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Relationships between fitness levels, physical activity participation, hemoglobin A1c levels, and motor proficiency in adolescent patients with type 1 diabetes.

Caroline E. Frye
University of Louisville

RELATIONSHIPS BETWEEN FITNESS LEVELS, PHYSICAL ACTIVITY PARTICIPATION, HEMOGLOBIN A1C LEVELS, AND MOTOR PROFICIENCY IN ADOLESCENT PATIENTS WITH TYPE 1 DIABETES

By
Caroline E. Frye
B.S., University of Kentucky, 2022
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Caroline E. Frye
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A Thesis Approved on

April 5, 2024

by the following Thesis Committee:

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Dr. Kristi M. King

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Dr. Jason R. Jaggers

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Dr. Kimberly Hartson

DEDICATION

This thesis is dedicated to my siblings. You all have shown me that I can do difficult things, and I hope this shows you all that you are capable of more than you know.

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I want to thank Dr. Kristi King, my mentor and thesis chair, for the invaluable help that she has given me throughout both the thesis process and graduate school, and for showing me how fun research can be. I also want to thank the other members of the committee, Dr. Jason Jaggers and Dr. Kimberly Hartson, for the time they have dedicated to assist with the thesis process and the knowledge they have shared with me. I would also like to thank my family members and friends for the support and patience they have shown towards me throughout the successes and trials I have encountered during these past few years. Finally, I want to thank Amy Sketch and the team at the Wendy Novak Diabetes Institute for being willing to teach and guide me through research, allowing me to participate in their ongoing protocols, and encouraging me to persevere further.

ABSTRACT

RELATIONSHIPS BETWEEN FITNESS LEVELS, PHYSICAL ACTIVITY PARTICIPATION, HEMOGLOBIN A1C LEVELS, AND MOTOR PROFICIENCY IN ADOLESCENT PATIENTS WITH TYPE 1 DIABETES

Caroline E. Frye

April 5, 2024

Physical activity is a critical component of a healthy lifestyle and can lead to improved fitness levels and blood glucose management, as well as decreased HbA1c levels.

PURPOSE: The purpose of this study was to determine if there are relationships between cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1C levels, and motor proficiency in adolescent patients with T1D.

METHODS: Pediatric patients with a diagnosis of T1D enrolled in a sports medicine program were invited to participate in this study. Retrospective clinical chart reviews were conducted to determine participant's sociodemographic and anthropometric measures and most recent HbA1c level. Assessments included cardiorespiratory fitness (VO_2max), hand grip strength, push-ups, sit-and-reach, body composition measured by bioelectric impedance analyses, and motor proficiency testing. Participants self-reported weekly PA minutes. A Spearman's correlation was conducted to evaluate the relationship among components of fitness, PA, HbA1c, and motor proficiency.

RESULTS: A total of 29 patients (14.03 ± 1.8 years; female, n = 15, 51.7%; white, n = 26, 89.7%) participated in the study. There were five statistically significant relationships: A negative correlation was found between VO_2 max and body fat, $r(23)=-.473$, $p = .017$; a positive correlation was found between max grip and pushups, $r(23) = .421$, $p = .036$; a negative correlation was found between pushups and body fat, $r(23) = -.400$, $p = .047$; a negative correlation was found between body fat and BOT standard, $r(24) = -.504$, $p = .009$; and a positive correlation was found between physical activity minutes and BOT standard, $r(17) = .575$, $p = .010$, $p<0.05$.

CONCLUSIONS: Based on the results from this current thesis study, future research should assess more aspects of physical activity and sport accumulation with motor proficiency scores. For example, quantifying daily activity with BOT™-2 scores would provide researchers with inferential analysis to compare motor proficiency scores of adolescents who meet the recommendation of 60 minutes or more of physical activity per day with those who do not. Continued research exploring the relationships between fitness, PA, HbA1c, and motor proficiency is warranted.

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INTRODUCTION

Diabetes Mellitus, a disease negatively affecting insulin efficiency, currently impacts 38.4 million people who live in the Unites States, with 5-10% of cases being Type 1 Diabetes (T1D) (American Diabetes Association [ADA], 2022; Holt et al., 2021). As of 2019, the number of individuals under the age of 20 years who were currently diagnosed with T1D was 244,000 in the United States (Centers for Disease Control and Prevention [CDC], 2022). To ensure optimal management of T1D, adolescents and their care teams must learn to keep track of their blood glucose levels and ensure proper insulin administration. Further, healthy nutrition habits and regular physical activity play a role in diabetes management. In fact, physical activity participation has been shown to contribute to increased health benefits, such as increased insulin sensitivity and lower hemoglobin A1c (HbA1c) levels (ADA, n.d.b.). However, close to 70% of children and adolescents with T1D are not meeting physical activity recommendations (Czenczek-Lewandowska et al., 2019). For those who are not meeting the recommendations, there is potential for blood glucose to rise to levels of hyperglycemia. Hyperglycemia has been attributed to numerous diseases, one of which is peripheral neuropathy. Neuropathy can cause tingling, pain, loss of feeling, and overall abnormal sensory and motor function in the extremities, such as feet and hands (ADA, n.d.e.); there are treatments that can assist with symptom management, but the condition is irreversible. Tests of motor proficiency can assess current and potential neuropathy, and its potential use would be for identifying risk of developing or early onset of peripheral neuropathy influenced by elevated HbA1c levels, and results can give care teams the ability to intervene and prevent onset or decrease severity.

Need for the Study

Physical activity is a critical component of a healthy lifestyle and can lead to improved fitness levels and blood glucose management, as well as decreased HbA1c levels (American College of Sports Medicine [ACSM], 2018; ADA, n.d.b.; United States Department of Health and Human Services [USDHHS], 2018). However, low physical activity and fitness levels can increase HbA1c levels, which could lead to hyperglycemia. Hyperglycemia could cause irreversible neuropathy and be associated with physical inactivity amongst adolescents. Diabetes care teams who understand the relationship among these variables may be able to intervene, thus attenuating onset or severity of neuropathy. Due to the potential implications of fitness and physical activity participation on HbA1c and neuropathy in adolescents with T1D, the variables and their associations must be assessed.

Purpose

The purpose of this study was to determine if there were relationships between cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c levels, and motor proficiency in adolescent patients with T1D.

Research Question

Are there relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c and motor proficiency in adolescents with T1D?

Hypothesis

There are relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c, and motor proficiency in adolescents with T1D.

Significance of Study

There are multiple studies that have discussed the implications of hyperglycemia associated with T1D and neuropathy, but only one has incorporated the Bruininks-Oseretsky Test of Motor Proficiency™ – second edition, also known as the BOT™-2 protocol in testing for any neuromuscular deficiencies (Mohammad et al., 2018; Andersen et al., 2005; Lesniewski et al., 2003; Casadei et al., 2021; Cleveland Clinic, n.d.b.; Callaghan et al., 2012' Feldman et al., 2019). Previous studies have investigated a connection between physical activity levels and the corresponding impacts on HbA1c and muscular function, but this study will focus on cardiorespiratory fitness, muscular strength and endurance, flexibility, body composition, physical activity, and hemoglobin A1c as a potential indicator of gross & fine motor proficiency (Wallymahmed et al., 2007; Michaliszyn & Faulkner, 2010; MacMillan et al., 2014; Lukacs et al., 2012).

Definition of Terms

Blood Glucose: level of glucose in the blood (Cleveland Clinic, n.d.a.)

Diabetes Mellitus: a group of metabolic diseases attributed to insulin secretion and/or insulin insensitivity (ADA, 2014)

Diabetic Neuropathy: a group of clinical syndromes caused by damage to the periphery nervous system (Feldman et al., 2019); could be caused by hyperglycemia (Orlando et al., 2022)

Exercise: planned, structured, and repetitive behavior that is performed for the purpose of improving or maintaining physical fitness (Caspersen et al., 1985)

Fitness: an outcome of exercise and is an attained set of attributes that relates to the ability to perform physical activity (Caspersen et al., 1985). Health-related components of fitness consist of cardiorespiratory fitness, muscular strength, muscular endurance, flexibility and body composition (American College of Sports Medicine, 2022b).

Glucose: mainly comes from carbohydrates in food and drinks, and is the body’s main source of energy (Cleveland Clinic, n.d.a.)

Hemoglobin: protein in red blood cells that carries oxygen to the body's organs and tissues and transports carbon dioxide from the organs and tissues back to the lungs (Mayo Clinic, n.d.)

Hemoglobin A1c: HbA1c; indicator of average blood glucose levels over the previous three months (Medline Plus, n.d.):

Normal: < 5.7% (ACSM, 2018)

Prediabetes: 5.7% - 6.4% (ACSM, 2018)

Diabetes Mellitus: ≥ 6.5% (ACSM, 2018)

Hyperglycemia: for a person managing diabetes, hyperglycemia is usually considered to be a blood glucose level greater than 180 mg/dL one to two hours after eating; people with type 1 diabetes usually have very high blood sugar (above 250 mg/dL) upon diagnosis (Cleveland Clinic, n.d.b.)

