health	-.23**	<.01
Self-reported Psychosocial Health	-.22**	<.01
Self-reported Total Scale Score	-.23**	<.01
Parent-reported Physical Health	-.20**	<.01
Parent-reported Psychosocial Health	-.21**	<.01
Parent-reported Total Scale Score	-.23**	<.01

Notes. DKA = diabetic ketoacidosis; HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$ (1-tailed); n = 180

A Spearman's rho correlation matrix was created to examine the relationship between HRQoL scales and number of hospitalizations in the past 6 months. There was a significant negative correlation between number of hospitalizations in the past 6 months and all self- and parent-reported HRQoL scales on the PedsQL. As the number of hospitalizations in the past 6 months increased, parent and self-reported physical, psychosocial, and overall health-related quality of life decreased (Table 29).

Table 29

Correlation (r_s) between number of hospitalizations in the past 6 months and HRQoL

	Number of hospitalizations in past 6 mths.	
	r_s	*p*
Self-reported Physical Health	-.21**	<.01
Self-reported Psychosocial Health	-.19**	<.01
Self-reported Total Scale Score	-.21**	<.01
Parent-reported Physical Health	-.25**	<.01
Parent-reported Psychosocial Health	-.21*	<.01
Parent-reported Total Scale Score	-.26**	<.01

Notes. HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

A Spearman's rho correlational matrix was completed to examine the relationship between HRQoL and number of hospitalizations since diagnosis. There was a significant negative correlation between number of hospitalizations since diagnosis and all self- and parent-

reported HRQoL scales. As the number of hospitalizations since diagnosis increased, physical, psychosocial, and overall health-related quality of life decreased (Table 30).

Table 30

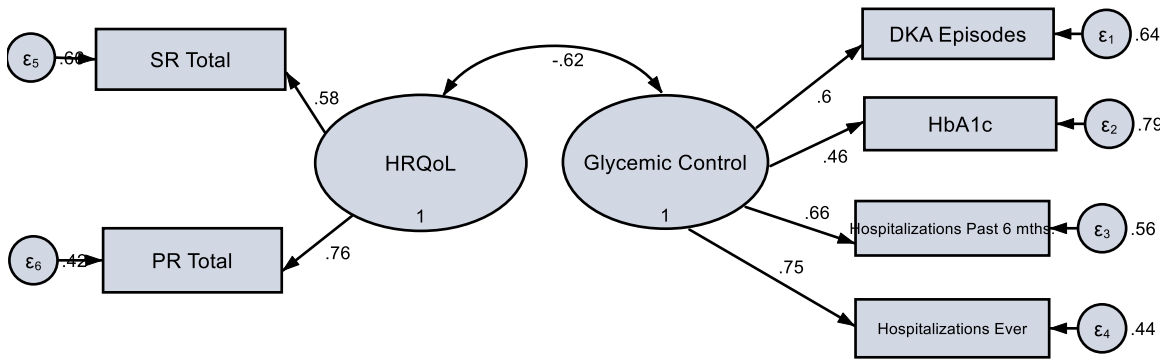
Correlations (r_s) between number of hospitalizations since diagnosis and HRQoL

	Number of hospitalizations since diagnosis	
	r_s	*p*
Self-reported Physical Health	-.23**	<.01
Self-reported Psychosocial Health	-.23**	<.01
Self-reported Total Summary Score	-.24**	<.01
Parent-reported Physical Health	-.24**	<.01
Parent-reported Psychosocial Health	-.28**	<.01
Parent-reported Total Summary Score	-.29**	<.01

Notes. HRQoL = health-related quality of life; * $p < .05$, ** $p < .01$ (1-tailed); n = 190

SEM was conducted to examine the relationship between glycemic control and HRQoL. It was hypothesized that these variables would negatively covary with one another. Results indicated the model chi-square was not significant, $\chi^2(8) = 3.31$, $p = .91$. The TLI and CFI were 1.07 and 1.00, respectively, while the RMSEA was .00, which indicates the model is a good fit for the data. Glycemic control significantly negatively covaried with HRQoL ($\beta(178) = -.62$ ($p < .001$). As glycemic control worsened, HRQoL also decreased (Figure 8; Table 31). Overall, the model accounted for a large amount of variance ($R^2 = .89$).

Figure 8. Model of glycemic control covarying with HRQoL



Notes. HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 31

Standardized coefficient, standard error, significance level, and effect sizes for model showing the covariance between glycemic control and HRQoL

Variable	β	*SE*	*p*	R^2
Covariance of GC and HRQoL	-.62	.10	<.001	--
HbA1c	.46	.09	<.001	.21
Hospitalizations past 6 mths.	.66	.08	<.001	.44
Hospitalizations Ever	.75	.05	<.001	.56
Number of DKA Episodes	.60	.09	<.001	.36
SR Total Score (PedsQL)	.58	.09	<.001	.34
PR Total Score (PedsQL)	.76	.11	<.001	.58

Table 31 continued

Variable	β	*SE*	*p*	R^2
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.56	.11	--	--
Error of Hospitalizations Ever	.44	.08	--	--
Error of DKA Episodes	.64	.10	--	--
Error of SR Total Score	.66	.11	--	--
Error of PR Total Score	.42	.17	--	--

