Levels and patterns of physical activity in children and adolescents with Type 1 diabetes and associated metabolic and physiologic health outcomes

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Levels and Patterns of Physical Activity in Children and Adolescents With Type 1 Diabetes and Associated Metabolic and Physiologic Health Outcomes

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Background: The current study objectively assessed physical activity (PA) levels and patterns in children and adolescents with type 1 diabetes and compared the metabolic and physiologic health profiles of those achieving and those not achieving the current recommendation of 60 minutes a day (minutes·D^{-1}) of at least moderate intensity PA. ***Method:*** 37 children and adolescents (20 boys, 17 girls) aged 12.7 ± 2.1 years (mean ± SD), disease duration 5.9 ± 3.0 years participated. PA was assessed using heart rate monitoring. Peak VO_2, BMI, sum of 5 skinfolds, HbA_{1c}, and daily insulin dosage were also determined. ***Results:*** Mean accumulated time in moderate-to-vigorous intensity PA was 53.6 ± 31.4 minutes·D^{-1}. Levels of vigorous-intensity PA were low, mean 8.3 ± 10.2 minutes·D^{-1}. When controlling for age, no differences in metabolic or physiologic health outcomes were evident between those individuals achieving, and those not achieving, 60 minutes·D^{-1} of moderate-to-vigorous intensity PA. PA predominantly occurred in short bouts lasting 5 minutes or less. ***Conclusion:*** The efficacy of accumulating 60 minutes·D^{-1} of moderate-to-vigorous intensity PA, in the form of short duration, intermittent bouts of largely unplanned PA, to promote health gains in children and adolescents with type 1 diabetes is questionable.

Keywords: physical activity, exercise, pediatric, physical fitness, metabolic health

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Physical activity (PA) is recommended to children and adolescents with type 1 diabetes as a means of ameliorating the known risk factors for vascular disease. In particular, PA can be used to improve glycemic control, cardiovascular fitness, the lipoprotein profile, and to reduce blood pressure.[1] Current recommendations are that children and young people should achieve a total of at least 60 minutes of at least moderate intensity PA (MPA) each day.[2] It is unclear, however, whether children with type 1 diabetes heed the advice and participate in the recommended levels of PA to gain health benefits. The inherent difficulties associated with objective assessment of PA coupled with methodological inconsistencies have meant that this is an area that has received little research attention and as such, variable findings have so far been reported.

PA levels in the patient with type 1 diabetes are determined by a complex integration of factors, just as they are in children without diabetes, namely biological (including age, maturation, gender, motor skill, heredity), psychological, pedagogical, and environmental.[3] In addition, health status of the child with type 1 diabetes and the burden of the disease and its management may impact on PA levels in the patient with type 1 diabetes such as: poor knowledge of disease or exercise benefits, parental control, poor self efficacy, prior negative experiences.[4] This may mean that children with type 1 diabetes are not as active as they should be, even though they are capable of sport to the highest level.

Three recent studies have reached contradictory conclusions with regard to determining how much PA children with type 1 diabetes engage in.[5–7] Särnblad et al[5] found that adolescent girls with type 1 diabetes approached the recommended level of 60 minutes of at least MPA per day. In direct contrast, Massin et al[6] reported daily moderate-to-vigorous intensity PA (MVPA) levels of just 20 to 25 minutes in boys and girls with type 1 diabetes, and Valerio et al[7] found 75% of their sample did not reach a target of 60 minutes of at

least MPA 5 or more times a week. It is therefore unresolved as to whether the PA habits of children with type 1 diabetes are sufficient for immediate and future health benefits, or are in fact insufficient to the extent that they may contribute to adverse health outcomes.

The differences highlighted above in previous research findings may be a result of the methods used to assess PA. Objective methods such as continuous heart rate monitoring and triaxial accelerometry provide more valid data than self-reports of PA.[8] This is particularly so in children, as they are less conscious of time than adults and engage in PA which is chaotic both in time and intensity.[9] Only Särnblad et al[5] and Massin et al[6] have reported objective data, using uniaxial accelerometry and heart rate monitoring respectively. However, the reliability of PA data are affected by the number of days assessed and Massin et al recorded only 1 day of heart rate data per child thus compromising the reliability of their data. The strongest study in this area methodologically is Särnblad's who recorded 7 days of accelerometer data per child. This resulted, though, in a small sample size of 26 which was limited to adolescent girls and gave no qualitative information regarding patterns of PA.

The accurate assessment of PA, particularly in children, continues to challenge researchers. Accelerometry is currently the most commonly used objective method of PA assessment in youth[10]. In epidemiological studies it is feasible and provides accurate physical activity data.[11] However, data from accelerometry are typically expressed as 'movement counts,' and the interpretation of these in relation to PA intensity is contentious and varies widely between studies.[10] Accelerometry is also poor at capturing activities such as cycling or hill walking. The use of heart rate for the determination of MVPA has not received as much attention as accelerometry. Early studies were criticized for using universal heart rate intensity cut points to assess PA despite large interindividual variation in heart rate in young people. This limitation is overcome, though, if heart rate reserve (HRR), the difference between maximum heart rate and minimum heart rate, is used to estimate time spent in MVPA, as it allows for individual calibration in the interpretation of the data. Corder et al[10] showed that estimated MVPA from heart rate data interpreted using 50% HRR was comparable to estimated MVPA from uniaxial accelerometry in the same individuals, and concluded that heart rate monitoring has the potential to be valuable for the assessment of MVPA. In the current study we used heart rate monitoring over 4 days, interpreted using HRR, to assess PA volumes and patterns objectively in girls and boys.