Hypoglycemia: blood glucose of less than 70 mg/dL (ADA, n.d.c.)

Physical Activity: any bodily movement produced by the contraction of skeletal muscles that results in energy expenditure. The energy expenditure can be measured in kilocalories (Caspersen et al., 1985)

Type 1 Diabetes Mellitus: T1D; the destruction of the beta cells housed within the pancreas via autoimmune malfunction which leads to insulin deficiency (ADA, n.d.a.)

CHAPTER 2

LITERATURE REVIEW

Around 1.25 million people in the United States are managing type 1 diabetes (T1D), with 200,000 of those individuals being youth (Jones & Foli, 2018). Adolescents have the highest diagnosis rate of all age groups (Andrade & Alves, 2019). Despite having a diagnosis, only 21% of this population have reported maintaining optimal glucose levels (Datye et al., 2015). The transition from youth to adolescence can be difficult, but research shows that some adolescents do not fully grasp what is required for them in terms of glucose management, which can increase risks of comorbidity, and even death (Jones & Foli, 2018).

Diabetes Management: Insulin and Glucose Care

Glucose management and insulin administration are the foundation of proper T1D care, and insulin needs vary based on blood glucose levels. There are multiple ways to check blood glucose: some individuals prefer to prick their fingers four times a day, which is the minimum amount recommended by the Mayo Clinic (n.d.), while others utilize a continuous glucose monitor (CGM). Blood glucose levels can fluctuate based on food and drink consumption (American Diabetes Association, n.d.a.). In addition, CGMs detect an individual’s glucose level every five minutes and inform the wearer of their status (Everett & Wisk, 2022). CGMs are preferred by some individuals who manage T1D because CGMs can eliminate the multi-daily finger pricks and can be worn for multiple days before having to change the sensor. Users have also reported an improvement in quality of life due to the CGM's ability to give the user accurate glucose reports, building a trustworthy reliance between the product and its consumer (Jiao et al., 2022).

In addition to blood glucose, insulin levels need to be monitored consistently throughout any given day and must be adjusted based on blood glucose levels. Multiple daily insulin injections are one way to administer insulin, but some individuals prefer to use an insulin pump. Insulin pumps eliminate the need for multi-daily injections, and adjustments can be made on the pump's monitor; insulin pumps can last for at least four years (Everett & Wisk, 2022; American Diabetes Association, n.d.f.). According to Fredette et al. (2021), out of the 90% of healthcare providers that have patients with T1D wearing insulin pumps, 29% stated that one of the main reasons for using a pump is the prevention of complications from diabetes. In addition, a 5-10% decrease in HbA1c levels were seen in individuals who use an insulin pump (Rytter et al., 2023).

A higher level of maturity is required when monitoring insulin intake and adjusting glucose consumption based on needs, but some adolescents may not possess the maturity required to perform the life-maintaining observation required by T1D (Jones & Foli, 2018). An adolescent's cognitive state could be partially explained by physiological mechanisms, such as the continuing development of the prefrontal cortex, but "emotional autonomy" could hold a greater weight (Jones & Foli, 2018). Adolescents could find it hard to develop a sense of self and individuality when taking greater responsibility for T1D maintenance, especially when dealing with both internal and external social stigma in these formative years; one study showed that some adolescents perceive their diagnosis to be a burden on their families, and fear complications associated with T1D appearing while at school or in public (Nieuwesteeg et al., 2012). Anderson et al. (2017) found that youth who felt overwhelmed or burdened by T1D were less likely to sufficiently monitor their blood glucose levels, which could lead to poor health and symptom mismanagement.

Physical Activity

The more exercise an individual participates in, the more likely they are to report having a better quality of life (Anderson et al., 2017). Therefore, all individuals, especially those with T1D, should participate in physical activity at a moderate-to-vigorous intensity for at least 60 minutes every day (USDHHS, 2021). Physical activity has many health-related properties, of which increased insulin sensitivity could be one of the most important benefits for those with T1D; insulin is able to uptake glucose and put it into storage with increased efficiency. In addition, increased physical activity participation has been linked to improved fitness levels (King et al., 2021). Blood glucose management and HbA1c levels have been shown to be improved with consistent physical activity as well (MacMillan et al., 2014). However, adolescents do not meet these physical activity recommendations, with 35% and 18% of high school males and females, respectively, meeting physical activity recommendations (Kann et al., 2018). Also, King et al. (2021) saw that less than 8% of their sample did not meet physical activity recommendations; a different study found that 80% of adolescents spent their time in a sedentary state (Michaliszyn & Faulkner, 2010). Lukacs et al. (2012) found that children of both sexes who had T1D had worsened fitness capabilities compared to their age-related counterparts who did not have T1D, potentially due to limited physical activity participation or complications with metabolic control, such as a hypoglycemic episode (Mendonca et al., 2022).

As mentioned, physical activity has been shown to decrease blood glucose and HbA1c levels, but many adolescents are not meeting the recommendations. High HbA1c levels can be indicators of disease risk, and complications associated with poor HbA1c levels have been shown to occur only a few years after diagnosis (MacMillan et al., 2014). In a study conducted by Anderson et al. (2017), only 29.1% of youth between the ages of 13-18 achieved optimal HbA1c levels, and a connection between quality of life and HbA1c was shown: the better an individual's HbA1c, the more likely they are to have a better quality of life (Anderson et al., 2017). In the study conducted by Anderson et al. (2017), The International Society for Pediatric and Adolescent Diabetes regards optimal levels of HbA1c as <7.5% for ages 8-18 years.

Individuals who do not meet the daily physical activity recommendations have been shown to have increased HbA1c levels (King et al., 2021). In addition, improvements in HbA1c levels have been seen in individuals with T1D who perform aerobic and resistance exercise for long durations at higher intensities for multiple days a week (MacMillan et al., 2014; Michaliszyn & Faulkner, 2010).

Components of Fitness

Cardiorespiratory Fitness

Cardiorespiratory (aerobic) fitness is an essential component of an exercise routine, and a lack of participation could lead to adverse health events. Individuals with T1D could develop cardiovascular complications, especially if they spend a large amount of time in a sedentary position (Wu et al., 2019). Additionally, an increased cardiorespiratory fitness has been associated with a decrease in HbA1c levels; Wu et al. (2019) identified that cardiovascular complications decrease as cardiorespiratory fitness increases, and that frequency and duration have a direct relationship with cardiorespiratory fitness levels. A study completed by Michaliszyn & Faulkner (2010) found that adolescents with T1D had both their recent HbA1c levels and their average values decrease after completion of the McMaster cycle test.

Cardiorespiratory fitness can be measured via an individual's VO_2 max, which determines how the participant's body is able to take in, distribute, and utilize oxygen (ACSM, 2018b). A normal VO_2 max is between 90-110% of an individual's predicted VO_2 max, with the Below Expected range being between 80-90% and the Above Normal range being between 110%+; some factors that contribute to predicted VO_2 max include age, height, ethnicity, sex, and weight. In addition, one study found that poor cardiorespiratory fitness could be associated with poor HbA1c levels (Lukacs et al., 2012).

Muscular Strength

Muscular strength is defined by the body's ability to exert force against a given resistance (Cronkleton, 2019). Muscular strength, like other fitness components, has been shown to be negatively impacted by high levels of blood glucose. A study conducted by Andersen et al. (2005) reported that isometric muscle strength decreased after a period of hyperglycemia, but no change was observed in isokinetic muscle strength between hyperglycemia and normoglycemia. Strength can assist with daily activities, and those who struggle with strength may see a decrease in the actions they are able to complete, such as moving a household object. Wallymahmed et al. (2007) found a positive relationship between hand grip strength and maximal oxygen uptake, and a negative relationship between hand grip strength and HbA1c level; as hand grip strength increases, HbA1c levels decrease.

Muscular Endurance

Muscular endurance is the ability of one's muscle(s) to move continuously with little-to-no fatigue (ACSM, 2018b). Lukacs et al. (2012) saw a significant difference between females with type 1 diabetes and females without T1D when completing sit-ups and a bent arm hang. Females with T1D had lower scores than their control counterparts. Similar results were seen in males, but an insignificant difference was seen in the bent arm hang in males within the ages of 8-12 years old. The lower the score, the more easily fatigued the muscle group used in the exercise.

Flexibility

Flexibility is the range of motion attained at any given joint (ACSM, 2018b). Unlike other fitness components, T1D may not have a large impact on flexibility or could differ based on sex. Lukacs et al. (2012) found that Sit and Reach scores between females and their control counterparts, even when separated into two age groups, were not statistically significant; flexibility in 13–18-year-old females with T1D was increased when compared to girls of the same age without T1D. However, Sit and Reach scores between males and their control counterparts were statistically significant amongst both age groups, with those with T1D achieving lower scores than males without T1D (Lukacs et al., 2012).