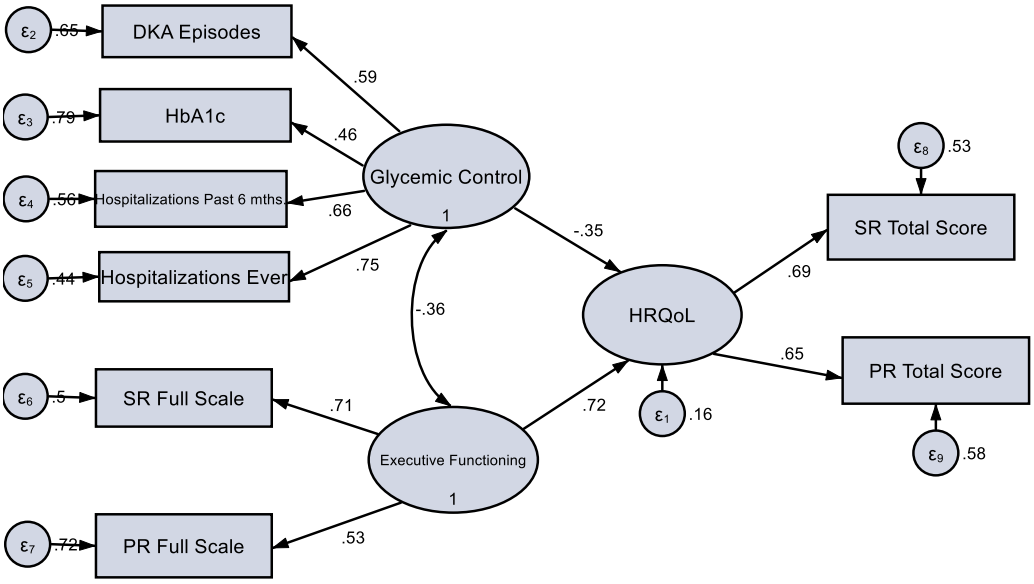
Notes. HRQoL = health-related quality of life; PedsQL = Pediatric Quality of Life Inventory; GC = glycemic control; HbA1c = glycated hemoglobin; DKA = diabetic ketoacidosis; mths = months; SR = self-report; PR = parent-report; n = 178

Research Question 8. Testing the model

To test the hypothesis that the data fits the hypothesized model, SEM of the proposed model was conducted (Figure 9). The model using the Satorra-Bentler chi-square adjustment was significant, $\chi^2(17) = 27.43$, $p = .05$. The TLI and CFI were .92 and .95, respectively, and the RMSEA was .06, which indicates adequate model fit for the data. Executive functioning, $\beta(178) = .72$ ($p < .001$) significantly predicted HRQoL, with improvements in executive functioning predicting improvements in HRQoL. Additionally, glycemic control significantly predicted HRQoL $\beta(178) = -.35$ ($p < .01$), with worse glycemic control (higher HbA1c, more hospitalizations, more DKA episodes) predicting lower HRQoL. A large portion of the variance of HRQoL was explained in the model ($R^2 = .84$), while 96% of the overall variance explained in the model. There was also a significant covariance between glycemic control and executive

functioning β(178) = -.36 (p < .01). Worse glycemic control was associated with worse executive functioning (Table 32).

Figure 9. Hypothesized model showing the relationship between glycemic control, executive functioning, and HRQoL.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months; HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 32

Standardized coefficient, standard error, significance level, and effect sizes for model showing the relationship between glycemic control, executive functioning and HRQoL

Variable	β	*SE*	*p*	R^2
EF → HRQoL	.72	.11	<.001	--
GC → HRQoL	-.36	.11	<.01	--
Covariance of GC and EF	-.36	.11	.01	.50
SR Full Scale score (CEFI)	.71	.08	<.001	.28
PR Full Scale Score (CEFI)	.53	.08	<.001	.21
HbA1c	.46	.09	<.001	.44
Hospitalizations past 6 mths.	.66	.08	<.001	.56
Hospitalizations Ever	.76	.05	<.001	.35
Number of DKA Episodes	.59	.09	<.001	.47
SR Total Score (PedsQL)	.69	.06	<.001	.42
PR Total Score (PedsQL)	.65	.08	<.001	--
Error of HRQoL	.16	.14	--	--
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.56	.11	--	--
Error of Hospitalizations Ever	.44	.08	--	--
Error of DKA Episodes	.65	.10	--	--
Error of SR Full scale	.50	.12	--	--

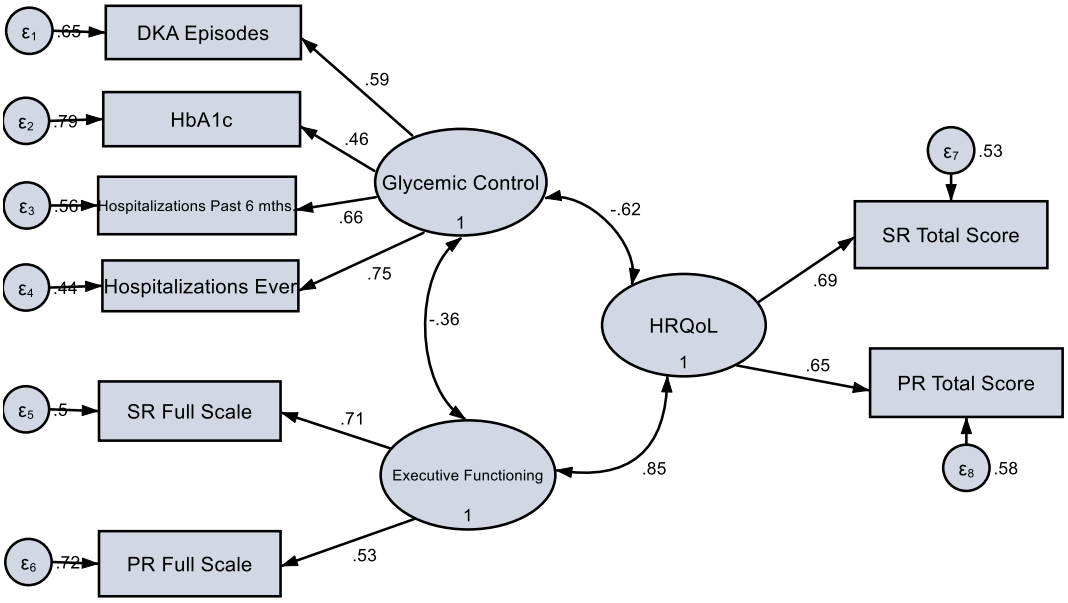
Table 32 continued

Variable	β	*SE*	*p*	R^2
Error of PR Full scale	.72	.08	--	--
Error of SR Total Score	.53	.08	--	--
Error of PR Total Score	.58	.11	--	

