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Review

Physical activity, sedentary behaviors, physical fitness, and their relation to health outcomes in youth with type 1 and type 2 diabetes: A review of the epidemiologic literature

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Abstract

Diabetes is a leading chronic disease of childhood and adolescence. In addition to the well-known auto-immune, insulin-dependent diabetes mellitus (type 1 diabetes (T1D)), the past two decades have witnessed the emergence of type 2 diabetes (T2D) in children and adolescents, which previously was only seen in middle-aged or older adults. One of the key components of diabetes management is physical activity (PA). The beneficial effects of increased PA and decreased sedentary behavior are extremely important in youth with diabetes because of the markedly increased long-term risk of cardiovascular disease in this population compared to persons without diabetes. This review aims to comprehensively summarize the epidemiologic, observational research published and listed in PubMed between 1970 and 2012 on PA and sedentary behaviors, as well as physical fitness in children and adolescents with T1D and T2D. Additionally, we describe briefly the state of knowledge on perceived barriers of PA in persons with diabetes, with a focus on hypoglycemia. Finally, we provide an overview of the epidemiological literature pertaining to health benefits of increased PA in youth with T1D and T2D and briefly discuss the topic of exercise-related hypoglycemia.

Keywords: Cardiovascular risk; Children; Exercise; Glycemic control; Hypoglycemia; Physical activity; Physical fitness; Sedentary behavior; Type 1 diabetes mellitus; Type 2 diabetes mellitus; Youth

1. Introduction

One of the leading chronic diseases of childhood and adolescence is auto-immune, insulin-dependent diabetes mellitus, which now is commonly referred to as type 1 diabetes (T1D). In T1D, the destruction of pancreatic beta cells leads to insulin deficiency and lifelong dependency on insulin therapy. Unfortunately, the risk of T1D is increasing worldwide at about 2%–3% per year, which has recently been confirmed for non-Hispanic white youth in the United States (USA).[1–3] In 2001, more than 140,000 youth under the age of 20 years in

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the USA were affected by this incurable disease[4] and likely about 3 million persons of all age groups in total.[5,6] Recent estimates from the SEARCH for diabetes in youth study[7] suggest that the burden has substantially increased from 2001 to 2009.[8,9] Despite improvements in treatment of T1D, the trends for cardiovascular complications have not improved.[10] Persons with T1D still exhibit a greater than three-fold higher risk of acute cardiovascular disease (CVD) compared to persons without diabetes, resulting in approximately 7 years of lower life expectancy.[11−15] Among youth with T1D, 14% have two or more CVD risk factors,[16] 6% have hypertension,[17] and 19% present with lipid abnormalities.[18] While adiposity historically has not been considered a characteristic of T1D, the prevalence of overweight (22%) in youth with T1D is higher than their peers without diabetes (16%), while the prevalence of obesity is lower in T1D (13%) than in youth without diabetes (17%).[19] The increases in adiposity in T1D may offset some of the improvements made in T1D care in the past.[20]

Furthermore, the past two decades have witnessed the emergence of type 2 diabetes (T2D) in youth, formerly known as non-insulin dependent diabetes mellitus, and previously only seen in middle-aged or older adults.[21−24] In 2006−2007, the SEARCH for Diabetes in Youth study published some of the first population-based data on the prevalence and incidence of youth T2D in the USA and found that T2D was present in all racial and ethnic groups.[4,25] More recent estimates from SEARCH suggest that the prevalence has increased by more than 20% from 2001 to 2009.[26] Overweight and obesity are extremely common in T2D, affecting about 90% of youth[19] and 92% have two or more CVD risk factors.[16] Hypertension affects approximately 23% of youth with diabetes and lipid abnormalities about 33%.[18] Youth with T1D have been designated Tier 1 (high) risk for CVD by the American Heart Association (AHA), as they constitute a population for which there is "pathological and/or clinical evidence for manifest coronary heart disease before 30 years of age".[27] Youth with T2D have been designated as Tier 2 (moderate) risk for CVD, which is defined as "pathophysiological evidence for arterial dysfunction indicative of accelerated atherosclerosis before 30 years of age".[27]

In this context, the importance of physical activity (PA) is evident, as it is one of the few behavioral factors that have been shown to decrease the risk of CVD and many other chronic conditions.[28,29] PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure.[29] It is therefore not surprising that PA is recognized as one of the four cornerstones of care for persons with diabetes, along with medical nutritional therapy (MNT), glucose monitoring, and medication-based (insulin-based for T1D) management for the achievement of good glycemic control.[30] Patient care is highly advanced for insulin treatment, glucose monitoring and MNT.[31] However, clinical guidelines for exercise and PA, although largely based on evidence on the relation of PA and T2D, are still evolving for T1D youth. In addition, physical fitness, a broad concept encompassing several specific types of fitness including aerobic power, strength, flexibility, and balance[32] is important for persons with diabetes[33] and also is closely related to all-cause mortality.[34,35] Therefore, it is included in our review.

According to the 2008 Physical Activity Guidelines for Americans, "being physically active is one of the most important steps that Americans of all ages can take to improve their health".[28] Children and adolescents should engage in 60 min daily of moderate-to-vigorous PA (MVPA). The recommendations by the American Academy for Pediatric[36] and the World Health Organization[37] are essentially identical. A joint statement issued by the American Diabetes Association and the American College of Sports Medicine recommends 150 min/week of moderate-to-vigorous activity for adults with T2D, "spread out during at least 3 days during the week, with no more than 2 consecutive days between bouts of aerobic activity".[38] Additionally, "…persons with type 2 diabetes should undertake moderate-to-vigorous resistance training at least 2−3 days/week".[38] Current data suggest that only 8% of U.S. youth meet the 60-min/day MVPA recommendation, based on accelerometer data, and that many youth exhibit sedentary behavior and are subsequently largely physically inactive.[39] Summarizing what is known about current PA in youth with T1D and T2D in the USA and worldwide is one of the key aims of this review. Additionally, we also aim to summarize information on sedentary behaviors, defined as "… any waking behavior characterized by an energy expenditure $\leq$1.5 METs while in a sitting or reclining posture" according to the Sedentary Behaviour Research Network (SBRN).[40] We focus on the health risks of sedentary behavior because physical inactivity has been identified as the fourth leading risk factor for global mortality causing an estimated 3.2 million deaths globally.[29] Therefore, it is essential that more information be obtained regarding PA and sedentary behaviors in T1D and T2D youth.

Recently, Chimen et al.[41] published a comprehensive review on the health benefits of PA in T1D focusing on intervention studies. While intervention studies are the gold standard to determining causality, they typically reflect very specific, controlled conditions. Observational research, on the other hand, offers insights into the actual behavior of individuals in free-living situations. Thus, this review will focus on epidemiologic research on PA, and sedentary behaviors and physical fitness in children and adolescents (henceforth referred to as "youth") with T1D and T2D, with youth broadly considered as persons in the first two decades of life. Specifically, this review will address the following:

1. What is known about PA, sedentary behaviors, and physical fitness in youth with T1D and T2D, including the most frequent types, intensities, and settings of PA behaviors in real-life settings?
2. What is known about perceived barriers to PA, including fear of hypoglycemia, in youth with T1D?
3. What can be learned from observational research to date about the health benefits of PA, sedentary behaviors, and physical fitness in youth with T1D and T2D?

2. Methods

Epidemiological studies on PA and diabetes mellitus in youth were identified through Medline/PubMed (MeSH) and key word search terms were “type 1 diabetes mellitus”, “type 2 diabetes mellitus”, “insulin dependent diabetes mellitus”, “IDDM”, and “NIDDM” for diabetes mellitus, “physical activity”, “exercise”, “physical fitness” for PA and fitness, “sedentary lifestyle”, “sedentary behavior”, “sedentary behaviour”, “television”, “video game”, “internet”, “homework”, “reading”, “physical inactivity”, “media use”, “sitting” for sedentary behavior, and “children”, “youth”, “adolescent”, “children, preschool” for youth.