Body Composition

Body composition is comprised of fat mass and fat free mass. Components within the concept of fat free mass are total body water, bone mineral density, and dry lean mass. Individuals should strive for fat free mass to be high, and for fat mass to be low. A decrease in lean body mass has been attributed to poor health and higher HbA1c levels (Wierzbicka et al., 2018). An increase in total body water can indicate optimal hydration, and a healthy bone mineral density can indicate strong bones.

Body Mass Index (BMI) is an anthropometric measurement used to evaluate an individual's height and weight, and place an individual in one of several categories, which include underweight, optimal weight, overweight, and obese. BMI interpretation should be completed with caution when evaluating a muscular individual; since BMI only accounts for height and weight, and fat free mass weighs more than fat mass, the BMI classification might interpret this individual as overweight or obese. One study found that in a sample of females within the age range of 9-19 years old, there was an inverse relationship between physical activity participation and BMI: as physical activity participation increased, BMI decreased (Kimm et al., 2005).

Peripheral Neuropathy

Peripheral neuropathy is a disease characterized by detrimental changes to an individual's neuromuscular system and can lead to irreversible impairment due to the malfunction of nerve innervations (Lukacs et al., 2012; Orlando et al., 2021). Individuals with peripheral neuropathy have reported pain, tingling within the periphery, touch sensitivity, and consequential foot problems, such as an ulcer (Casadei et al., 2021). Sensory function tends to degrade before motor function (Orlando et al., 2021). Peripheral neuropathy has been seen in patients with diabetes, with up to 50% of individuals with diabetes being diagnosed with the disease; hyperglycemia has been identified as one of the potential causes of peripheral neuropathy (Orlando et al., 2021; Callaghan et al., 2021).

Hyperglycemia associated with diabetes has been shown to play a part in axonal degeneration (Casadei et al., 2021), as well as a malfunction of sensory neurons, muscle fibers, and motor units (Orlando et al., 2021). In addition, the glycation of muscle fibers can impair proper function and could limit muscular strength. When an action potential is unable to adequately travel, firing can occur in disharmony (Orlando et al., 2021). One study found that individuals who have both diabetes and peripheral neuropathy have a 20x greater chance of falling compared to their healthier counterparts (MacGilchrist et al., 2010). The higher the HbA1c, the greater the chance of developing neuropathy (Casadei et al., 2021). In a study conducted by Mizokami-Stout et al. (2020), 11% of their sample was found to have diabetic peripheral neuropathy.

Glycemic control interventions have been shown to reduce the risk of developing neuropathy (Callaghan et al., 2012), as well as detect neuropathy before full onset (Casadei et al., 2021). Neuropathy cannot be cured, but exercise has been shown to ease pain associated with the disease. A HbA1c of < 7% has been shown to decrease chances of developing neuropathy by 60% (Casadei et al., 2021).

Motor Proficiency

One test that has been used to evaluate fine motor skills and dexterity is the Bruininks-Oseretsky Test of Motor Proficiency™ – second edition, also known as the BOT™-2. The purpose of the BOT™-2 test is to determine any neural deficits associated with decreased motor skills (Brown, 2018). The long form version of the BOT™-2 uses eight subtests to determine overall motor ability and can take a little over an hour to complete and score (Mancini et al., 2019). The protocols incorporated into the testing battery are fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper-limb coordination, and strength. In a study by Mohammad et al. (2018), participants with T1D had a mean HbA1c level of 7.8 ± 1.6%, and BOT™-2 scores revealed that youth with T1D had statistically significant lower scores compared to their counterparts who did not have T1D. Children with T1D struggled the most with strength, agility, and manual coordination, which could have been attributed to the required motor control for ambulatory function, grasping, and coordination (Mohammad et al., 2018).

CHAPTER 3

METHODS

Study Design

This cross-sectional study was conducted at the Wendy Novak Diabetes Institute, a nationally certified pediatric diabetes care and academic medical center located in the Southeast region of the United States. At this center, pediatric endocrinologists, registered nurses, registered dieticians, certified diabetes educators, and clinical exercise physiologists treat pediatric patients diagnosed with T1D up to 26 years of age. Within the Institute is the Christensen Family Sport and Activity Program, in which a Clinical Exercise Physiologist and Registered Nurse host an array of sports, physical activity and fitness programming for patients in the Institute. One of the standard practices at this sports medicine clinic includes a comprehensive fitness testing and education programming. Participants can engage in dedicated 1) fitness testing and 2) fitness education appointments. Based upon the participant's physical activity level and the types of physical activity they pursue, additional (and optional) fitness testing and education appointments are available up to two times per year for participants who wish to engage in a wider array of sport-specific testing and education throughout their physical activity and/or sport season(s).

For this study, data were pulled from clinical pediatric sports medicine participants' medical charts and from sports medicine records collected by clinical exercise physiologists during the fitness testing appointment within the sports medicine clinic. As part of the clinical practice, parent/guardian informed consent and child assent were acquired. The participant could choose to withdraw from participation in the fitness testing for any reason at any time. Although data are continuously gathered for multiple studies being conducted by the institute, data from this current study were collected from May 2023 – January 2024. The study was approved by the University of Louisville Institutional Review board and Norton Healthcare Institutional Review board.

Setting

Upon referral to the sports and activity program, a staff member reached out to the participant to schedule the fitness testing appointment. The participants were instructed to not eat at least four hours prior to their scheduled appointment time, unless medically necessary, to maintain their insulin regimen as they would on a regular day, and to dress in exercise attire (*e.g.*, shorts, t-shirt, athletic shoes).

Upon arrival, the participants checked in and were called back to the Christensen Family Sports and Activity Lab conference room to complete consent/assent paperwork. After consent was given, participants were taken to the Christiansen Family Sports and Activity Lab to complete the fitness assessment.

Participants

Participants were either clinician referred or self-referred to the Sports and Activity program. Patients of Norton Children's Hospital Pediatric Endocrinology were able to participate. The fitness assessments were conducted on children with a diagnosis of T1D who met inclusion criteria and met no exclusion criteria.

Human Subject Informed Consent

This study utilized paper informed consent/assent documents. Patients presenting to the Wendy Novak Diabetes Institute who fit the criteria were invited to participate in the study. If they expressed interest in the study, the exercise physiologist went through the informed consent/assent documents with the participant and parent/legal guardian. If accompanied by a legal guardian, supporting documentation was presented and scanned to the medical record as part of the standard check-in process. See Appendix A.

After the clinical exercise physiologist went through the informed consent/assent documents, the participant and parent/legal guardian were given time to ask questions and for clarification on any areas of the informed consent/assent documents. Once questions were answered, or if they had no questions, and participants and parent/legal guardians wanted to continue with the research study, the informed consent/assent documents were signed. Copies of the signed informed consent/assent documents were given to the participant and their parent/legal guardian.

Inclusion and Exclusion Criteria

The inclusion criteria for this study were male and female participants ages 11-17 with a T1D diagnosis who were patients with the Norton Children's Medical Group (Wendy Novak Diabetes Institute and Pediatric Endocrinology), and who participated in the fitness testing. The exclusion criteria were any participant with chronic medical, psychiatric condition, or laboratory abnormality that would jeopardize patient safety with participation in the study. The participant also could not have a previous diagnosis of neuropathy.

Research Question

Are there relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c and motor proficiency in adolescents with type 1 diabetes?

Hypothesis

There are relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1C, and motor proficiency in adolescents with type 1 diabetes.

Data Collection

The main procedure involved with this research study involved data collection by scoring the various fitness assessments discussed above, and a medical chart review. See Appendix B. This study did not involve an intervention, nor was anyone randomized. Each participant was accompanied by a parent or legal guardian. If the participant or parent/legal guardian had questions or concerns regarding the study, a research staff member could answer any questions.

Chart Review

Chart review data were retrieved from participants' medical records via electronic health records. The records were maintained in the clinical database as part of routine care in the Pediatric Endocrinology Clinic. These data included sociodemographic, anthropometric, diabetes monitoring and treatment plans, and hemoglobin A1c (HbA1c) levels.

Sociodemographic, Anthropometric, and Diabetes Monitoring and Treatment Plan Data

The sociodemographic and anthropometric characteristics utilized were participant's ethnicity, race, sex, age, date and duration of T1D diagnosis, and body mass index (BMI). Diabetes monitoring was assessed, including if the participant used a continuous glucose monitor (CGM), if the participant used an insulin pump, and the type of treatment plan was recorded.

Hemoglobin A1c (HbA1c)

The HbA1c level was obtained from the participants' most recent diabetes clinic appointment. HbA1c, the most prevalent and accessible measure of determining glucose control, was used as an indicator of the average blood glucose levels over the past three months.

Fitness Testing Appointment

Patients typically followed this order when participating in the fitness testing appointment:

1. Informed Consent & Child Assent
2. Steps 1-3 of the BOT™-2 Short Form
3. Pre- Testing Glucose and Lactate Check
4. Body Composition
5. Flexibility
6. Muscular Strength
7. Steps 4-8 of the BOT™-2 Short Form / Muscular Endurance
8. Cardiorespiratory Fitness
9. Post- Testing Glucose and Lactate Check

Diabetes History

Participants were asked about their insulin regimen (multi daily insulin injections or pump), including the date it was last changed and the placement site. If the participant used a CGM, they were asked the date it was last changed and the placement site. The participants were asked the time of their last meal and a description of what they consumed, along with the time and amount of their last insulin injection or bolus. Participants were asked to fast for four hours prior to coming in; consumption could impact results. They were also asked about any pain or injuries, and the over-the-counter supplements they were taking, if any.