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; mths = months; SR = self-report; PR = parent-report; n = 178

A second SEM model was conducted to examine if the relationship between variables was better explained by covariance, rather than prediction (Figure 10). Using the Satorra-Bentler scaled test adjustment, the model chi-square was significant, $\chi^2(17) = 27.43$, $p = .05$. The TLI and CFI were .92 and .95, respectively, and the RMSEA was .06, which indicates poor to adequate model fit for the data. Executive functioning, $\beta(178) = .85$ ($p < .001$) significantly covaried with HRQoL, with higher executive functioning associated with higher HRQoL. Executive functioning also significantly covaried with glycemic control $\beta(178) = -.36$ ($p < .01$), with poorer glycemic control associated with lower executive functioning. Finally, glycemic control significantly covaried with HRQoL $\beta(178) = -.62$ ($p < .001$), with poorer glycemic control associated with lower HRQoL. Although the model explained 93% of the variance, fit indicines indicated the model was not the optimal fit for the data (Table 33).

Figure 10. The covariance between glycemic control, executive functioning, and HRQoL



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months; HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 33

Standardized coefficient, standard error, significance level, and effect sizes for the model examining the covariance between glycemic control, executive functioning, and HRQoL

Variable	β	*SE*	*p*	R^2
Covariance of EF and HRQoL	.85	.09	<.001	--
Covariance of EF and GC	-.36	.11	<.01	--
Covariance of GC and HRQoL	-.62	.10	<.001	--
SR Full Scale score (CEFI)	.71	.08	<.001	.50
PR Full Scale Score (CEFI)	.53	.08	<.001	.28
HbA1c	.46	.09	<.001	.21
Hospitalizations past 6 mths.	.66	.08	<.001	.44
Hospitalizations Ever	.75	.05	<.001	.56
Number of DKA Episodes	.59	.09	<.001	.35
SR Total Score (PedsQL)	.69	.06	<.001	.47
PR Total Score (PedsQL)	.65	.08	<.001	.42
Error of HRQoL	1	--	--	--
Error of EF	1	--	--	--
Error of GC	1	--	--	--
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.56	.11	--	--
Error of Hospitalizations Ever	.44	.08	--	--

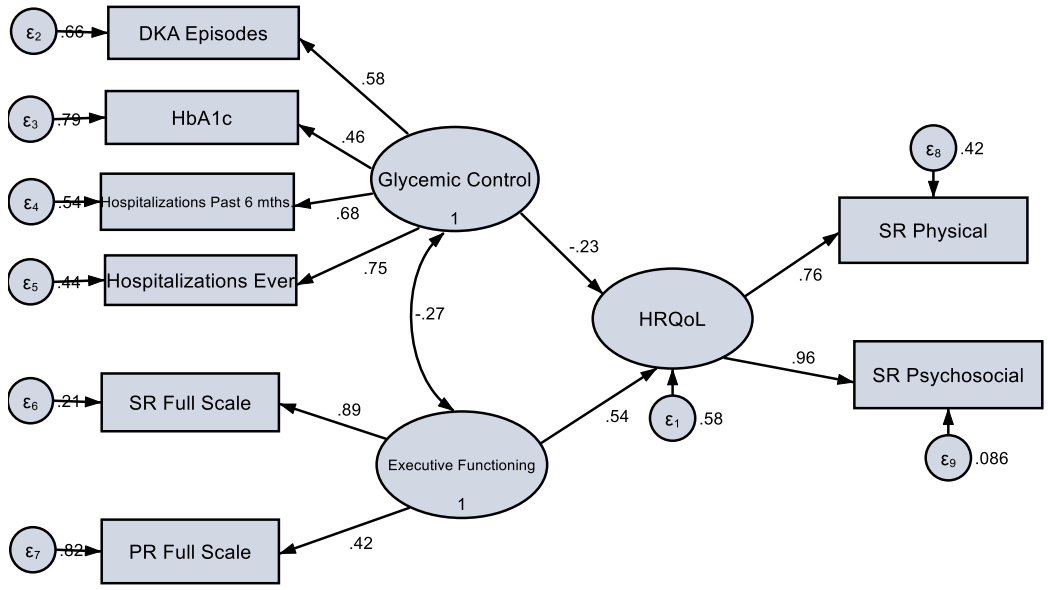
Table 33 continued

Variable	β	*SE*	*p*	R^2
Error of DKA Episodes	.65	.10	--	--
Error of SR Full scale	.50	.12	--	--
Error of PR Full scale	.72	.08	--	--
Error of SR Total Score	.53	.08	--	--
Error of PR Total Score	.58	.11	--	--

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; EF = executive functioning; GC = glycemic control; mths = months; SR = self-report; PR = parent-report; n = 178

Since the model with executive functioning predicting self-report Physical and Psychosocial Health Summary scores was found to best fit the data, this model was integrated into the hypothesized model (Figure 11). Using the Satorra-Bentler scaled test adjustment, the model chi-square was not significant, $\chi^2(17) = 16.05$, $p = .52$. The TLI and CFI were 1.01 and 1.00, while the RMSEA was .00, indicating good model fit. Executive functioning significantly predicted self-reported Physical and Psychosocial quality of life, $\beta(178) = .54$ ($p < .001$), while glycemic control significantly predicted HRQoL, $\beta(178) = -.23$ ($p = .01$), with poorer glycemic control associated with lower executive functioning. Finally, glycemic control significantly covaried with executive functioning, $\beta(178) = -.27$ ($p = .01$), with poorer glycemic control associated with lower HRQoL. The model explained 95% of the variance (Table 34).

