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Association of Type 1 Diabetes With Standardized Test Scores of Danish Schoolchildren

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IMPORTANCE Type 1 diabetes has been associated with cardiovascular disease and late complications such as retinopathy and nephropathy. However, it is unclear whether there is an association between type 1 diabetes and school performance in children.

OBJECTIVE To compare standardized reading and mathematics test scores of schoolchildren with type 1 diabetes vs those without diabetes.

DESIGN, SETTING, AND PARTICIPANTS Population-based retrospective cohort study from January 1, 2011, to December 31, 2015 (end date of follow-up), including Danish public schoolchildren attending grades 2, 3, 4, 6, and 8. Test scores were obtained in math (n = 524 764) and reading (n = 1 037 006). Linear regression models compared outcomes with and without adjustment for socioeconomic characteristics.

EXPOSURES Type 1 diabetes.

MAIN OUTCOMES AND MEASURES Primary outcomes were pooled test scores in math and reading (range, 1-100).

RESULTS Among 631 620 included public schoolchildren, the mean (SD) age was 10.31 (SD, 2.42) years, and 51% were male; 2031 had a confirmed diagnosis of type 1 diabetes. Overall, the mean combined score in math and reading was 56.11 (SD, 24.93). There were no significant differences in test scores found between children with type 1 diabetes (mean, 56.56) and children without diabetes (mean, 56.11; difference, 0.45 [95% CI, −0.31 to 1.22]). The estimated difference in test scores between children with and without type 1 diabetes from a linear regression model with adjustment for grade, test topic, and year was 0.24 (95% CI, −0.90 to 1.39) and 0.45 (95% CI, −0.58 to 1.49) with additional adjustment for socioeconomic status.

CONCLUSIONS AND RELEVANCE Among Danish public schoolchildren, there was no significant difference in standardized reading and mathematics test scores of children with type 1 diabetes compared with test scores of children without diabetes.

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Supplemental content

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Type 1 diabetes leads to microvascular and macrovascular complications[1] and increased risk of cardiovascular mortality. The elevated risk of neuroglycopenia and hyperglycemia associated with diabetes has been suggested to affect cognitive performance,[2] but results are mixed. Some studies have linked diabetes in children to lower academic performance,[3-7] while other studies have found no differences in performance when comparing children with and without diabetes.[8-11] Other studies have focused on the association between adverse diabetes outcomes such as hypoglycemia, diabetic ketoacidosis, and poor metabolic control and cognitive skills. A recent study found that hypoglycemia adversely affects the working memory of the brain.[12] Furthermore, research has shown that mild hypoglycemia has a negative effect on language processing,[13] and poor metabolic control has been associated with lower academic achievement.[4,8,9,14] However, most of these studies were conducted on smaller, nonrandom samples of patients with diabetes.

In Denmark, all children in public schools are tested in reading and math using standardized tests. The primary objective of this study was to compare test scores for children with diabetes with scores for children without diabetes, with and without adjustment for socioeconomic status.

Methods

The study was approved by the Danish Data Protection Agency. The Danish Registry of Childhood and Adolescent Diabetes (DanDiabKids) was approved by the Danish Health Data Authority (file No. 14/915976). These approvals constitute the necessary legal requirements, and informed consent is not required.

This study was a population-based retrospective registry study of all children attending grades 2, 3, 4, 6, and 8 in Danish public schools from January 1, 2011, to December 31, 2015. Because tests were only mandatory for students in public schools, the sample was restricted to students who attended public schools. Students were tested in reading in grades 2, 4, 6, and 8 and in math in grades 3 and 6.

Students were initially identified through Statistics Denmark and subsequently linked with background information from different administrative registries, based on unique personal identity numbers. These data were then augmented with test scores from the Danish National Tests. The DanDiabKids database[15] was used to identify the population of children diagnosed with diabetes (including yearly measures of hemoglobin A_{1c} [HbA_{1c}]). Children with diabetes who had at least 1 test score and children with diabetes who had at least 1 HbA_{1c} measurement before a test were included. DanDiabKids is a national database containing information based on patient journals, clinical examination, and blood samples. Data are uploaded to DanDiabKids by clinicians from all pediatric clinics in Denmark, in connection to yearly visits scheduled in close proximity to each patient's birthday.