PA assumes an additional role in children with type 1 diabetes than the general youth population as it is part of the diabetes treatment triad (insulin, diet, and PA).[1] A bout of PA can acutely lower blood glucose levels and therefore hypothetically repeated bouts over time may impact on chronic glycemic control. There have, though, been conflicting reports regarding the relationship between habitual PA and glycemic control with some studies reporting a negative relationship[6,7] and others reporting no association.[5,12] In addition to the metabolic benefits, performing adequate PA in type 1 diabetes is paramount as it has the potential to ameliorate known cardiovascular disease risk factors, such as adiposity, to which this population have an increased susceptibility.

The aims of this investigation were therefore 2-fold: first, to clarify levels and patterns of PA in children and adolescents with type 1 diabetes; and second, to determine whether those children achieving the current target of 60 minutes·D^{-1} of at least MPA possess better metabolic and physiological health profiles than those not achieving the target.

Methods

Participants

Thirty-seven children and adolescents (20 boys and 17 girls; [mean ± SD] age 12.7 ± 2.1 years), with a duration of type 1 diabetes of at least 2 years, were recruited from 2 National Health Service (NHS) hospitals in the North West of England. Participants were excluded if they had: secondary disease complications according to normal clinical criteria; a chronic illness other than type 1 diabetes; or were taking medication other than insulin. All children were treated with multiple subcutaneous insulin injections (2–4 per day). Participant characteristics are provided in Table 1. Informed written assent/consent to participate in the study was obtained from all children and their parent/guardians. Ethical approval for the study was obtained from the University Ethics Committee and the 2 relevant NHS Trusts.

Anthropometric Measurements

Adiposity was estimated from skinfold thicknesses using Harpenden Skinfold Calipers (British Indicators Ltd. Birmingham, England). The 5 skinfold sites used were the biceps, triceps, subscapular, suprailiac, and medial calf. All measurements were taken on the right side of the body in triplicate after carefully anatomically locating and marking. With the skinfold caliper jaws placed perpendicular to the raised fold, each skinfold measurement was taken 2 seconds after jaw pressure release. A minimum of 3 measurements were taken at each of the 5 sites and the median value at each site was calculated. The sum of 5 skinfolds was determined for each subject as an indicator of total body fatness and therefore the problems associated with the conversion of skinfold measurements to percentage body fat using skinfold prediction equations were avoided.[13] Body height was measured to the nearest 0.1cm using a wall-mounted stadiometer (British Indicators Ltd. Birmingham, England) and body weight to the nearest 0.10kg using beam balance scales (Avery, Birmingham, England), with subjects wearing light clothing, shoes removed. Body mass index (BMI) was calculated as body weight divided by body height squared (kg/m^2).

Determination of Peak VO_2

Participants were fully habituated to the laboratory environment and familiarized on relevant equipment including the treadmill before commencement of any tests. Peak VO_2 was assessed using a discontinuous, progressive treadmill exercise test to voluntary exhaustion. Following a resting 30µl capillary blood lactate sample (Lactate Pro, Arkwray Inc, Shiga, Japan) a 3-minute warm-up was performed at 7.6 ± 1.2 km/hr (mean ± SD) followed by a further capillary blood lactate sample and a short rest. Subjects then began the peak VO_2 test which consisted of 3 minute stages of constant velocity running beginning at zero gradient and increasing by 2.5% at the end of each 3 minute work-stage. Treadmill test velocity was between 7 and 12km·hr^{-1} (9.0 ± 1.5km·hr^{-1}) and this was determined according to age, maturation, and competence during warm-up/familiarization. A rest period of 60s separated each 3-minute work-stage, during which time a blood lactate sample was collected. Expired air was collected in meteorological (MET) balloons (Cranlea Medical Electronic, Birmingham, England) during the final 30s of each work-stage, and the final 30s of the test, for determination of expired oxygen and carbon dioxide concentrations and total volumes, using precalibrated dry-gas analyzers (Servomex 470A and 1400, Servomex, Crowborough, England; Harvard Dry Gas Meter, Harvard Apparatus, Edenbridge, England respectively). Oxygen uptake for each MET balloon was calculated on a PC using the Haldane transformation calculations.[14] Heart rate was measured at 5s intervals throughout the test protocol using short range radio telemetry (Polar Sports Tester, Kempele, Finland). The highest VO_2 value attained during the test was accepted as peak VO_2 if test end-point criteria had been met, namely subjective fatigue and volitional exhaustion, a final heart rate within 10beats. min^{-1} of the age-predicted maximum (220-age), and a final respiratory exchange ratio of 1.15 or above.[15] If test-end point criteria were not met, subjects' peak VO_2 data were excluded from the analysis.

Estimation of Habitual PA

Habitual PA was estimated using continuous heart rate monitoring (Polar Sportstester, Kempele, Finland), a technique which has previously been validated in 5 to 10 year olds[16] and widely used in pediatric research.[17,18] This technique does not permit the direct quantification of PA but rather heart rate is instead used to objectively determine the relative stress placed on the cardiovascular system.