Figure 11. Model showing the relationship between glycemic control, executive functioning, and self-report HRQoL.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months; HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 34

Standardized coefficient, standard error, significance level, and effect sizes for model showing the relationship between glycemic control, executive functioning and self-report HRQoL

Variable	β	*SE*	*p*	R^2
EF → HRQoL	.54	.09	<.001	--
GC → HRQoL	-.23	.09	.01	--
Covariance of GC and EF	-.27	.10	.01	--
SR Full Scale score (CEFI)	.89	.11	<.001	.79
PR Full Scale Score (CEFI)	.42	.08	<.001	.18

Table 34 continued

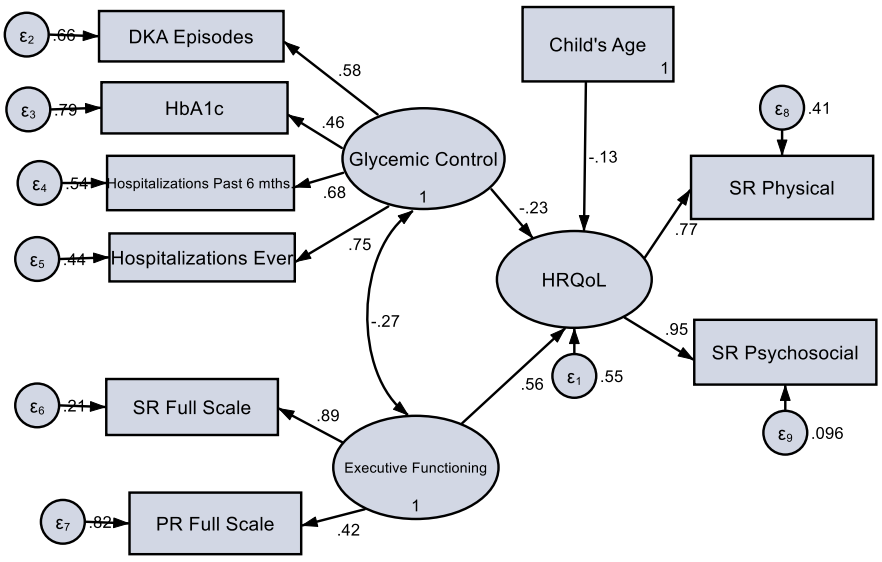
Variable	β	*SE*	*p*	R^2
HbA1c	.46	.09	<.001	.21
Hospitalizations past 6 mths.	.68	.08	<.001	.56
Hospitalizations Ever	.75	.06	<.001	.34
Number of DKA Episodes	.58	.09	<.001	.58
SR Physical (PedsQL)	.76	.05	<.001	.91
SR Psychosocial (PedsQL)	.96	.05	<.001	--
Error of HRQoL	.58	.09	--	--
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.54	.11	--	--
Error of Hospitalizations Ever	.44	.09	--	--
Error of DKA Episodes	.66	.11	--	--
Error of SR Full scale	.21	.20	--	--
Error of PR Full scale	.82	.07	--	--
Error of SR Physical	.42	.08	--	--
Error of SR Psychosocial	.09	.09	--	

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; EF = executive functioning; GC = glycemic control; mths = months; SR = self-report; PR = parent-report; n = 178

Additionally, age was added to the model to see if it was a significant predictor of the variance (Figure 12). Using the Satorra-Bentler scaled test adjustment, the model chi-square was

not significant, $\chi^2(24) = 23.61$, $p = .48$. The TLI and CFI were both .99, while the RMSEA was .00, indicating good model fit. Factor loadings for glycemic control, executive functioning and self-report HRQoL remained the same as the model without age. Child's age significantly predicted self-reported HRQoL, $\beta(178) = -.13$ ($p = .04$), with younger age associated with better HRQoL. On the other hand, the model explained 95% of the variance, so the addition of age in the model did not add to what is explained in the variance of the model without age (Table 35).

Figure 12. Model showing the relationship between glycemic control, executive functioning, self-report HRQoL, and age.



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months; HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 35

Standardized coefficient, standard error, significance level, and effect sizes for model showing the relationship between glycemic control, executive functioning, self-report HRQoL, and age

Variable	β	*SE*	*p*	R^2
EF → HRQoL	.56	.09	<.001	--
GC → HRQoL	-.23	.09	.01	--
Age → HRQoL	-.13	.06	.04	--
Covariance of GC and EF	-.27	.10	.01	--
SR Full Scale score (CEFI)	.89	.11	<.001	.79
PR Full Scale Score (CEFI)	.42	.08	<.001	.18
HbA1c	.46	.09	<.001	.21
Hospitalizations past 6 mths.	.68	.08	<.001	.56
Hospitalizations Ever	.75	.06	<.001	.34
Number of DKA Episodes	.58	.09	<.001	.58
SR Physical (PedsQL)	.77	.05	<.001	.91
SR Psychosocial (PedsQL)	.95	.05	<.001	--
Error of HRQoL	.55	.09	--	--
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.54	.11	--	--
Error of Hospitalizations Ever	.44	.09	--	--
Error of DKA Episodes	.66	.11	--	--
Error of SR Full scale	.21	.20	--	--