Initially, 837 articles were identified in PubMed with the combination of above MeSH and key word search terms. We limited our search to include entries from January 1, 1970 to August 31, 2012, written in English and performed on human subjects, which reduced the number of articles to 760. We then used the filters from PubMed to remove clinical trials (124), meta-analysis studies and reviews (137), clinical guidelines (4), and editorials (15). In the end, 480 articles were included in the manual review process.

One member of the research team (XM) reviewed these articles (titles and abstracts) identified from PubMed in order to identify those that clearly focused on PA (or physical fitness) and diabetes mellitus in youth and had been conducted with an observational study design (e.g., cross-sectional studies, case-control studies, cohort studies, follow-up studies, case studies, and reports). For articles without abstracts or without study design information in the abstract, we requested the full-length version of the article. Further review of eligible observational studies was conducted by research team members (ADL, XM) with the inclusion criteria in mind. To meet out inclusion criteria, studies had to present original data and results on PA, sedentary behaviors or physical fitness in youth with T1D or T2D and had to be observational in nature. In the 480 studies, most studies were performed among adults, did not focus on PA or fitness, or were conducted with intervention designs (as the systematic identification of clinical trials as a publication type in PubMed was only introduced in 2008 and applied retrospectively through 1991). In the end, there were 38 studies meeting our inclusion criteria. Among these, one letter was included because the authors reported original results.

The reference list of each eligible publication was carefully reviewed to identify additional studies (3 studies) which were not identified in the PubMed search. If multiple publications originated from the same study, all were included as long as the results were not duplicative. We also included one study focusing on energy expenditure measured using Armbands and two studies that were in press. In the end, $n = 44$ observational studies on PA, sedentary behaviors, or physical fitness and diabetes in youth were included.

Furthermore, since hypoglycemia can be a serious consequence of PA in persons with T1D and T2D, we also examined these 44 publications for studies examining barriers to physical activities, specifically fear of hypoglycemia, and provided a brief overview of the issue. While a comprehensive review of hypoglycemia is a topic onto itself,[42–45] our interest here was in how hypoglycemic fear affects PA and therefore we focused our paper accordingly. Lastly, we discussed the epidemiologic studies focusing on health benefits of PA or fitness in youth with T1D or T2D in the interest of supplementing the intervention literature, which has been summarized previously.[41]

3. Results

3.1. PA, sedentary behaviors, and physical fitness in youth with T1D and T2D

The literature on PA and sedentary behaviors in youth with diabetes is still quite finite. PA research for persons with T1D has been increasing rapidly in the past decade, whereas for persons with T2D it is still extremely limited. In the following section, we summarize the literature with respect to (1) the type of instruments used to assess PA and sedentary behavior, (2) the amount and type of activity and the amount of sedentary behaviors observed in youth with diabetes, (3) how the amounts in youth with T1D and T2D compare to each other and to youth without diabetes, and (4) what is known about fitness levels in youth with diabetes. Table 1 provides a brief summary of all epidemiologic studies on PA, sedentary behaviors, and physical fitness in youth with diabetes that were included in this review. Papers are listed alphabetically by the first author’s last name and the citation number is included as superscripts.

3.1.1. Assessment methods for PA and sedentary behaviors

Table 1 provides an overview of the types of instruments used to assess PA and sedentary behavior.[46–89] About half of the studies published to date have utilized questionnaires (either self-reported by the participants or their parents) with the other half relying on objective measurement of PA. Questionnaire-types ranged from short screener instruments,[46,50,54,56,57,60,62,64,67,69] to longer structured instruments such as the previous day PA recall (PDPAR),[59] 3-day PA recall (3DPAR),[58,61] 7-day PA recall,[51,52,68] the PA questionnaire (PAQ-A),[49,53] other structured instruments,[48,50,63] and the use of diaries.[65] The vast majority of these instruments have been validated, and there were only four studies for which we could not confirm whether validation had occurred.[48,63,65,66] Objective assessment of PA or physical fitness included using heart rate monitoring,[73,74,80,84] exercise/fitness testing,[70,71,78,88] pedometers (also known as step counters),[82] and accelerometers (activity monitors that measure position and motion).[59,85,87] One study used Armband technology.[53] Before considering what is known to date about the amount and type of activity observed in youth with diabetes, it is important to point out that a large proportion of published descriptive papers have relied on sample sizes of less than 100 youth, including (with a few exceptions)[46,50,51,54,56–58,60,62–64,67,69,78,80–82] the majority of studies that used objective measurements.

In reviewing the literature, one needs to keep in mind that in general, self-report of PA is likely to be overestimated.[90,91]

Table 1
Summary of observational studies on PA, sedentary behavior, or physical fitness in youth with diabetes by instrument type.

Author[a]	Place & time	Study design	Age range (mean ± SD, year)	Sample size & composition	PA, fitness, and sedentary behavior	
					Instrument & respondent	Type of activity, fitness, or sedentary behavior assessed
Questionnaires/interviews						
Aman et al.[46]	International, 2009	Cross-sectional	11.0−19.0	2269 T1D	Questionnaire Patient	Moderately physically active (causing increased heart rate and/or breathlessness) for 60 min, days in last week; hours watching TV during 1 day
Benevento et al.[47,c]	Italy, 2010	Cross-sectional	10.0−35.0	86 T1D	Questionnaire Patient	Weekly hours spent in sports; daily hours spent on TV watching or computer use
Bernardini et al.[48]	Italy, 2004	Cross-sectional	10.0−18.0	91 T1D	Questionnaire Patient	RPA, time weekly spent for PA and the type of exercise usually performed in school and spare time, min/week
Chen et al.[49]	Taiwan China, 2008	Case-control	8.0−12.0	93 T1D 107 controls	PAQ-C questionnaire Participant	Nine items referring to physical activity during the past 7 days, physical activity level was determined according to the mean scale of the nine items as low (≤2), moderate (2−3), and high activity (>3)
Fainardi et al.[50]	Italy, 2011	Case-control	11.0−13.0	124 T1D 214 controls	Questionnaire Participant	RPA, occasions/week, min/day, session time in the day and 7 days before the questionnaire; TV watching and videogames playing
Faulkner et al.[51,b]	USA, 2010	Cross-sectional	13.0−18.0	109 T1D 42 T2D	7DPAR questionnaire Cycle ergometer Patient	RPA, MET/day; VO_{2peak} (mL/kg/min)
Faulkner et al.[52]	USA, 2005	Cross-sectional	13.0−18.0	105 T1D 27 T2D	7DPAR questionnaire Patient	RPA, sleep (1.0 MET), light (1.5 METs), moderate (4.0 METs), hard (6.0 METs), and very hard (10 METs)
Fintini et al.[53,b]	Italy, 2012	Case-control	10.2 ± 0.8	35 T1D 31 controls	PAQ questionnaire Treadmill Sensewear armband	Sedentary activity (h/day), PA (h/day), total daily energy expenditure (cal/day), MET/day, VO_{2max} (mL/kg/min)
Galler et al.[54]	Germany, 2011	Cross-sectional	13.7 ± 4.1	296 T1D	Questionnaire Patient	RPA and media consumption, h/week
Guillory et al.[55]	USA, 2012	Cross-sectional	9.0−17.0	75 T2D	GAQ questionnaire Patient	MVPA was calculated based on MET values for youth for each of 28 activities, min/day
Herbst et al.[56]	Germany, Austria, 2007	Cross-sectional	3.0−18.0	23,251 T1D	Questionnaire Patient/parent	RPA defined as performed regularly for at least 30 min/week, exclude school sports, RPA0 (none), RPA1 (1−2 times/week), RPA2 (≥3 times/week)

Table 1 (*continued*)