Pre- and Post- Testing Blood Glucose and Lactate Measures Check

Upon arrival to the sports and activity lab, and after steps one through three of the BOT™-2 protocol were conducted, a clinical exercise physiologist checked the participants' blood glucose and blood lactate. A Contour® glucometer and lancet device were utilized for blood glucose checks. A Lactate Plus Meter was used for blood lactate checks. If the blood glucose was $\geq$ 250 mg/dL, the participant was instructed to administer their insulin correction dose, provided by their clinician, and a urinary ketone test was performed. The participant provided a urine sample, and the clinical exercise physiologist would utilize a medical Chemstrip® to test for ketones. If urinary ketones were moderate to large, the VO_2 max testing would be excluded at the initial fitness appointment, and a follow-up would be scheduled. If the blood glucose was $\geq$ 300 mg/dL with no or small ketones, the participant was instructed to give a conservative insulin correction of 50% of their calculated correction dose. The participant would be retested fifteen minutes after they administered their correction dose.

Once the clinical exercise physiologist determined the blood glucose levels to be in the safe range for physical activity, the fitness testing appointment was conducted.

Upon completion of all tests, a posttest glucose level and lactate level check were performed within five minutes.

Cardiorespiratory Fitness

Cardiorespiratory fitness was measured via Maximal Oxygen Uptake (VO_2 max). The Bruce protocol was utilized on a Woodway ELG treadmill. Participants walked on a treadmill in 3-minute bouts, starting at a 1.7 mph and 10.0% grade. At each 3-minute increment stage, the speed was increased by either 0.8 or 0.9 mph, and grade was increased by 2.0%. Modifications to the grade or speed were made based on the participant's baseline level of fitness. This test took approximately 10-20 minutes. Maximum heart rate and maximum lactate were recorded, along with end-of-stage heart rate and Rating of Perceived Exertion (RPE). The participants were connected to the ParvoMedics TrueOne 2400 metabolic gas exchange analyzer by way of respiratory mask. VO_2 max results were recorded in relative measures.

After the graded exercise test, if the participant's blood glucose had decreased below pre-test levels, the participant was treated for hypoglycemia with a carbohydrate-rich snack, such as apple juice or peanut butter crackers. Blood glucose was then rechecked at 15 minutes. This process was repeated until their blood glucose had risen.

Muscular Strength

Muscular strength was measured using a Lafayette Hydraulic Hand Dynamometer® and measured the dynamic strength of a participant's grip. The individual sat straight up with the testing arm held at a 90-degree angle. Once position was correct, the participant squeezed the hand dynamometer in a maximal effort for five seconds. The measurement from the hand dynamometer was recorded in kilograms. The process was attempted twice per hand with a minimum 1-minute rest between repetitions (ACSM, 2022b). Both trials on each limb were utilized.

Muscular Endurance

Muscular endurance was measured based upon the number of push-ups completed by a patient during the BOT™-2 testing battery. The patient could perform either knee push-ups or full push-ups. The maximum number of push-ups completed within 30 seconds was recorded.

Flexibility

Flexibility was measured via a Baseline Sit n' Reach Trunk Flexibility Box. Participants sat on the floor with their shoes off, and their feet flat against the box divider. Then, the participants put one hand on top of the other, and pushed the box's slider as far as they could. Each participant was given two attempts, and each attempt was measured in centimeters; the highest attempt in centimeters was used for data analysis.

Body Composition

Body composition was measured via the InBody 770 analyzer; it is a tetrapolar multi-frequency bioimpedance analyzer using a frequency of 1,000 kH, while simultaneously being used as a scale. The measured parameters of body composition include the following: body fat (BF) and its segmental analysis, total body water (TBW) and its components of extracellular water (ECW) and intracellular water (ICW), and fat free mass and its components of body cell mass (BCM), extracellular mass (ECM), and skeletal muscle mass (SMM). For this study, total body water, skeletal muscle mass, and lean body mass were used and recorded in pounds. BMI, another body composition measure, was determined by dividing the participant's weight (kilograms) by height (meters) squared.

Physical Activity Participation

Participants were asked by the clinical exercise physiologist how many minutes of physical activity they accumulated in the past week. A continuous score in minutes was recorded. Next, they were asked what sports they play. The types of sports were recorded. These questions were adapted from the Youth Risk Behavior Surveillance System (YRBSS) items of asked “During the past 7 days, on how many days were you physically active for a total of at least 60 minutes per day? (Add up all the time you spent in any kind of physical activity that increased your heart rate and made you breathe hard some of the time.)” with response options “A. 0 days B. 1 day C. 2 days D. 3 days E. 4 days F. 5 days G. 6 days H. 7 days” and “During the past 12 months, on how many sports teams did you play? (Count any teams run by your school or community groups.)” with response options “A. 0 teams B. 1 team C. 2 teams D. 3 or more teams” to assess physical activity participation (CDC, 2023a).

Motor Proficiency

The Bruininks-Oseretsky Test of Motor Proficiency – second edition short form (BOT™-2), is a standardized, norm-referenced gross and fine motor skill control assessment designed to be used by health, research, and education professionals in the assessment of those between the ages of four and 21 years presenting with suspected mild to moderate motor control difficulties (Brown, 2018). The subtests within the protocol are:

1 – Fine Motor Precision

2 – Fine Motor Integration

3 – Manual Dexterity

4 – Bilateral Coordination

5 – Balance

6 – Running Speed and Agility

7 – Upper-Limb Coordination

8 – Strength as assessed by Push-up type (full or knee) was documented for Subtest 8.

Before each testing session, chairs for the participant and the administrator and a table were set out, along with a balance beam. In addition, the dominant hand and foot of the participant was determined before any testing was started; dominant limbs were considered for fine motor precision and upper-limb coordination.

Fine motor precision was evaluated using tests of coordination, accuracy, and careful attention. Tests of fine motor integration consisted of tracing and creating one's own depiction of an object. Manual dexterity was measured by moving several different objects within a predetermined amount of time (e.g., number of successful attempts of picking a penny up with one hand, transferring it to other hand, and placing in a box within 15 seconds). Bilateral coordination was determined using both limbs to complete different tasks, such as jumping and tapping synchronously, until the participant was asked to stop or was unable to continue. Tests of balance were successful if the participant did not fall or wobble within either a predetermined amount of time or if a maximum number of repetitions were achieved. Running speed and agility were measured via hopping on one leg for a predetermined amount of time. A ball was used for upper-limb coordination to catch, along with additional movements. Strength was measured using tests that targeted various muscle groups (e.g., pushups for upper body, sit-ups for abdominal), and by counting the number of repetitions that could be performed within a predetermined amount of time. For this test, each participant decided if they wanted to perform full or knee push-ups for upper body (chest, shoulders, triceps) strength; they did not have to perform both types. A composite score, standard score, and a percentile rank were recorded. A higher score indicates increased motor proficiency.

Data Analysis

Frequencies and measures of central tendency were run for the participants' sociodemographic, anthropometric, diabetes monitoring and treatment plans, fitness levels, physical activity participation, HbA1c, and motor proficiency characteristics. To test the relationship among the continuous variables of fitness levels, HbA1c, and motor proficiency, a Spearman correlation coefficient (*r*) matrix was employed. A correlation matrix can indicate whether two continuous variables are related. It provides correlation coefficient that describes the strength and direction of the relationship and whether it is significant or not. The cells in the table show the correlation between two intersection variables. A correlation matrix is used to summarize relationships and can provide a basis from with future research and types of analysis can be conducted. An alpha level of 0.05 was set for all statistical tests.

CHAPTER 4

RESULTS

The purpose of this chapter is to present the results of the thesis research study. A description of the sample is presented, and the results answering the research question is explained along with the statistical products utilized to conduct the analyses.

Purpose of the Study

The purpose of this study was to determine if there were relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c levels, and motor proficiency in adolescent patients with type 1 diabetes.

Research Question

Are there relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c, and motor proficiency in adolescents with type 1 diabetes?

Hypothesis

There are relationships between cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c, and motor proficiency in adolescents with type 1 diabetes.

Characteristics of the Participants

The thesis study sample consisted of 29 pediatric endocrinology patients from the Wendy Novak Diabetes Institute, a nationally certified pediatric diabetes care and academic medical center located in Louisville, Kentucky. The participants' ages ranged from 11 to 17 years (14.03 ± 1.8). The most frequently reported ages were 15 years old (24.1%), 13 years old (17.2%), 14 years old (17.2%), and 11 years old (13.8%). The sex classification of the sample was almost even, 15 females (51.7%) and 14 males (48.3%), as shown by Table 1.