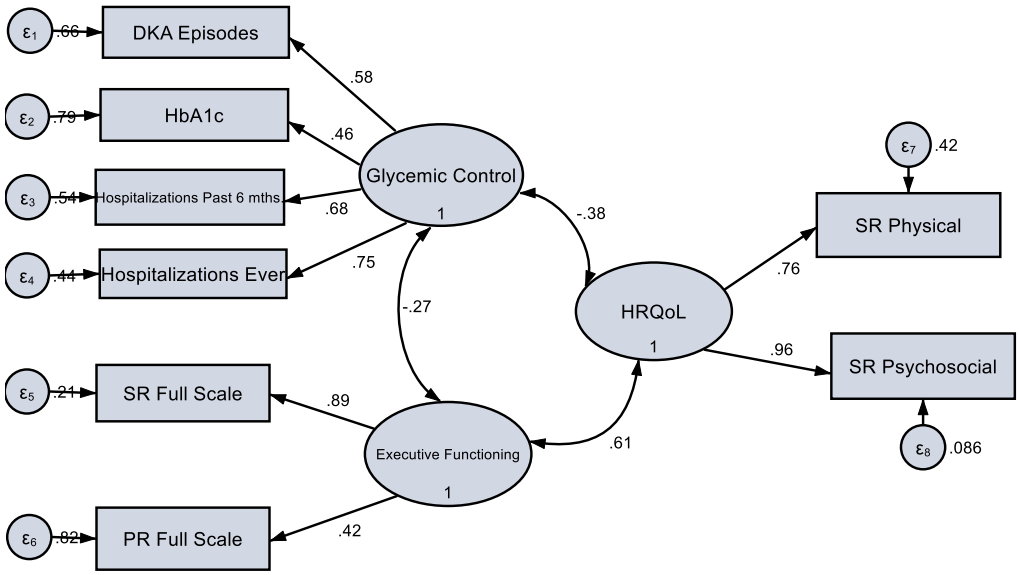
Table 35 continued

Variable	β	*SE*	*p*	R^2
Error of PR Full scale	.82	.07	--	--
Error of SR Physical	.41	.08	--	--
Error of SR Psychosocial	.10	.09	--	

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; EF = executive functioning; GC = glycemic control; mths = months; SR = self-report; PR = parent-report; n = 178

A model examining the covariance of glycemic control, executive functioning, and self-report Physical and Psychosocial Health Summary scores on the PedsQL was also analyzed (Figure 13). Using the Satorra-Bentler scaled test adjustment, the model chi-square was not significant, $\chi^2(17) = 16.05$, $p = .52$. The TLI and CFI were 1.01 and 1.00, while the RMSEA was .00, indicating good model fit. Executive functioning significantly covaried with self-reported Physical and Psychosocial quality of life, $\beta(178) = .61$ ($p < .001$), while glycemic control significantly covaried with HRQoL ($\beta(178) = -.38$ ($p = .01$). Finally, glycemic control significantly covaried with executive functioning, $\beta(178) = -.27$ ($p = .01$), with poorer glycemic control associated with lower HRQoL. The model explained 99% of the variance, indicating this may be the best model for the data (Table 36). Age was not examined in this model since it is impossible to correlate endogenous variables with exogenous variables.

Figure 13. The covariance between glycemic control, executive functioning, and self-report HRQoL



Notes. DKA = diabetic ketoacidosis; HbA1c = glycated hemoglobin; mths. = months; HRQoL = health-related quality of life; SR = self-report; PR = parent-report

Table 36

Standardized coefficient, standard error, significance level, and effect sizes for the model examining the covariance between glycemic control, executive functioning, and self-report HRQoL

Variable	β	*SE*	*p*	R^2
Covariance of EF and HRQoL	.61	.08	<.001	--
Covariance of GC and HRQoL	-.38	.10	<.001	--
Covariance of GC and EF	-.27	.10	<.01	--
SR Full Scale score (CEFI)	.89	.11	<.001	.79

Table 36 continued

Variable	β	*SE*	*p*	R^2
PR Full Scale Score (CEFI)	.42	.08	<.001	.18
HbA1c	.46	.09	<.001	.21
Hospitalizations past 6 mths.	.68	.08	<.001	.46
Hospitalizations Ever	.76	.05	<.001	.56
Number of DKA Episodes	.58	.09	<.001	.34
SR Physical (PedsQL)	.76	.05	<.001	.58
SR Psychosocial (PedsQL)	.96	.05	<.001	.91
Error of HbA1c	.79	.08	--	--
Error of Hospitalizations past 6 mths.	.54	.11	--	--
Error of Hospitalizations Ever	.44	.09	--	--
Error of DKA Episodes	.66	.11	--	--
Error of SR Full scale	.21	.20	--	--
Error of PR Full scale	.82	.07	--	--
Error of SR Physical	.42	.08	--	--
Error of SR Psychosocial	.09	.09	--	--

Notes. HRQoL = health-related quality of life; CEFI = Comprehensive Executive Function Inventory; PedsQL = Pediatric Quality of Life Inventory; EF = executive functioning; GC = glycemic control; mths = months; SR = self-report; PR = parent-report; n = 178

CHAPTER V

DISCUSSION

This study examined the relationship between glycemic control, executive functioning, and health-related quality of life in youth with type 1 diabetes. There is little research that has explored the association between executive functioning and HRQoL and this is one of the first studies to examine the relationship between these variables in youth with type 1 diabetes. The proposed model hypothesized that executive functioning would predict HRQoL, while glycemic control would covary with HRQoL, and glycemic control and executive functioning would also covary. Moreover, age and sex were hypothesized to significantly correlate and predict glycemic control and executive functioning. In the overall model, executive functioning was found to be a significant predictor of self-report HRQoL by itself, but the addition of glycemic control was necessary for executive functioning to predict parent-report HRQoL. These findings are consistent with past research that found a significant association between executive functioning and HRQoL in other medical conditions (de Vries & Geurts, 2015; Grech et al., 2015; Laffond et al., 2011; Krpan et al., 2007). Furthermore, in a study by Jaser et al. (2012), self-management mediated coping and quality of life in youth with type 1 diabetes.