Author[a]	Place & time	Study design	Age range (mean ± SD, year)	Sample size & composition	PA, fitness, and sedentary behavior	
					Instrument & respondent	Type of activity, fitness, or sedentary behavior assessed
Herbst et al.[57]	Germany, Austria, 2006	Cross-sectional	3.0−20.0	19,143 T1D	Questionnaire Patient/parent	RPA defined as performed regularly for at least 30 min/week, exclude school sports, RPA0 (none), RPA1 (1−2 times/week), RPA2 (≥3 times/week)
Lobelo et al.[58]	USA, 2010	Case-control	10.0−20.0	384 T1D 90 T2D 173 Controls	3DPAR questionnaire Participant	About 80 activities and EM use and television use, 30-min time increment, VPA (>6 METs), MVPA (>3 METs), MPA (3−6 METs)
Maahs et al.[59,b]	USA, 2012	Cross-sectional	15.0 ± 2.0	30 T1D	PDPAR questionnaire Accelerometer Patient	The respondent reported the dominant activity and the approximate intensity of that activity for that period; sedentary, ≤50 counts/min; light, 51−2000; moderate, 2001−2900; and vigorous, >2900
Margeirsdottir et al.[60]	Norway, 2007	Cross-sectional	13.1 ± 3.7	538 T1D	Interview Patient/parent	Daily time spent watching TV or using a computer (including time spent playing computer games), h/day
Nadeau et al.[61,b]	USA, 2009	Case-control	12.0−19.0	14 T2D 13 obese controls 12 lean controls	3DPAR questionnaire Cycle ergometer Participant	Habitual PA as a 3-day average of MET/day; exercise testing (VO_{2peak}, respiratory exchange ratio, peak work rate)
Overby et al.[62]	Norway, 2009	Cross-sectional	11.0−19.0	723 T1D	Questionnaire Patient	Activity on weekdays and weekends and during and after school, VPA (>6 METs), MPA (3−6 METs)
Raile et al.[63]	Germany, 1999	Case-control	6.0−18.0	142 T1D 97 controls	Questionnaire Patient	Time spent for PA and sports in school, in competitive sports, and in spare time, h/week
Rothman et al.[64]	USA, 2008	Cross-sectional	12.0−21.0	103 T2D	Questionnaire Patient	Exercise behaviors: frequency of exercise for more than 20 min (time/week), TV viewing (h/day)
Sackey et al.[65]	UK, 1996	Cross-sectional	12.3 ± 3.5	58 T1D, T2D	6-day PA diary Patient	Daily activity from Friday to Wednesday, each activity was assigned a score and activity score was calculated by the scheme of the scoring
Salvatoni et al.[66]	Italy, 2005	Follow-up	8.98 ± 3.90	69 T1D	Questionnaire Patient	RPA, hours of PA in past week
Schweiger et al.[67]	USA, 2010	Cross-sectional	11.0−19.0	203 T1D girls	PACE+ questionnaire Patient	60 min MVPA day/week

(*continued on the next page*)

Table 1 (*continued*)

Author[a]	Place & time	Study design	Age range (mean ± SD, year)	Sample size & composition	PA, fitness, and sedentary behavior	
					Instrument & respondent	Type of activity, fitness, or sedentary behavior assessed
Shaibi et al.[68,b]	USA, 2009	Cross-sectional	15.8 ± 1.8	40 T2D	7DPAR questionnaire Cycle ergometer Patient	MVPA, VO_{2peak} (mL/kg/min)
Valerio et al.[69]	Italy, 2007	Case-control	13.6 ± 4.1	407 T1D	Questionnaire Patient	MVPA in spare time and number and kind of sports played in the last 12 months, number of 60 min MVPA day/week
Objective PA monitors						
Arslanian et al.[70]	USA, 1990	Case-control	12.0−19.0	27 T1D 10 controls	Cycle ergometer Participant	VO_{2max} (mL/kg/min)
Austin et al.[71]	USA, 1993	Case-control	15.6 ± 2.5	59 T1D 18 Controls	Cycle ergometer Participant	VO_{2max} (mL/kg/min)
Baraldi et al.[72]	Italy, 1992	Case-control	9.0−15.0	33 T1D 47 Controls	Treadmill Participant	VO_{2max} (mL/kg/min)
Edmunds et al.[73]	UK, 2010	Cross-sectional	12.7 ± 2.1	37 T1D	Heart rate monitoring Patient	Habitual physical activity: VPA (≥75% HRR), MVPA (≥50% HRR); VO_{2peak}
Edmunds et al.[74]	UK, 2007	Cross-sectional	12.8 ± 2.1	36 T1D	Heart rate monitoring Patient	Habitual physical activity: VPA (≥75% HRR), MVPA (≥50% HRR); VO_{2peak}
Gusso et al.[75]	New Zealand, 2008	Case-control	12.0−18.0	12 T1D girls 8 T2D girls 20 controls	Cycle ergometer	VO_{2max}
Heyman et al.[76]	France, 2005	Case-control	8.5−13.0	17 T1D boys 18 controls	Cycle ergometer Patient	PWC_{170}
Heyman et al.[77]	France, 2007	Case-control	13.3−18.2	19 T1D girls 19 controls	Cycle ergometer Patient	PWC_{170}, VO_{2max}
Huttunen et al.[78]	Finland, 1984	Case-control	6.0−18.0	178 T1D	PWC test Patient	Four successive sessions, 4 min
Kornhauser et al.[79]	Mexico, 2011	Cross-sectional	10.0−18.0	10 T1D	Cycle ergometer Patient	VO_{2max}
Massin et al.[80]	Belgium, 2005	Cross-sectional	3.0−16.0	127 T1D	Heart rate monitoring Patient	Light (20%−40% HRR), moderate (40%−50% HRR), vigorous (>50% HRR)
Michaliszyn et al.[81]	USA, 2009	Cross-sectional	15.3 ± 1.9	109 T1D	Cycle ergometer Patient	VO_{2peak}
O'Neill et al.[82]	USA, 2012	Case-control	10.0−20.0	304 T1D 49 T2D 127 controls	Pedometers participant	Step/day, 7 days
Poortmans et al.[83]	Belgium, 1986	Case-control	16.2 ± 0.7	17 T1D 17 controls	Cycle ergometer Patient	PWC_{170}, VO_{2max}
Roche et al.[84]	UK, 2008	Cross-sectional	12.5 ± 2.0	29 T1D	Heart rate monitoring Treadmill test Patient	Habitual PA: VPA (≥75% HRR), MVPA (≥50% HRR); VO_{2peak}
Särnblad et al.[85]	Sweden, 2005	Case-control	15.7 ± 2.1	26 T1D girls 49 controls	Accelerometer Patient	Accelerometer worn for 7 days, SLPA (<1952 counts/min), MVPA (>1952 counts/min)
Shaibi et al.[86]	USA, 2008	Case-control	16.4 ± 0.6	13 T1D boys 13 controls	Cycle ergometer Patient	VO_{2peak}
Trigona et al.[87]	Switzerland, 2010	Case-control	6.0−17.0	32 T1D 42 controls	Accelerometer Treadmill test Participant	SLPA (<1999), MVPA (>2000); VO_{2max}

Table 1 (*continued*)

Author[a]	Place & time	Study design	Age range (mean ± SD, year)	Sample size & composition	PA, fitness, and sedentary behavior	
					Instrument & respondent	Type of activity, fitness, or sedentary behavior assessed
Williams et al.[88]	Australia, 2011	Case-control	5.0−14.0	88 T1D 62 controls	Submaximal step test Participant	The heart rate response to stepping was recorded before the test, after 2 min of exercise and 5 s after completion of the test
Wittmeier et al.[89]	Canada, 2012	Case-control	13.0−18.0	27 T2D 110 controls	Cycle ergometer Patient	VO_{2peak}

Abbreviations: T1D = type 1 diabetes; T2D = type 2 diabetes; 3DPAR = 3-day physical activity recall; 7DPAR = 7-day physical activity recall; PDPAR = previous day physical activity recall; PACE+ = patient-centered assessment and counseling for exercise plus nutrition; PAQ-C = physical activity questionnaire for children; PWC = physical working capacity; EM = electronic media; PA = physical activity; RPA = regular physical activity; VPA = vigorous physical activity; MVPA = moderate/vigorous physical activity; MPA = moderate physical activity; SLPA = sedentary-to-light physical activity; MET = metabolic equivalent; HRR = heart rate reserve; VO_{2max} = maximal oxygen consumption; VO_{2peak} = peak oxygen consumption.