Outcome Measures

The pooled reading and math test score was the primary outcome. Each test evaluates a student's abilities within 3 profile areas. In reading, these are language comprehension, decoding, and reading comprehension. In math, they are numbers and algebra, geometry, and mathematics in use.[16] The tests are computer-based, adaptive (students are presented with questions of varying difficulty drawn from a national question bank based on a computerized continuous assessment of the student's proficiency level), and objective (teachers cannot influence scoring or questions asked). Tests are initially scored on a computer according to a Rasch model[17] within each profile area[18] and then mapped (by the Danish Ministry of Education) into a single score in math and a single score in reading, with scores ranging between 1 and 100.

The tests have been shown to be highly predictive of exit examination grades and have been used for other research purposes.[18-21] The tests are considered low stakes compared with exit examinations because they are only used to provide feedback on learning progress to students and not used for sanctioning of teachers or schools.

Because socioeconomic status can influence academic outcomes, the association between diabetes and test scores was adjusted for this potential confounder. In addition, subgroup analyses of the primary outcome were performed to assess factors that might affect the association, including early onset of diabetes, duration of diabetes, and diabetes control measured by HbA_{1c} level and presence of diabetic ketoacidosis.

Secondary outcomes were investigated only in children with diabetes to assess whether diabetes control might influence test scores, including the association between HbA_{1c} level, diabetic ketoacidosis, and hypoglycemia and the pooled test score.

All outcomes and analyses were repeated for math and reading test scores separately.

Clinical Measures

All clinical measures were obtained from DanDiabKids, including diabetes type, HbA_{1c} level, self-care (including self-monitoring of blood glucose levels), treatment (including pen or pump use; insulin dose), episodes of severe hypoglycemia or diabetic ketoacidosis, and other clinical measures (eg, blood pressure, body mass index).[15] HbA_{1c} levels were measured centrally using the standardized method described by the *International Federation of Clinical Chemistry* and determined using high-pressure liquid chromatography (Tosoh Bioscience), with a reference range of 4.3% to 5.8%. Severe hypoglycemia and diabetic ketoacidosis were defined according to the *International Society for Pediatric and Adolescent Diabetes* guidelines.[22] Severe hypoglycemia was defined as episodes with loss of consciousness or seizure with blood glucose level less than 63 mg/dL (3.5 mmol/L) or regain of consciousness after treatment with glucagon or glucose. Episodes of severe hypoglycemia were the number of self-reported episodes treated at home and hospitalizations for hypoglycemia the last year before data upload. Episodes of diabetic ketoacidosis were the registered number of hospital admissions for diabetic ketoacidosis the last year before data upload.

The mean value of the 3 latest HbA_{1c} measurements (recorded yearly) before the school test was used as the measure of HbA_{1c} level (if fewer measurements were available, the mean of those was used). The treatment target for Danish children with diabetes was HbA_{1c} level less than 7.5%. Poor control was defined as HbA_{1c} level greater than 8.6%, which is the cutoff used by several pediatric clinics in Denmark as an indicator for the need for extra visits or psychosocial interventions.

Key Points

Question What is the association between type 1 diabetes and standardized test scores in schoolchildren?

Findings In this population-based retrospective cohort study including 631 620 Danish public schoolchildren, there was no significant difference in standardized reading and mathematics test scores of children with type 1 diabetes compared with test scores of children without diabetes (adjusted test score difference, 0.45 points; test score range, 1-100 points).

Meaning Among Danish schoolchildren, type 1 diabetes was not significantly associated with differences in standardized test scores.

Diabetic ketoacidosis and hypoglycemia were recorded if the child had any episode of either diabetic ketoacidosis (dichotomous) or severe hypoglycemia (dichotomous) in the same time window as the HbA_{1c} measures. Dates of birth, diabetes onset, and school test were used to calculate age at onset and diabetes duration at school test.

Socioeconomic Status

Data on socioeconomic covariates were obtained from administrative registries with *Statistics Denmark*, including information on sex and birth order for all children. For parents, information included age, income, highest completed education, number of children in the household, marital status, residential zip code, whether the parent had insulin-dependent diabetes measured by insulin prescription claims, and whether the parent was an immigrant or descendent. Immigrants are Danish residents not born in Denmark, with neither of their parents born in Denmark. Descendants are Danish residents born in Denmark, with neither of their parents born in Denmark. All socioeconomic covariates were measured when the child was 5 years old.

Statistical Analysis

Means of selected variables were compared between children with and without diabetes.