On the other hand, based on the model examining the covariance between executive functioning, HRQoL, and glycemic control, the relationship between executive functioning and self-reported HRQoL may be better explained by covariance, rather than prediction. Executive functioning and self-reported HRQoL significantly covaried with one another, such that as executive functioning increased, HRQoL also increased. In the model where all variables covaried, 99% of the variance was explained, compared to the 95% of the variance explained in the model of glycemic control and executive functioning predicting self-report HRQoL. More

research is needed to elucidate the exact mechanisms of this relationship and future studies should focus on further exploratory model analyses.

In line with the hypothesized model, glycemic control significantly covaried with parent- and self-reported HRQoL. As glycemic control became poorer (increased HbA1c, more hospitalizations, more DKA episodes), self-report HRQoL decreased. Consistent with past research demonstrating a significant association between glycemic instability and physical and psychosocial quality of life (Jacobson et al., 2013; Lawes et al., 2014; Lawerence et al., 2012; Viklund & Ortqvist, 2014), as well as diabetes-specific quality of life (DQoL; Ingerski et al., 2010). In another SEM model, glycemic control significantly predicted self-report HRQoL. Currently, there has been little research that has explored if HRQoL and glycemic control significantly predict one another. One study did find lower DQoL to be a significant predictor of worse glycemic control over time (Hood et al., 2014); however, as demonstrated in this study, a bidirectional relationship between glycemic control and HRQoL may be a better explanation for this interaction.

In the overall model, glycemic control and executive functioning were found to significantly and negatively covary with one another, indicating that as one variable increased, the other decreased. These results build on the current research of a significant association between glycemic control and executive functioning (Brismar et al., 2007; Guadieri et al., 2008). Although adherence was not examined in the current study, past research has also found that executive functioning is associated with treatment adherence, as well as glycemic control in type 1 diabetes (Berg et al., 2007; McNally et al., 2010). Furthermore, executive functioning has been found to either predict adherence (Bagner et al., 2007) or mediate adherence and glycemic

control in type 1 diabetes (Smith et al., 2014). Future research should continue to explore the interrelationship of executive functioning and health outcomes in pediatric type 1 diabetes.

Age, Glycemic Control, and Executive Functioning

Additionally, it was hypothesized that age would be associated with glycemic control and executive functioning. There were no significant correlations between glycemic control and age and age did not significantly predict glycemic control. These results are inconsistent with previous findings that found age to be a significant predictor of glycemic control, with older age associated with poorer glycemic control (Acerini et al., 2001; Forga et al., 2015; Levine et al. 2001). This discrepancy may be due to the small range of ages (12 to 18-years-of-age) included in this study. A wider range of ages may have provided a greater variation of glycemic control and provided more information on the association between these variables.

On the other hand, child's age was a significant covariate with child's sex when examining executive functioning. More specifically, child's age and sex together were significantly associated with self-report Inhibitory Control, but no parent-reported executive functioning scales. As age increased, self-reported inhibition also increased, but these associations were small. These results are somewhat consistent with previous research findings that suggest executive functioning improves and develops over time and that age is associated with greater executive functioning skills (Anderson, 2002; De Luca et al., 2003). Once again, the limited age range of participants in the study (12 to 18-years-of-age) may have impacted the results regarding age.

When the child's age was added to the overall model, age did significantly predict HRQol, such that younger age was associated with better HRQoL. Although the model with age included explained 95% of the variance, this was not an increase in variance explained compared

to the model without child's age, which was also 95%. Future studies should include wider age ranges, as this may provide a clearer picture of how age impacts glycemic control, executive functioning, and HRQoL.

Sex, Glycemic Control, and Executive Functioning

Sex was found to be a small, but significant factor in glycemic control and executive functioning. Female sex was associated with more hospitalizations since diagnosis; however, sex did not significantly predict glycemic control. These results are somewhat consistent with previous research. Female sex has been found to be associated with higher levels of HbA1c (Hanberger et al., 2008; Samuelsson et al., 2016) and a greater risk of health complications resulting from type 1 diabetes (Rohan et al., 2013). Future research should continue to explore how sex impacts glycemic control and health outcomes in type 1 diabetes.

Regarding executive functioning, sex was only slightly related to Emotion Regulation on the self-report CEFI, with males reporting better Emotion Regulation. Moreover, sex did not significantly predict parent or self-report executive functioning. The current research on the association between sex and executive functioning is mixed. While some research indicates females are better at planning and attention (Naglieri & Rojahn, 2001), as well as inhibitory control and self-regulation (Yuan et al., 2008), other studies have not found significant differences in executive functioning between sexes (Chan, 2001; Hill et al., 2014; Solianik et al., 2016). Future research should continue to explore how sex may impact executive functioning.

