THE IMPACT OF PHYSICAL ACTIVITY ON EXECUTIVE FUNCTION AND HEALTH-RELATED QUALITY OF LIFE IN YOUTH WITH TYPE 1 DIABETES MELLITUS

A Dissertation

by

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ABSTRACT

Greater levels of physical activity (PA) in youth with type 1 diabetes mellitus (T1DM) has been shown to positively impact quality of life (QoL) in addition to improving physiologic and psychological outcomes. In adults with diabetes, greater levels of PA have also been positively associated with executive functioning (EF), though this relationship remains relatively unexplored in youth. Little is known about the relationship between health-related quality of life (HRQoL) and EF. Health status and psychosocial variables have been implicated as possible mediators in the relationship between PA and EF, though research with children is sparse. While studies with older adults have shown improvements in QoL and EF with PA interventions, the interrelationship between PA, HRQoL, and EF has not yet been investigated. Using a sample of 116 youth with T1DM recruited from a large tertiary care children's hospital in the southern United States, this study analyzed if engagement in PA was related to age, sex, EF, and HRQoL. It also investigated if HRQoL was related to EF. Relationships were explored using regression analyses, controlling for time since diabetes diagnosis and socioeconomic status. The study also sought to test HRQoL as a mediator in the relationship between PA and EF.

Results did not demonstrate that age or sex alone predicted PA, but age, sex, TSD, and SES explained significantly predicted PA level. PA was not found to significantly predict HRQoL or EF in any capacity, nor did HRQoL predict EF. Sans significant results between PA, EF, and HRQoL, a mediational relationship could not be explored. Future studies may seek to use a broader range of ages, a more accurate measure of PA to draw conclusions, and limit the length of the study protocol to maintain participant motivation and manage fatigue. Furthermore, increasing sample size may lead to finding significant results.

DEDICATION

This dissertation is dedicated to RC, Mom, Dad, and Richie. Each of you has helped me to get to where I am today. You inspired and encouraged me to pursue my Ph.D. This is the beginning of a new chapter in my life, and I know each of you will continue to push me to aspire to greater and more challenging things.

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NOMENCLATURE

T1DM	Type 1 diabetes mellitus
PA	Physical activity
QoL	Quality of life
HRQoL	Health-related quality of life
EF	Executive function
HbA1c	Hemoglobin A1c
SES	Socioeconomic status
TSD	Time since diagnosis
PedsQL™	The PedsQL™ 4.0 Generic Core Scale: Measurement Model for the Pediatric Quality of Life Inventory
CEFI	Comprehensive Executive Function Inventory
RPAQ-A	Revised Physical Activity Questionnaire for Adolescents

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee comprised of Cynthia A. Riccio, Ph.D. (chair), William A. Rae, Ph.D. (co-chair), and Susan A. Bloomfield, Ph.D. of the College of Education and Human Development and James W. Varni, Ph.D., Professor Emeritus of the College of Architecture.

The data analyzed for Chapter IV were provided by Dr. James W. Varni through the PedsQL™3.2 Diabetes Module Field Test Study. Data were collected at Children's Health Children's Medical Center Dallas in Dallas, Texas by Morgan B. Drake, M.Ed. and the student. Data entry and reconciliation were completed by Elena Doskey, Ph.D., Vincent P. Aguirre, M.S., Morgan B. Drake, M.Ed., and the student. All other work conducted for the dissertation was completed by the student independently.

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CHAPTER I

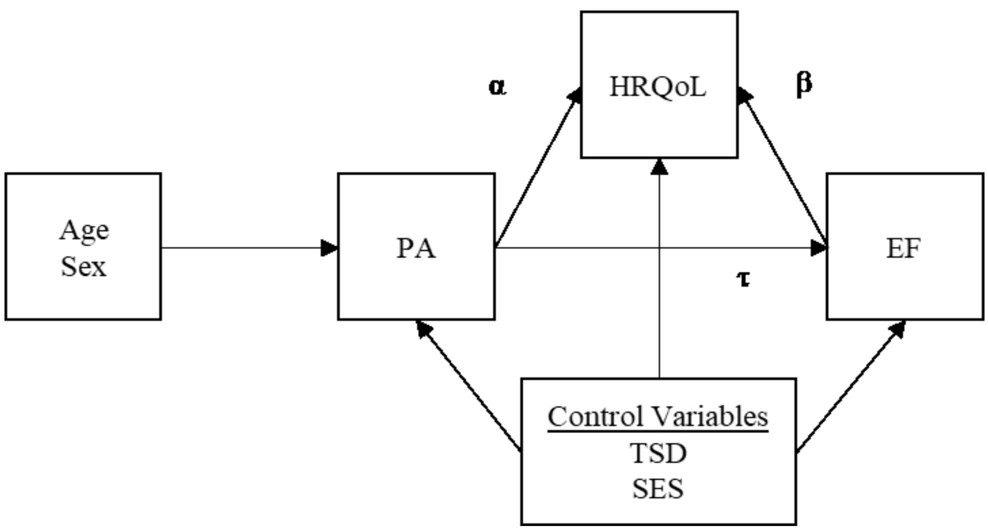
INTRODUCTION

Statement of the Problem

The purpose of this study is to add to what is known about the impact of physical activity on executive function and health-related quality of life in youth with type 1 diabetes mellitus. Additionally, this study seeks to better understand the interrelationship of the 3 variables. Greater levels of physical activity in youth with diabetes have been shown to positively impact quality of life in addition to improving physiologic and psychological outcomes. At the same time, earlier type 1 diabetes onset and lower socioeconomic status have been shown to negatively impact physical and psychological outcomes. In adults with diabetes, greater levels of physical activity have also been positively associated with executive functioning, though this relationship remains relatively unexplored in children and adolescents. Little is known about the relationship between health-related quality of life and executive functioning. Health status and psychosocial variables have been implicated as possible mediators in the relationship between physical activity and executive function, though research with children is sparse. While studies with older adults have shown improvements in quality of life and cognitive function with physical activity interventions, the interrelationship between physical activity, health-related quality of life, and executive function and specific components of these variables have not yet been investigated. To address this significant gap in the empirical literature, this study will analyze if engagement in physical activity is related to cognitive functioning, specifically executive function, and/or health-related quality of life, while controlling for time since diagnosis and socioeconomic status. The analysis will also seek to better understand the interplay of all 3 factors, with health-related quality of life as a possible mediator in the potential relationship between physical activity and executive function.

The hypothesized model (Figure 1) examines the relationship between physical activity, executive functioning, and health-related quality of life in youth with type 1 diabetes mellitus. It also explores the impact of age and sex on participation in physical activity, and indicates the control variables of time since diagnosis and socioeconomic status.

Figure 1. Hypothesized model



Definition of Terms

Physical Activity (PA): PA is defined as any bodily movement produced by skeletal muscles that require energy expenditure (World Health Organization, 2017). PA encompasses sports, lifestyle activities, and weekend play activities, which are active and require energy consumption (Caspersen, Powell, & Christenson, 1985). PA in youth ranges from walking to school to participation in organized sports (Annan, 2013). For the purpose of this study PA, exercise, and physical fitness are subsumed under the term PA.

Health-Related Quality of Life (HRQoL): HRQoL refers to the extent to which a medical condition affects the physical, cognitive, social, and psychological functioning of the impacted person.

Executive Function (EF): EF refers to a collection of higher order cognitive processes associated with the prefrontal cortex that assist in goal directed behaviors. EF includes inhibition, working memory, and mental flexibility, which allow an individual to plan, organize, initiate behavior, self-regulate, and focus attention.

Socioeconomic Status (SES): SES is the social standing of an individual or group (American Psychological Association, 2018). It encompasses income, educational attainment, occupation, and perceptions of social status. SES is a reliable predictor of outcomes, including physical and psychological health, across the lifespan. Lower SES has been linked to negative health and psychological outcomes (American Psychological Association, 2018).

Time Since Diagnosis (TSD): TSD can also be defined as disease duration, although the first manifestations of the condition may precede the time of diagnosis. The term TSD is often used with diseases such as diabetes and hypertension (J. C. Davis et al., 2006). For some individuals with type 1 diabetes, the first year of diagnosis is marked by fluctuations in HRQoL as they experience remission periods and challenges in adapting to their new medical regimen (da Costa & Vieira, 2015).

CHAPTER II

LITERATURE REVIEW

Diabetes Mellitus

Diabetes mellitus (diabetes) is a national health concern. Each year approximately 1.4 million Americans are diagnosed with a form of diabetes, and 2015 data indicates it is the 7th leading cause of death in the United States (American Diabetes Association, 2018b). Estimates from 2012 suggest that of the approximately 29.1 million Americans with diabetes, 1.25 million of those Americans had type 1 diabetes mellitus (T1DM; American Diabetes Association, 2018b). Even more concerning is that health officials suspect that cases may be underreported (American Diabetes Association, 2018b).

Diabetes is one of the most severe chronic illnesses afflicting children and adolescents (Dabelea & Klingensmith, 2008). Approximately 208,000 Americans under the age of 20 have one of the types of diabetes, representing .25% of that population (American Diabetes Association, 2018a). In youth 10-19 years old, T1DM is more prevalent than type 2 diabetes mellitus (T2DM), and in 2008-2009 the annual incidence of T1DM was 18,436 youths (American Diabetes Association, 2018a). Moreover, rates of T1DM have increased in the past few decades both in the US and around the world (Soltesz, Patterson, & Dahlquist, 2007).

T1DM was previously called insulin-dependent diabetes mellitus or juvenile-onset diabetes. T1DM can occur at any age; however, peak age for onset is in the mid-teens, with half of T1DM cases diagnosed under the age of 20 (American Diabetes Association, 2018a; Schub & Kornusky, 2015). In the last 10 years, the incidence of T1DM in children younger than 5 years of age has increased (Schub & Kornusky, 2015).

There is no known way to prevent T1DM. In individuals with T1DM, the body's immune system initiates or mediates the destruction of beta cells in the pancreas. Beta cells are responsible for producing insulin, which lowers glucose (blood sugar) levels in the blood. As a result of beta cell destruction, people with T1DM have limited to no production or secretion of insulin in their body, and the result is an excess of glucose in the bloodstream. A buildup of glucose in the bloodstream results in hyperglycemia, while hypoglycemia occurs when blood sugar levels are too low. Both hyper- and hypoglycemic episodes put those with T1DM at risk for complications up to and including death.

Current regimens for adolescents with diabetes include four main components: (a) insulin delivery to the bloodstream either by injection or pump to maintain appropriate blood glucose levels, (b) blood glucose monitoring to assess control, (c) maintenance of a healthy diet, and (d) regular PA to assist in maintenance of glycemic control and preservation of quality of life (QoL; American Diabetes Association, 2018a). It is currently recommended that youth adhere to the four pronged treatment regimen in order to assist with maintaining ideal glycosylated hemoglobin (HbA1C) values below 7.5% to minimize complications and improve long-term health outcomes (American Diabetes Association, 2010).

Complications of Diabetes

Complications of unmanaged or mismanaged diabetes, including hyper- and hypoglycemia, are numerous and result in the disruption metabolism within the body (Schub & Kornusky, 2015). This disruption leads to systemic imbalances, decreased blood flow to tissue, insufficient glucose delivery to the brain and retina, vascular breakdown, and neuropathy. These issues become manifest as diabetic ketoacidosis, hypertension, dyslipidemia, cardiovascular disease, heart attack, stroke, eye problems, gangrene of the limbs, and kidney disease. In addition to adhering to treatment and routine recommendations to prevent these complications, it is important for individuals with T1DM to undergo regular screenings for nephropathy, hypertension, dyslipidemia, neuropathy, and retinopathy (Schub & Kornusky, 2015). Of note, longer TSD has been associated with poorer outcomes, specifically levels of HRQoL (da Costa & Vieira, 2015) and cognitive functioning (Ferguson et al., 2005; Northam et al., 2001) when compared to individuals with later onset, suggesting the global influence that the chronicity and impact of the disease has on brain development and daily functioning.

Cardiovascular Issues

Despite improvements in the treatment of T1DM, the rates of cardiovascular complications have not improved (Pambianco et al., 2006). Cardiovascular disease is the leading cause of mortality later in life for individuals with diabetes (Cooper & Caldwell, 1999). When compared with individuals without diabetes, individuals with T1DM demonstrated a more than three-fold risk of cardiovascular disease (Soedamah-Muthu et al., 2006). This increased risk represents a lower life expectancy by roughly seven years (Laing et al., 2003; Soedamah-Muthu et al., 2006). In youth with T1DM, 14% have two or more cardiovascular disease risk factors (B. L. Rodriguez et al., 2006). In addition, roughly 6% have hypertension and 19% demonstrate lipid abnormalities (Kershnar et al., 2006; B. L. Rodriguez et al., 2010). While adiposity has not historically been considered a characteristic of T1DM, youth with the disease have a higher prevalence of overweight (22%) than youth without T1DM (16%), despite showing less obesity (13%) than healthy peers (17%; (Liu et al., 2010). For youth with T1DM at higher risk for cardiovascular complications and risk factors, it is important to note that literature suggests that they are at a key time in their cardiovascular development where irreversible long-term negative changes can likely be prevented (Liese, Ma, Maahs, & Trilk, 2013).