[a] The studies were sorted by the last name of the first authors.

[b] This study included both questionnaire and objective activity test for PA.

[c] 56 of 86 participants were schoolchildren and 30 were adults with a regular employment.

With this caveat in mind, the following picture emerges on PA (Table 2) and sedentary behavior patterns (Table 3) in youth with diabetes, each of which will be discussed sequentially by type of diabetes.

3.1.2. PA levels in youth with T1D

Studies using shorter questionnaires or screener items with more global assessments of PA suggest that T1D youth are not entirely inactive, as results range from 22 to 76 min/day of self-reported PA, recognizing that these studies span a variety of settings and age groups.[47,48,50,54,56,57,63,66] According to the largest study of self-reported PA to date published by Herbst et al.,[56,57] youth in Germany and Austria reported an average of 1.3 units of 30 min/week of regular PA that was conducted outside of school. About 45% were not physically active at all, 37% engaged in 1−2 units of regular PA per week, and 18% in 3 or more units.

More detailed information can be obtained from studies distinguishing different levels of intensity of activity based on self-report, i.e., vigorous PA (VPA), moderate PA (MPA), the aggregated category of MVPA (which is particularly important as it links to current guidelines), sedentary behavior (SB), and light PA (LPA). Note that for the sake of comparability across studies, as before, we converted study-specific measurement units to minutes per day. According to studies relying on self-report, time spent in VPA by adolescents with T1D (10 years and older) ranged from 3 to 57 min/day.[58,62] Time spent in MVPA ranged from 65 to 156 min/day in adolescent boys with T1D and from 50 to 156 min/day in adolescent girls with T1D.[58,62] Monitor-based studies suggest that the lower end of these ranges may be more realistic, with studies ranging from 6 to 25 min of VPA[74,80,84] and 46−70 min/day of MVPA.[74,80,84,85,87] These rather wide ranges are likely due to the wide age range examined in the study populations. For the sake of comparison to a general population of youth, accelerometer data from the 2003−2004 NHANES indicate that during ages 12−15, adolescent boys and girls obtain about 45 and 25 min/day of MVPA, respectively, whereas 16−19 years old boys and girls spend 33 and 20 min/day of MVPA, respectively.[39] Most studies suggest that boys with diabetes tend to be more active than girls with diabetes.[46,48,58,62,66,69,74,84] One study reported PA in terms of metabolic equivalents of a task (METs).[51,52]

In terms of meeting recommendations, we focused on youth reaching at least 60 min of MVPA per day, in line with current recommendations issued in the USA and by the World Health Organization.[28,37] Data based on 3DPAR suggest that about 81%−82% of youth with T1D achieve 60 min of MVPA per day,[58] which is likely a substantial overestimate given that the average of pedometer-based steps per day (Girls: 6773 ± 2986; Boys: 8071 ± 3702) was substantially lower than the recommended levels (e.g., school-age boys: 13,000−15,000, school-age girls: 11,000−12,000, and adolescent boys and girls: 10,000−11,700).[82,92] Trigona et al.[87] reported that 35% of youth with T1D spent a minimum of 60 min per day engaged in MVPA. Schweiger et al.[67] reported an average of 3.1 days for meeting the recommendations, with only 4.7% of youth meeting the recommendation of 60 min of PA each day, and 35% on 5 or more days, but 30% reported only one or no days per week of 60 min of PA. Aman et al.[46] reported 4.2 days of meeting the 60-min recommendation for boys and 3.6 days for girls with T1D in a typical week. In comparison, accelerometer data from the U.S. national NHANES study suggest that only 11% of boys and 4% of girls aged 12−19 participate in the recommended amount of PA. Accelerometry is currently the gold standard for measurement of PA of all ages.[93,94]

New measurement tools of PA and energy expenditure are continuously being developed. SenseWear armbands are versatile monitors that allow for convenient collection and analysis regarding PA in the free-living environment. The instrument has shown reasonable concordance with doubly labeled water for measuring daily energy expenditure in free-living.[95] A recently published study reported that the amount

Table 2
Amount and type of PA observed in youth with diabetes.

Author	All	Males	Females
Type 1 diabetes			
Studies with global measure of activity or sedentary behavior			
Benevento et al.[47,b]	PA: 22.7 ± 19.3 min/day		
Bernardini et al.[48]	Exercise: 62.6 ± 31.6 min/day Sports: 26.6 ± 22.1 min/day Spare time: 36 ± 22.6 min/day	Exercise: 67.1 ± 41.1 min/day	Exercise: 56.6 ± 29.3 min/day
Chen et al.[49]	Low level: 29/93 = 31.2% Moderate level: 45/93 = 48.4% High level: 19/93 = 20.4%	–	–
Fainardi et al.[50]	PA: 76.2 ± 49.4 min/day	–	–
Faulkner et al.[51]	PA: 34.9 ± 3.5 METs/day	–	–
Faulkner et al.[52]	PA: 34.7 ± 3.1 METs/day	–	–
Galler et al.[54]	PA: 43.7 ± 38.6 min/day	–	–
Herbst et al.[56]	30 min RPA[c]: 1.29 times/week Not physically active: 44.7% RPA[c] 1–2 times/week: 37.0% RPA[c] ≥times/week: 18.3%	–	–
Herbst et al.[57]	30 min RPA[c]: 1.30 times/week	–	–
O'Neill et al.[82]	7413 ± 3415 steps/day	6773 ± 2986 steps/day	8071 ± 3702 steps/day
Raile et al.[63]	PA: 58.3 min/day	–	–
Salvatoni et al.[66]	PA: 25.7 ± 24.8 min/day	PA: 33.4 ± 24.8 min/day	PA: 21.4 ± 18 min/day
Studies measuring intensity			
Aman et al.[46]	–	60 min MVPA[j] (last week): 4.1 ± 2.5 days 60 min MVPA[j] (typical week): 4.2 ± 2.4 days	60 min MVPA[j] (last week): 3.3 ± 2.4 days 60 min MVPA[j] (typical week): 3.6 ± 2.2 days
Edmunds et al.[74]	MVPA[d]: 57.00 ± 32.50 min/day VPA[d]: 9.81 ± 12.43 min/day	MVPA[d]: 66.40 ± 34.02 min/day VPA[d]: 15.59 ± 15.37 min/day	MVPA[d]: 47.59 ± 28.86 min/day VPA[d]: 4.03 ± 3.36 min/day
Fintini et al.[53]	PAQ PA: 36 ± 18 min/day Armband PA ≥3 METs: 108 ± 48 min/day 1.8 ± 0.3 METs/day Total energy expenditure: 1308.3 ± 231.2 cal/day Active energy expenditure: 406.4 ± 258.6 cal/day	–	–
Lobelo et al.[58,a]	–	VPA[e]: 57 ± 6 min/day MVPA[e]: 156 ± 9 min/day MPA[e]: 102 ± 12 min/day Meeting VPA standard: 48.7 ± 4.3% Meeting MVPA standard: 82.3% ± 3.5%	VPA[e]: 36 ± 6 min/day MVPA[e]: 156 ± 9 min/day MPA[e]: 117 ± 9 min/day Meeting VPA standard: 39.4% ± 4.2% Meeting MVPA standard: 81.3% ± 3.4%
Maahs et al.[59]	VPA[f]:6–9 min/day MPA[f]: 9–11 min/day LPA[f]: 259–278 min/day SPA[f]: 592–632 min/day	–	–
Massin et al.[80]	**Preschool children:** VPA[g]: 21.3 ± 9.4 min/day MPA[g]: 39.1 ± 24.3 min/day LPA[g]: 192.7 ± 78.1 min/day **School children:** VPA[g]: 19.0 ± 14.8 min/day MPA[g]: 37.9 ± 15.9 min/day LPA[g]: 168.9 ± 76.7 min/day **Teenagers:** VPA[g]: 25.2 ± 15.3 min/day MPA[g]: 45.6 ± 26.9 min/day LPA[g]: 166.3 ± 67.5 min/day	–	–