Glycemic Control and Executive Functioning

Consistent with previous research, there were low significant negative correlations between glycemic control and executive functioning domains. More specifically, as HbA1c increased, self-report Organization, Self-Monitoring, Attention, Emotion Regulation, and

Inhibitory Control, and all parent-reported executive functioning scales decreased. As the number of DKA episodes increased, all parent-reported executive functioning scales decreased, but there were no significant correlations with self-report executive functioning. Increases in the number of hospitalizations in the past 6 months were related to decreases in all parent-report executive functioning scales, but no self-report executive functioning scales. Moreover, increases in the number of hospitalizations since diagnosis were associated with decreases in all parent-reported executive functioning scales and self-report Inhibitory Control and Organization. Overall, results indicated that poorer glycemic control was associated with global parent-reported executive functioning deficits. For self-report, only increases in HbA1c and number of hospitalizations since diagnosis were associated with lower executive functioning in some domains.

These results are consistent with findings that poor glycemic control is associated with deficits in attention (Cameron et al., 2014; Cato et al., 2014; Lin et al., 2010; Nguyen et al., 2010), working memory (Cameron et al., 2014; Lin et al., 2010; Nguyen et al., 2010; Shehata & Eltayeb, 2010), planning (Northam et al., 2001; Primozic et al., 2011; Rasmussen et al., 2011), emotion and self-regulation (Glasgow et al., 2007; Graziano et al., 2011; Hughes et al., 2012; Rohan et al., 2011), problem-solving (Glasgow et al., 2007; Hills-Briggs & Gemell, 2007), and inhibition (Rovet & Alvarez, 1997). The discrepancy in results based on self- and parent-report highlights the importance of gathering data from both youth and their caregivers, rather than relying on one source of information.

Glycemic Control and HRQoL

The association between HRQoL and glycemic control was also examined. Small significant negative correlations between HbA1c and self-report Psychosocial and Total HRQoL,

as well as parent-reported Psychosocial, Physical, and overall HRQoL were found. As HbA1c increased (poorer glycemic control), HRQoL decreased. Additionally, there were small significant negative correlations between the number of DKA episodes and all self- and parent-report HRQoL, whereby an increase in DKA episodes resulted in a decrease in Physical, Psychosocial, and Total HRQoL. Moreover, there were significant negative correlations between the number of hospitalizations since diagnosis and number of hospitalizations in the past 6 months with both parent and self-report Physical, Psychosocial, and Total HRQoL. Increases in the number of hospitalizations since diagnosis and over the past 6 months were associated with decreases in HRQoL. The negative relationships between glycemic control and HRQoL were consistent with findings that glycemic instability contributes to physical, psychosocial, and overall decreases in HRQoL (Delamater, 2009; Graue et al., 2004; Hood et al., 2011; Penckofer et al., 2012). Conversely, good glycemic control has been found to be associated with better quality of life in most studies (Hoey et al., 2001; Reid et al., 2013).

Executive Functioning and HRQoL

Finally, there were medium significant positive correlations between all parent and self-report executive functioning domains and all self and parent-reported HRQoL scales (Physical Health Summary scores, Psychosocial Health Summary scores, and Total Scale scores). As executive functioning increased, physical, psychosocial, and overall HRQoL also increased. Additionally, executive functioning was found to significantly predict self-reported HRQoL and had a small effect size. This model accounted for 78% of the overall variance, with increases in executive functioning predicting increases in HRQoL. When glycemic control was included in the model, executive functioning once again significantly predicted self-report HRQoL, with

95% of the variance explained. Additionally, executive functioning was found to significantly and positively covary with parent and self-report HRQoL.

On the other hand, the models of executive functioning predicting total HRQoL scores and parent-report HRQoL, without the inclusion of glycemic control, were not a good fit for the data. These models indicated that glycemic control may need to be included to explain the association between executive functioning and parent-report HRQoL. Conversely, there is a significant association between executive functioning and self-report HRQoL regardless of the inclusion of information about glycemic control. These findings may be related to the fact that parent-report executive functioning had more correlations with glycemic control compared to self-report executive functioning and glycemic control. These results highlight the importance of gathering both parent and youth-report to gain a clearer picture of functioning.

Overall, these findings are consistent with results indicating an association between lower quality of life and deficits in executive functioning in those diagnosed with autism (de Vries & Geurts, 2015), multiple sclerosis (Grech et al., 2015), benign tumors (Laffond et al., 2011), traumatic brain injury (Krpan et al., 2007), congenital heart disease (Neal et al., 2015), and epilepsy (Sherman et al., 2006).

Implications for Clinical Practice

The findings of this study emphasize the need for health professionals to screen and monitor executive functioning, as this variable is associated with glycemic control and HRQoL in youth with type 1 diabetes. Results from this study indicate that executive functioning may be able to predict self-report HRQoL in those with type 1 diabetes. Clinician awareness of patient executive functioning may help to identify those who need additional support and intervention. Moreover, there is a significant association between glycemic control, executive functioning, and

HRQoL and treatment in one area may lead to gains in the other areas. As a result, intervention that targets executive functioning may lead to improvements in glycemic control, medical outcomes, and patient HRQoL. Executive functioning interventions and cognitive training have shown to be promising in treating those with a traumatic brain injury, stroke, autism spectrum disorder, cognitive decline due to age, and attention-deficit/hyperactivity disorder (Diamond & Ling, 2016). Thus, executive functioning interventions that include techniques such as goal setting, organizational strategies, structured planning, overlearning information, monitoring outcomes, and modifying approaches to achieve goals may improve medical and psychosocial outcomes in those with pediatric type 1 diabetes.