A researcher visited the child's home at approximately 8:00 AM and attached and set up a heart rate monitor (Polar Sports Tester, Kempele, Finland). This consisted of a lightweight transmitter which was attached to the child's chest using either an elasticated belt or 50mm diameter Skintact foam ECG electrodes and a receiver worn on the wrist, which was set to record at 60s intervals. Children and parents were instructed not to modify their usual daily activities and encouraged to engage in their normal school, sport, and lifestyle activities. A researcher returned at approximately 7:00 PM to stop and remove the monitor. Heart rate was monitored this way on 2 weekdays, and 2 days plus 1 night at the weekend. A minimum monitoring period of 3 days is recommended for pediatric PA assessment.[19] For the weekend recording, the monitor was left continuously collecting data from 8:00 AM on the Saturday until 7:00 PM on the Sunday. Subjects also completed a PA recall questionnaire,[20] at the end of the week in which heart rate monitoring was conducted, for heart rate file editing purposes.

Heart rate files were downloaded onto a PC for analysis (Polar Precision Performance Software 3.0., Polar, Kempele, Finland) and were edited in conjunction with the PA recall diary for spurious perturbations or loss of skin contact. Percentage HRR (%HRR)[21] was used for the evaluation of levels of PA at 2 intensities in this study, as has been reported in the literature elsewhere.[22,23] Resting heart rate (an average of the lowest 5 consecutive heart rates during sleep) was subtracted from maximal heart rate (the value at the end of the peak VO_2 test) (HR_{max}—HR_{rest}) to calculate HRR. Two intensity thresholds were calculated: ≥50%HRR and ≥75%HRR corresponding to MVPA and VPA respectively.[22] The threshold 50%HRR is considered to be equivalent to 50% of maximal aerobic power, an intensity that is classified as moderate intensity, and is the intensity threshold identified in current PA guidelines above which health benefits can be secured.[2] The higher VPA threshold, 75% HRR, has recently gained prominence in the adult literature for its health benefits.[24] The total accumulated time spent in minutes per day above each intensity of HRR was used to establish levels of MVPA and VPA for each participant. As no significant difference was found between weekend and weekday PA, total daily PA above each intensity was determined by calculating the mean duration (minutes) over the corresponding number of heart rate data collection days.

In addition to the determination of accumulated minutes per day of MVPA and VPA, participants' PA patterns were also analyzed in terms of the number of times over the collection period (4 days) they engaged in MPA (50% to 74%HRR) and VPA (≥75%HRR) activity bouts lasting for 5, 10, and 20 minute continuous periods. This method permits a more qualitative insight into the patterns of PA.

Transmitter interference and/or loss of skin contact prevented the procurement of full data sets for each participant. Heart rate files were included in the PA analysis if their duration lasted a minimum of 8 hours and using this criterion 49% of children had complete data sets, 30% had 3 complete files, and a further 22% had 2 complete files. All participants with 2 or more data files of >8hours duration were included in the PA analysis.

Glycemic Control

Glycosylated hemoglobin values (HbA_{1c}) for all subjects were determined to the nearest 0.1% via latex immuno-

agglutination inhibition techniques (Bayer DCA 2000, Bayer Diagnostics, Newbury, Berkshire, UK) during routine clinical monitoring. The HbA_{1c} measurements were taken within 6 weeks of both the laboratory visit and assessment of PA. The normal laboratory values for nondiabetic individuals are between 2.0 and 6.5%.

Data Analysis

Statistical analysis was performed using SPSS for Windows (Version 16.0). Normality was tested using the Kolmogorov-Smirnov test. Independent *t* tests were used to determine whether gender differences existed in physiological characteristics, heart rate variables, or levels of PA between boys and girls. Two activity groups were created based on whether participants achieved current PA recommendations,[2] namely <60 minutes·D^{-1} above 50%HRR (low-active) and ≥60 minutes·D^{-1} above 50%HRR (high-active). Differences in physiological and metabolic characteristics between the 2 activity groups were assessed using Analysis of Covariance (ANCOVA) with activity group the fixed factor and age a covariate. Assumptions for use of ANCOVA such as equality of variance and homogeneity of regression slopes were tested and met for all dependent variables tested therefore data are untransformed. Statistical significance was set at $P < .05$ throughout. Means ± SD are reported.

Results

Independent *t* tests revealed that sum of 5 skinfolds was significantly greater in the girls in the study compared with the boys ($P < .01$), as shown in Table 1. This was also true for BMI ($P < .01$). There were no other significant differences between the girls and boys in the study in their physiological or clinical characteristics.

Heart rate monitoring and the maximal treadmill incremental test revealed that mean resting heart rate and mean maximal heart rate were 67.1 ± 8.1 and 204.5 ± 7.6 bpm respectively, which produced mean HRR thresholds at 50% and 75% of 136.1 ± 5.7 and 170.5 ± 6.0bpm respectively (Table 2). No significant differences were evident in resting, maximal, 50%HRR or 75%HRR thresholds between boys and girls ($P > .05$).