A majority of the children who participated were White (*n* = 26, 89.7%), two participants were Black or African-American (6.9%), and one participant did not report their race (3.4%). None of the participants reported being American Indian/Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, or of more than 1 race. All participants in this study had documented T1D. Multi-daily insulin injections were used by 7 of the participants (24.1%), and 22 of the participants used an insulin pump (75.9%). All 29 participants used a CGM (100.0%). Table 1 presents the characteristics of the participants and the diabetes care plan of the participants.

Table 1. Characteristics of the Patients (*N* = 29)

Descriptive Variable	Frequency (*n*)	Percentage (%)
Ethnicity		
Hispanic or Latino	2	6.9
Not Hispanic or Latino	27	93.1
Total	29	100.0
Race		
Black or African American	2	6.9
White	26	89.7
Unknown/Not Reported	1	3.4
Total	29	100.0
Sex		
Female	15	51.7
Male	14	48.3
Total	29	100.0
CGM[a]		
Use CGM	29	100.0
Do not use CGM	0	0.00
Total	29	100.0
Insulin Pump		
Use Insulin Pump	22	75.9
Do not use Insulin Pump	7	24.1
Total	29	100.0

[a] CGM = Continuous Glucose Monitor

Table 2 presents descriptive statistics of select questions from medical chart characteristics. Participants' BMI ranged from 17.7 kg/m^2 to 38.5 kg/m^2 with a mean score of 23.0 ± 4.3 kg/m^2. The years of T1D diagnosis duration ranged from 0.08 to 13.2 years, with a mean duration of 4.2 ± 3.5 years. Minutes of physical activity accumulated over the past week ranged from 120 to 1800 minutes, with a mean score of 608.1 ± 425.6. HbA1c levels ranged from 5.8% to 13.0% with a mean percent of 8.2 ± 1.7.

Table 2. Descriptive Statistics (*N* = 29)

Descriptive Variable	N	Minimum	Maximum	Mean	Std. Deviation
Age in Years	29	11	17	14.03	1.8
T1D Diagnosis Years	29	0.08	13.2	4.2	3.5
BMI	29	17.7	38.5	23.0	4.3
Recent HbA1c	29	5.8	13.0	8.2	1.7
PA Per Week in Minutes	21	120	1800	608.1	425.6
Motor Proficiency	26	32	59	48.4	7.5

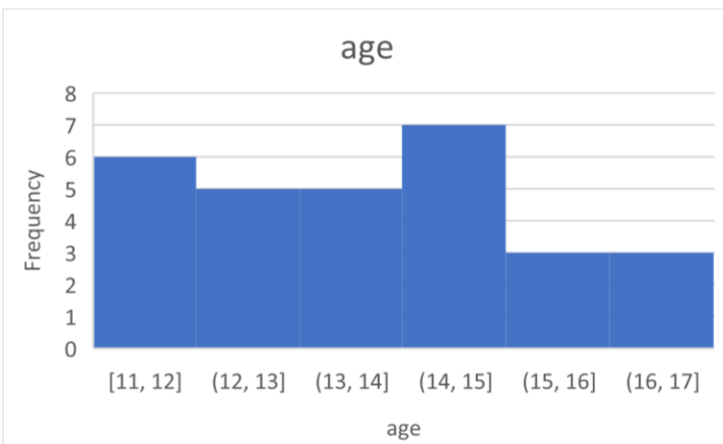

Figure 1. Participants' Age in Years

Components of Fitness

The components of fitness measured were cardiorespiratory endurance, muscular strength, muscular endurance, flexibility, and body composition, as shown in Table 3. Cardiorespiratory endurance was assessed through VO_2 max testing. Out of the 29 study participants, 25 completed the VO_2 max test (86.2%). Scores ranged from 23 ml/kg/min to 53 ml/kg/min, with a mean of 40.8 ± 8.2.

Muscular strength was assessed through maximum hand grip strength. All 29 study participants completed the hand grip strength test (100.0%). Scores ranged from 22 kg to 70 kg, with a mean of 35.7 ± 11.5. Muscular endurance was assessed through the number of push-ups completed within 30 seconds. Out of the 29 study participants, 25 completed the push-ups (86.2%). Push-ups completed ranged from 0 to 35, with a mean of 17.5 ± 7.5.

Flexibility was assessed through maximum sit-and-reach score. All 29 study participants completed the sit-and-reach (100.0%). Scores ranged from 13.0 cm to 48.0 cm, with a mean of 28.6 ± 8.6. Body composition was assessed via body fat percentage collected through bioelectrical impedance analysis. All 29 study participants completed the body composition testing. Percentages ranged from 3.0% to 42.9%, with a mean of 23.1 ± 9.9.

Table 3. Components of Fitness (*N* = 29)

Fitness Components	N	Minimum	Maximum	Mean	Std. Deviation
VO_2 max	25	23	53	40.8	8.2
Max Hand Grip	29	22	70	35.7	11.5
Push-ups	25	0	35	17.5	7.5
Max Sit-and-Reach	29	13.0	48.0	28.6	8.6
Body Fat %	29	3.0	42.9	23.1	9.9

Physical Activity Level

Physical activity level was determined based off survey data collected. The survey was completed by 21 adolescents, resulting in a 72.4% response rate. Minutes per week ranged from 120 to 1800 minutes, with a mean of 608.1 ± 425.6, as displayed in Table 2.

There were 16 reported sports teams in which participants engaged. The most frequently reported physical activity sports team was basketball (*n* = 10). The second most frequently reported were soccer (*n* = 4), tennis (*n* = 4), cross country (*n* = 4), and track (*n* = 4).

Table 4. Activities Participated In (*N* = 29)

Activity	Frequency (n)
Basketball	10
Baseball	3
Soccer	4
Bike Riding	1
Tennis	4
Cross Country	4
Running 5Ks	1
Dance	2
Field Hockey	1
Football	2
Golf	1
Softball	1
Swim	2
Volleyball	3
Track	4
Wrestling	2

Hemoglobin A1c

Recent hemoglobin A1c was determined based off retrospective chart review data. The chart review was conducted for all 29 participants. Hemoglobin A1c ranged from 5.8% to 13.0%, with a mean of 8.2 ± 1.7, as shown in Table 2.

Motor Proficiency

Motor proficiency was assessed using the BOT™-2 Short Form and measured using the standard score and descriptive category. The testing was performed by 26 participants, resulting in an 89.7% completion rate. The standard score ranged from 32 to 59, with a mean of 48.4 ± 7.5. The most common standard score was 59 (n = 6, 17.2%).

Descriptive categories were established for all 26 participants who completed the BOT™-2 Short Form (100.0%), as displayed in Table 5. The most common descriptive category was “Average” (n = 24, 92.3%). The second most common descriptive category was “Below Average” (n = 2, 7.7%). None of the participants fell under the categories of “Well-Below Average”, “Above Average”, or “Well-Above Average”.

Table 5. BOT™-2 Short Form (*N* = 26)

Descriptive Categories	Frequency (*n*)	Percentage (%)
Well-Below Average	0	0.0
Below Average	2	7.7
Average	24	92.3
Above Average	0	0.0
Well-Above Average	0	0.0
Total	26	100.0

Underlying Assumptions of the Correlation Analysis

To determine the normality of the data, a test of the underlying assumptions of the correlation. A Shapiro-Wilk test of Normality showed that the pushups were not normally distributed (p < .05). However, the other variables were fairly normally distributed. See Table 6.

Table 6. Test of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
HbA1c	.901	15	.100
Active Min/Week	.838	15	.012
VO_2max	.934	15	.317
Grip	.887	15	.061
Pushup #	.810	15	.005
Sit and Reach	.933	15	.297
BF%	.907	15	.123
BOT Standard	.903	15	.106

Spearman Rank Correlation

Based on the results of the tests of normality, Spearman rank correlation was conducted to assess the relationship between components of fitness, physical activity participation, HbA1c, and motor proficiency. See Table 7.

Table 7. Spearman Correlation of Fitness Components, PA, HbA1c and Motor Proficiency

	VO2max	Grip	Pushup #	Sit and Reach	BF %	Active Min/Week	HbA1c
VO2max	1.000						
Grip	.015	1.000					
Pushup #	.248	.421*	1.000				
Sit and Reach	-.260	-.006	-.075	1.000			
BF %	-.473*	-.324	-.400*	.210	1.000		
Active Min/Week	.035	.167	.449	.077	-.172	1.000	
HbA1c	.045	.277	-.101	-.183	-.161	-.166	1.000
BOT Standard	.254	.201	.329	-.077	-.504**	.575*	-.099

*statistically significant

There were five statistically significant relationships (See Table 8). The strength of all the relationships was moderate, and two relationships were positive, and three relationships were negative. Specifically, they are:

- A negative correlation was found between VO_2 max and body fat, $r(23)=-.473$, $p = .017$.
- A positive correlation was found between max grip and pushups, $r(23) = .421$, $p = .036$.
- A negative correlation was found between pushups and body fat, $r(23) = -.400$, $p = .047$.
- A negative correlation was found between body fat and BOT standard, $r(24) = -.504$, $p = .009$.
- A positive correlation was found between physical activity minutes and BOT standard, $r(17) = .575$, $p = .010$.