Limitations and Future Research

One of the limitations of the existing study is the missing data for number of DKA episodes. Although the 180 participants who did have information regarding number of DKA episodes were included in the analyses, this missing data lead to a decrease in power for some analyses. Additionally, low endorsement of a history of seizures and hypoglycemia meant these variables could not be used in the hypothesized analyses and model. Past research indicates seizures and hypoglycemia are related to deficits in overall executive functioning (Graveling et al., 2015; Ryan et al., 1990) and more specifically attention (Bjorgaas et al., 1997; Cato et al, 2014; Hannonen et al, 2008; Rovet & Alvarez, 1997; Rovet & Ehrlich, 1999), problem solving (Asvold et al., 2010), working memory (Hannonen et al., 2008; Lin et al., 2010; Sommerfield et al., 2003), and planning (Ly et al., 2011). Although this study did find significant associations between glycemic control and executive functioning, these correlations were small. The addition of more participants with a history of hypoglycemia and/or seizures may have made these associations stronger.

An additional limitation of the study was the restricted age-range. Participants had to be between ages 12 to 18 to participate in the study and this age-limit was set due to the age requirement for the self-report CEFI (12-years-old). Inclusion of younger participants may have given more information about how age impacts glycemic control and executive functioning, as age was not found to be a significant predictor for these domains. Future studies should include a wider age range to gain a clearer picture of the interrelationship between age, glycemic control, and executive functioning.

Another limitation in this study was the use of self and parent-report measures of executive functioning only, rather than tests that ask the participants to directly perform tasks of executive functioning. Self and parent-reports of executive functioning can be impacted by perception and may not provide the best picture of actual executive functioning. Inclusion of tasks of executive functioning may have provided more detailed and accurate information of participant executive functioning. Additionally, the lack of teacher-report hinders the opportunity for more diverse viewpoints of the participant's executive functioning. Tasks at school are more cognitively demanding, and therefore, teacher input may have provided a more accurate perception of the participant's executive functioning. Future studies should consider including tasks of executive functioning and teacher-report of executive functioning in their research design.

In the future, research should continue to examine the factors that contribute to glycemic control, medical outcomes, and HRQoL. As youth survive with type 1 diabetes into adulthood, it is essential health care providers are aware of the variables that can contribute to optimal outcomes and better quality of life. Furthermore, future research should focus on exploring how executive functioning impacts health outcomes and physical and psychosocial functioning in

those with a chronic medical condition. Executive functioning interventions have shown promise in remediating cognitive deficits in those with other chronic medical conditions, and future research should explore the potential impact of executive functioning interventions on functioning and outcomes in pediatric type 1 diabetes.

CHAPTER VI

SUMMARY AND CONCLUSION

This study adds to the current research on quality of life, executive functioning, and glycemic control in pediatric type 1 diabetes. Although manty studies have focused on executive functioning and glycemic control or glycemic control and quality of life, there are few other current studies that examine the association between these variables in pediatric type 1 diabetes. Results from this study indicate that executive functioning can predict HRQoL in youth with type 1 diabetes, and that executive functioning, glycemic control, and HRQoL are interrelated in this population. Future research should continue to focus on the variables that impact medical outcomes and HRQoL in youth with chronic illnesses, as well as examine the potential effectiveness of executive functioning interventions in ameliorating glycemic instability and poor HRQoL in youth with type 1 diabetes.

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APPENDIX

PedsQL™ 3.2 Diabetes Module Field Test
Medical Chart Review

Date: _____ / _____ / _____
MM DD YYYY

Data Collection Site: _____

Participant's 4 Digit Study ID#: ☐☐☐☐

Primary Diabetes Diagnosis: *Please check one*

☐ Type 1 Diabetes Mellitus

☐ Type 2 Diabetes Mellitus

Secondary Diagnosis/Diagnoses: *Please check "Yes" or "No" for each secondary diagnosis*

☐ Yes ☐ No Autoimmune Thyroid Disease - (Circle one: Hypothyroidism/Hyperthyroidism)
☐ Yes ☐ No Celiac Disease
☐ Yes ☐ No Hypertension
☐ Yes ☐ No Nephropathy
☐ Yes ☐ No Dyslipidemia
☐ Yes ☐ No ADHD
☐ Yes ☐ No Asthma
☐ Yes ☐ No Autism Spectrum Disorder
☐ Yes ☐ No Intellectual Disability
☐ Yes ☐ No Other: _____

Date of Diabetes Diagnosis: _____ / _____ **OR** **Time Since Diagnosis:** _____
(Month) (Year) (Years and months)

Does the patient currently use an insulin pump? *Please check one:* ☐ Yes ☐ No

Does the patient currently use Continuous Glucose Monitoring (CGM)? *Please check one:* ☐ Yes ☐ No

Most Recent Hemoglobin A1c Level (HbA_{1c}):

Value _____ % Normal range _____ %

Date: _____ / _____ / _____
MM DD YYYY

Most Recent BMI:

Value _____ Percentile _____ %

Date: _____ / _____ / _____
MM DD YYYY

In the past 6 months how many times was the patient seen in an Urgent Care Center, Emergency Department, and/or required hospitalization because of his/her diabetes?

Please circle one: 0 1 2 >3 Unknown

What was the problem (check all that apply)?

☐ Ketones ☐ Diabetic ketoacidosis (DKA) ☐ Hypoglycemia (low blood sugars) ☐ Seizure

☐ Other: _____ ☐ Unknown

Since the patient was diagnosed with diabetes, how many times was the patient seen in an Urgent Care Center, Emergency Department, and/or required hospitalization because of his/her diabetes?

Please circle one: 0 1 2 >3 Unknown

What was the problem (check all that apply)?

☐ Ketones ☐ Diabetic ketoacidosis (DKA) ☐ Hypoglycemia (low blood sugars) ☐ Seizure

☐ Other: _____ ☐ Unknown

Has the patient experienced diabetic ketoacidosis (DKA) since being diagnosed with diabetes (circle one)?

a. Yes (if yes, how many times?) ___ *b.* No *c.* Unknown