The mean accumulated time spent performing MVPA for all study participants was 53.6 ± 31.4 minutes·D^{-1}. As shown in Figure 1, boys tended to perform more PA

Table 1 Clinical, Physiological and Anthropometric Characteristics of Participants for Whole Group and by Gender

Parameter	Girls	Boys	All
Age (years)	13.2 ± 1.9	12.6 ± 2.3	12.9 ± 2.1
Disease duration (years)	6.4 ± 3.0	5.5 ± 3.0	5.9 ± 3.0
Weight (kg)	54.5 ± 12.7	44.0 ± 13.2	48.9 ± 13.8
Height (cm)	153.6 ± 11.2	151.9 ± 14.3	150.4 ± 12.8
BMI (kg/m^2)	23.2 ± 4.3**	18.9 ± 2.5	21.0 ± 4.0
HbA_{1c} (%)	9.9 ± 1.7	9.6 ± 1.6	9.7 ± 1.6
Daily insulin dosage (U)	59.6 ± 18.8	50.9 ± 21.5	54.9 ± 20.8
SBP (mmHg)	112.3 ± 7.8	110.8 ± 9.0	111.5 ± 8.3
DBP (mmHg)	70.0 ± 12.5	66.9 ± 9.5	68.3 ± 11.1
Peak VO_2	39.6 ± 9.2	43.3 ± 7.3	41.9 ± 8.3
Sum of 5 skinfolds	77.2 ± 38.9**	50.1 ± 14.6	62.0 ± 32.4

Note. Data are expressed as mean ± SD. The groups were compared using independent *t* tests. * $P < .05$, ** $P < .01$, significant difference between boys and girls.

Table 2 Mean Heart Rate Values (± SD) Including Resting, Maximum and Percentage of HRR for Whole Group, and Also by Gender

Variable	Girls	Boys	All
HR_{rest}	68.1 ± 7.8	66.2 ± 8.5	67.1 ± 8.1
HR_{max}	204.4 ± 8.2	204.5 ± 7.3	204.5 ± 7.6
50%HRR	136.6 ± 6.1	135.8 ± 5.5	136.1 ± 5.7
75%HRR	170.5 ± 6.6	170.5 ± 5.6	170.5 ± 6.0

Note. Data are expressed as mean ± SD. The groups were compared using independent *t* tests. * $P < .05$, ** $P < .01$, significant difference between boys and girls.

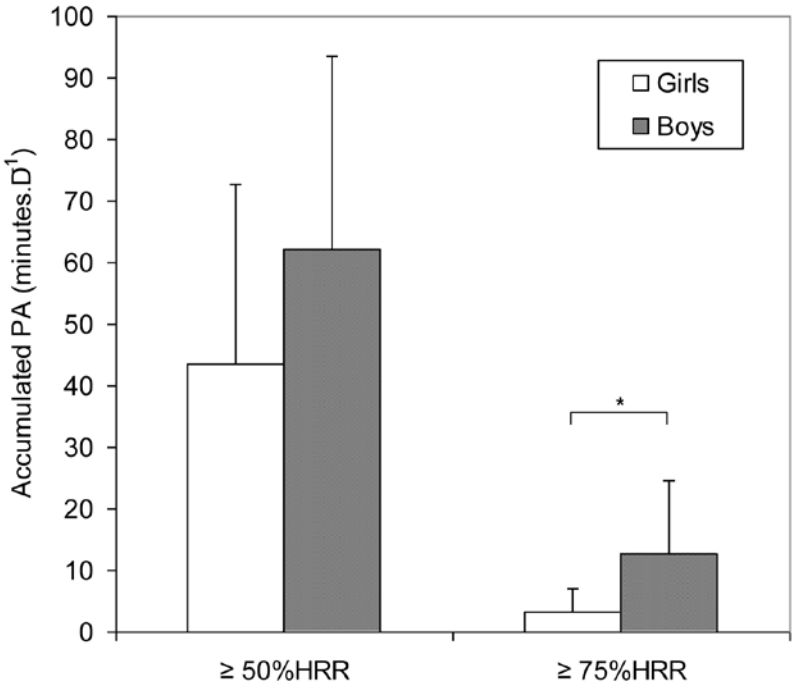

Figure 1 — Mean daily accumulated physical activity (minutes·D^{-1}) for boys and girls for MVPA (>50%HRR) and VPA (>75%HRR). Error bars depict +SD. * Between groups $P < .05$.

at this moderate-to-vigorous intensity compared with the girls (62.2 ± 31.5 vs. 43.5 ± 29.1 minutes·D^{-1}), but this difference was not significant ($P > .05$). Overall, 41% of the children with type 1 diabetes attained the target of 60minutes.D^{-1} of at least MPA. Low levels of VPA were displayed by the children with a mean accumulated time spent performing VPA of 8.3 ± 10.2 minutes·D^{-1} for the whole group. Higher levels of VPA were performed by the boys daily compared with the girls in the study (12.6 ± 12.0 vs. 3.4 ± 3.5 minutes·D^{-1}, $P < .05$), see Figure 1.

Analysis of variance revealed that those children in the high-active group were significantly younger ($P < .005$) than those in the low-active group. When age was controlled for, ANCOVA revealed that there were no significant differences between the low- and high-active groups for HbA_{1c} or daily insulin dosage (U·kg^{-1}) (Table 3). Likewise, peak VO_2, BMI, and the sum of 5 skinfolds were not significantly different between the low- and high active groups when age was controlled for.