Table 8. Statistically significant relationships

Correlation	Significance	*p* Value
VO_2 max & Body Fat %	-.473	0.017
Max Hand Grip & Push-up	.421	0.036
# Push-up # & Body Fat	-.400	0.047
%	-.504	0.009
Body Fat % & BOT Standard		
Activity Minutes & BOT Standard	.575	0.010

Summary

This chapter presented the results of the thesis research question based upon the retrospective chart review data, fitness testing, sport participation survey data, and motor proficiency testing, along with sociodemographic, anthropometric, and diabetes monitoring and treatment plan characteristics. The sample of 29 pediatric endocrinology patients were recruited and data were analyzed. The research question examined if relationships existed among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c and motor proficiency. Results from the Spearman rank correlation concluded that there were five statistically significant correlations between variables.

CHAPTER 5

DISCUSSION

Purpose

The purpose of this study was to determine if there were relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c levels, and motor proficiency in adolescents with type 1 diabetes.

Research Question

Are there relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c, and motor proficiency in adolescents with type 1 diabetes?

Hypothesis

There are relationships among cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition, physical activity participation, hemoglobin A1c, and motor proficiency in adolescents with type 1 diabetes.

Summary

Results from this thesis study of 29 adolescent participants with type 1 diabetes indicated that there were five statistically significant relationships among fitness, physical activity participation, HbA1c, and motor proficiency variables. Each significant relationship, as well as variables that were not significant, will be discussed below. Limitations and direction for future research will be presented. Lastly, conclusions, practical significance, and recommendations will be presented.

Motor Proficiency

A positive correlation was found between physical activity participation and motor proficiency. Further, body composition played a significant role in being negatively associated with motor proficiency. The importance of quantifying the relationship among variables with motor proficiency is especially important in understanding and potentially intervening or mitigating the potential development of peripheral neuropathy in patients with T1D. Fine motor skills have been found to be inadequate in children with T1D, potentially due to poor glycemic control, as well as physical activity participation (Kiliçöz et al., 2022); physical activity has been associated with greater gross motor proficiency skills (Dapp et al., 2021). Physical activity participation can improve components of fitness, which in turn can positively impact motor proficiency (Liu et al., 2023). Hypertension and other macrovascular factors could cause peripheral neuropathy, of which physical activity participation and healthy lifestyle habits are known to decrease the severity and likelihood of these factors (Mah & Pacaud, 2014). Increased sedentary behavior has been associated with insulin resistance (Pop-Busui et al., 2022). Pop-Busui et al. (2022) recommend exercise as a nonpharmacological interventional therapy for peripheral neuropathy due to the benefits that exercise and physical activity can have on hyperglycemia, axonal generation, mitochondrial expression, gait, inflammatory markers, and overall quality of life, even to go as far as being the only interventional therapy to regenerate small-diameter cutaneous sensory axons. In addition, physical activity participation is known to be related to body composition and overall health (Liu et al., 2023). Cattuzzo et al. (2014) found that inadequate movement patterns could be caused by increased fat mass, making it more difficult to perform limb functions. Fat mass could also impact posture as well, which could decrease muscle strength and impact motor proficiency (Liu et al., 2023). Franceschi et al. (2022) identified BMI as a risk factor for peripheral neuropathy, but BMI does not necessarily correlate with an individual's body fat percentage. From what has been seen, very few studies have assessed motor proficiency in children who have T1D and have investigated other variables that could impact motor proficiency, making this study innovative.

Although this relationship was not investigated, there could be a link between the duration of T1D diagnosis and the diagnosis of peripheral neuropathy (Pop-Busui et al., 2022). There is documentation that in individuals who have been diagnosed with T1D for less than ten years, there is low prevalence of peripheral neuropathy (Pop-Busui et al., 2022). However, rates of prevalence increase as the duration of T1D diagnosis increases past ten years of diagnosis, up to 34% around a duration of T1D diagnosis of 25 years (Pop-Busui et al., 2022). For the pediatric population, screening can start annually with a duration of T1D diagnosis of two to five years (Donaghue et al., 2018).

Fitness Relationships

As expected in much of the scientific literature, the results of this thesis study corroborate with the negative relationship body composition has when compared with fitness. In this current study, a negative correlation was found between VO_2 max and body fat. Alonso-Fernández et al. (2019) found that in a group of adolescents who performed high intensity interval training (HIIT) training during a warm-up, body fat percentage decreased, whereas VO_2 max increased over a period of time. Aerobic activity can lead to an increase in VO_2 max and a more vascularized adipose tissue, which can help decrease fat mass and body fat percentage (Alonso-Fernández et al., 2019).

In addition, a negative correlation was found between pushups and body fat. A study conducted by Garcia-Pastor et al. (2016) saw that in their sample of adolescents, individuals who could complete more pushups had a lower body fat percentage than their peers, which could be explained by a decrease in inflammatory serum markers; those who tend to have higher inflammatory serum markers could be more prone to obesity. Nazari et al. (2023) also saw a decrease in inflammatory markers in an experimental exercise group of adolescents with T1D, in which one of the exercises performed was pushups, but the decrease was not statistically significant.

Also, as expected, a positive correlation was found between max grip and pushups in this study. Although these findings are not surprising in the scientific literature, it is important to emphasize the role fitness components play in promoting healthy body composition as well as motor proficiency. High amounts of fat mass have been associated with increased risk of cardiovascular disease as indicated by high blood pressure and dyslipidemia (Calella et al., 2019). However, regular physical activity participation has been shown to increase components of fitness, such as cardiorespiratory fitness, which can increase GLUT-4 expression, and therefore assist with glucose control (Huerta-Uribe et al., 2022).

Physical Activity

Although there are no statistically significant relationships between physical activity participation and other variables besides motor proficiency in this study, findings from other research corroborate the benefit of physical activity and fitness levels and HbA1c. When adolescents with T1D meet the daily physical activity recommendations, they can obtain health benefits and improved diabetes management (USDHHS, 2018; MacMillan et al., 2014). Ostman et al. (2018) found that total daily insulin dose, waist circumference, and measurements of blood cholesterol improved with physical activity. More specifically, an increase in high density lipoproteins (HDLs) and a decrease in low density lipoproteins (LDLs) can occur with regular participation in physical activity (Aljawarneh et al., 2018). In addition to the improvement in waist circumference, an increase in lean body mass was observed (Ostman et al., 2018). Enhanced insulin sensitivity has been attributed to an increase in fat-free mass, which can assist in ameliorating insulin levels (Alonso-Fernandez, 2019).

When an adolescent can manage their blood glucose levels well, an incorporation of gradual increases of duration and intensity of exercise can help to further control blood glucose (Aljawarneh et al., 2018). HbA1c levels can decrease with participation in regular physical activity, contributing to better glycemic control, while also helping to decrease hypoglycemic episodes during physical activity (Aljawarneh et al., 2018). Inconsistent physical activity has also been shown to contribute to a decrease in bone mineral density; on the other hand, regular physical activity has been shown to decrease the risk of diabetic retinopathy via an increase in the retinal vascular caliber (Aljawarneh et al., 2018).

Hemoglobin A1c

Poor glycemic control and large fluctuation in blood glucose were recognized in individuals managing an influx of pain with their peripheral neuropathy (Pop-Busui et al., 2022). Franceschi et al. (2022) identified more than nine articles in their systematic review that found HbA1c to be a risk factor of peripheral neuropathy. Blood glucose levels can vary, and will not always be fully regulated, which could lead to a history of different HbA1c for each participant, and possibly have led to no significant relationships involving HbA1c.

Limitations and Future Research

One limitation identified in this thesis study was how participants were asked about their physical activity and sport participation. Instead of asking the exact questions as given by the Youth Risk Behavior Surveillance System (YRBSS), patients were asked which sports they played, or other ways that they were active, and how many minutes a week they participated in activities. The open-ended nature of the response options could have contributed to a lack of clarity and could have impacted the responses from the participants. Children and adolescents may not always realize when they are being active or may be active on their own outside of an adult's eyeline, so quantifying minutes of physical activity can be difficult. An increase in specificity when quantifying sports, such as having the participants identify what their favorite sport to participate in is and therefore limiting the answer to one sport, could be helpful in accuracy in the future. Additionally, self-report, subjective measures may be susceptible to recall bias and the potential for social desirability when verbally answering the physical activity questions, thus impacting the validity of the physical activity scores. Further, a potential outlier of 1800 minutes of physical activity per week was reported by one participant. Future analyses could re-analyze the data to determine if the results were screwed or impacted by the large number.

In addition, the pushups were performed as part of the BOT™-2 protocol. Within the protocol, the participants could choose if they want to perform full (knees up) pushups, or knee (knees down) pushups; they were asked to perform the type of pushup that they could complete more repetitions of successfully. The choice of pushup style could have impaired a participant's ability to perform as many pushups as they could in the time allotted.