Linear regression models were estimated to investigate the relationship between diabetes and test scores. Diabetes was coded with the value 1 for children with a confirmed diagnosis of diabetes and 0 for all other observations. Children who developed diabetes between tests were coded as 0 before onset and 1 after onset. The regression-based comparison between children with and without diabetes was performed considering test scores in math and reading as distinct observations, which were then pooled and analyzed jointly in the regression analyses. Cluster-robust standard errors were used to adjust for within-individual correlation attributable to multiple observations per child (a child could possibly be observed with several test scores over time and test topic). For test scores to be comparable across grades and topics, all regression models were adjusted for grade-, topic-, and year-specific effects. Additionally, models were adjusted for socioeconomic status.

To assess the robustness of these results, a case-sibling analysis was performed. Children with diabetes were compared with their siblings without diabetes using linear regression models and adding maternal fixed effects. Additionally, a grade- and topic-specific comparison between children with and without diabetes was performed by repeating the linear regression analysis separately by grade and topic.

Linear regression was also used to compare subgroups of children with diabetes to children without diabetes. To analyze aspects of associations with early disease onset and test scores, children diagnosed before school start (before age 6 years) were considered in 1 subgroup. Associations of diabetes duration and test scores were investigated in the subgroup of children with disease duration longer than 4 years (cutoff identified post hoc from mean value in data). To identify associations of diabetes control and test scores, subgroups of children with mean HbA_{1c} levels greater than 7.5% and greater than 8.6% were considered. The last subgroup consisted of children with diabetic ketoacidosis at onset. Only test score observations for which the subgroup criteria were met at the point of the test were included in each subgroup. These models were estimated with and without adjusting for socioeconomic status. Differences between subgroups were tested by estimating the linear regressions jointly (Seemingly Unrelated Regression Equations) and then testing for equality of coefficients of interest across regressions.

For secondary outcomes among children with diabetes, we assessed the relationship between HbA_{1c} levels and test scores by estimating kernel-weighted local means ("lpoly" command in Stata), with and without adjustment for socioeconomic status. Furthermore, we estimated linear regression models to assess the linear relationship between test scores and HbA_{1c} levels, diabetic ketoacidosis, and hypoglycemia within the group of children with diabetes (with and without adjustment for socioeconomic status).

To assess the importance of missing data on test scores, all children with missing test scores were assigned the lowest possible score, and the main analysis re-estimated to determine if conclusions changed. Among children with diabetes, HbA_{1c} level was compared by missing or nonmissing test score. Among children with diabetes, test scores were compared by missing or nonmissing values of HbA_{1c}.

The primary analysis was replicated, discarding observations in which diabetes onset was within 6 months from the day of the test. All main analyses and the kernel-weighted local mean analysis of test scores and HbA_{1c} level among children with diabetes were prespecified. The subgroup analyses were specified post hoc.

All statistical analyses were performed using Stata 15 (StataCorp). All statistical testing was 2-sided, and $P < .05$ was considered statistically significant. Because of the potential for type I error due to multiple comparisons, findings for analyses of secondary end points should be interpreted as exploratory.

Results

Of 744 516 children attending grades 2 through 8 overall, 2473 had diabetes. Of these children, 631 620 (85%) attended public schools, and of these, 2031 had diabetes. Children with diabetes were not more likely to attend public schools than children without diabetes (odds ratio [OR], 0.97 [95% CI, 0.88 to 1.07]). A total of 608 655 students took at least 1 test, and 1 561 770 test scores were identified (n = 1 037 006 in reading and n = 524 764 in math). Of the children with diabetes, 1878 had at least 1 test score (n = 4234 test scores) and 1729 had HbA_{1c} levels measured before a test (n = 3684 test scores). Children with diabetes were more likely to miss a test than children without diabetes (6.3% vs 3.8%; difference, 2.5 percentage points [95% CI, 1.8 to 3.2]).

Table 1. Background Characteristics of Children With and Without Type 1 Diabetes[a]