Cognitive Impairment and Academic Outcomes

In addition to cardiovascular complications, diabetes is also a predisposing factor for cognitive impairment. Studies of populations with diabetes have found links to deficits in brain functioning in the areas of intelligence, verbal skills, memory, visuospatial abilities, processing speed, and psychomotor efficiency (Bade-White & Obrzut, 2009; Biessels, Deary, & Ryan, 2008; Bjørgaas, 2012). In a 16-year longitudinal study, Ly, Anderson, McNamara, Davis, and Jones (2011) compared general intelligence, memory, and EF of youth with T1DM with healthy matched controls. No differences were found between groups on memory or general intelligence, but youth with T1DM performed worse on tasks of EF. Similarly, Ohmann and colleagues (2010) compared adolescents with T1DM with a control group and found differences in cognitive flexibility, planning, and concept formation, with adolescents with T1DM performing worse. Much of the literature suggests that deficits evolve over time as glycemic fluctuations accumulate; however, research has shown that neurocognitive decline may be identified as soon as 2–3 years post-diagnosis (Ryan, 2006). In a 6-year longitudinal study, newly diagnosed children with diabetes were compared to healthy peers (Northam et al., 2001). At baseline there was no difference between the groups, but 2 years later the children with diabetes evidenced slower development on specific intelligence subtests (Northam, Anderson, Adler, Werther, & Andrewes, 1995; Northam et al., 1998). By year 6, children with diabetes performed at a lower level on intelligence, attention, processing speed, long-term memory, and executive skills measures than healthy peers (Northam et al., 2001). Cato and colleagues (2014) found that frequency of hyperglycemia was linked to learning, memory, intelligence, and EF deficits in children with T1DM compared to healthy peers. Hyperglycemia and diabetic ketoacidosis have been linked to deficits in attention and working memory in other studies as well (Cameron et al., 2014; 2014; Lin, Northam, Rankins, Werther, & Cameron, 2010; Shehata & Eltayeb, 2010). Hypoglycemia has also been associated with deficits in youth with T1DM in the areas of attention, working memory, planning, and problem-solving (Asvold, Sand, Hestad, & Bjorgaas, 2010; Bjørgaas, Gimse, Vik, & Sand, 1997; 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).

Studies have investigated the underlying neurobiological mechanisms that may contribute to cognitive functioning decline and deficits. Ho, Sommers, and Lucki (2013) proposed that problems with learning and emotional control were rooted in diabetes' negative effects on hippocampal neurogenesis, dendritic remodeling, as well as increased apoptosis. Brain scans by researchers, Salem, Matta, Tantawy, Hussein, and Gad (2002), evidenced cerebrovascular changes such as reduced cerebral perfusion, especially in the basal ganglia and frontal regions, resulting in reduced cerebral blood flow in posterior brain regions. Other factors that may contribute to cognitive decline associated with diabetes are neuronal damage in various areas of the brain, cerebral edema, and lower grey matter volumes in the cerebellum, thalamus, and temporal-occipital cortex (Arbelaez, Semenkovich, & Hershey, 2013; Bjørgaas, 2012; Mauras et al., 2015).

The mechanisms behind cognitive impairment are not yet fully understood; however, research has explored diabetes-generated cognitive deficits via changes in insulin secretion, glucose intolerance, and insulin resistance (Ronnemaa et al., 2008). Greater impairment in cognitive functioning is associated with earlier onset of the disease, as glycemic fluctuations may negatively impact the formation of brain structures during childhood (Biessels et al., 2008). Due to the fact that young children's brains are still developing, they are more sensitive to the cumulative effect of glycemic fluctuations, particularly severe fluctuations (Ryan, 2006). Xia et al. (2013) found that more severe and consistent episodes of hyperglycemia altered the amplitude of low-frequency fluctuations in a variety of areas of the brain.

Given that academic success is highly dependent on neuropsychological functions, cognitive deficits associated with T1DM may have substantial effects on academic performance (Hannonen et al., 2012). This may account for academic difficulty and lower academic achievement frequently observed in children and adolescents with T1DM (Dahlquist, Källén, & Swedish Childhood Diabetes Study, 2007; Hannonen et al., 2012). In general, students with T1DM have lower grades and are more likely to be identified as having a learning disability than healthy peers (Dahlquist et al., 2007; Holmes, Fox, Cant, & Lampert, 1999). Additionally, students with T1DM are more likely to be retained and are at greater risk for dropping out of school than healthy students (Dahlquist et al., 2007; Holmes et al., 1999). It also has been found that students with T1DM graduate at lower rates from high school and enroll at lower rates in postsecondary education than healthy peers (Haas & Fosse, 2008). One possible factor that could contribute to academic difficulty is the fact that children and adolescents with T1DM miss more days of school than their healthy peers resulting in less instructional time (Holmes et al., 1999).

Mental Health Concerns

Children with chronic illness and disability are at increased risk for mental health concerns due to the added stress their condition places on normal developmental demands (Huff, McClanahan, & Omar, 2010). In addition to physiological and cognitive impairment, T1DM has been associated with a number of psychiatric and neurodegenerative disorders (Biessels et al., 2008). The findings from one study suggested that individuals with T1DM were referred for mental health issues 12 years after diagnosis more often than healthy controls of the same age (Northam, Lin, Finch, Werther, & Cameron, 2010). Researchers following youth with T1DM over a decade-long period demonstrated that approximately half of the participants developed a psychological disorder (Kovacs, Goldston, Obrosky, & Bonar, 1997), with 27.5% of the youth meeting criteria for depression (Kovacs et al., 1997). Studies have found a two to three-fold incidence of depression in individuals across the lifespan with T1DM compared to the general population (Grey, Whittemore, & Tamborlane, 2002; Kokkonen, Lautala, & Salmela, 1997). Furthermore, up to one third of people with T1DM suffer from moderate to severe depression, anxiety, or both (Anderson, Freedland, Clouse, & Lustman, 2001; Grigsby, Anderson, Freedland, Clouse, & Lustman, 2002). In studies specifically investigating anxiety and the link with diabetes, researchers found increased rates of anxiety when compared with healthy individuals (Dantzer, Swendsen, Maurice-Tison, & Salamon, 2003). One study found that approximately 14% of those with diabetes had diagnosable generalized anxiety disorder and up to 40% had subclinical levels of anxiety (Grigsby et al., 2002). Several studies also have identified a positive association between T1DM and eating, behavioral, and mood disorders (Dantzer et al., 2003; Grey et al., 2002; Kovacs et al., 1997; Northam, Matthews, Anderson, Cameron, & Werther, 2005). In adolescence, diabetes self-management is gradually turned over to the patient, which is challenging in and of itself. Mental health issues further complicate the process and can interfere with the attainment of skills necessary for successful adherence to a diabetes regimen. As such, studies have found an inverse relationship between depressive symptoms and glycemic control, as well as the negative effect anxiety has on disease management and glycemic control in adolescents with T1DM (Helgeson, Siminerio, Escobar, & Becker, 2009; Mortensen &

Hvidore Study Group on Childhood, 2002; Naar-King, Podolski, Ellis, Frey, & Templin, 2006; Van Tilburg et al., 2001). Finally, disordered eating patterns in adolescents with T1DM, which include insulin omission and dose reduction as weight control tactics, result in increased rates of diabetes-related complications (Ackard et al., 2008; Neumark-Sztainer et al., 2002). It is worth noting that internalizing disorders are not only associated to poor diabetes adherence, glycemic control, and health outcomes, but also poor academic performance (Delamater, 2009; Hood, Rausch, & Dolan, 2011; Stahl-Pehe et al., 2014).

Socioeconomic Status Complicates Diabetes Management

Various studies have demonstrated the impact of SES on physical and psychological outcomes, specific to individuals with diabetes. While not a complication of diabetes, SES can convolute diabetes care and contribute to the aforementioned issues. Low SES has been significantly associated with poor glycemic control in multiple studies (Gallegos-Macias, Macias, Kaufman, Skipper, & Kalishman, 2003; Hassan, Loar, Anderson, & Heptulla, 2006), as well as poorer diabetes management skills and less developed understanding of diabetes (Chaturvedi, Stephenson, & Fuller, 1996). Given that much of the literature suggests that cognitive deficits evolve as glycemic fluctuations accumulate (Ryan, 2006), it can be posited that lower SES and poorer glycemic control may in turn negatively impact cognitive functioning. However, no studies were found that demonstrated this relationship. Studies have also implicated lower SES with lower HRQoL (Naughton et al., 2008). More specifically, Lawrence et al. (2012) demonstrated that females age 5-7 years old whose parents had less than a college degree and Medicaid/Medicare insurance had lower HRQoL. Da costa et al. (2015) also showed that lower parental education negatively impacted QoL, but specifically regarding adolescents' concerns about their health, appearance, and future. It has been posited that lower parental education may be associated with a lack of information and the anticipation of socioeconomic difficulties in the future (da Costa & Vieira, 2015), while lower SES in general has been linked to health disparities and less access to resources to facilitate good diabetes management (Lawrence et al., 2012).

HRQoL

QoL is defined in both psychology and exercise literature. In the psychology literature, Pavot and Diener (1993) defined QoL as life satisfaction established by cognitive judgments. The PA literature according to Lox, Ginis, Martin and Petruzzello (2006) defines QoL as the subjective and objective assessment of overall quality of one's life and the areas that are present in one's life. The terms QoL and HRQoL are sometimes used interchangeably, with other phrases such as "health status" or "functional status" also replacing those terms in medical research; however, both terms are only part of the broader construct of HRQoL (World Health Organization, 1947). HRQoL refers to QoL in domains that can be affected by health interventions (Lox et al., 2006). Cameron (2003) defined HRQoL as the "extent to which a disease or medical condition impacts upon the daily physical, emotional, and contextual wellbeing of an individual" (p.132). The World Health Organization (1947) uses the term, "wellbeing" as an element in the definition of health, with health defined as "a state of complete physical, mental, and social wellbeing and not merely an absence of disease or infirmity" (p.1). Given these definitions, instruments measuring HRQOL must be multidimensional, and at minimum include the areas of physical, mental, and social health dimensions (World Health Organization, 1948).

HRQoL represents subjectively reported, patient or parent-proxy, well-being in areas both directly and indirectly related to a chronic illness (Varni, Seid, & Kurtin, 2001; Wallander, Schmitt, & Koot, 2001). HRQoL measures allow researchers to investigate general and disease-specific effects of illness on an individual (Rubin & Peyrot, 1999; Varni & Limbers, 2009). This differs from the focus of previous instruments, which solely investigated the presence or absence of symptoms of an illness or the disease itself. HRQoL measures and studies explore constructs that include physical symptoms, disease management, barriers to management, disease-related worries, and social, academic, and emotional functioning (Lawrence et al., 2012; Varni, Burwinkle, Seid, & Skarr, 2003; Varni & Limbers, 2009). More broadly, the inclusion of HRQoL measures may assist with tracking and monitoring of community health, optimizing risk assessment and resource allocation, identifying health disparities, and better understanding health outcomes from policy decisions and interventions (Centers for Disease Control, 2000).

QoL and HRQoL have been investigated in various populations including healthy individuals, older adults, and patients with chronic illness, however HRQoL is still in its relative infancy as an outcome in health research (Varni & Limbers, 2009). In pediatric populations with chronic illness, the evaluation of HRQoL has become an important component in clinical trials, clinical practice improvement, and health care service research and assessment (Fayers & Machin, 2000; Varni, Seid, & Kurtin, 1999). Benefits of utilizing HRQoL measures in pediatric populations include facilitating identification of subgroups of youth at risk for health issues, determining the impact or burden of specific illnesses, and informing prevention and intervention efforts (Kaplan, 2001).

HRQoL and Diabetes

Chronic illness significantly and negatively impacts HRQoL in child populations (Delamater et al., 2001; Hood et al., 2011; Nardi et al., 2008). Furthermore, the additional responsibility and stress resulting from chronic illness can further complicate the complex transition from childhood to adolescence experienced by all individuals (Polonsky, 2000). Recently, the American Diabetes Association (2010) suggested that clinicians include QoL assessments in all diabetes care, reinforcing the importance of caring for the whole individual instead of just addressing disease symptoms. HRQoL is an important consideration for individuals with diabetes given that their illness requires lifelong adherence to their diabetes regimen, and they are at risk for complications stemming from their chronic disease.