Also, willingness to participate could have impacted scores. All patients signed the consent and assent forms, but levels of effort varied from participant to participant; it is very likely that scores could have been skewed because a participant thought a test was too easy, or that they did not have full interest in completing a test. For future research, an increase in sample size is warranted. By increasing the sample size, more relationships could be discovered, the current relationships could become stronger, or become non-significant.

The conduction of a correlational study assessing the strength and direction of relationships provides researchers with a pathway for future research endeavors. Based on the results from this current thesis study, future research should assess more aspects of physical activity and sport accumulation with motor proficiency scores. For example, quantifying daily activity with BOT™-2 scores would provide researchers with inferential analysis to compare motor proficiency scores of adolescents who meet the recommendation of 60 minutes or more of physical activity per day with those who do not.

Conclusion and Clinical Recommendation

Although many variables were evaluated, five significant relationships were discovered: VO_2 max and body fat percentage, max grip strength and pushups, pushups and body fat percentage, body fat percentage and BOT™-2 standard score, and minutes of physical activity performed in one week and BOT™-2 standard score. Specifically, this means that significant relationships between cardiorespiratory fitness and body composition, muscular strength and muscular endurance, muscular endurance and body composition, body composition, and motor proficiency, and physical activity participation and motor proficiency were identified. These findings can help diabetes care teams to encourage physical activity and fitness to their adolescent patients with T1D, as well as all patients with T1D, for both the benefits specific to T1D, as well as the overall health benefits.

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APPENDICES

APPENDIX A

INFORMED CONSENT AND RESEARCH AUTHORIZATION

Effect of Sports and Activity Program on Health Outcomes in Individuals with Diabetes Mellitus at the Wendy Novak Diabetes Center
(Parent/Guardian)

IRB#: 20.0936

Investigator: Bradly Thrasher DO, 411 E. Chestnut Street, Louisville, KY 40202

Site(s) where study is to be conducted: Norton Children's Endocrinology, Novak Center for Children's Health, 411 East Chestnut Street, Louisville, KY 40202

Phone number for subjects to call for questions: (502) 588-3430

24-Hour Contact Number: (502) 629-6000, please ask for the pediatric endocrinologist on call and notify the doctor that you or your child is a research study participant.

Study Subject Number: _______________

Summary Information

The purpose of this study is to determine if participating in a sports and activity program improves blood sugar control in individuals who have diabetes mellitus.

Participants in this study will attend sessions to evaluate their fitness level and glycemic variability: 1) Fitness Initial, 2) Fitness Follow Up (optional), 3) Fitness Education. During the initial fitness visit a team member reviews the participant's fitness, health, and diabetes management goals. Participants will receive instruction for self-monitoring of nutrition and activity as well as tracking blood glucose levels. Additionally, participants will undergo standard fitness tests to determine baseline fitness level. This visit typically takes 2 hours. The fitness follow-up is optional and occurs no sooner than 48 hours after the initial visit. This visit is recommended if additional fitness tests are needed based on the participant's activity goals. This visit typically takes 1 hour. Lastly, during the fitness education session the participant's nutrition, activity, and blood glucose data are reviewed and discussed with the participant. The information collected is used to provide further safety and treatment guidance for managing diabetes mellitus while participating in physical activity. This visit typically takes 1 hour.

There are risks to this study that are described in this document. Risks include injuries during fitness testing which include falling, awkward landing of foot, and muscle soreness. Additionally, participants may experience hypo- or hyperglycemia.

If you are interested in learning more about this study, please continue to read below.

Introduction and Background Information

Your child is invited to take part in a research study because your child has diabetes mellitus. The study is being conducted under the direction of Bradly Thrasher DO, Assistant Professor at the University of Louisville. The study will be conducted at the Novak Center for Children's Health. Approximately 100 local participants will be invited to take part in this research.

APPENDIX B

Participant Name: ______________________Participant ID: ________________ Date: ______________ DOB: ______________ Age: _________

All Encompassing

☐ Fitness Initial

☐ Fitness Follow Up # _____

Anthropometrics

Height ________cm ________in BMI _______

Weight ________kg ________lbs

Blood Values

Pretest

Glucose __________mg/dL CGM Reading __________mg/dL

Posttest

Glucose __________mg/dL CGM Reading __________mg/dL

Pretest Lactate __________mmol/L

Posttest Lactate __________mmol/L

Diabetes Details

Date of Onset: ___________

Last Diabetes Appt: __________ Most Recent HbA1c: __________

* Only test if pretest glucose is >250 mg/dL

Ketones

☐ None ☐ Trace ☐ Small ☐ Moderate ☐ Large

Insulin Regiment (check one): ☐ Multi Daily Insulin ☐ Pump: ________________________

Last Changed: ___________ Placement: ____

Continuous Glucose Monitor (CGM): _________________________________

Last Changed: ___________Placement: ____

Percent Time in Range: ____________

Last Meal

Time: _________Description: ____

Last Injection/Bolus

Time: _________Amount: ___________

Pain/Injuries? ____

OTC Supplements: ____

Sports and Physical Activity

Currently Active: ☐ Yes ☐ No

If yes, what: ____

Days and Duration: ____

Patient Concerns, Questions, Goals:
____
____
____
____

Fitness Testing

Hand Grip Strength

Right _________kg __________kg

Left __________kg __________kg

Sit and Reach

Trial 1: __________cm

Trial 2: __________cm

Vertical Jump

Trial 1: ____________in

Trial 2: ____________in

Trial 3: ____________in

InBody

Body Fat % ____________

Total Body Water ___________lbs Total Body Water Percent _____________

Lean Body Mass ___________lbs Lean Body Mass Percent _____________

Skeletal Muscle Mass ___________lbs Skeletal Muscle Mass Percent _____________

Resting Metabolic Rate

RMR ____________RQ ___________CV ____________

BOT™-2

Composite Score: _________ **Standard Score:** _________ **Percentile Rank:** _________

Descriptive Category: ____________________ **Dominant Hand:** _______________

Push up type: ☐ Full ☐ Knee

Graded Exercise Test

Exercise Time: __________

Max VO2: __________ml/kg/min

Percent Predicted VO2:_________

Max HR: __________

Predicted Max HR: __________

Max Lactate Value: __________

Test Type:			
Time	HR	BP	RPE
Pre-Test			
End of Exercise			
2-min Post Ex			
5-min Post Ex			

Comments:
____
____
____
____

Completed Assessment: ____ Date: ___________
Assisted By: ____ Date: ___________

CURRICULUM VITAE

Caroline Frye

Education

Master of Science (MS), May 2024
University of Louisville; Louisville, KY
Concentration: Exercise Physiology
Thesis: Relationships between fitness levels, physical activity participation, hemoglobin A1c levels, and motor proficiency in adolescent patients with type 1 diabetes

Committee: Dr. Kristi King (Chairperson), Dr. Jason Jaggers and Dr. Kimberly Hartson
Partnership: Amy Sketch, Research Scientist, Wendy Novak Diabetes Institute

Bachelor of Science (BS), May 2022
University of Kentucky, Lexington, KY
Concentration: Kinesiology
Minor in Coaching (Sport and Fitness)
Summa Cum Laude – 4.0 GPA

Work Experience

Instructor, August 2023 – December 2023
University of Louisville, Department of Health and Sport Sciences, Louisville, KY

- Created lesson plans, assignments & quizzes, and taught undergraduate students
    - HSS 184: Healthy Lifestyles I, 1 section

Graduate Assistant, August 2022 - Current
University of Louisville, Department of Health and Sport Sciences, Exercise Physiology program, Louisville, KY

- **Research Experience**, May 2023 – Current
    - Novak Center for Children's Health, Wendy Novak Diabetes Institute, Christensen Family Sport and Activity Program, 411 E. Chestnut Street, Louisville, KY, 40202
    - Assist faculty in collecting research data from human subjects, analyzing data, and preparing manuscripts and presentations for university, local, and peer-reviewed audiences
    - Collaborate with primary investigator, research staff, and clinic staff
- **Teaching Assistant,** August 2022 - Current
    - Assist faculty in administering exercise tests, teaching undergraduate students & grading assignments, and maintaining exercise physiology laboratory equipment

- HSS 202: Human Anatomy and Physiology, 1 section
- HSS 377: Foundations of Quantitative Statistics, 1 section
- HSS 387: Biomechanics, 4 sections
- HSS 391: Advanced Human Anatomy and Physiology II Lab, 8 sections
- HSS 395: Fitness Assessment and Prescription, 1 section
- HSS 396: Lab Methods in Fitness Evaluation, 4 sections
- HSS 486: Advanced Exercise Physiology, 2 sections
- EXP 601: Lab Methods in Exercise Physiology, 1 section

Bingocize Volunteer, August 2023 – October 2023
Christian Health Center, Louisville, KY

- Led modified exercises between rounds of bingo for residents of an assisted living facility

Hospital Operations Intern, May 2022 – August 2022
Norton Hospital, Norton Healthcare, Louisville, KY

- Devised and carried out a project to reorganize the surgical core
- Collaborated with Registered Nurses and the Business Manager to identify needed tools and remove unnecessary items
- Will save the department $10K+ a year and prevent excessive overstock if the project guidelines are maintained