Characteristics	% Diabetes (n = 2031)	% No Diabetes (n = 629 589)	Difference (95% CI)
Child			
Sex			
Male	49.3	51.1	−1.8 (−4.0 to 0.4)
Female	50.7	48.9	1.8 (−0.4 to 4.0)
Firstborn	44.0	43.0	1.0 (−1.1 to 3.2)
Living with both parents	66.9	67.8	−0.9 (−2.9 to 1.2)
No. of children in household, mean (SD)	2.3 (1.3)	2.3 (2.1)	0.00 (−0.5 to 0.06)
Parental			
Father			
Age, mean (SD), y	37.6 (5.8)	37.7 (5.7)	−0.1 (−0.4 to 0.2)
Income percentile rank, mean (SD)	74.0 (24.5)	74.3 (24.6)	−0.3 (−1.4 to 0.8)
Master's degree or higher	8.5	10.6	−2.1 (−3.3 to −0.8)
Immigrant or descendant[b]	12.5	14.9	−2.5 (−4.1 to −0.9)
Insulin-dependent diabetes	6.5	0.8	5.8 (4.7 to 6.8)
Mother			
Age, mean (SD), y	34.9 (4.8)	35.0 (4.8)	−0.2 (−0.4 to 0.1)
Income percentile rank, mean (SD)	63.3 (21.7)	63.8 (22.1)	−0.4 (−1.4 to 0.5)
Master's degree or higher	7.6	8.7	−1.0 (−2.2 to 0.1)
Immigrant of descendant[b]	11.4	14.7	−3.2 (−4.6 to −1.8)
Insulin-dependent diabetes	2.5	0.5	2.1 (1.4 to 2.7)
Test[c]			
Test score, mean (SD) (n = 1 561 770 scores)	56.56 (25.31)	56.11 (24.93)	0.45 (−0.31 to 1.22)
Math (n = 524 764 scores)	56.06 (25.10)	55.68 (25.22)	0.38 (−0.95 to 1.70)
Reading (n = 1 037 006 scores)	56.81 (25.41)	56.32 (24.78)	0.48 (−0.45 to 1.42)
Math tests per child, mean (SD) (n = 631 620 children)	0.83 (0.69)	0.83 (0.66)	0.00 (−0.03 to 0.03)
Reading tests per child, mean (SD) (n = 631 620 children)	1.65 (0.81)	1.64 (0.77)	0.01 (−0.03 to 0.04)
Missing test score of all possible tests[d]	6.3	3.8	2.5 (1.8 to 3.2)
HbA_{1c} by missing test score, mean (SD), % (n = 3865 scores)			
Score missing	8.3 (1.3)		0.4 (0.3 to 0.6)
Score not missing	7.9 (1.1)		
Test score by missing HbA_{1c}, mean (SD) (n = 4234 scores)			
HbA_{1c} missing	55.38 (26.44)		−1.35 (−3.71 to 1.00)
HbA_{1c} not missing	56.74 (25.13)		
Clinical			
Used continuous glucose monitor	9.5		
Used insulin pump	64.0		
DKA at onset	18.3		
≥1 Severe hypoglycemic episodes	7.0		
≥1 DKA episodes	4.2		

Abbreviations: DKA, diabetic ketoacidosis; HbA_{1c}, hemoglobin A_{1c}.

[a] Child and parental characteristics were measured when the child is 5 years old. HbA_{1c} is the mean value from the 3 yearly ambulatory control visits before the school test. Severe hypoglycemia is a dichotomous variable equal to 1 if the child reported having at least 1 episode of hypoglycemia in any of the 3 yearly ambulatory visits before the school test; these are both self-reported episodes of severe hypoglycemia treated at home and hospitalized episodes. A blood glucose level less than 63 mg/dL (3.5 mmol/L) should have been documented or the child should have gained consciousness after treatment with either glucagon or glucose. Diabetic ketoacidosis is a dichotomous variable equal to 1 if the child had at least 1 hospitalization for DKA in any of the 3 yearly ambulatory visits before the school test.

[b] Immigrants are Danish residents not born in Denmark, with neither of their parents born in Denmark. Descendants are Danish residents born in Denmark, with neither of their parents born in Denmark.

[c] Test scores range from 0 to 100.

[d] Based on the children's grade enrollment, n = 1 623 234 test scores should be observed, but only n = 1 561 770 tests were completed.

Mean age of the study population was 10.31 (SD, 2.42) years (at first test), and 51% were male. The comparison of background characteristics between children with and without diabetes (**Table 1**) showed that fathers of children with diabetes were less likely to have a master's degree (8.5% vs 10.6%; difference, −2.1 percentage points [95% CI, −3.3 to −0.8]) or be immigrants or descendants (12.5% vs 14.9%; difference, −2.5 percentage points [95% CI, −4.1 to −0.9]) and were more likely to have insulin-dependent diabetes (6.5% vs 0.8%; difference, 5.8 percentage points [95% CI, 4.7 to 6.8]). Mothers of children with diabetes were less likely to be immigrants or descendants (11.4% vs 14.7%; difference, −3.2 percentage points [95% CI, −4.6 to −1.8]) and more likely to have insulin-dependent diabetes (2.5% vs 0.5%; difference, 2.1 percentage