Measurement of HRQoL is especially important because youth with diabetes endorse lower health perception, satisfaction with life, and HRQoL, in addition to higher rates of anxiety and depression than healthy peers (Faulkner, 2003; Goldney, Phillips, Fisher, & Wilson, 2004; Hood et al., 2011; Kalyva, Malakonaki, Eiser, & Mamoulakis, 2011; Nardi et al., 2008; Sundberg, Sand, & Forsander, 2015). Studying HRQoL is particularly critical when working with adolescents with diabetes, as they simultaneously face developmental challenges and assume increasing responsibility of their diabetes care (March & Parks, 2016). Studies have demonstrated that adolescents tend to report greater levels of depression and anxiety than healthy children and those with diabetes (Hanberger, Ludvigsson, & Nordfeldt, 2009; Hoey et al., 2001; Nardi et al., 2008; Wagner, Müller–Godeffroy, Von Sengbusch, Häger, & Thyen, 2005). More specifically, Wagner et al. (2005) found that children experienced greater HRQoL than adolescents with T1DM, who endorsed higher levels of depression and anxiety. Greater knowledge of adolescents' perception of their QoL is a key component to developing successful approaches to treatment adherence as they transition from childhood to adolescence and experience body maturation, identity development, and a greater desire for autonomy (Faulkner, 2010).

Thanks to advancing literature, medical knowledge, and technology, life expectancy for those with T1DM has increased; however, avoiding complications when at all possible produces the best outcomes. In patients with diabetes, impairments in general and HRQoL have been associated with suboptimal outcomes, including but not exclusive to poor glycemic control (Guttmann-Bauman, Flaherty, Strugger, & McEvoy, 1998; Hoey et al., 2001; Lawrence et al., 2012; Nansel, Weisberg-Benchell, Wysocki, Laffel, & Anderson, 2008; Naughton et al., 2008). Emphasizing optimal physiological health through adherence to an insulin regimen, glucose monitoring, maintaining healthy diet, and engaging in routine PA, as well as regularly assessing HRQoL has the potential to improve prevention of long-term complications and treatment outcomes (Faulkner, 2010; Ingerski, Laffel, Drotar, Repaske, & Hood, 2010).

HRQoL and EF

There is sparse research on the relationship between EF and QoL, particularly regarding T1DM. One study was found studying adolescents with T1DM, which demonstrated a positive relationship between self-management and QoL (Jaser et al., 2012). Studies are more numerous with other clinical populations. In children with autism spectrum disorder, there was a correlation between lower QoL in the domains of emotional, academic, and social functioning and weakness in various areas of EF (de Vries & Geurts, 2015). Neal et al. (2015) demonstrated that lower psychosocial health was associated with EF deficits in children with repaired Tetralogy of Fallot. Sherman, Slick, and Eyrl (2006) found that EF deficits in children diagnosed with epilepsy correlated with lower HRQoL. Additionally, Schraegle and Titus (2016) found specifically that deficits in working memory predicted lower HRQoL. Finally in a study of children with benign brain tumors, a correlation between symptoms of depression, EF deficits, and lower QoL was uncovered (Laffond et al., 2012). In adult populations, EF is positively correlated with HRQoL in individuals with ADHD (Brown & Landgraf, 2010), and poorer performance in cognitive flexibility and working memory tasks predicted increased stress and lower QoL in adults with multiple sclerosis (Grech et al., 2015).

PA

PA is defined as any movement produced by skeletal muscles that necessitates energy expenditure (World Health Organization, 2017). PA encompasses sports, lifestyle activities, and weekend play activities, which are active and require energy consumption (Lukacs & Barkai, 2015), PA in youth ranges from walking to school to participation in organized sports (Annan, 2013). The term PA is frequently used interchangeably with exercise and physical fitness, however each term is a different concept.

Exercise is defined as any body movement resulting in increased metabolic demand to intentionally develop one or more facets of physical fitness (Lukacs & Barkai, 2015). Exercise is often a planned activity that is structured and systematic (Caspersen et al., 1985). In contrast, fitness is defined as "possession of adequate levels of strength, endurance, and mobility to provide for successful participation in occupational effort, recreational pursuits, familial obligation, and that is consistent with a functional phenotypic expression of the human genotype" (Kilgore & Rippetoe, 2007, p. 37).

Fitness determines the ability to recruit the respiratory, cardiovascular, and musculoskeletal systems to perform physically strenuous tasks such as sport, exercise, or work (Lukacs & Barkai, 2015). Youth who are said to be "fit" are of normal body fat, have a well-functioning immune system, and are generally physiologically well (Lukacs & Barkai, 2015). For the purpose of this literature review, studies of PA, exercise, and physical fitness are all included and subsumed under the term PA. Additionally, while the five components of type, intensity, duration, repetition, and frequency typically refer to exercise they will be used in reference to the all-encompassing term PA (N. R. Rodriguez, Di Marco, & Langley, 2009).

Benefits of PA

The benefits of PA for all populations, young, and old alike have been recognized for quite some time. The Physical Activity Guidelines for Americans states, “being physically active is one of the most important steps that Americans of all ages can take to improve their health” (US Department of Health and Human Services, 2008, p. 1). Extensive research has been conducted on the benefits of exercise in the domains of physical health, cognitive function including school performance for youth, and well-being throughout the life span, (Colcombe & Kramer, 2003; Esteban-Cornejo et al., 2014; Etnier et al., 1997; Taras, 2005). In healthy populations, PA has been shown to reduce the risk of coronary heart disease, stroke, osteoporosis, and certain cancers, such as colon and breast cancer, as well as to improve musculoskeletal fitness (Great Britain Department of Health, 2004; US Department of Health and Human Services, 2008; Warburton, Nicol, & Bredin, 2006). Not only is the risk of disabilities and diseases reduced with PA, the morbidity and mortality of many chronic diseases, including those listed, is decreased (US Department of Health and Human Services, 2011). In contrast, lower levels of PA have been linked to greater incidences of diseases including hypertension and diabetes (Laaksonen et al., 2002). Moreover, a sedentary lifestyle has been linked to cancer, heart disease, arthritis, and depression (Stroth, Hille, Spitzer, & Reinhardt, 2009).

In children, increasing total PA is linked to decreased adiposity and lowered odds of overweight and obesity (Eather, Morgan, & Lubans, 2013; Ford, Perkins, & Swaine, 2013; Gutin et al., 1999; Kriemler et al., 2010; Verstraete, Cardon, Clercq, & Bourdeaudhuij, 2007). Additionally, moderate to vigorous exercise was found to result in reductions in triglycerides and glucose, and an increase in high-density lipoprotein (HDL) cholesterol (Kriemler et al., 2010). As might be expected, PA also is associated with increased aerobic fitness and muscular strength (Eather et al., 2013; Kriemler et al., 2010; Meinhardt, Witassek, Petrò, Fritz, & Eiholzer, 2013; Meyer et al., 2014). Structurally, PA is linked to increases in bone density and greater bone mineral content (Gutin et al., 1999; Janz et al., 2006).

From a psychological perspective, there is strong evidence that PA has numerous benefits. In healthy populations, PA is linked to reductions in depression, anxiety and stress, as well as enhanced self-esteem (Calfas & Taylor, 1994). Moreover, Field, Miguel, and Sanders (2001) found that adolescents who engaged in more PA reported greater relationship quality, less drug use, and less depression. In high school students PA is associated with higher HRQoL scores, while sedentary behavior is linked to lower scores (Jalali-Farahani, Amiri, & Chin, 2016). Additionally, it has been noted that PA is linked to improvements in mood state, perceived help, body image, self-concept, and greater sense of self-sufficiency and personal adjustment (Kirkcaldy & Shephard, 1990). It is proposed that due to facilitation of cognitive and perpetual processing, type A behavior is reduced, stress management skills are enhanced, and psychological performance is augmented (Kirkcaldy, Shephard, & Siefen, 2002).

Benefits of PA specific to diabetes

The objective of regular PA, particularly for children and adolescents with T1DM, is to improve short-term and long-term health and enhance QoL (Leclair, de Kerdanet, Riddell, & Heyman, 2013). In the context of T1DM, PA is one of the few behavioral factors proven to decrease the risk of cardiovascular disease and other chronic conditions, is linked to improved cognitive functioning, and is known to improve psychological outcomes (US Department of Health and Human Services, 2008; World Health Organization, 2017). Studies with adult diabetic populations demonstrate that regular PA is a proven intervention for preventing premature heart disease, improving cardiovascular fitness, reducing risk factors for macrovascular disease, increasing overall life expectancy, decreasing insulin requirements, lowering blood pressure, and improving overall QoL (Aaron, Storti, Robertson, Kriska, & LaPorte, 2002; Cacciari, Milani, Balsamo, & Dammacco, 2002; Cole, Bellizzi, Flegal, & Dietz, 2000; Daly, Duncan, McDonough, & Williams, 2002; Kimm et al., 2002; Prochaska, Sallis, & Long, 2001; Riddoch et al., 2004; Sallis, Prochaska, Taylor, Hill, & Geraci, 1999; Thomas, Alder, & Leese, 2004). Studies have shown that PA also reduces risk factors such as overweight, dyslipidemia, and hypertension in individuals with T1DM (Austin, Warty, Janosky, & Arslanian, 1993).

Physiological benefits in youth

Various health benefits have also been documented in children and adolescents with T1DM. Perhaps one of the most promising findings for youth with T1DM who are at increased risk for cardiovascular disease from an early age, is that PA has been linked to a reduction in cardiovascular risk (Herbst, Kordonouri, Schwab, Schmidt, & Holl, 2007). Cardiac autonomic neuropathy is a complication of diabetes, commonly assessed by heart rate variability. Low heart rate variability is associated with hyperglycemia, recurrent hypoglycemia, increased arterial stiffness, and a significantly increased mortality (Adler et al., 2009; Pop-Busui et al., 2009; Prince et al., 2010; Ziegler et al., 2008). Regular PA has been shown to increase heart rate variability in T1DM youth (S.-R. Chen, Lee, Chiu, & Jeng, 2008; Faulkner, 2010). Research has also yielded positive results that link PA to improved triglyceride levels, systolic and diastolic blood pressure, endurance capacity, aerobic fitness, and body composition (fat to muscle mass ratio), as well as a decrease in fat mass (Heyman et al., 2007; Lehmann, Kaplan, Bingisser, Bloch, & Spinas, 1997; Marrero, Fremion, & Golden, 1988; Michaliszyn & Faulkner, 2010; Mosher, Nash, Perry, LaPerriere, & Goldberg, 1998; Seeger et al., 2011; Sideravičiūtė, Gailiūnienė, Visagurskienė, & Vizbaraitė, 2006). Kriska, LaPorte, Patrick, Kuller, and Orchard (1991) found that an increase in spontaneous PA between the ages of 14 and 17 years old decreases the incidence of nephropathy and neuropathy in adults with T1DM. Links have been found between PA and improvement in bone mineral density (Maggio et al., 2012), vascular function (Seeger et al., 2011), and antioxidant capacity (Woo et al., 2010). In addition, PA has been shown to acutely reduce blood sugar levels, increase insulin sensitivity, and increase insulin-stimulated glucose uptake by the muscle (Åman et al., 2009; Dela, Mikines, von Linstow, Secher, & Galbo, 2006; Ludvigsson, 1980; Schmitz et al., 2002). Studies have shown that PA reduces levels of certain insulin resistance indicators, such as gherlin and leptin (Heyman et al., 2007; Huber et al., 2010). Considering that puberty increases insulin resistance, particularly in females, results correlating regular PA with increased tissue insulin sensitivity are encouraging (Amiel, Sherwin, Simonson, Lauritano, & Tamborlane, 1989; Arslanian, Nixon, Becker, & Drash, 1990; Baevre, Søvik, Wisnes, & Heiervang, 1985; Landt, Campaigne, James, & Sperling, 1985). While it has been found that regular PA improves insulin sensitivity in youth with T1DM, this is not always associated with decreased daily insulin doses and better glycemic control (Baevre et al., 1985; Faulkner, 2010; Heyman et al., 2007; Landt et al., 1985; Tunar et al., 2012). In fact, there have been mixed results in terms of the relationship between PA and glycemic control, as measured by glycated hemoglobin (Valerio et al., 2007). HbA1c provides an average of blood glucose levels over the past 3 months (National Institute of Diabetes & Diseases, 2014). Lipid profile and glycemic control are highly correlated showing parallel improvement or worsening (Leclair et al., 2013). Torres-Tamayo et al. (1998) found that improvement in the lipid profile can be observed in as little as two weeks after the initiation of intensive PA. It is important to note that positive changes in lipid profile and glycemic control help to reduce the risk of developing vascular complications (Leclair et al., 2013).