Table 2 (*continued*)

Author	All	Males	Females
Overby et al.[62]	–	**6–10 years old:** VPA[e]: 0.5 ± 4 min/day MPA[e]: 88 ± 53 min/day **11–19 years old:** VPA[e]: 8 ± 24 min/day MPA[e]: 57 ± 49 min/day	**6–10 years old:** VPA[e]: 0.3 ± 4 min/day MPA[e]: 70 ± 51 min/day **11–19 years old:** VPA[e]: 3 ± 14 min/day MPA[e]: 47 ± 42 min/day
Roche et al.[84]	MVPA[d]: 46.6 ± 24.5 min/day VPA[d]: 5.8 ± 6.0 min/day	MVPA[d]: 57.1 ± 24.6 min/day VPA[d]: 8.9 ± 6.7 min/day	MVPA[d]: 35.2 ± 19.4 min/day VPA[d]: 2.6 ± 2.8 min/day
Särnblad et al.[85]	–	–	MVPA[h]: 56 ± 20 min/day LPA[h]: 314 ± 60 min/day SPA[h]: 443 ± 60 min/day
Schweiger et al.[67]	–	–	60 min MVPA[k] (last week): 2.6 ± 2.3 days 60 min MVPA[k] (typical week): 3.1 ± 2.2 days
Trigona et al.[87]	MVPA[i] (95%CI): 53.3 (32.9–73.7) min/day SLPA[i] (95%CI): 618.6 (548.9–688.2) min/day %MVPA[i] (95%CI) (% in total PA): 7.6 (5.9–9.3) N of subjects with MVPA[i] > 60 min/day (%): 9 (35)	–	–
Valerio et al.[69]	60 min MVPA[k]: 2.8 ± 2.5 days/week	60 min MVPA[k]: 3.5 ± 2.6 days/week	60 min MVPA[k]: 2.1 ± 2.3 days/week
Type 2 diabetes			
Faulkner et al.[51]	PA: 33.7 ± 1.6 METs/day	–	–
Faulkner et al.[52]	PA: 33.5 ± 1.4 METs/day	–	–
Guillory et al.[55]	MVPA: 6.5 ± 4.5 min/day	MVPA: 7.3 ± 4.7 min/day	MVPA: 6.0 ± 4.4 min/day
Lobelo et al.[58,a]	–	VPA[e]: 33 ± 12 min/day MVPA[e]: 153 ± 24 min/day MPA[e]: 120 ± 21 min/day Meeting VPA standard: 35.9% ± 9.7% Meeting MVPA standard: 64.6% ± 7.8%	VPA[e]: 33 ± 9 min/day MVPA[e]: 141 ± 15 min/day MPA[e]: 111 ± 15 min/day Meeting VPA standard: 32.9% ± 6.6% Meeting MVPA standard: 71.3% ± 5.3%
Nadeau et al.[61]	Habitual PA: 64.0 ± 18.8 METs/day	–	–
O'Neill et al.[82]	4959 ± 3474 steps/day	4565 ± 3633 steps/day	6175 ± 2708 steps/day
Rothman et al.[64]	Excise frequency (20 min): None: 18% 1–3 times/week: 48% ≥4 times/week: 34%	–	–
Shaibi et al.[68]		MVPA: 38.8 ± 27.2 min/day	MVPA: 32.3 ± 26.9 min/day

Abbreviations: 3DPAR = 3-day physical activity recall; 7DPAR = 7-day physical activity recall; PACE+ = patient-centered assessment and counseling for exercise plus nutrition; PAQ-C = physical activity questionnaire for children; RPA = regular physical activity; VPA = vigorous physical activity; MVPA = moderate/vigorous physical activity; MPA = moderate physical activity; SLPA = sedentary-to-light physical activity; LPA = light physical activity; MET = metabolic equivalent; HRR = heart rate reserve; PA = physical activity.

[a] Data were collected in 30 min blocks per day and were converted to min/day for comparability to other studies.

[b] 56 of 86 patients were schoolchildren and 30 were adults with a regular employment.

[c] 30 min RPA was defined as PA performed regularly at least once a week for at least 30 min (school sports were excluded).

[d] Time spent above 50% HRR was classified as MVPA and above 75% HRR was classified as VPA.

[e] VPA, ≥6 METs; MVPA, ≥3 METs; MPA, 3–6 METs.

[f] VPA was defined as >2900 counts/min; MPA was defined as 2001–2900 counts/min; LPA was defined as 50–2000 counts/min; SPA was defined as <50 counts/min.

[g] LPA was defined as 20%–40% HRR, MPA was defined as 40%–50% HRR, and VPA was defined as >50% HRR.

[h] MVPA was defined as >1952 counts/min; LPA was defined as 100–1952 counts/min; SPA was defined as <100 counts/min.

[i] MVPA was defined as >1999 counts/min; SLPA was defined as ≤1999 counts/min.

[j] 60 min MVPA was defined as an activity causing increased heart rate and/or breathlessness for more than 60 min.

[k] 60 min MVPA was defined as number of days in which subjects had accumulated 60 min of moderate/vigorous physical activity during the previous days and for a typical week.

Table 3
Amount and type of sedentary behavior observed in youth with diabetes.

Author	All	Males	Females
Type 1 diabetes			
Aman et al.[46]	–	TV use weekday: 120 ± 90 min/day TV use weekend: 168 ± 102 min/day Computer use weekday: 90 ± 96 min/day Computer use weekend: 126 ± 120 min/day	TV use weekday: 126 ± 84 min/day TV use weekend: 168 ± 102 min/day Computer use weekday: 72 ± 84 min/day Computer use weekend: 90 ± 96 min/day
Benevento et al.[47,b]	TV watching: 141.6 ± 54 min/day Computer use: 255 ± 193.8 min/day	–	–
Fainardi et al.[50]	TV viewing: 113.68 ± 92.82 min/day Videogames playing: 94.44 ± 74.39 min/day	–	–
Fintini et al.[53]	PAQ sedentary behavior: 624 ± 90 min/day Armband: 990 ± 192 min/day	–	–
Galler et al.[54]	Media consumption: 174 ± 108 min/day	–	–
Lobelo et al.[58,a]	–	TV use: 132 ± 9 min/day EM use: 207 ± 12 min/day Meeting EM use standard: 34.8% ± 4.3% Meeting TV use standard: 55.1% ± 4.6%	TV use: 126 ± 9 min/day EM use: 147 ± 12 min/day Meeting EM use standard: 49.1% ± 4.2% Meeting TV use standard: 58.4% ± 4.2%
Margeirsdottir et al.[60]	TV viewing: 114 min/day		
Overby et al.[62]	–	**6–10 years old:** TV viewing: 105 ± 44 min/day Computer use: 70 ± 39 min/day **11–19 years old:** TV viewing: 126 ± 58 min/day Computer use: 105 ± 71 min/day	**6–10 years old:** TV viewing: 102 ± 46 min/day Computer use: 40 ± 27 min/day **11–19 years old:** TV viewing: 136 ± 59 min/day Computer use: 59 ± 50 min/day
Type 2 diabetes			
Lobelo et al.[58,a]	–	TV use: 171 ± 21 min/day EM use: 219 ± 24 min/day Meeting EM use standard: 29.5% ± 9.8% Meeting TV use standard: 46.7% ± 9.7%	TV use: 147 ± 15 min/day EM use: 165 ± 18 min/day Meeting EM use standard: 47.6% ± 6.6% Meeting TV use standard: 56.9% ± 6.6%
Rothman et al.[64]	TV viewing: ≤1 h/day: 32% 2–3 h/day: 39% ≥4 h/day: 29%	–	–