PA patterns of participants were also established by calculating the frequency of MPA and VPA activity bouts lasting for 5, 10, and 20 minute continuous periods over the heart rate monitoring period (4 days). The PA patterns of participants are shown in Table 4. The most common duration of MPA undertaken by the boys and girls was a 5 minute bout, with the majority of boys and girls achieving 3 or more 5 minute bouts of continuous activity over the 4 collection days (90.0% of boys, 58.8% of girls). A number of children performed 3 or more sustained 10 minute bouts of MPA over the 4 collection days (boys 50.0%; girls 29.4%) although performance of just 1 or 2 continuous 10 minute bouts of MPA over the collection period was more common in both sexes. Few children partook in 20 minute continuous bouts of MPA with 85.0% of girls and 45.0% of boys failing to undertake a single 20 minute bout of MPA in 4 days of heart rate monitoring.Sustained periods of VPA lasting more than 5 minutes were infrequent in both boys and girls. Forty percent of boys and 64.7% of girls failed to perform a single continuous 5 minute bout of VPA over the 4 days of heart rate monitoring. Similarly, 60% of boys and 100% of girls failed to record a 10 minute bout of VPA over the data collection period and this figure increased to 85% and 100% for boys and girls respectively for sustained 20 minute bouts of VPA.

Table 3 Clinical, Physiological, and Anthropometric Characteristics of participants Based on PA Status

Variable	High-active	Low-active	ANCOVA
n	15	22	—
Gender	12 boys, 3 girls	8 boys, 14 girls	—
Age (years)	11.7 ± 1.9	13.6 ± 1.8	Group[a]
Disease duration (years)	5.9 ± 2.8	5.9 ± 3.2	Group[a]
Weight (kg)	43.1 ± 10.8	54.7 ± 14.4	Age[b]
Height (cm)	150.0 ± 11.3	155.7 ± 13.8	Age[b]
BMI	19.1 ± 3.1	22.5 ± 4.2	Nonsignificant
HbA_{1c} (%)	9.5 ± 1.2	10.0 ± 1.9	Nonsignificant
Daily insulin dosage (U)	48.3 ± 19.3	63.0 ± 20.2	Age[b]
Daily insulin dosage ($U \cdot kg^{-1}$)	1.4 ± 0.5	1.2 ± 0.2	Nonsignificant
Peak VO_2	40.5 ± 7.5	42.2 ± 9.5	Nonsignificant
Sum of 5 skinfolds	58.6 ± 30.1	72.1 ± 34.1	Nonsignificant

Note. Data represent mean ± SD. The two physical activity groups were compared using analysis of covariance (ANCOVA) with age the covariate unless otherwise specified.

[a] $P < .005$ between groups ANOVA (without age adjustment).

[b] $P < .001$ ANCOVA.

Table 4 The Distribution of Bouts of MPA (50–74%HRR) and VPA (≥75%HRR) Lasting 5, 10, and 20 Consecutive Minutes, in Girls and Boys Over 2 Week Days and 2 Days at the Weekend (4 Days Total); Expressed as Number of Participants (% of Participants)

Duration of bout	No. of bouts	MPA (50–74%HRR)		VPA (≥75%HRR)	
		Boys (n = 15)	Girls (n = 14)	Boys (n = 15)	Girls (n = 14)
5 minutes					
	0	1 (5.0)	3 (17.6)	8 (40.0)	11 (64.7)
	1	1 (5.0)	2 (11.8)	2 (10.0)	5 (29.4)
	2	0 (0)	2 (11.8)	3 (15.0)	1 (5.9)
	≥3	18 (90.0)	10 (58.8)	7 (35.0)	0 (0)
10 minutes					
	0	3 (15.0)	3 (17.6)	12 (60.0)	17 (100)
	1	3 (15.0)	5 (29.4)	6 (30.0)	0 (0)
	2	4 (20.0)	4 (23.6)	0 (0)	0 (0)
	≥3	10 (50.0)	5 (29.4)	2 (10.0)	0 (0)
20 minutes					
	0	9 (45.0)	15 (88.2)	17 (85.0)	17 (100)
	1	5 (25.0)	1 (5.9)	2 (10.0)	0 (0)
	2	1 (5.0)	1 (5.9)	1 (5.0)	0 (0)
	≥3	5 (25.0)	0 (0)	0 (0)	0 (0)

Discussion

Regular PA is associated with health and well-being benefits for children, including those with type 1 diabetes.[1] To help in the promotion of active lifestyles, guidelines have been developed about the amount of PA that is required to maintain children's current and future health, these are currently at least 60 minutes·D^{-1} of at least MPA.[2] PA should be promoted with caution to children with type 1 diabetes as it can have positive, but also negative, consequences depending on their insulinemic and glycemic state before exercise.[25,26] However, the American Diabetes Association position statement[1] on PA and exercise states that children who are free from secondary complications can participate safely in PA so long as they have careful instructions in self management and the treatment of hypoglycemia. In the current study we found that in a representative group of boys and girls with type 1 diabetes, and no secondary complications, only 41% are achieving the recommended target of 60minutes·D^{-1}. Therefore, over half of children in this sample are missing out on potential health benefits of PA and, in fact, may be adversely affecting their future health by leading insufficiently active lifestyles.