Facility Manager, May 2021 – May 2022
University of Kentucky, Campus Recreation and Wellness, Lexington, KY

- Performed facility inspections, inventory, cleaning audits, and nightly reports for two multi-million-dollar facilities
- Conducted monthly risk management drills with First Aid/CPR/AED emphasis to gauge employee emergency action plan knowledge
- Interviewed potential employees and assessed employee performance by conducting evaluations of 160+ staff members

Research Projects

Wendy Novak Diabetes Institute, affiliated with UofL School of Medicine

1. Resistance Training Methods Impact on Glycemic Excursion and Metabolic Pathways in Type 1 Diabetes Mellitus, May 2023 – Current
   a. Assess glucose response to different resistance training methods
   b. To assess for correlation between lactate and glucose using different resistance training methods
2. Effect of Sports and Activity Program on Health Outcomes in Individuals with Diabetes Mellitus at the Wendy Novak Diabetes Center, May 2023 – Current
   a. Primary aim: improve glycemic control of individuals with diabetes participating in physical activity
      i. Performing: fitness testing, glucose control and activity monitoring, and diabetes and exercise education

b. Secondary aims: explore acute glucose response to fitness testing and explore patient-initiated contact regarding diabetes management with diabetes educators while participating in a sport and activity clinical program

Peer-Reviewed Research Presentations

1. Thrasher, B. J., Sketch, A. E., Olajuyigbe, T., **Frye, C. E.**, Wintergerst, K. A. (June 2024). *Relationships between diagnosis duration, motor proficiency, and physical fitness in youth with T1D.* Poster presentation at American Diabetes Association 84th Scientific Sessions, Orlando, FL.
2. Sketch, A. E., Olajuyigbe, T., **Frye, C. E.**, Wintergerst, K. A., & Thrasher, B. J. (May 2024). *Impact of a sports and activity program on a 14-year-old athlete with new onset T1D.* Poster presentation at the 2024 Annual American College of Sports Medicine Meeting and World Congresses, Boston, MA.
3. **Frye, C. E.**, King, K. M., Sketch, A. E., Jaggers, J. R., Hartson, K. R., Olajuyigbe, T., Thrasher, B. J., Wintergerst, K. A. (May 2024). *Relationships between fitness, physical activity, hemoglobin A1c, and motor proficiency in adolescents with T1D.* Poster presentation at the 2024 Annual American College of Sports Medicine Meeting and World Congresses, Boston, MA.
4. **Frye, C. E.**, King, K. M., Sketch, A. E., Jaggers, J. R., Hartson, K. R., Olajuyigbe, T., Thrasher, B., & Wintergerst, K. (March 2024). *Relationships amongst fitness components, physical activity, hemoglobin A1c, and motor proficiency in adolescents with T1D.* Oral presentation at Graduate Student Regional Research Conference, Louisville, KY.
5. **Frye, C. E.**, King, K. M., Sketch, A. E., Jaggers, J. R., Hartson, K. R., Olajuyigbe, T., Thrasher, B., & Wintergerst, K. (February 2024). *Adolescents with T1D and the relationship between fitness, physical activity, hemoglobin A1c, and motor proficiency.* Oral presentation at Spring Research Conference, Louisville, KY.
6. King, K. M., Jaggers, J., R., **Frye, C.**, McKay, T. E., Sketch, A. E., Watson, S., Thrasher, B. J., & Wintergerst, K. A. (May 2023). *Sociodemographic characteristics and program compliance of children newly diagnosed with type 1 diabetes participating in a clinical sports medicine program*. Poster presentation at the 2023 Annual American College of Sports Medicine Meeting and World Congresses, Denver, CO.
7. **Frye, C.**, King, K. M., Jaggers, J., R., McKay, T. E., Sketch, A. E., Watson, S., Thrasher, B. J., & Wintergerst, K. A. (March 2023). *Program compliance and demographic characteristics of children with recent type 1 diabetes diagnoses enrolled in a clinical sports medicine program*. Oral presentation at the Graduate Student Regional Research Conference, Louisville, KY.
8. **Frye, C.**, King, K. M., Jaggers, J., R., McKay, T. E., Sketch, A. E., Watson, S., Thrasher, B. J., & Wintergerst, K. A. (March 2023). *Children with recent type 1 diabetes diagnoses enrolled in a clinical sports medicine program: Program compliance and sociodemographic characteristics*. Oral presentation for Spring Research Conference, Cincinnati, OH.

Invited Presentations

1. **Frye, C. E.** (October 2023). Graduate school lecture. Presented to University of Louisville undergraduate students registered for HSS 310: Healthy Lifestyles II, Louisville, Kentucky.
2. **Frye, C. E.** (April 2023). Graduate school lecture. Presented to University of Louisville undergraduate students registered for HSS 184: Healthy Lifestyles I, Louisville, Kentucky.
3. **Frye, C. E.** (March 2023). Children and aging lecture. Presented to University of Louisville undergraduate students registered for HSS 486: Advanced Exercise Physiology, Louisville, Kentucky.
4. **Frye, C. E.** (February 2023). Cardiorespiratory fitness lecture. Presented to University of Louisville undergraduate students registered for HSS 184: Healthy Lifestyles I, Louisville, Kentucky.
5. **Frye, C. E.** (November 2022). Metabolic concerns lecture. Presented to University of Louisville undergraduate students registered for HSS 395: Fitness Assessment and Prescription, Louisville, Kentucky.
6. **Frye, C. E.** (September 2022). Bones lecture. Presented to University of Louisville undergraduate students registered for HSS 202: Human Anatomy and Physiology, Louisville, Kentucky.

Internal Funding Sources

1. Frye, C. E. (January 2024 – May 2024). *National American College of Sports Medicine Conference*
    a. Description: Grant for graduate students traveling to National American College of Sports Medicine conference Boston
    b. Role: Presenter
        i. Sketch, A. E., Olajuyigbe, T., **Frye, C. E.**, Wintergerst, K. A., & Thrasher, B. J. *Impact of a sports and activity program on a 14-year-old athlete with new onset T1D.*
        ii. **Frye, C. E.**, King, K. M., Sketch, A. E**.**, Jaggers, J. R., Hartson, K. R., Olajuyigbe, T., Thrasher, B. J., Wintergerst, K. A. *Relationships between fitness, physical activity, hemoglobin A1c, and motor proficiency in adolescents with T1D.*
    c. Funding Source: University of Louisville Graduate Student Council
    d. Funding Amount: $350.00

2. Frye, C. E. (January 2023 – May 2023). *National American College of Sports Medicine Conference*
    a. Description: Grant for graduate students traveling to National American College of Sports Medicine conference Denver
    b. Role: Presenter
        i. King, K. M., Jaggers, J., R., **Frye, C.**, McKay, T. E., Sketch, A. E., Watson, S., Thrasher, B. J., & Wintergerst, K. A. *Sociodemographic characteristics and program compliance of children newly diagnosed with type 1 diabetes participating in a clinical sports medicine program*.
    c. Funding Source: University of Louisville Graduate Student Council
    d. Funding Amount: $200.00

Professional Membership, Certifications, Skills and Development, and Awards

Professional Membership

1. American College of Sports Medicine (ACSM) member, March 2023 – Current
2. Exercise is Medicine-On Campus, 2021 – 2022, 2024

Certifications

1. CPR/AED/First Aid Certification, August 2019 – Current

Professional Skills

1. Statistical Package for Social Sciences (SPSS), June 2023
2. EPIC, May 2023: trains healthcare professionals on EMR system
3. REDCap, May 2023: Secure web application for building and managing online surveys and databases
4. Fitness testing: VO2max/submax, lactate threshold, hydrostatic weighing, blood pressure/heart rate, resting metabolic rate, muscular strength and endurance, bioelectrical impedance analyses, anaerobic capacity and power, FMS, ECG, ForceDecks
5. Motor Proficiency testing: BOT™-2
6. Citi Program, August 2022: Human Subjects and HIPAA Research
7. Citi Program, August 2022: RCR Basic Course

Professional Development and Committee Participation

1. University of Louisville, Exercise is Medicine-On Campus Leadership Team, February 2024 - Current
2. University of Louisville, Research Grant Committee, Graduate Student Council, September 2023 - Current
3. University of Louisville, Graduate Student Council Representative for Exercise Physiology, August 2022 – Current

Awards & Honors

1. University of Louisville, College of Education and Human Development, Ellis J. Mendelsohn Award, April 2024
2. University of Louisville Graduate Dean's Citation, April 2024
3. University of Louisville Exercise is Medicine-On Campus – Silver Level, March 2024
4. University of Louisville Faculty Favorite, 2022 - 2023
5. University of Kentucky Campus Recreation and Wellness Employee of the Year, May 2022
6. University of Kentucky Campus Recreation and Wellness Merit Award, May 2022
7. Alpha Phi Omega Gold Sash Recipient, Spring 2021
8. Alpha Phi Omega-Alpha Zeta Most Outstanding Officer, Spring 2021