Abbreviations: EM = electronic media, generally defined as TV and computer use; TV = television.
[a] Data were collected in 30 min blocks per day and were converted to min/day for comparability to other studies.
[b] 56 of 86 participants were schoolchildren and 30 were adults with a regular employment.

of PA measured by SenseWear armbands (1.8 ± 0.8 h/day) was higher than that assessed by self-reported questionnaire (0.6 ± 0.3 h/day) among children with T1D.[53] The SenseWear armband has been validated in children.[94]

Comparison of PA levels in youth with and without T1D yielded inconsistent results. In a few studies, including our own, both groups exhibited similar levels of self-reported VPA, MVPA, electronic media and TV use[49,50,53,58,61] and there were no statistically significant differences in terms of steps per day.[82] However, other studies have found PA levels of T1D youth to be lower than in controls without diabetes[69,87] including in two small accelerometer-based studies[85,87] and one using SenseWear armbands.[53] One study reported higher activity levels in youth with T1D than in controls.[63]

3.1.3. *PA in youth with T2D*

With respect to youth with T2D, very little epidemiologic research has been published.[51,52,55,58,61,64,68,82] Our own work suggests a very low number of steps per day among girls and boys (4565 ± 3633; 6175 ± 2708, respectively).[82] Self-reported amounts of MVPA observed in youth with T2D range from 7 to 153 min/day in boys and 6–141 min per day in girls.[55,58,68] Faulkner et al.[51,52] reported an average of 34 METs per day, while Nadeau et al.[61] reported a markedly higher average of 64 METs per day in youth with T2D. The proportion of youth with T2D who meet the 60-min MVPA standard is about 65% for boys and 71% for girls based on self-reported information,[58] yet the average of pedometer-based steps per day is less than half of the recommended levels.[82,92]

Compared to youth without diabetes, T2D youth seem to engage in markedly less PA.[58,82] In terms of steps per day, O'Neill et al.[82] suggest a 1500–2000 step difference, depending on gender. The few studies that have compared activity levels between youth with T1D and T2D seem to indicate that activity levels are lower in T2D than in T1D.[51,52,58,82] This difference may be as large as 2000 steps per day[82] and more than one metabolic equivalent.[51]

3.1.4. *Sedentary behavior levels in youth with T1D and T2D*

Table 3 summarizes data on sedentary behaviors in youth with T1D and T2D. With respect to sedentary behaviors in

T1D youth, all studies to date consistently report a large amount of TV watching, ranging approximately between 110 and 140 min/day for adolescent boys and girls alike.[46,47,50,58,60,62] Time spent on computer use by youth with T1D ranges from 40 min to 255 min/day.[47,62] Total time spent on electronic media use and computer use, however, seems greater for boys than for girls, similar to that reported in youth without diabetes[39] (90 *vs.* 72 min daily of weekday computer use[46]; 105 *vs.* 59 min daily average computer use[62]; 207 *vs.* 147 min daily average electronic media).[58] Total media use was estimated by Galler et al.[54] at 174 min/day. Weekend use of TV and electronic media was greater than weekday use.[46] With respect to recommendations pertaining to TV watching, recent data by Overby et al.[62] from Norway, Benevento et al.[47] and Galler et al.[54] from Germany, Rothman et al.[64] and Lobelo et al.[58] from the USA[58] suggest that T1D youth markedly exceed the recommendation of $\leq$2 h of TV per day, whereas an international study by Aman et al.[46] reported TV on weekday markedly below the recommendation.

Electronic media use in T2D youth seems to be very high with on average 3.6 h for boys and 2.9 h/day for girls, of which the majority is spent watching TV.[58] Rothman et al.[64] reported that only 32% of their population watched one hour of TV or less per day, while the remained watched 2 or more hours. Compared to youth without diabetes,[96,97] youth with T2D seem to engage in markedly more sedentary behaviors.[58,82]

3.1.5. Physical fitness in youth with T1D and T2D

A noteworthy number of studies also shed light on physical fitness levels in youth with T1D and T2D (Table 4). Physical fitness can be categorized as cardiorespiratory fitness, muscular strength, flexibility, or balance. For this review, physical fitness is defined as cardiorespiratory fitness (as determined by maximal oxygen consumption (VO_{2max}) or peak oxygen consumption (VO_{2peak}) depending on the study criteria), or power output during a standardized heart rate (PWC_{170}).[98] Four studies to date report very consistent fitness levels of VO_{2peak} of about 34−41 mL/kg/min in youth with T1D, which is considered in the low cardiorespiratory fitness range for youth[51,52,70,71,99] Fitness levels in youth with T2D are lower than in T1D youth (at about 25 mL/kg/min).[61,68,75,89] This study also compared VO_{2peak} and peak work rate for T2D youth compared to control youth and found markedly lower levels of fitness in T2D youth.[61] In comparison, for cardiorespiratory fitness levels in youth, data from NHANES 1999−2002 indicate that 12−19 years old boys have an estimated VO_{2max} range of 44.6−47.6 mL/kg/min, while 12−19 years old girls have an estimated VO_{2max} range of 39.7−39.5 mL/kg/min, and that approximately 65% of 12−19 years old boys and girls meet criterion-referenced standards (FITNESSGRAM®) that are linked to health outcomes.[100]

Another measure of cardiorespiratory fitness, the physical working capacity (PWC_{170}) test, is a cycle ergometer test that predicts the power output (watts) at a projected heart rate of 170 beats per minute (bpm). This test is standardized to determine physical fitness[98] and has been used to some success to track physical fitness from youth to adulthood.[101] Heyman et al.[76,77] found that 13−18 years old girls with diabetes had a PWC_{170} ranging from 1.66 to 2.28 w/kg.

3.2. Fear of hypoglycemia as a specific barrier to PA in youth with diabetes

While there are many barriers to PA behaviors in general, fear of hypoglycemia is an important additional and highly prevalent concern for persons with diabetes, as evidenced by several extensive reviews.[42−44] The Hypoglycemia Fear Survey is one of the most common instruments used to assess this issue.[42,102] As reviewed by Barnard et al.,[42] hypoglycemia avoidance behaviors by parents of youth with T1D typically include having fast-acting sugars on hand and frequent feedings.[103]

Two recent studies have also shown that fear of hypoglycemia is a concrete barrier to PA in adults and children.[104,105] The Barriers to PA in Diabetes Questionnaire (BAPAD-1) was developed and validated by Dube et al.[105] in youth and young adults with T1D, ages 11−20, with frequency of hypoglycemia ranging from 0 to 12% and HbA_{1c} levels ranging from 7.2% to10%. Constructs include perceived fears related to diabetes, physical abilities, time constraints, and environment. Participants indicate the degree of likelihood that an issue will keep them from participating in regular PA. The BAPAD-1 has been shown to have very good psychometric properties and test−retest reliability.[105] Furthermore, a recent study has shown that the BAPAD-1 has good predictive validity when evaluated against accelerometer in persons with T1D.[106]

None of the 44 studies meeting the criteria of this review reported any data on fear of hypoglycemia. Thus, to date, there seems to be a lack of large, representative studies of T1D youth that have addressed the relation between fear of hypoglycemia and specific types of PA, including using self-reported information on the types of activity and objective information on the amount and intensity of activity, at least within the studies abstracted in PubMed.