Psychological benefits in youth

From a psychological perspective, PA through participation in organized sports or activity programs, results in improved socialization, greater social integration with peers, reduced clinical depression, and enhanced well-being and self-esteem in healthy children (Great Britain Department of Health, 2004; Strauss, Rodzilsky, Burack, & Colin, 2001). Research with individuals with T1DM is limited. In adults with T1DM, Zoppini, Carlini, and Muggeo (2003) found that greater levels of PA were associated with significantly greater life satisfaction than their inactive counterparts. Similarly, Stewart et al. (1994) demonstrated that highly active adults with T1DM perceived themselves as having greater physical functioning and psychological health at 2-year follow up than less active participants. In youth, Aman et al. (2009) found a positive correlation between PA and factors such as greater well-being, fewer symptoms, less worry, greater perception of health, and better QoL. Loman and Galgani (1996) explored the PA beliefs of 30 adolescents. They found that the majority of the participants believed that PA had a positive influence on how they felt and was a good method to socialize with others.

Type, Intensity, Frequency, Repetition, and Duration of PA

Results from longitudinal studies have confirmed what was suspected from cross-sectional studies; there is a correlation between various health indicators and the amount of PA undertaken by the child or adolescent (Åman et al., 2009; S.-R. Chen et al., 2008; Faulkner, 2010; Herbst et al., 2007; Sackey & Jefferson, 1996; Schweiger, Klingensmith, & Snell-Bergeon, 2010; Trigona et al., 2010; Valerio et al., 2007; Vanelli et al., 2006). For example, an increase in aerobic capacity is linked to factors such as heart volume and muscle mass improvement following regular PA (Heyman et al., 2007; Larsson, Persson, Sterky, & Thoren, 1964). Regarding intensity, even light and moderate PA was shown to benefit metabolic control in children but not in adolescents (Massin, Lebrethon, Rocour, Gérard, & Bourguignon, 2005). With respect to frequency, Ludvigsson (1980) found improvements in HbA1C with increasing PA. Additionally, studies exploring the impact of chronic aerobic exercise in adolescents with poor glycemic control demonstrated significant decreases in HbA1c (Michaliszyn & Faulkner, 2010; Ruzic, Sporis, & Matkovic, 2008; Sideravičiūtė et al., 2006). Combined training of aerobic and muscle strengthening exercise showed slight reductions of HbA1c in adolescents with T1DM (Bernardini et al., 2004; D'hooge et al., 2011; Heyman et al., 2007). In general, both pure endurance and a combination of endurance and strength training demonstrate positive effects (Leclair et al., 2013).

Recommended Levels of PA in Youth with Diabetes

Current guidelines recommend 60 minutes of moderate to vigorous PA (MVPA) each day for healthy children and adolescents as well as those with T1DM (Herbst et al., 2007; Mohammed et al., 2014; US Department of Health and Human Services, 2008). Various sources offer this recommendation including the American Academy for Pediatrics (Hagan, Shaw, & Duncan, 2008) and the World Health Organization (2017). Research indicates the importance of following the current guideline of 60 minutes of MVPA in order to promote the health and psychological benefits enumerated previously, but it also emphasizes the benefit of PA in general even when performed at a lighter intensity for longer periods (Massin et al., 2005; Poitras et al., 2016).

Despite the positive associations between PA and physiological and psychological outcomes, the level of PA undertaken by non-diabetic and diabetic individuals remains a concern (Valerio et al., 2007). Only 27% of students are meeting the suggested 60 minutes of MVPA per day (Medicine). Furthermore, studies show that levels of MVPA per day are even lower for individuals with chronic illness (Lukacs & Barkai, 2015; Maggio et al., 2010). Studies have demonstrated that adolescents with T1DM accumulate 17 fewer minutes of MVPA than those without T1DM (Komatsu et al., 2005; Lukacs & Barkai, 2015). In a large population-based investigation, approximately 43% of individuals with T1DM surpassed international guidelines for time spent in inactivity (Margeirsdottir et al., 2008). From an age perspective, one study indicated that adolescent males and females between the ages of 12-15 performed approximately 45 and 25 min/day of MVPA, respectively (Troiano et al., 2008). By the ages of 16-19 males and females engaged even less in MVPA, 33 and 20 min/day, respectively (Troiano et al., 2008). Gender differences in PA participation have been found across various studies with populations with diabetes (Åman et al., 2009; Bernardini et al., 2004; Edmunds, Roche, Stratton, Wallymahmed, & Glenn, 2007; Lobelo et al., 2010; Øverby et al., 2009; Roche, Edmunds, Cable, Didi, & Stratton, 2008; Salvatoni et al., 2005; Valerio et al., 2007).

Barriers to PA

Fitness level

Studies have proposed reasons for this disparity in PA between healthy individuals and youth with T1DM. One possible explanation offered is lower levels of fitness (Leclair et al., 2013). One study demonstrated that PA level is significantly associated with self-perceived physical fitness in youth with T1DM (O'Neill et al., 2012). Research has shown that as youth with T1DM age, their aerobic fitness decreases. In a study looking at prepubescent boys, their aerobic fitness was preserved; however, prepubescent girls' fitness already had begun to decline (Heyman, Briard, Gratas-Delamarche, Delamarche, & Kerdanet, 2005; Lukacs & Barkai, 2015). By adolescence, aerobic fitness in both boys and girls with T1DM was often at a lower level than healthy peers (Austin et al., 1993; Gusso et al., 2008; Lukacs & Barkai, 2015). For those adolescents with poor metabolic control, fitness impairment was even more significant (Fintini et al., 2012; Lukacs & Barkai, 2015; Williams, Guelfi, Jones, & Davis, 2011). In terms of gender, girls with T1DM present with lower fitness levels than boys with T1DM, whereas the same gender difference was not demonstrated in healthy youth (Arslanian et al., 1990).

Hypoglycemia

Another factor implicated in lower levels of PA in youth with diabetes is hypoglycemia. Hypoglycemia may be one of the most oft cited reasons for lower rates of activity in young individuals with T1DM. Research in the area of PA and youth with T1DM frequently acknowledge that the fear of hypoglycemia may be a barrier to PA participation (Bernardini et al., 2004; Brazeau, Rabasa-Lhoret, Strychar, & Mircescu, 2008). Researchers have documented a decrease in blood glucose levels during continuous moderate intensity exercise, which increases the chances of hypoglycemia, referred to as exercise-induced hypoglycemia (Leclair et al., 2013). Hypoglycemia is most often associated with participation in prolonged moderate intensity PA (60 plus minutes) (Diabetes Research in Children Network Study Group, 2005). There are various factors in conjunction with PA that contribute to glycemic fluctuations including PA duration, intensity, frequency of engagement in particular PA, metabolic control, blood glucose levels, type and timing of insulin injections and food intake, insulin absorption, muscle mass required for activity, conditioning, degree of stress, and timing of activity (Robertson, Adolfsson, Riddell, Scheiner, & Hanas, 2008). One possible explanation for mixed results regarding metabolic control and PA is difficulty and inexperience in managing glycemic fluctuations in relation to exercise and the variety of other factors discussed previously (Riddell & Iscoe, 2006). It is hypothesized that a combination of fear of hypoglycemia and the previously mentioned factors may push individuals to consume excess carbohydrates, decrease insulin dosages too much, and as a result eliminate positive impacts on blood sugar disposal that may actually induce hyperglycemia and impair glycemic control (Leclair et al., 2013; Ramalho et al., 2006). This might explain significant decreases in daily insulin doses, but no improvement in glycemic control (D'hooge et al., 2011; Ramalho et al., 2006). Studies have shown that with regular timing of exercise, amount of insulin, and pre-exercise meal, the glycemic response to 60 minutes of moderate PA is not random, but replicable, demonstrating that it is safe for youth to participate in PA (Metcalf, 2013).

Recommendations in Association with PA

Due to the complexity of metabolic fluctuations inherent in PA for T1DM, guidelines for glycemic control, blood glucose monitoring, and food intake particular to participation in PA must be adhered to (Leclair et al., 2013). Medical professionals often talk to families about the avoidance of hypoglycemia when engaging in PA. Studies have found that when T1DM youth stop or decrease their insulin dose during moderate intensity continuous PA, hypoglycemia risk is decreased during the PA and the following night (Admon et al., 2005; Diabetes Research in Children Network Study Group et al., 2006; Taplin et al., 2010). When PA is initiated at the same time as peak insulin action or during insulin bolus action, it is suggested that the individual decrease their insulin dose at the meal prior to PA (Heyman, Briard, Dekerdanet, Gratas-Delamarche, & Delamarche, 2006; Peirce, 1999). It is important to note that a reduction in insulin can protect against hypoglycemia immediately following PA and overnight following the

PA; however the insulin reduction could contribute to hyperglycemia (Diabetes Research in Children Network Study Group et al., 2006; Taplin et al., 2010). Insulin reduction should occur approximately 60-90 minutes prior to PA to allow circulating insulin levels to fall once PA begins (Robertson, Adolfsson, Scheiner, Hanas, & Riddell, 2009).

Insulin modification is but one method to prevent hypoglycemia. Individuals also may vary the duration, intensity, and modality of PA that is undertaken. Adolfsson, Nilsson, Albertsson-Wikland, Kerstin, and Lindblad (2012) found that bouts of high intensity intermittent PA protects against late-onset hypoglycemia when compared to continuous moderate intensity exercise. They proposed that the increase of stress hormones (i.e., epinephrine or cortisol) as a result of intermittent high intensity exercise (sprints), which recruit more glucose from the liver into the bloodstream, helps to protect against hypoglycemia. The benefit of adding sprints to a workout to break up periods of moderate intensity exercise is supported by a litany of research (Bussau, Ferreira, Jones, & Fournier, 2006; Guelfi, Jones, & Fournier, 2005; Guelfi, Ratnam, Smythe, Jones, & Fournier, 2007; Iscoe & Riddell, 2011; Yardley et al., 2012). It also is recommended that youth with T1DM eat their regular meals and possibly a small snack before exercise, and eat something within 30 minutes to two hours of stopping PA (American Diabetes Association, 2018a).

While not addressed as frequently as hypoglycemia, blood glucose also may be high during or after exercise, especially during bouts of high intensity PA when glucose-raising hormone levels are increased (Admon et al., 2005; American Diabetes Association, 2018a; O'Neill et al., 2012). Youth with T1DM are advised to check their blood glucose prior to initiation of PA (American Diabetes Association, 2018a). In cases where blood sugar is high, ketones should be checked. A positive test for ketones indicates that vigorous activity should be avoided. An absence of ketones in blood or urine when the individual is feeling well indicates that it is safe to exercise (American Diabetes Association, 2018a).

In order to maintain reasonable glucose control during and after activity, the youth, family members, teachers, coaches, and friends should be made aware of basic strategies to prevent blood sugar fluctuations. The youth and their parent/guardian should consider initial glucose levels, time of the last rapid acting insulin injection, injection site, diet, time of the day, and exercise type when attempting to anticipate the metabolic effect of exercise (Leclair et al., 2013). Additionally, it is recommended that youth and their parents become familiar with individualized responses to PA (American Diabetes Association, 2018a). Monitoring blood glucose levels frequently before and after exercise can help to illuminate the benefits of activity, as well as individual reactions to different forms of PA. Despite the decrease in blood glucose levels during MVPA, various strategies can account for the drop in glucose and maintain blood sugar at appropriate levels, allowing for the safe participation in strenuous PA. Reliable monitoring and fluctuation control strategies make it possible for the American Diabetes Association to assert that ‘‘all patients with diabetes should be given the opportunity to benefit from the many valuable effects of exercise’’ and all forms of physical exercise, including competitive sports, should be accessible to children with diabetes (American Diabetes Association, 2004; Colberg et al., 2016).

PA & EF

Definition of EF

EF is defined as higher-level cognitive processes that supervise more basic cognitive functions. These higher-level processes are goal-directed, self-regulatory operations involved with selecting, scheduling, and coordinating processes involved in perception, memory, and action. EF consists of initiation and inhibition, working memory, and cognitive flexibility or shifting (Diamond, 2006; Pennington & Ozonoff, 1996). EF is associated with the prefrontal cortex and develops from early childhood through adolescence (Blakemore & Choudhury, 2006; Diamond, 2006). Paralleling this development of EF from childhood through early adulthood, we see decreases in grey matter and increases in white matter density (Blakemore & Choudhury, 2006; Sowell et al., 2004). Development of EF allows for better self-regulation, decision-making, mental health, and academic performance (Gailliot, 2008). EF may play a role in a child's ability to understand the most advantageous times to apply knowledge and then act at those moments (Tomporowski, Davis, Miller, & Naglieri, 2008). An inability to plan, update working memory, and control impulses makes it more difficult for a child to stay on task in class and perform well academically (St Clair-Thompson & Gathercole, 2006).