Comparison between studies in this area is difficult due to the use of different measurement instruments and protocols to assess PA. In respect of previous research involving young people with type 1 diabetes, the PA levels of our participants partly concur with the recent findings of Massin et al[6] and Valerio et al[7] who reported that children with type 1 diabetes have PA levels below the recommended threshold. More detailed analysis of our data identified gender differences in the daily accumulation of MVPA with girls demonstrating lower mean levels (44 minutes·D^{-1}) than boys (62 minutes·D^{-1}). Translated as percentages our data reveal that only 60% of boys and 23.5% of girls in the current study actually accumulated 60 minutes·D^{-1} of MVPA, leaving large proportions of both boys (40%) and girls (76.5%) in the category of suboptimal PA. This latter finding contrasts fairly sharply with the research of Särnblad et al[5] whereby it was reported that girls aged 12 to 16 years with diabetes achieve the 60 minutes·D^{-1} recommendation. Unlike the current study which used heart rate monitoring and a threshold of >50% HRR to identify MVPA, Särnblad's data comes from uniaxial accelerometry whereby a cut-off of 1952 counts/min was used to define MVPA. There was no evidence presented in the Särnblad paper that use of the accelerometer count range of >1952 counts/minute to correspond to the predefined PA intensity of moderate or higher was empirically calibrated from simulated PA such as running, walking or free-living activity. Given that accelerometer counts used to define MVPA range widely, from >300 to >3200 counts per minute,[27] it is questionable whether the raw accelerometer signal characterizes a physiological phenomenon such as PA behavior as well as it might without a biological translation. Therefore, although the variety of methodologies used to assess PA levels in the pediatric population makes synthesis of these data more complicated, the main body of evidence, combined with our findings, seems to suggest that PA levels are below optimal levels in children with type 1 diabetes.

Suboptimal levels of PA, as found in the current study, are not unique to children and adolescents with type 1 diabetes, and previous research suggests that children and adolescents without type 1 diabetes also fail to accumulate 60 minutes·D^{-1} of at least MPA.[23,28] A review of 26 studies[23] concluded that healthy young people aged 3 to 17 years perform on average 44 minutes·D^{-1} above the 50%HRR threshold, which is inferior to our group mean of 54 minutes·D^{-1} in children with type 1 diabetes at the same intensity. In addition to demonstrating that the girls with type 1 diabetes in the current study were less likely than their male counterparts to be adequately active, it was also apparent that the younger participants were more likely to achieve the 60 minute MVPA daily target than their older peers. These age and gender related observations are also synonymous with the wider research literature involving nondiabetic children and adolescents and so our trends do not appear to be exclusive to patients with type 1 diabetes.[23,28–30] Our study, like others, has identified adolescent females as being the most susceptible group to low levels of PA.

An important finding from our data is that VPA may be particularly low in children and adolescents with type 1 diabetes. VPA has recently been highlighted as important for health benefits and the American College of Sports Medicine PA recommendations for adults have been revised to reflect this.[24] The guidelines for children have not been revised but data from the Amsterdam growth and health study found participation in greater VPA was predictive of reduced coronary heart disease risk factors.[31] The present data showed children participated in low levels of VPA, accumulating just 8 minutes per day on average, and analysis by gender revealed a significant difference with worryingly low levels of VPA in girls. In adults there is convincing evidence that VPA has a clearer association with coronary heart disease risk reduction than MPA[32] and that higher levels of VPA are inversely correlated with coronary heart disease risk. Certainly if VPA in childhood predicts adult vascular-related mortality or morbidity, the type 1 diabetic patients in this study disadvantage their health further than the natural etiology of the disease already ordains, through such low levels of VPA. Future research should elucidate the value of VPA as opposed to MPA on short- and long-term metabolic and vascular health in type 1 diabetes.

Since PA is known to have an acute blood glucose lowering effect[26] and to increase insulin sensitivity in type 1 patients with diabetes,[33] the hypothesis that habitual PA will be associated with greater metabolic control has been investigated by previous authors, but results have so far proved inconclusive. We therefore conducted a series of comparisons between high and low active individuals to determine whether physiologic health indicators and metabolic characteristics, which are linked to diabetic comorbidity risk, differed by activity status. ANCOVA revealed that there were no differences between the high-

active and low-active groups in either glycemic control or daily insulin dosage ($U \cdot kg^{-1}$) when age was controlled for. Likewise, adiposity represented by BMI and the sum of 5 skinfolds, although lower in the high-active group, did not significantly differ between groups when age was controlled for. Lastly, peak VO_2, an indicator of cardiorespiratory fitness and a strong predictor of cardiovascular disease risk, did not significantly differ between the 2 activity groups. Therefore our data suggest that in this group of young type 1 patients with diabetes, accumulating 60 minutes of MVPA daily does not translate into a superior physiologic or metabolic health profile.

Insofar as glycemic control is concerned, it is possible that we did not detect differences between the high- and low-active groups because of the effects of puberty on HbA_{1c}. Hormonal changes that occur during adolescence create additional difficulties for controlling HbA_{1c} which may counter the salutary effects of PA. Cross-sectional and interventional studies have demonstrated that PA positively impacts on glycemic control in children up to the age of 12 years[6,34] but not in teenagers.[35] In accord with previous research therefore, we speculate, that differences in glycemic control according to activity status may be more readily apparent in younger children not undergoing pubertal hormone fluctuations, but limited numbers in this study precluded further analyses by age while the confounding effects of insulin dose and regimen and calorie intake were controlled for.