3.3. Health benefits of PA in youth with diabetes

A comprehensive review of published intervention research focusing on the health benefits of PA in youth with T1D was recently published by Chimen et al.[41] The authors concluded that PA (1) "…improves insulin requirements in type 1 diabetes but shows a limited effect on glycemic control", (2) "…improves lipid levels, endothelial function and insulin resistance but not blood pressure," and (3) "…is associated with reduced CVD and mortality in patients with type 1 diabetes". In this section of the review, we provide a brief overview of the current epidemiological studies which addressed these three groups of research questions (Table 5) in free-living populations.

With respect to insulin requirements and glycemic control in T1D youth, there is clearly a continuing need to identify ways to improve glycemic control in youth as various studies, including clinical trials, have shown that intensive glycemic control prevents or delays the progression of microvascular

Table 4
Physical fitness in youth with diabetes.

Author	Instrument	Measurement
Type 1 diabetes		
Arslanian et al.[70]	Cycle ergometer	VO_{2max}: 34.9 ± 8.6 mL/kg/min
Austin et al.[71]	Cycle ergometer	VO_{2max}: 33.7 ± 7.0 mL/kg/min
Baraldi et al.[72]	Treadmill exercise test	VO_{2max}: 41.2 ± 5.9 mL/kg/min
Faulkner et al.[51]	Cardiopulmonary metabolic cart and cycle ergometer	VO_{2peak}: 34.7 ± 8.9 mL/kg/min
Fintini et al.[53]	Treadmill exercise test	VO_{2max}: 36.2 ± 7.4 mL/kg/min
Gusso et al.[75]	Cycle ergometer	VO_{2max}: 31.6 ± 2.0 mL/kg/min
Heyman et al.[76]	Cycle ergometer	PWC_{170}: 85.6 ± 4.0 w PWC_{170}: 2.28 ± 0.09 w/kg
Heyman et al.[77]	Cycle ergometer	PWC_{170}: 107.6 ± 26.2 w PWC_{170}: 1.66 ± 0.34 w/kg VO_{2max}: 30.6 ± 4.0 mL/kg/min
Kornhauser et al.[79]	Cycle ergometer	VO_{2max}: 37.5 ± 2.4 mL/kg/min
Michaliszyn et al.[81]	Cycle ergometer	VO_{2peak}: 34.7 ± 8.9 mL/kg/min
Poortmans et al.[83]	Cycle ergometer	PWC_{170} for HbA1 <8.5%: 2.80 ± 0.05 w/kg PWC_{170} for HbA1 >8.5%: 2.56 ± 0.12 w/kg VO_{2max} for HbA1 <8.5%: 40.6 ± 1.3 mL/kg/min VO_{2max} for HbA1 >8.5%: 38.5 ± 1.0 mL/kg/min
Roche et al.[84]	Treadmill exercise test	VO_{2peak}: 41.4 ± 8.2 mL/kg/min
Shaibi et al.[86]	Cycle ergometer	VO_{2peak}: 3.1 ± 0.2 L/min
Trigona et al.[87]	Treadmill exercise test	VO_{2max} (95%CI): 45.5 (43.0–48.0) mL/kg/min
Williams et al.[88]	Submaximal step test	Recovery heart rate: 125 ± 13 beats/min
Type 2 diabetes		
Faulkner et al.[51]	Cardiopulmonary metabolic cart and cycle ergometer	VO_{2peak}: 25.4 ± 5.9 mL/kg/min
Gusso et al.[75]	Cycle ergometer	VO_{2max}: 20.3 ± 2.0 mL/kg/min
Nadeau et al.[61]	Cycle ergometer	VO_{2peak}: 21.8 ± 4.2 mL/kg body mass/min VO_{2peak}: 42.8 ± 7.6 mL/kg lean body mass/min
Shaibi et al.[68]	Cycle ergometer	VO_{2peak} for boys: 28.1 ± 5.7 mL/kg/min VO_{2peak} for girls: 22.0 ± 5.8 mL/kg/min
Wittmeier et al.[89]	Cycle ergometer	VO_{2peak}: 38.4 ± 7.9 mL/kg FFM/min

Abbreviations: VO_{2max} = maximal oxygen consumption; VO_{2peak} = peak oxygen consumption.

complications of diabetes and the risk of macrovascular disease.[107–109] The SEARCH study has shown that 17% of T1D youth and 27% of T2D youth[110] had poor glycemic control ($HbA_{1c} \geq 9.5\%$), consistent with several others.[111,112] As summarized by Chimen et al.[41] PA does seem to impact on glycemic control in intervention studies. Additionally, there are a number of observational studies that are consistent with this conclusion.[46,48,65,69,80] For example, Schweiger et al.[67] demonstrated that self-reported MVPA of at least 60 min on 3 days/week in T1D youth was significantly associated with good glycemic control. Galler et al.[54] reported that among youth with T1D, those who spent 3.9 or more hours per day utilizing media (i.e., TV or computer) had higher HbA_{1c} levels. The Hvidoere Study Group reported an association of computer time with increased HbA_{1c} levels but no association with PA.[46] Lastly, in a large, multi-center practice-based study, Herbst et al.[57] found that self-reported PA of 30 min once a week was associated with good glycemic control in T1D youth. However, there are also a number of observational studies that did not find a significant impact of PA onHbA_{1c} levels or glycemic control.[50,51,73,74,85]

With respect to CVD risk factors such as lipid levels, insulin resistance, and blood pressure, there are several epidemiologic studies which are consistent with the positive findings in the review.[41] Concretely, Herbst et al.[56] observed associations with dyslipidemias, triglycerides, total, LDL and HDL cholesterol and blood pressure. Valerio et al.[69] reported associations with triglycerides and metabolic control, but a study by Faulkner[51] did not support associations with a variety lipid levels.

Non-invasive techniques now exist to evaluate cardiovascular function well before diabetes-related vascular disease becomes irreversible.[113–118] Pulse wave velocity (PWV) and augmentation index (AIx), both measures of arterial stiffness, are associated with CVD risk factors including in T1D.[119–123] In fact, PWV has been shown to predict mortality in T1D independently of traditional CVD risk factors and glycemic control.[120] Cardiac autonomic neuropathy is another common chronic complication of diabetes, commonly assessed by heart rate variability (HRV). Low HRV is associated with hyperglycemia, recurrent hypoglycemia, increased arterial stiffness and a significantly increased mortality, independent of other risk factors.[124–127] Moreover, cardiac autonomic neuropathy has been shown to be prevalent in newly-diagnosed T1D patients, including youth.[128–131] Thus, evidence suggests that youth with diabetes are at a critical juncture of their

Table 5
Effect of PA and sedentary behaviors on health outcomes among youth with diabetes.