For those with diabetes, EF is critical to diabetes management and treatment adherence especially since care is multistep and somewhat complex requiring monitoring of glucose, diet, exercise, and insulin (McNally, Rohan, Pendley, Delamater, & Drotar, 2010; Rasmussen, Ward, Jenkins, King, & Dunning, 2011; Smith et al., 2014). Given the long-term and involved nature of diabetes management, patients rely on planning, attention, working memory, and problem solving to maintain adherence and optimal health.

Specific domains of EF

Etnier and Chang (2009) cautioned about assigning improvements in specific executive functions to the effect of PA because the construct of EF has been broadly construed in the literature using measures that do not comprehensively assess EF and some that are not identified by neuropsychologists as measures of EF. Furthermore, they warn that various components of EF contribute to the completion of tasks making it somewhat difficult to tease apart which facet of EF is involved or being influenced by PA (Etnier & Chang, 2009). Despite these cautionary remarks and in an effort to better understand the impact of PA on specific EF domains in healthy populations, Guiney and Machado (2013) conducted a review of the literature across age ranges. They found that PA primarily benefited working memory capacity, with cross-sectional data suggesting possible positive impacts in selective attention and inhibitory control for youth.

Impact of PA on EF in Non-diabetic Populations

Studies have indicated a positive relationship between PA and cognitive performance in general in youth (Sibley & Etnier, 2003). In studies of long-term versus short-term PA and the effects on EF, both have proved effective (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; C. L. Davis et al., 2011; Ellemberg & St-Louis-Deschenes, 2010; Lambrick, Stoner, Grigg, & Faulkner, 2016; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009). Van der Niet et al. (2015) explored the impact of daily PA on EF. They found that more sedentary behavior was related to worse inhibition, while greater levels of overall PA was associated with better faster planning (van der Niet et al., 2015). Additionally, children who spent more time spent in MVPA demonstrated even faster planning execution time (van der Niet et al., 2015). Ellemberg and St-Louis-Deschenes (2010) demonstrated that after 30 minutes of PA children demonstrated significant improvement on EF tasks when compared to children who watched television for the same period. Lambrick et al., (2016) found that children who completed continuous (running without a break) and intermittent (periods of activity with rest breaks between) exercise both demonstrated improvements on a Stroop EF task with maintained effects lasting 30 minutes after PA. Another study investigated the impact of various physical education sessions on immediate and delayed recall (Pesce et al., 2009). Both immediate and delayed recall was higher following physical education sessions. While it is suggested that PA alone influences EF, the combination of PA and cognitive engagement has an even greater impact (Best, 2010). Budde et al. (2008) explored the impact of a short bout of coordinative exercise on cognition in healthy adolescents. Coordinative exercise is a PA that activates the cerebellum, which is associated not only with motor functions but attention, working memory, and verbal learning (Budde et al., 2008). Results revealed improved performance in the coordinative exercise group as well as the exercise as usual group, however the progression for the coordinative exercise was significantly greater.

Impact of PA on EF in clinical populations

Not only has research linked PA to beneficial impacts on EF in healthy populations, but in clinical populations as well. Various researchers have explored the impact of PA on EF in children and adolescents with ADHD, a disorder characterized by EF deficiencies (Gapin & Etnier, 2010). Short bursts of PA were associated with beneficial effects on EF in healthy children and those with ADHD (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Additionally, long-term PA has been associated with positive effects on EF of children with ADHD, regardless of the type of PA (Ziereis & Jansen, 2015). In a sample of children with ADHD, Chang, Liu, Yu, and Lee (2012) investigated the impact of moderate intensity exercise for 30 minutes versus watching a running/exercise-related video. The exercise group evidenced improved performance on the Stroop Test and the Wisconsin Card Sorting Test. C.L. Davis et al. (2011) investigated the impact of chronic PA over a 3-month period on EF in overweight children. Results demonstrated that PA bolstered concentration and attention performance as well as mathematics achievement across groups of children provided with different intervention doses. Chen, Ringenbach, Crews, Kulinna and Amazeen (2015) explored the impact of a short bout of moderate PA on EF in youth and young adults with Down syndrome. Results indicate both nonsignificant and significant levels of improvement in various areas of EF after PA.

Academics

The literature also demonstrates that academic achievement, which heavily recruits EF, has been positively associated with PA in both large and small-scale studies. Hillman et al. (2009) looked at the cognitive impact of single bouts of moderate intensity exercise (walking) on EF and academics. The team found that improvements in response accuracy and better performance on achievement testing indicated that PA improved the cognitive control of attention in preadolescent children helping to increase academic performance. Castelli, Hillman, Buck, and Erwin (2007) investigated the impact of PA on the academic achievement of third- and fifth-grade children. Results showed a positive association between aerobic physical fitness and reading, mathematics, and total academic achievement (Castelli et al., 2007). Dwyer, Sallis, Blizzard, Lazarus, and Dean (2001) investigated the impact of PA on academic achievement in a sample of approximately 8,000 children and adolescents. The study demonstrated significant correlations between a measure of physical fitness, self-report of PA, and academic achievement (Dwyer et al., 2001). Grissom (2005) explored the impact of PA on performance of children and adolescents on the California Standards Test, a measure of language arts and mathematics proficiency. Students in grades 5, 7, and 9 evidenced strong correlations between PA scores and academic achievement, with females demonstrating a stronger relationship between the two variables than males.

PA & EF in Diabetic Populations

While there is a paucity of research on the impact of PA on EF in child and adolescents with T1DM, there have been studies exploring the role of PA with regard to improved EF in adults with diabetes. Baker et al. (2010) added evidence to support the positive effect of PA on cognition in adult patients who were prediabetic and diagnosed with T2DM. In their review, Valiente-Barroso, Alvarado-Izquierdo, and García (2015) found that cognitive performance in patients with T1DM and T2DM was inversely related to age and cardiopathology, and years of schooling and PA were related to greater cognitive performance. Colberg, Somma, and Sechrist (2008) showed that patients with T2DM who engaged in PA spent less time in sedentary behavior and demonstrated higher cognitive function. Tonoli et al. (2015) investigated the impact of high intensity PA on EF in 10 individuals with T1DM aged 18-44 years old and matched health controls. At baseline, EF was better in the controls. Post PA, no significant differences in EF were found. Finally, Anderson-Hanley, Arciero, Westen, Nimon, and Zimmerman (2012) demonstrated that adults with diabetes who engaged in PA showed significant EF gains, while their healthy counterparts who also participated in PA did not.

Mechanisms

The mechanism for the beneficial effect of PA, specifically in the cognitive domain, has not been proven nor agreed upon. Several overarching mechanisms drawn from animal and human studies have been proposed as possible mediators of the positive effects of PA: increased cerebral blood flow, changes in neurochemical and hormone secretion, and permanent structural changes in the brain (Chodzko Zajko & Moore, 1994; Erickson et al., 2007; Etnier et al., 1997).

Cerebral blood flow

Chodzko-Zajko and Moore (1994) put forth the cerebral circulation hypothesis, which posits that routine exercise enhances the transportation of blood and thus oxygen in the brain, resulting in increased availability of resources. A greater availability of resources appears to translate to increased cognitive performance (Lambrick et al., 2016). Research supports this theory. Post PA, researchers have found that mean cerebral blood flow is elevated (Poulin, Syed,

& Robbins, 1999). Additionally, in animal studies, chronic PA was found to influence angiogenesis, new blood vessel formation and extension in the brain, which enhances brain perfusion capacity (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Ding et al., 2006; Swain et al., 2003).

Neurochemicals & Hormone Secretion

In animal studies, PA has been shown to increase brain-derived neurotrophin factor (BDNF), neuron growth factor (NGF; Neeper, Gómez-Pinilla, Choi, & Cotman, 1996), and serotonin (Mizutani et al., 2013). BDNF and serotonin coregulate each other. BDNF, NGF, and serotonin are linked to regulation of synaptic plasticity, neurogenesis, and neuron survival (Mizutani et al., 2013; Neeper et al., 1996). Furthermore, NGF protects neurons from hypoglycemia (Neeper et al., 1996). Zimmer et al. (2016) demonstrated elevations in serotonin levels in humans following PA. Increased neurotransmitter secretion in the central nervous system as a result of PA triggers elevated arousal, which enhances cognitive performance (Anish, 2005). Erickson et al. (2007) demonstrated that estrogen levels might impact outcomes of aerobic fitness on cognitive function. Hormones such as human growth factor (HGF) and insulin-like growth factor (ILG-1), that are released during strength training may effect and enhance the impact of PA in older adults, as a result of the impact on neuronal growth, differentiation, and performance (Colcombe et al., 2004). The effect of bolstering neural growth and neuron survival influences learning and memory, which is key for cognitive functioning (Verburgh, Königs, Scherder, & Oosterlaan, 2014).

Brain structure

Other theories of change focus on impacts in brain structure. One theory suggests that PA-induced neural plasticity may enhance cognitive functioning (Verburgh et al., 2014). For example, observed changes in the neuroplasticity of the hippocampus lead to several neurovascular structures and glial cells being affected (Foster, Rosenblatt, & Kuljiš, 2011). Neurogenesis and upregulation of neurotrophic factors, which play a critical role in neural growth and neuron survival, have been reported in response to PA, which impact processes essential to cognitive functioning (Dishman et al., 2006; Ferris, Williams, & Shen, 2007; Flöel et al., 2010; Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011). Additionally, high levels of PA are linked to larger brain volumes specifically in the basal ganglia, hippocampus, and dorsal striatum when compared to children with lower PA levels (Chaddock, Erickson, Prakash, Kim, et al., 2010; Chaddock, Erickson, Prakash, VanPatter, et al., 2010). Conversely, Guiney and Machado (2013) found that the no treatment control group of their study showed a decrease in the volume of the left insula. Recall that the frontal and parietal cortices have been specifically associated with EF (Kramer et al., 1999). In aging populations, significant decreases in tissue density of the frontal, parietal, and temporal cortices are common; however, participants who engaged in cardiovascular fitness saw far less of a loss in tissue density (Colcombe et al., 2004). More specifically and in other populations, PA has been demonstrated to maintain the gray and white matter tracts in those same brain regions, as well as the temporal cortex (Colcombe & Kramer, 2003).

It was previously believed that by young adulthood the brain's neural circuitry was established and fixed (Tomporowski, Lambourne, & Okumura, 2011). The studies on animals and humans indicate that the central nervous system is dynamic and alterable even in older adulthood. Given this information, children may experience greater benefit from PA considering that their brains are in a state of differentiation with their central nervous system still developing (Cabeza, 2001). It is possible that PA may facilitate optimal neural growth and development in children and adolescents (Tomporowski et al., 2011).

Other Factors

The way the relationship between PA and cognition is impacted by third variables is somewhat unexplored. Third variables affect the relationship between dependent and independent variables (Baron & Kenny, 1986). Third variables may be present as moderators, which impact the direction of the relationship, or mediators, which explain the relationship between variables (Etnier, 2008; Thompson, 2006). Direct influences of PA on the mechanisms discussed above are often cited when examining PA's effect on cognition. It has been hypothesized that PA's effect on mediator variables also contributes to enhancement of cognition (Spirduso, Poon, & Chodzko-Zajko, 2007). Energetics theory posits that physiological and psychological states can impact cognitive performance (Spirduso et al., 2007); however, the identification of mediators in the relationship between PA and EF are infrequently investigated (Etnier, 2008; Etnier, Nowell, Landers, & Sibley, 2006). Etnier (2008) named QoL, motivation, self-efficacy, pain, and disease state (e.g., diabetes) as possible mediators in the relationship between PA and cognition in older adults. Spirduso et al. (2007) incorporated these mediating variables into their theoretical model of the relationship between PA and cognition in aged adults. Studies that explore possible meditating variables in child and adolescent populations are few. Sigfúsdóttir, Kristjánsson, and Allegrante (2007) showed that self-esteem and depression seemed to mediate the relationship between PA and scholastic achievement. The significant association between PA and academic achievement became non-significant when self-esteem and depressed mood were included in statistical analyses (Sigfúsdóttir et al., 2007). Kristjánsson, Sigfúsdóttir, and Allegrante (2010) showed that self-esteem weakly mediated the relationship between PA and academic achievement. PA was positively associated with scholastic achievement, but less so when self-esteem was added into the model (Kristjánsson et al., 2010). Despite few investigations into mediating variables in the relationship between PA and EF in children and adolescents, Tomporowski and colleagues (2011) put forth a model similar to that proposed by Spirduso et al. (2007) for youth. The model included health, psychosocial, and fitness factors as mediators in the relationship between PA and cognition (Tomporowski et al., 2011).