Furthermore analysis of PA patterns displayed by our participants indicated that repeated short bouts of MPA are being undertaken, mainly 5 minutes in duration or less, interspersed with periods of low-intensity activity or rest. Ten and twenty minute continuous bouts of activity above the moderate intensity threshold are less common and in fact, the latter are extremely rare in the girls. Although mean total MVPA for the whole group was 54 $minutes \cdot D^{-1}$, this was accumulated through short sporadic bursts of predominantly moderate intensity activity and was not continuous or vigorous, a finding which is reflected in the wider pediatric literature.[17] As discussed above adult PA recommendations have been amended to explicitly include VPA, a proviso was also added that while PA targets may still be reached by accumulating PA over the day, for bouts of activity to count, they need to be a minimum of 10 minutes in duration.[24] Therefore, given the children achieving 60 $minutes \cdot D^{-1}$ in the current study were not significantly different in their glycemic control or physiological profiles than those not achieving 60 $minutes \cdot D^{-1}$, we question whether repeatedly performing short (1–5 minute) episodes of MPA is the most fruitful format for type 1 patients with diabetes to gain metabolic and physiologic health benefits.

Short, unplanned bouts of PA are a challenge to the patient with type 1 diabetes due to the complexity of the neuro-hormonal response to exercise in this population. For exercise to be positive rather than detrimental metabolically, there is a need for a good insulinemic[25] and glycemic state[26] before exercise. Research tells us that the type (continuous or intermittent), duration, and timing of exercise dictate the subsequent blood glucose and counter-regulatory hormonal response. More specifically, exercise which includes intermittent short bouts of high intensity work produces a significantly higher epinephrine response to a single continuous moderate-intensity bout in type 1 diabetes.[36] The altered counter-regulatory hormone responses to intermittent versus continuous exercise is considered to partly contribute to the attenuated BG lowering effect and elevated blood lactate response of intermittent exercise.[36] Therefore, given the established importance of exercise type on the metabolic cost of an exercise bout, the intermittent patterns of PA displayed by the children and adolescents in the current investigation will by necessity impact upon substrate utilization and ultimately the efficacy of exercise for improving glycemic control, adiposity, and oxidative metabolism (peak VO_2). We suggest that the therapeutic value of well anticipated exercise of a more continuous nature as opposed to the short sporadic bouts seen in this study are worthy of further investigation with a view to optimizing exercise prescription guidelines for type 1 diabetes.

A limitation from this study was that numbers prevented us from analyzing the sample further by age and gender. As discussed above, hormonal fluctuations during puberty may counter the effects of PA and future studies should thus ensure a large enough sample size to allow more detailed analyses which separate children and adolescents. Although we have identified some novel data with regard to PA patterns in children and adolescents with type 1 diabetes the generalizability of our findings will be to some extent affected by our sample size and the study may in part, require some replication on a larger scale. In addition the use of cross-sectional data precludes the interpretation of cause and effect in the relationships between PA and metabolic and physiologic factors. Future research using longitudinal and intervention designs should be conducted to investigate the causality of any relationships between PA and metabolic and physiologic factors.

A strength of the current study's design is its detailed analysis of PA patterns and intensity. Analysis of this type will help in our understanding of the relative benefits of PA of varying duration, frequency, and intensity for children with type 1 diabetes. The validity of heart rate monitoring as a method for assessing physical activity in youth has been confirmed. Heart rate is strongly related to oxygen consumption and energy expenditure across a wide range of values.[37–39]

In conclusion, we have determined that PA levels of young type 1 patients with diabetes are suboptimal and a large proportion are failing to achieve the recommended 60 $minutes \cdot D^{-1}$ MPA threshold,[2] especially adolescent girls. Daily PA tends to be made up of short duration bouts of activity rather than continuous or sustained activity, mimicking the patterns seen in nondiabetic children and adolescents. Accumulating 60 minutes of MVPA daily did not translate into superior glycemic control or a better physiological health profile in this sample, and this could

be due to the way in which PA is being performed. PA should still be promoted in children and adolescents with type 1 diabetes as it is invaluable in this population for its ability to impact on adult health and ameliorate risk factors for peripheral and cardiovascular complications to which people with type 1 diabetes are predisposed.[1] Future research should determine the optimal exercise prescription for young people with type 1 diabetes by comparing the medium-term metabolic and physiological effects of continuous versus short repeated bouts of PA.