Author	PA measures	Health outcomes															
		Metabolic or cardiovascular disease related outcomes												Other outcomes			
		A1C	HYPO	KETO	TRI	CHO	LDL	HDL	HRV	CE	FMD	BP	BMI	HP	PWB	QoL	SMR
Type 1 diabetes																	
Aman et al.[46]	MVPA, TV, CU	$+_{CU}$[a]	NS	NS									NS	+			
Benevento et al.[47,b]	PA, TV, CU	$+_{PA}$[a]															
Bernardini et al.[48]	RPA	−	NS														
Chen et al.[49]	PA								+								
Edmunds et al.[73]	VPA, MVPA	NS													NS		
Edmunds et al.[74]	VPA, MVPA	NS											NS				
Fainardi et al.[50]	PA, TV, VP	NS															
Faulkner et al.[51]	PA								+	+							
Faulkner et al.[52]	PA	NS			NS	NS	NS	NS						+		+	
Herbst et al.[56]	RPA	−	NS										−				
Herbst et al.[57]	RPA	−			−	$-_{15-18y}$[a]	$-_{9-18y}$[a]	+				−	−				
Galler et al.[54]	PA, EM	$+_{EM}$[a]															
Massin et al.[80]	LPA, MPA, VPA	−															
Roche et al.[84]	VPA, MVPA																NS
Sackey et al.[65]	PA	−															
Salvatoni et al.[66]	PA	−										NS	NS				
Särnblad et al.[85]	MPA, LPA, SPA	NS															
Schweiger et al.[67]	MVPA	−															
Trigona et al.[87]	MVPA										NS						
Valerio et al.[69]	MVPA	−			−												
Type 2 diabetes																	
Faulkner et al.[51]	PA								+	+							
Faulkner et al.[52]	PA	NS			NS	NS	NS	NS						NS		NS	

Note: − means significantly negative association; + means significantly positive association; NS means no significant association.
Abbreviations: PA = physical activity; RPA = regular physical activity; VPA = vigorous physical activity; MVPA = moderate vigorous physical activity; MPA = moderate physical activity; LPA = light physical activity; SPA = sedentary physical activity; TV = television viewing; CU = computer use; VP = videogames playing; EM = electronic media use; A1C = hemoglobin A1c; HYPO = hypoglycemia; KETO = ketoacidosis; TRI = triglycerides; CHO = cholesterol; LDL = low-density lipoprotein cholesterol; HDL = high-density lipoprotein cholesterol; HRV = heart rate variability; CE = cardiovascular endurance; FMD = flow mediated dilation; BP = blood pressure; BMI = body mass index; HP = health perception; PWB = psychological well-being; QoL = quality of life; SMR = skin microvascular reactivity.
[a] The associations were significant only in specific age groups (15−18 years old or 9−18 years old) or for specific sedentary behaviors (computer use or electronic media use).
[b] 56 of 86 participants were schoolchildren and 30 were adults with a regular employment.

cardiovascular health, at which irreversible changes can likely be prevented.

The association of PA and CVD risk in T1D youth may resemble the association in youth without T1D,[132] but to the best of our knowledge very few studies have examined this relationship. The literature on PA and measures of arterial stiffness is entirely limited to T2D and suggests a strong health-promoting effect of PA on arterial stiffness in adults[133−135] and youth.[136,137] With respect to cardiac autonomic function, habitual PA increases HRV.[138] Two studies have shown positive associations of PA with HRV in youth with T1D[49,51] and T2D.[51] There is also evidence for youth without diabetes.[139−142] Gutin et al.[140,141] demonstrated that 4 months of aerobic exercise training and games designed to maintain a heart rate >150 beats/min improved HRV in obese youth. Buchheit et al.[139] observed that preadolescent youth have enhanced HRV indexes with VPA (measured by accelerometery), but not with MPA, suggesting that more intense activities may be necessary to observe more favorable HRV in young people. In summary, only very limited data exist on the relationship of PA to cardiovascular function in youth with T1D and T2D.

With respect to studies of physical fitness on health outcomes in youth with diabetes (Table 6), the literature suggests inverse associations between fitness levels and glycemic control and lipid levels in youth with T1D, although results are not entirely consistent.[61,70,71,81,89] In youth with T2D, only two studies were found with conflicting results with respect to glycemic control[51,61] and two with somewhat confliction results with respect to lipid levels.[51,89]

Finally, it is important to consider hypoglycemia, not only as a barrier to PA as reviewed above, but also as a potentially dangerous consequence of PA in persons with T1D. The literature on the relation of PA to hypoglycemia is inconsistent. The DirecNet Study Group reported results of a prolonged moderate aerobic exercise intervention in 50 T1D youth which suggested that hypoglycemia is common (86%) if pre-exercise glucose levels are below 120 mg/dL.[143] Furthermore, nighttime hypoglycemia also was more common following afternoon exercise. In contrast, the two large epidemiologic studies did not find an

Table 6
Effect of physical fitness on health outcomes among youth with diabetes.

Author	Fitness measure	Health outcomes												
		Metabolic/cardiovascular diseases related outcomes										Other outcomes		
		IS	A1C	TRI	CHO	LDL	HDL	FFA	FMD	BMI	MAL	HP	QoL	SMR
Type 1 diabetes														
Arslanian et al.[70]	VO_{2max}		−											
Austin et al.[71]	VO_{2max}		−	−	−	−	NS			NS				
Faulkner et al.[51]	VO_{2peak}		−	−	−	−	NS					+	NS	
Kornhauser et al.[79]	VO_{2max}										+			
Michaliszyn et al.[81]	VO_{2peak}		−	NS	−	NS								
Roche et al.[84]	VO_{2peak}													+
Trigona et al.[87]	VO_{2max}								NS					
Williams et al.[88]	Recovery heart rate		+							NS		NS		
Type 2 diabetes														
Faulkner et al.[51]	VO_{2peak}		NS	NS	NS	NS	NS					NS	NS	
Nadeau et al.[61]	VO_{2peak}	+	−					−						
Wittmeier et al.[89]	VO_{2peak}	+		−										

Note: − means significantly negative association; + means significantly positive association; NS means no significant association.
Abbreviations: VO_{2max} = maximal oxygen consumption; VO_{2peak} = peak oxygen consumption; IS = insulin sensitivity; A1C = hemoglobin A1c; TRI = triglycerides; CHO = cholesterol; LDL = low-density lipoprotein cholesterol; HDL = high-density lipoprotein cholesterol; FFA = fasting free fatty acids; FMD = flow mediated dilation; BMI = body mass index; MAL = microalbuminuria; HP = health perception; QoL = quality of life; SMR = skin microvascular reactivity.

association of PA with risk of hypoglycemia,[46,57] but both were based on self-reported data. Thus, more research is needed assessing the real-life PA patterns objectively, paired with state-of-the art measure of glucose levels, to better understand the relationship between PA and hypoglycemia and how to avoid hypoglycemia so that youth with T1D can benefit from the positive effects of PA on health. Another related issue is that of consumption of food and specifically carbohydrates prior to, during, or after PA to prevent hypoglycemia which may be potentially offsetting some of the benefits of PA on healthy weight maintenance.

4. Conclusion

In summary, the epidemiologic evidence on the health benefits of PA and physical fitness, as well as the detrimental influence of sedentary behavior is generally quite consistent with that of intervention studies recently reviewed by Chimen et al.[41] With respect to the influence of PA on hypoglycemia, there is clearly more need for research, especially in real-life settings, as the current literature is quite inconsistent. Fear of hypoglycemia is likely an important barrier to PA in youth with T1D, and more research is needed on how to address this barrier. Furthermore, epidemiologic data to date suggest that a large proportion of youth with diabetes do not engage in sufficient amounts and intensities of PA to meet current recommendations of 60 min of MVPA per day and that a large proportion of youth with diabetes watch excessive amounts of TV. Fitness levels of youth with diabetes seem to be in the low range, with youth with T2 having poorer fitness levels than youth with T1D. Furthermore, there is an absence of large, representative studies using state-of-the-art objective assessment instruments such as accelerometers or other technologies in populations of youth with T1D or T2D. Very few studies have had sufficient sample sizes to describe activity levels by race or ethnic characteristics and these suggest that activity levels may be markedly lower in minority populations.[67,82] There are virtually no data on what types of activities youth with diabetes engage in, and if those differ from youth without diabetes.[48,50,69] What is also not known is if youth with diabetes experience an age-related decline in activity levels that exceeds that observed in youth without diabetes.[39,66] Given that diabetes is one of the most common chronic conditions in youth, there is clearly a need for research addressing the aforementioned gaps in knowledge. A detailed description of prevailing PA and sedentary behavior amounts and patterns, using state-of-the-art objective and self-reported assessment instruments can provide the basis for much needed public health and clinical intervention efforts targeted at improving the health of this vulnerable population.

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