PA, HRQoL, and EF

The literature exploring PA, HRQoL, and EF is scarce and has been conducted exclusively with older adults. A community-based 12-week intervention of physical and leisure activities demonstrated improvements in QoL and some elements of cognitive function (cognitive domains of attention, memory, visuospatial function, language, and reasoning) but not EF (Kamegaya, Araki, Kigure, & Yamaguchi, 2014). Langlois and colleagues (2012) investigated the impact of a 3-week PA intervention on physical capacity, cognitive performance (including EF), and QoL. Compared to control group, the intervention yielded improvements in all areas. No known studies explore the interrelationship between PA, HRQoL, and EF.

CHAPTER III

METHODS

The purpose of this study was to investigate the relationship between PA, HRQoL, and EF in youth with T1DM. PA, HRQoL, and EF were explored using self-report measures. A power analysis was used to determine the appropriate number of participants needed in order to ensure statistical significance. Various regression analyses were utilized to explore study questions and hypotheses.

Participants

The study recruited 165 child and adolescent participants from 12 to 18-years old at Children's Health Children's Medical Center Dallas, a large tertiary care children's hospital in the southern United States. Inclusion criterion was English-language speakers with T1DM. Children with T2DM and diabetes insipidus were not included, as differing forms of diabetes introduce possible confounding variables into the study: differing levels of PA, HRQoL, and EF, as well as medical treatment. Exclusion criteria were a known intellectual disability, chromosomal disorder, or developmental delay, which can be associated with conditions such as spina bifida and cerebral palsy. These conditions could have influenced the ability to understand and complete self-report measures, as well as impact the variables being investigated in this study (PA, HRQoL, EF). Written informed consent was obtained from the guardian and/or participants who were 18 years old. Verbal assent was obtained and documented for children under the age of 18. Institutional Review Board approval was granted from Texas A&M University College Station Campus, University of Texas Southwestern Medical Center, and by Children's Health Children's Medical Center Dallas.

Of the 165 participants that were recruited, data from 49 (29.7% of the data) of them were excluded from analysis. Forty participants reported that their levels of PA in the last 7 days were not representative of their PA levels over the last 3 to 4 months, suggesting that the data that they contributed might not be reliable information from which conclusions could be based, particularly since the EF measure is report from the last 3 to 4 months. Those participants were excluded from the analysis. An additional 7 participants began the study protocol, but elected to discontinue participation and did not complete the CEFI or RPAQ-A, and 2 more did not complete the RPAQ-A. These 9 participants were excluded due to missing data on multiple key variables within the statistical analyses. Three participants were missing CEFI data, but these cases were included, as some analyses did not utilize CEFI data and these cases added to statistical power. The CEFI was the only measure included in the study that featured a consistency index and negative and positive impression scales to analyze raters' responses. No protocols demonstrated cautionary consistency indexes, thus no cases were excluded for this reason. Protocols with elevated negative or positive impression scales were included in the study, since it is possible that the ratings are valid for that participant. Characteristics of the remaining 116 participants are shown in Table 1.

Table 1 Participant Characteristics

	Range	n	%	Mean ± SD
Age (years)	12-18	116	---	14.92 ± 1.68
Sex		116		
Male		66	56.90	---
Female		50	43.10	---
TSD (years)		114	---	5.43 ± 3.80
SES		112		
6th grade or less		1	0.90	---
7th-9th grade		3	2.60	---
9th-12th grade		10	8.60	---
High school graduate		14	12.10	---
Some college or certification course		37	31.90	---
College graduate		34	29.30	---
Graduate or professional degree		11	9.50	---
Not known		2	1.70	---

Measures

PedsQL™ Family Information Form

Parents or 18-year-old individuals completed the PedsQL™ Family Information Form. The questionnaire collects demographic information on the youth and their parents, including child/adolescent's date of birth, gender, parental education, and if the child has a chronic illness.

Additional information includes number of days that the youth needed care or missed school because of health, the number of days the parent missed work due to the youth's health, and the effect of the youth's health on the parent's daily work routine in the last 30 days (Varni et al., 2001). For the purpose of this study only age and gender of the youth, as well as mother's level of education were used.

Medical Chart Review

After the visit was concluded, a study member completed the medical chart review. Information was recorded about the participant's diabetes history and functioning collected by the medical team during the visit. Information includes current HbA1c, body mass index, and TSD. The form was created by James Varni, Ph.D. in conjunction with endocrinologists. TSD was the only Medical Chart Review information used in this study.

PedsQL™ 4.0 Generic Core Scales

The PedsQL™ 4.0 Generic Core Scales is a non-disease specific measure of generic HRQoL in youth across 23 items (Varni & Limbers, 2009). The measure evaluates physical, emotional, social, and school functioning through self and parent-report. For this study only self-report forms were used, which measure HRQoL in youth from 12 to 18 years of age. Raters report the frequency of problems over the last 7 days using a Likert scale (0 = never through 4 = almost always). Items are reverse-scored and linearly transformed (0 = 100, 1 = 75, 2 = 50, 3 = 25, and 4 = 0). Higher scores indicate higher HRQoL and fewer issues (Varni & Limbers, 2009). The PedsQL™ yields a Total Scale Score, a Physical Health Summary Score, and a Psychosocial Health Summary Score, as well as four subscale scores: Physical Functioning, Emotional Functioning, Social Functioning, and School Functioning. However, the Physical Health Summary Score and the Physical Functioning score are composed of the same questions and are always equal. As such, only the Physical Health Summary Score will be reported. The PedsQL™ has acceptable validity and reliability (Hilliard et al., 2013; Varni et al., 2003). High construct validity demonstrates that healthy children and adolescents report less symptoms related to poor HRQoL than chronically ill youth (Varni et al., 2003; Varni et al., 2001). The measure has strong internal consistency as well, which ranges from 0.68 to 0.88 across scales on child and adolescent self-report through 18 years of age (Varni et al., 2003; Varni et al., 2001). All scales and subscales of the PedsQL™ were explored in this study.

Comprehensive Executive Function Inventory

The Comprehensive Executive Function Inventory (CEFI; Naglieri & Goldstein, 2013) is a 100-item measure that assesses parent, teacher, and self-report of EF in youth. The Self-Report form is used with youth ranging from 12 to 18 years old. Raters report frequency of behavior using a Likert scale. Ratings yield a standard score, with higher standard scores indicating EF strengths. Completion of the measure yields a Full Scale Score and nine subscales scores: Attention, Emotion Regulation, Flexibility, Inhibitory Control, Initiation, Organization, Planning, Self-Monitoring, and Working Memory. The CEFI is nationally normed, with sampling that aligned with results of the 2009 United States census (Naglieri & Goldstein, 2013). The CEFI shows acceptable reliability and validity. The Full Scale Score possesses strong test-retest reliability (corrected $r = 0.77$ to 0.91) across reporter forms (Naglieri & Goldstein, 2013). Naglieri and Goldstein (2013) found Full Scale Score internal consistency to be high across forms (range = 0.97 to 0.99). In this study, the Full Scale Score, and Attention, Inhibitory Control, and Working Memory subscales from the CEFI were used.

Revised Physical Activity Questionnaire for Adolescents

The Revised Physical Activity Questionnaire for Adolescents (RPAQ-A; Janz, Lutuchy, Wenthe, & Levy, 2008) is a 14-item questionnaire that assesses self-report of PA over the last 7 days. The measure is used with school-aged children who do not have recess or are approximately aged 14-20-years old. Participants indicate how often they participate in specific activities on a 5-point Likert scale. Completion of the RPAQ-A yields an Activity Summary Score and a Sedentary Summary Score, with higher scores indicating higher levels of activity and sedentary behavior, respectively. Reliability and validity are acceptable, and it is one of the few PA questionnaires that can be used during the school year and summer vacation, which is useful for the timeline of this study (Janz et al., 2008). The RPAQ-A demonstrates good internal consistency ranging from 0.72 to 0.88 (Janz et al., 2008). Janz, Lutuchy, and Wenthe (2008) show moderate concurrent validity with Actigraph activity monitors (*rho* = 0.56 and 0.63). In this study, the Activity Summary score was used. One question was added to the questionnaire to bring the item count to 15. The additional question asks if the reported information from the past 7 days is representative of the last 3-4 months. The purpose of adding this question was to facilitate alignment of PA results with Hba1c, which may be relevant to future studies utilizing this data.

Procedures

Study members approached all eligible participants in the waiting room of the Endocrinology clinic at Children's Health Children's Medical Center Dallas. Child assent was collected (for those under 18 years of age) once guardian consent was obtained. For 18-year olds with T1DM, consent from the individual was obtained. All measures were completed by the guardian and/or patient on a hospital provided iPad. Study staff remained present throughout questionnaire completion to answer questions. The guardian completed the PedsQL™ Family Information Form while the child completed the research protocol in the following order:

PedsQL™, CEFI, and RPAQ-A. Participants who were 18 years old without a guardian completed the PedsQL™ Family Information Form before all other measures. The youth were discouraged from consulting their guardian while completing the measures, to obtain the youth's perspective. If families had questions about questionnaire results and scores, the study member explained that scoring was not possible at that time, and that their responses would be analyzed in conjunction with responses of other participants. After each questionnaire was completed, which took thirty minutes to one hour depending on the participant; the study staff reviewed the measure to ensure that all items are were answered before saving the data and proceeding to the next form. The iPad entry eliminated the possibility of choosing more than one answer for each item. Additionally, the iPad software automatically assigned an identification number to each participant's protocol. After verification that the entire protocol had been completed, the guardian or 18-year-old participant was asked to complete a tax form in order to receive the 10-dollar Target gift card. After the visit, the study staff completed the Medical Chart Review. Study iPads were kept in locked cabinets with the research coordinator and on the Endocrinology clinic floor at Children's Health Children's Medical Center Dallas. The Family Information Form, PedsQL™, RPAQ-A, CEFI, and Medical Chart Review were mailed or sent electronically to Texas A&M University for double entry input and analysis. Data were encrypted to protect the information, but did not have identifiers that could link the data back to the participant's protected health information. Forms were stored in locked file cabinets in the Endocrinology office at Children's Health Children's Medical Center Dallas and the office of Dr. Robert W. Heffer at Texas A&M University in College Station, TX. Study iPads were kept in locked cabinets with the research coordinator and on the Endocrinology clinic floor at Children's Medical Center Dallas.

Statistical Analyses

Statistical analyses were run using IBM SPSS Statistics. Missing data was recoded and analyzed using t-tests and a chi-square to determine if complete and incomplete cases were significantly different for each variable. The maximum likelihood method that was originally proposed was not supported by the version of SPSS available at Texas A&M University. Series means were used to replace missing data. Cronbach's alpha (Cronbach, 1951) was used to measure the internal consistency of each scale and total score. Descriptive statistics investigated the skewness and kurtosis of the data. For all research questions, regression analyses were used to explore the relationships between variables in terms of the variance that predictors contributed to outcome variables. TSD was controlled for across all analyses. As previous literature has pointed out (da Costa & Vieira, 2015), newly diagnosed individuals may have been experiencing life changes that could have impacted the way in which they responded to the questionnaires. Additionally, mother's education level was used as a proxy for SES and was controlled for across analyses, due to previous research that has demonstrated potential impacts of SES on key variables in this study (Naughton et al., 2008). Father's education level was collected; however, the variable of mother's education was missing less data, 6.0% and 3.2%, respectively. Furthermore, using fewer predictors in a regression model increases statistical power. Study research questions and variables are as follows:

Research Question 1: Does age and/or sex predict PA level?

To determine if age and/or sex from the PedsQL™ Family Information Form predicted PA (Total Activity Score from RPAQ-A), regression analyses were run controlling for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form).

Research Question 2: Do greater levels of PA predict higher HRQoL and/or specific components of HRQoL?

To determine if PA (Total Activity Score from the RPAQ-A) predicted overall HRQoL (PedsQL™ Total Scale Score), physical health (Physical Health Summary Score from the PedsQL™), well-being (Psychosocial Health Summary Score, Emotional Functioning subscale, & Social Functioning subscale from the PedsQL™) or academics (School Functioning subscale from the PedsQL™), separate regression analyses were run for each set of variables controlling for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form).

Research Question 3: Does PA predict EF and/or specific components of EF?

To determine if PA (Total Activity Score from RPAQ-A) was associated with overall EF (Full Scale Score from the CEFI), as well as the areas of selective attention, inhibitory control, and working memory (Attention, Inhibitory Control, and Working Memory subscales from the CEFI) separate regression analyses were run for each set of variables controlling for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form).

Research Question 4: Does EF predict HRQoL?

To determine if overall EF scores (Full Scale Score from the CEFI) predicted overall HRQoL (PedsQL™ Total Scale Score), a regression analysis was conducted controlling for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form).

Research Question 5: What is the relationship between PA, HRQoL, and EF?