References

1. American Diabetes Association. Physical activity/exercise and diabetes. *Diabetes Care*. 2004;27:S58–S62.
2. Cavill N, Biddle S, Sallis JF. Health enhancing physical activity for young people: statement of the United Kingdom expert consensus conference. *Pediatr Exerc Sci*. 2001;13:12–25.
3. Bar-Or O, Rowland TW. *Pediatric Exercise Medicine: From Physiologic Principles to Health Care Application*. Champaign, IL: Human Kinetics; 2004.
4. Colberg S. *Diabetic Athlete's Handbook: Your Guide to Peak Performance*. Champagin, IL: Human Kinetics; 2008.
5. Sarnblad S, Ekelund U, Aman J. Physical activity and energy intake in adolescent girls with type 1 diabetes. *Diabet Med*. 2005;22:893–899.
6. Massin MM, Lebrethon MC, Gerard P, Bourguignon JP. Patterns of physical activity determined by heart rate monitoring among diabetic children. *Arch Dis Child*. 2005;90:1223–1226.
7. Valerio G, Spagnuolo MI, Lombardi F, Spadaro R, Siano M, Franzese A. Physical activity and sports participation in children and adolescents with type 1 diabetes. *Nutr Metab Cardiovasc Dis*. 2007;17:376–382.
8. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. Review article. *Sports Med*. 2001;31:439–454.
9. Freedson PS. Field monitoring of physical activity in children. *Pediatr Exerc Sci*. 1989;1:8–18.
10. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. *J Appl Physiol*. 2008;105:977–987.
11. Riddoch C, Andersen LB, Wedderkopp N, et al. Physical activity levels and patterns of 9- and 15-yr-old European children. *Med Sci Sports Exerc*. 2004;36:86–92.
12. Loman DG, Galgani CA. Physical activity in adolescents with diabetes. *Diabetes Educ*. 1996;22:121–125.
13. Claessens AL, Beunen G, Malina RM. Anthropometry, body composition and maturity. In: Armstrong N, Mechelen WV, eds. *Pediatric Exercise Science and Medicine*. Oxford: Oxford University Press; 2000.
14. Wilmore JH, Costill DL. Transformation in the computation of exercise VO_2 in man. *J Appl Physiol*. 1973;35:85–89.
15. Bird S, Davison R. *Guidelines for the Physiological Testing of Athletes*. Leeds, UK: British Association of Sport and Exercise Sciences; 1997.
16. Treiber FA, Musante L, Hartdagan S, Davis H, Levy M, Strong WB. Validation of a heart rate monitor with children. *Med Sci Sports Exerc*. 1989;21:338–342.
17. Armstrong N, Bray S. Physical activity patterns defined by continuous heart rate monitoring. *Arch Dis Child*. 1991;66:245–247.
18. Armstrong N. Young people's physical activity patterns as assessed by heart rate monitoring. *J Sports Sci*. 1998;16(Suppl.):S9–S16.
19. Bar-Or O. *Pediatric Sports Medicine for the Practitioner*. New York: Springer; 1983.
20. Sallis JF, Buono MJ, Roby JJ, Micale FG, Nelson JA. Seven-day recall and other physical activity self-reports in children and adolescents. *Med Sci Sports Exerc*. 1993;25:99–108.
21. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate; a longitudinal study. *Ann Med Exp Biol Fenn*. 1957;35:307–315.
22. Stratton G. Children's heart rates during physical education lessons: a review. *Pediatr Exerc Sci*. 1996;8:215–233.
23. Epstein LH, Paluch RA, Kalakanis LE, Goldfield GS, Cerny FS, Roemmich JN. How much physical activity do youth get? A quantitative review of heart rate measured physical activity. *Pediatrics*. 2001;108:e44.
24. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc*. 2007;39:1423–1434.
25. Chipkin SR, Klugh SA, Chasan-Taber L. Exercise and diabetes. *Cardiol Clin*. 2001;19:489–505.
26. Tansey MJ, Tsalikian E, Beck RW, et al. The Diabetes Research in Children Network. (DirectNet) study group. The effects of aerobic exercise on glucose and counterregulatory hormone concentrations in children with type 1 diabetes. *Diabetes Care*. 2006;29:20–25.
27. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc*. 2005;37:S523–S530.
28. Sleap M, Tolfrey K. Do 9 to 12 yr-old children meet existing physical activity recommendations for health? *Med Sci Sports Exerc*. 2001;33:591–596.
29. Trost SG, Pate RR, Sallis JF, et al. Age and gender differences in objectively measured physical activity in youth. *Med Sci Sports Exerc*. 2002;34:350–355.
30. Armstrong N, Kirby B, McManus A, Welsman J. Physical activity patterns and aerobic fitness amoung pre-pubescents. *Eur Phys Educ Rev*. 1996;2:19–29.
31. Twisk JW, Kemper HC, Van Mechelen W, Bertheke Post G. Clustering of risk factors for coronary heart disease, the longitudinal relationship with lifestyle. *Ann Epidemiol*. 2001;11:157–165.
32. Sesso HD, Paffenberger RS, Jr, Lee IM. Physical activity and coronary heart disease in men: the Harvard Alumni Health Study. *Circulation*. 2000;102:975–980.
33. Mosher PE, Nash MS, Perry AC, LaPerriere AR, Goldberg RB. Aerobic Circuit exercise training: effect on adolescents with well-controlled insulin-dependent diabetes mellitus. *Arch Phys Med Rehabil*. 1998;79:652–657.

34. Campaigne BN, Gilliam TB, Spencer ML, Lampman RM, Schork MA. Effects of a physical activity program on metabolic control and cardiovascular fitness in children with insulin-dependent diabetes mellitus. *Diabetes Care*. 1984;7:57–62.
35. Campaigne BN, Lampman RM. *Exercise in the Clinical Management of Diabetes*. Champaign, IL: Human Kinetics; 1994.
36. Guelfi KJ, Jones TW, Fournier PA. Intermittent high-intensity exercise does not increase the risk of early postexercise hypoglycemia in individuals with type 1 diabetes. *Diabetes Care*. 2005;28:416–418.
37. Maffeis C, Pinelli L, Zaffanello M, Schena F, Iacumin P, Schutz Y. Daily energy expenditure in free-living conditions in obese and non-obese children: comparison of doubly labeled water method and heart-rate monitoring. *Int J Obes Relat Metab Disord*. 1995;19:671–677.
38. Livingstone MB, Coward WA, Prentice AM, et al. Daily energy expenditure in free living children: comparison of heart-rate monitoring with doubly labeled water method. *Am J Clin Nutr*. 1992;56:343–352.
39. Eston RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. *J Appl Physiol*. 1998;84:362–371.