To determine if HRQoL mediated the relationship between PA and EF; with deficits in EF (CEFI Full Scale Score) being related to both lower levels of PA (Total Activity Score from RPAQ-A) and HRQoL (Total Scale Score from the PedsQL™), while controlling for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form), regression analyses were planned to investigate each relationship. The Sobel test was planned to explore HRQoL as a mediator in the relationship between PA and EF, while continuing to control for TSD (Medical Chart Review Form) and SES (PedsQL™ Family Information Form).

CHAPTER IV

RESULTS

Missing Item Responses

Missing data for the sample (n=116) were as follows: TSD (1.7%), mother's highest level of education (3.4%), CEFI Attention subscale (3.4%), CEFI Inhibitory Control subscale (2.6%), CEFI Working Memory subscale (2.6%), CEFI Total score (2.6%). There was no missing data for age, gender, PedsQL^{TM} scales, or RPAQ-A. To ensure that the cases missing data and those that were complete were similar, independent variable t-tests were conducted with each variable, except for gender. Results are summarized in Table 2. Comparison of missing and complete data on the variable of gender was analyzed using a chi-square test. Results are presented in Table 3. No significant differences were detected for any variable when comparing complete and incomplete data groups, indicating that the data was missing completely at random from the sample.

Table 2 Comparisons of Variables on Missing and Nonmissing Data (n = 116)

	Missing			Nonmissing			95% CI of Mean Difference		
	M	SD	n	M	SD	n		t	df
Age	14.92	1.07	13	14.92	1.74	103	-0.71, 0.72	0.00	21.01
TSD	5.01	3.74	11	5.47	3.82	103	-2.12, 3.04	0.39	12.34
Mother's Education	4.56	1.24	9	5.18	1.31	103	-0.34, 1.60	1.46	9.65
RPAQ-A									
Total activity	1.85	0.96	13	2.08	1.10	103	-0.38, 0.83	0.78	16.28
PedsQL™									
Total Score	85.37	11.03	13	81.46	12.81	103	-10.91, 3.09	-1.18	16.38
Physical health	88.46	11.86	13	86.83	13.00	103	-9.12, 5.86	-0.46	15.87
Psychosocial health	83.72	12.26	13	78.60	14.10	103	-12.89, 2.65	-1.40	16.30
Emotional functioning	81.92	15.62	13	77.24	18.82	103	-14.63, 5.27	-0.99	16.74
Social functioning	90.38	12.66	13	87.96	14.73	103	-10.46, 5.61	-0.64	16.39
School functioning	78.85	14.88	13	70.58	17.81	103	-17.74, 1.21	-1.84	16.67
CEFI									
Total score	100.50	15.17	10	100.34	15.10	103	-11.24, 10.92	-0.03	10.81
Selective attention	97.33	14.68	9	98.91	15.71	103	-9.91, 13.07	0.31	9.67
Inhibitory control	101.30	20.40	10	103.21	16.38	103	-12.87, 16.70	0.29	10.16
Working memory	100.30	19.42	10	101.05	14.27	103	-13.30, 14.79	0.12	9.97

$*p < 0.05$. $**p < 0.01$.

Table 3 Crosstabulation of Gender and Data Missingness (n = 116)

Gender	Missing	Nonmissing	$\chi 2$	Φ
Male	8 (6.9%)	58 (50.0%)	0.13	-0.03
Female	5 (4.3%)	45 (38.8%)		

*p < 0.05. **p < 0.01.

Descriptive Statistics and Internal Consistency Reliability Estimates

Skewness and kurtosis of the data was calculated and determined to be normal (West, Finch, & Curran, 1995). Internal consistency reliability estimates (Cronbach's alpha coefficients) are in 4. All measures surpassed the reliability cutoff of α ≥ 0.70 that is necessary to be considered internally consistent and acceptable for group comparison (Nunnally & Bernstein, 1994; Varni et al., 2001).

Table 4 Internal Consistency Reliability Estimates for the PedsQL™, CEFI, and RPAQ-A

Scales	Number of items	*n*	Mean ± SD	α
PedsQL™				
12 Year Olds				
Total score	23	12	35.33 ± 20.14	0.97
Physical health	8	12	10.83 ± 5.62	0.89
Psychosocial health	15	13	24.54 ± 14.49	0.96
Emotional functioning	5	13	9.15 ± 5.86	0.91
Social functioning	5	13	6.54 ± 4.03	0.86
School functioning	5	13	8.85 ± 5.56	0.91
13-18 Year Old				
Total score	23	105	35.16 ± 17.74	0.96
Physical health	8	105	10.61 ± 5.70	0.90
Psychosocial health	15	105	24.55 ± 12.54	0.94
Emotional functioning	5	105	8.32 ± 4.86	0.88

Table 4 Continued

Scales	Number of items	*n*	Mean ± SD	α
School functioning	5	105	10.0 ± 5.38	0.90
CEFI				
Total score	100	90	313.46 ± 140.92	0.99
Selective attention	12	111	40.71 ± 17.67	0.96
Inhibitory control	10	108	33.31 ± 14.41	0.94
Working memory	11	109	35.37 ± 14.56	0.93
RPAQ-A				
Total activity score	47	115	72.20 ± 33.70	0.96

Does age and/or sex predict PA level?

A multiple regression analysis was utilized to predict PA based on age and/or sex, while controlling for TSD and SES. The analysis revealed that neither age nor sex independently predicted PA level, but age, sex, TSD, and SES explained 27.8% of the variance ($R2 = 0.08$, $F(4,115)=2.32$, $p<0.05$), and significantly predicted PA ($\beta = 0.23$, $p<0.05$). Furthermore, SES significantly contributed to this finding. Findings of the regression can be seen in Table 5.

Table 5 Regression Model Estimating Effects of Age and Sex on PA (n = 116)

	Model 1			Model 2			Model 3		
Variables	B	SE	β	B	SE	β	B	SE	β
Constant	2.12	0.13							
Sex	-0.16	0.20	-0.07	-0.18	0.21	-0.08*	-0.13	0.20	-0.06
Age				-0.05	0.06	-0.08*	-0.05	0.06	-0.08
TSD							-0.04	0.03	-0.12
Mother's Education							0.20	0.08	0.23*
F		0.59			0.62			2.32	
Adjusted R^2		-0.00*			-0.01*			0.04	
Change in Adjusted R^2					0.01			0.07*	

*p < 0.05. **p < 0.01.

Do greater levels of PA predict higher HRQoL and/or specific components of HRQoL?

A multiple regression analysis was calculated to predict overall HRQoL based on PA, while controlling for TSD and SES. The analysis did not result in significant findings and is summarized in Table 6. Subsequent multiple regression analyses investigating specific components of HRQoL were conducted to predict physical health, 3 measurements of well-being (psychosocial health, emotional functioning, and social functioning), and academic functioning based on PA, while controlling for TSD and SES. None of the HRQoL component analyses resulted in significant findings. Results are summarized in Tables 7-11.

Table 6 Regression Model Estimating Effects of PA on Overall HRQoL (n = 116)

Variable	B	SE B	β
Constant	72.40	5.21	
PA	2.35	1.11	0.20*
TSD	0.08	0.31	0.02
Mother's Education	0.83	0.93	0.09
$R^2 = 0.06$			
F = 2.18			

*p < 0.05. **p < 0.01.

Table 7 Regression Model Estimating Effects of PA on Physical Health (n = 116)

Variable	B	SE B	β
Constant	77.85	5.27	
PA	2.75	1.12	0.23*
TSD	0.24	0.32	0.07
Mother's Education	0.43	0.94	0.04
$R^2 = 0.06$			
$F = 2.45$			

*p < 0.05. **p < 0.01.

Table 8 Regression Model Estimating Effects of PA on Psychosocial Health (n = 116)

Variable	B	SE B	β
Constant	69.50	5.78	
PA	2.13	1.23	0.17
TSD	-0.02	0.35	-0.01
Mother's Education	1.05	1.03	0.10
$R^2 = 0.04$			
$F = 1.73$			

*p < 0.05. **p < 0.01.

Table 9 Regression Model Estimating Effects of PA on Emotional Functioning (n = 116)

Variable	B	SE B	β
Constant	59.95	7.52	
PA	3.69	1.60	0.22*
TSD	0.00	0.45	0.00
Mother's Education	1.99	1.34	0.14
$R^2 = 0.08$			
F = 3.24*			

*p < 0.05. **p < 0.01.

Table 10 Regression Model Estimating Effects of PA on Social Functioning (n = 116)

Variable	B	SE B	β
Constant	78.46	6.05	
PA	1.47	1.29	0.11
TSD	0.24	0.36	0.06
Mother's Education	1.06	1.08	0.09
$R^2 = 0.03$			
F = 1.08			

*p < 0.05. **p < 0.01.

Table 11 Regression Model Estimating Effects of PA on Academic Functioning (n = 116)

Variable	B	SE B	β
Constant	70.10	7.44	
PA	1.24	1.58	0.08
TSD	-0.30	0.45	-0.06
Mother's Education	0.10	1.32	0.01
$R^2 = 0.01$			
F = 0.43			

*p < 0.05. **p < 0.01.

Does PA predict EF and/or specific components of EF?

A regression analysis investigating the effect of PA on overall EF, while controlling for TSD and SES did not yield significant results. Additional regression analyses examining the effect of PA on selective attention, inhibitory control, and working memory, while controlling for TSD and SES also did not result in significant findings. Findings are presented in Tables 12-15.

Table 12 Regression Model Estimating Effects of PA on Overall EF (n = 116)

Variable	B	SE B	β
Constant	88.31	6.08	
PA	3.02	1.29	0.22*
TSD	0.08	0.36	0.02
Mother's Education	1.05	1.08	0.09
$R^2 = 0.07$			
$F = 2.62$			

*p < 0.05. **p < 0.01.

Table 13 Regression Model Estimating Effects of PA on Selective Attention (n = 116)

Variable	B	SE B	β
Constant	87.98	6.36	
PA	2.08	1.35	0.15
TSD	0.06	0.38	0.02
Mother's Education	1.20	1.13	0.10
$R^2 = 0.04$			
$F = 1.50$			

*p < 0.05. **p < 0.01.

Table 14 Regression Model Estimating Effects of PA on Inhibitory Control (n = 116)

Variable	B	SE B	β
Constant	94.93	6.83	
PA	2.57	1.45	0.17
TSD	-0.22	0.41	-0.05
Mother's Education	0.78	1.21	0.06
$R^2 = 0.04$			
F = 1.63			

*p < 0.05. **p < 0.01.

Table 15 Regression Model Estimating Effects of PA on Working Memory (n = 116)

Variable	B	SE B	β
Constant	93.39	6.04	
PA	2.27	1.28	0.17
TSD	0.37	0.36	0.10
Mother's Education	0.18	1.07	0.02
$R^2 = 0.04$			
F = 1.37			

*p < 0.05. **p < 0.01.

Does EF predict HRQoL?

Regression analyses exploring the effect of overall EF on overall HRQoL, while controlling for TSD and SES did not result in significant findings. Table 16 summarizes the results.

Table 16 Regression Model Estimating Effects of EF on HRQoL (n = 116)

Variable	B	SE B	β
Constant	32.45	7.55	
PA	0.47	0.07	0.55**
TSD	0.00	0.26	0.00
Mother's Education	0.53	0.78	0.05
$R^2 = 0.31$			
F = 16.81**			

*p < 0.05. **p < 0.01.

What is the relationship between PA, HRQoL, and EF?

Without finding a significant relationship between PA and any aspect of HRQoL, PA and any aspect of EF, and EF on HRQoL, results did not support the hypothesis that the variables were interrelated, and thus no mediational relationships could be present in this study using the selected variables. The planned Sobel test was discarded.

CHAPTER V

CONCLUSIONS

The purpose of the study was to explore the impact of PA on EF and HRQoL in youth with T1DM to contribute to education, prevention, and treatment for that population, and ultimately to improve medical and mental health outcomes. Secondarily, the study sought to examine the interrelationship of PA, EF, and HRQoL, as well as to test HRQoL as a possible mediator underlying the relationship between PA and EF, to more completely comprehend the relationship and create more effective interventions.

The importance of PA in diabetes management regimens is well documented for its utility in improving and staving off negative physiological and psychological outcomes common to individuals with diabetes. For other populations, PA has also been shown to improve EF and HRQoL. It is less clear how PA impacts EF and HRQoL in youth with T1DM. Few studies that have explored the impact of PA on EF, or the theorized mediational role of HRQoL with these two variables. No studies have investigated this interrelationship in youth or individuals with T1DM. Determining the relationship of these 3 variables would provide healthcare and mental health professionals with data to consider prioritizing HRQoL as a point of intervention to attenuate negative cognitive impacts in this population. Additionally, mediational information would create the potential to more efficiently design PA interventions that more precisely target change mechanisms.

Does age and/or sex predict PA level?

It is note worthy that age and gender when taken together with SES and TSD significantly predicted PA. Additionally, SES significantly contributed to this finding. It is possible that improved education and knowledge of the benefits of exercise, increased access, social pressures to be fit, and PA as a social outlet contributed to this finding. This is however, contrary to hypothesis, as neither age nor sex alone predicted PA levels, despite adequate representation of males and females in this study. This is in contrast to age and gender differences in PA participation found across various studies with individuals with diabetes who did not include SES or TSD (Åman et al., 2009; Lobelo et al., 2010; Øverby et al., 2009). One possible reason that age or gender was not found to predict PA is because of how PA was measured. In general, self-report measures of PA are less sensitive to light forms of PA. It is possible that youth in this sample participated in lighter forms of PA throughout the week, so PA levels were artificially depressed. Additionally, while self-report has been validated for the measurement of PA in youth, it can be difficult to recall levels of PA over the past 7 days with accuracy (Sylvia, Bernstein, Hubbard, Keating, & Anderson, 2014). Furthermore, youth tend to exhibit intense, but sporadic bursts of PA which may make tallying total PA difficult (Sylvia et al., 2014). With regard to age, it is unclear if the age range was too restricted to demonstrate this relationship with this sample (M=14.92; SD=1.68), since previous research demonstrated adolescent males and females between the ages of 12-15 performed more MVPA than the ages of 16-19 (Troiano et al., 2008). It is possible that participants were engaging in lower intensity PA than previous research, and previous study results do not generalize to lower levels of activity, while as previously discussed, the RPAQ-A was not sensitive enough to light PA. The result supports previous research in this area in which older participants and females reported less PA (Åman et al., 2009; Loman & Galgani, 1996).

Do greater levels of PA predict higher HRQoL and/or specific components of HRQoL?

PA has been demonstrated to result in improved socialization, greater social integration with peers, reduced symptoms of depression, and enhanced well-being and self-esteem in healthy children (Great Britain Department of Health, 2004; Strauss et al., 2001). In youth with T1DM, a positive correlation was found between PA and well-being, fewer diabetes-related symptoms, less worry, greater perception of health, and better QoL (Åman et al., 2009; Faulkner, 2010; Leclair et al., 2013). In contrast to these findings, results of this study did not find PA to be a significant predictor of HRQoL in general, or of any specific aspects of HRQoL. Previous studies that have found these links have not controlled for TSD and SES, which may at least partially explain the difference in findings. It is also possible that the participants' levels of PA were not high or intense enough to influence a significant change in HRQoL. Similar results to those of this study were found with a sample of 36 children with T1DM, in which no significant associations between PA and psychological well-being were discovered (Edmunds et al., 2007).

Does PA predict EF and/or specific components of EF?

Studies have indicated a positive relationship between PA and cognitive performance in general in youth (C. L. Davis et al., 2011; Lambrick et al., 2016). Not only has research linked PA to beneficial impacts on EF in healthy populations, but in clinical populations, such as children and adolescents with ADHD (Pontifex et al., 2013; Ziereis & Jansen, 2015), overweight (C. L. Davis et al., 2011), and Down syndrome (C. C. Chen et al., 2015). In patients with T1DM and T2DM, regular PA was related to greater cognitive performance (Valiente-Barroso et al., 2015), and in a small sample of individuals with T1DM aged 18-44 years old high intensity PA improved EF (Tonoli et al., 2015). Contrary to these findings, the results of this study did not find a relationship between PA, EF, or any component of EF. Possible explanations for this are the results from a study of T1DM and T2DM do not generalize to a sample of T1DM alone, the levels of participant PA were not high or intense enough to create significant change in EF, the PA measure was not sensitive enough to low levels of participant PA, and/or the effects of PA on EF do not apply to youth with T1DM, as they had with other healthy and clinical populations.

Does EF predict HRQoL?

There is sparse research on the relationship between EF and HRQoL, particularly regarding T1DM. A study was found examining adolescents with T1DM, which demonstrated a positive relationship between EF and QoL (Perez et al., 2016). In children with autism spectrum disorder, there was a correlation between lower QoL in the domains of social, emotional, and academic functioning and weakness in cognitive flexibility, emotional control, inhibition, working memory, planning, and organization (de Vries & Geurts, 2015). Furthermore, results from studies exploring the relationship between HRQoL and EF in children with repaired Tetralogy of Fallot (Neal et al., 2015), epilepsy (Sherman et al., 2006), and craniopharyngioma (Laffond et al., 2012) found significant relationships. In contrast to the findings, the present study did not find that EF predicted HRQoL. It is possible that the relationship discovered with other clinical populations in previous studies does not generalize to youth with T1DM. This relationship has not been well explored in the diabetes literature, but the present study has an important difference from the contrasting T1DM findings presented by Perez et al. (2016). The current study did not restrict the sample to specific HbA1c levels, but Perez and colleagues (2016) only included youth with HbA1c values between 8.0 and 12.0%. Findings have been mixed, but some literature has demonstrated a significant link between glycemic control and EF (Berg et al., 2014). Greater variation in HbA1c in the current sample may have suppressed the effects found by Perez and colleagues (2016).

What is the relationship between PA, HRQoL, and EF?

The literature exploring PA, HRQoL, and EF is scarce and has been conducted exclusively with older adults, but two studies have found HRQoL and cognitive functioning gains with increased PA (Kamegaya et al., 2014; Langlois et al., 2012). While QoL has been theorized to be a possible mediator in the relationship between PA and cognition (Spirduso et al., 2007; Tomporowski et al., 2011), few studies have explored this relationship. Two studies with youth found constructs of HRQoL seemed to mediate the relationship between PA and scholastic achievement, but did not explore EF specifically (Kristjánsson et al., 2010; Sigfúsdóttir et al., 2007). While the present study cannot support theoretical models proposing HRQoL as a mediating factor in the relationship between PA and EF, it is one of the few studies that intentionally sought to explore this relationship, particularly with youth. Despite insignificant results, it is possible that additional research with different and larger samples, measures, and populations may find different results than the current study.

Implications, Limitations, and Future Directions

With research and greater knowledge, diabetes regimens have become more efficient and targeted. As a result, outcomes and life expectancy have improved over time. Even so, diabetes management, particularly for individuals diagnosed with T1DM at a young age, is a laborious and complex process that involves near constant and continual vigilance and investment. Results of this study are congruent with previous research that found an association between age and gender and levels of PA, however only when TSD and SES are also considered. Additionally, findings demonstrated that SES significantly contributed to this finding. These findings demonstrate the need to consider patient age, gender, TSD, and SES when working with youth with T1DM, especially since PA is a crucial aspect of diabetes care. It is possible that improved education and knowledge of the benefits of exercise, increased access, social pressures to be fit, and PA as a social outlet contributed to this finding; however, this should not stop providers from continuing to supply patients and families with additional information about the importance of PA in terms of health and long-term outcomes, especially as female patients mature. Talking to parents and patients about openness to learning more about accessible ways to incorporate additional PA into their lifestyle may be helpful in assessing motivation for change, determining knowledge level, and subsequently increasing levels of activity.

A more comprehensive understanding of PA as a specific and important aspect of diabetes care regarding EF and HRQoL, and the interplay of these variables could not be determined. While there were no significant findings in this study, it is important to point out the documented physiological impacts of PA on individuals with diabetes, and previous literature supporting the utility of PA in improving QoL. The elevated incidence of mental health concerns (i.e., anxiety and depression) in youth with T1DM (Dantzer et al., 2003; Grey et al., 2002; Grigsby et al., 2002), and prior literature that demonstrates the positive impact of PA on mental health should fortify PA's position as another tool in the healthcare and mental health provider's toolbox that is free and more fun than other interventions.

The sample size (n=116) of this study very closely approached the ideal sample size for a statistical power of 0.95 for regression analyses with 3 (ideal n=119) and 4 predictors (ideal n=129). Power reached 0.95 for the 3-predictor regression models (research questions 2 through 4) using the sample of 116, but the 4-predictor regression model investigating if age and/or sex predicted PA reached a statistical power of only 0.92. Ideally, a larger sample size for both 3 and 4-predictor regression models was desired. It is possible that a larger sample size may have yielded additional significant results.

Excluding participants whose PA report was not typical of the last 7 days and those who missed that question reduced the number of participants who were included in the study by approximately 30%. Initially, this question was added to the current study to enable future data analyses exploring PA, EF, and HbA1c, however upon further reflection, this question also served to indicate if PA ratings were representative and useful when comparing PA with the time periods that the CEFI and HbA1c measured. Additionally, the PedsQL™ measured the last 7 days, like the RPAQ-A. Comparing results of two measures (PedsQL™ and RPAQ-A), in which the PA level was atypical for the participant, with the CEFI had the potential to skew study results. It could be argued that information from participants who missed that question should have been included, and the mean of the series substituted for that value to increase statistical power of the study. It was impossible though, to determine if that participant's data was valid for comparison with the other variables, so the decision was made to exclude the data for those participants.

The current study did not aim to collect a predetermined number of youth at specific ages between 12 and 18 years old to make sure that each age was well represented in the data. Furthermore, the use of the self-report CEFI restricted the lower bound of the age range to 12. Increasing the variety of ages represented in the study across the 12 to 18-year-old range may have yielded significant results. Additionally, given that adolescents typically engage in less PA than younger children (Komatsu et al., 2005; Lukacs & Barkai, 2015; Troiano et al., 2008), including participants below the age of 12 may have revealed a relationship between age, gender, HRQoL, EF and PA.

The current study did not include non-English speaking patients, despite some measures being published in other languages. Given the diversity of a large metropolitan city like Dallas, including measures in languages other than English would have lent greater heterogeneity to the sample and made it more generalizable to other populations. In terms of heterogeneity, this sample included well-controlled and not well-controlled individuals, making no distinction between results for those with high A1c and those with well-regulated A1c. It is possible that this could have resulted in spurious results.

As noted previously, it is important to reiterate that maternal education level was a proxy for SES. While somewhat constrained in this study by not having a true measure of SES and still desiring to include a proxy variable, it is possible that including a more accurate variable of SES would result in different findings. As such, when reporting out these results it is important to be clear about maternal education level being used as a variable to represent SES.

The gold standard of assessment for total energy expenditure or PA (Shephard, 2003), is doubly labeled water (DLW; Hackney, 2016), however limitations in access, funding, and study design prevented its use. Accelerometers, which are less precise than DLW, but becoming more accessible and frequently used for their accuracy and ease of use over questionnaires, demonstrate moderate concurrent validity with the RPAQ-A (rho = 0.56 and 0.63; Janz et al., 2008). Even so, the use of a self-report PA questionnaire is a limitation of this study and may have had an impact on the results. In terms of effort, participants need only to remember to wear an accelerometer to obtain a more accurate measure of PA, while this study's participants needed to take the time and care to read through the questionnaire, reflect on their activity, and record their responses. Additionally, self-report of PA is generally robust when measuring vigorous activity, but less so with light to moderate levels of activity (Jacobs, Ainsworth, Hartman, & Leon, 1993), which may have obscured relationships between the variables if the sample engaged in light to moderate PA.

The current study was part of a larger research project conducted by Texas A&M University and Children's Health Children's Medical Center Dallas. As a result, multiple questionnaires not included in this study were administered earlier in the larger study's protocol order. Total completion time for the larger study's protocol ranged from thirty minutes to one hour depending upon the participant. Formal data regarding protocol completion time was not collected, however given the somewhat lengthy process, it is possible that by the time participants reached the CEFI and RPAQ-A, fatigue, boredom, and/or a desire to end their office visit and collect the ten-dollar gift card influenced their responses. As discussed above and if it was feasible, a less effortful measure of PA such as an accelerometer may have yielded different study results. Given the study's limitations, the RPAQ-A, which is one of the few PA self-reports that can be used in summer months, was a more reasonable measure of PA, but increased the length of the study protocol. Other briefer measures of EF may have shortened protocol length as well.

In conclusion, previous research has demonstrated the impact of age and sex on PA, though these findings had to also take into account TSD and SES to find significant results, noting that SES contributed significantly. Despite a lack of significant results for the impact of PA on HRQoL and EF and a relationship between HRQoL and EF, previous literature supports these connections, making it a worthwhile avenue of continued research. Future studies may seek to use a broader age range, measures in a greater diversity of languages, a different more accurate variable for SES, and a more precise measure of PA to draw conclusions and limit the length of the study protocol to maintain participant motivation and manage fatigue. Furthermore, increasing sample size may lead to finding significant results. Given the considerations mentioned above, future research with youth with T1DM in relation to PA, EF, and HRQoL is important to bolster the literature and more completely understand the mechanism by which PA is effective and the domains in which it is beneficial.

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