Table 2. Linear Regression Models—Test Score Outcomes for Children With and Without Diabetes[a]

Variable	Mean Score Difference (95% CI)	*P* Value
Model 1: Adjustment for Grade-, Topic-, and Year-Specific Effects		
Child has diabetes	0.24 (−0.90 to 1.39)	.68
Model 2: Adjustment for Grade-, Topic-, and Year-Specific Effects and SES		
Child has diabetes	0.45 (−0.58 to 1.49)	.39
Child characteristics		
Male	−2.85 (−2.96 to −2.74)	<.001
Immigrant or descendant[b]	−8.14 (−8.39 to −7.89)	<.001
Living with both parents	1.95 (1.82 to 2.07)	<.001
Firstborn	3.17 (3.04 to 3.30)	<.001
No. of siblings		
0	Reference	
1	0.65 (0.42 to 0.89)	<.001
2	0.41 (0.16 to 0.66)	<.001
≥3	−1.26 (−1.55 to −0.97)	<.001
Maternal characteristics		
Educational attainment[c]		
Primary school	Reference	
High school	7.93 (7.68 to 8.18)	<.001
Vocational	3.72 (3.54 to 3.90)	<.001
Short higher education	7.67 (7.37 to 7.96)	<.001
Middle secondary education	9.44 (9.24 to 9.65)	<.001
Master's degree or above	13.36 (13.10 to 13.62)	<.001
Income quartile[d]		
1 (lowest)	Reference	
2	0.25 (−0.06 to 0.57)	.11
3	0.86 (0.67 to 1.05)	<.001
4 (highest)	2.32 (2.12 to 2.53)	<.001
Insulin-dependent diabetes	−1.46 (−2.27 to −0.66)	<.001
Paternal characteristics		
Educational attainment[c]		
Primary school	Reference	
High school	8.25 (7.98 to 8.51)	<.001
Vocational	3.03 (2.87 to 3.20)	<.001
Short higher education	6.59 (6.33 to 6.84)	<.001
Middle secondary education	9.29 (9.08 to 9.50)	<.001
Master's degree or above	11.62 (11.39 to 11.86)	<.001
Income quartile[d]		
1 (lowest)	Reference	
2	0.26 (−0.09 to 0.61)	.14
3	−0.14 (−0.36 to 0.07)	.19
4 (highest)	1.19 (1.00 to 1.39)	<.001
Insulin-dependent diabetes	−0.88 (−1.51 to −0.25)	.006

Abbreviation: SES, socioeconomic status.

[a] Total, n = 608 655 children and n = 1 561 770 test scores (n = 1878 children with diabetes and n = 4234 test scores). Both regressions are controlled for grade-, topic-, and year-specific effects. The outcome is in the interval 1 to 100.

[b] Immigrants are Danish residents not born in Denmark, with neither of their parents born in Denmark. Descendants are Danish residents born in Denmark, with neither of their parents born in Denmark.

[c] Examples for vocational: carpenter, mason. For short higher education: real estate agent, florist. For middle secondary education: nurse, engineer.

[d] In 2011: quartile 1, 0 kr-6000 kr; quartile 2, 6001 kr-247 000 kr; quartile 3, 247 001 kr-365 000 kr; quartile 4, greater than 365 000 kr. Income is measured as earnings.

points [95% CI, 1.4 to 2.7]). Among children with diabetes, mean duration of diabetes was 4.5 (SD, 3.3) years (first percentile, 0.1 year; 99th percentile, 13 years), 18.3% had diabetic ketoacidosis at onset, and 64.0% used insulin pumps.

Primary Outcome

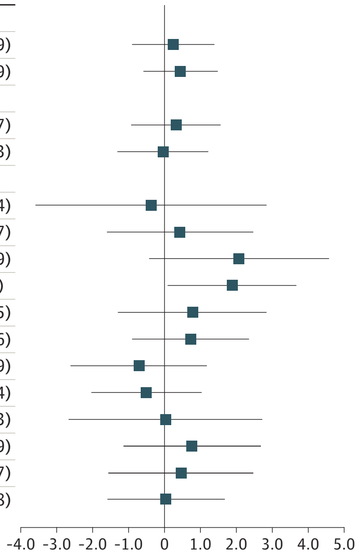
The overall mean pooled test score was 56.11 (SD, 24.93). There was no statistically significant difference between test scores from children with vs without diabetes (mean, 56.56 vs 56.11; difference, 0.45 [95% CI, −0.31 to 1.22]). The estimated difference from the linear model adjusted for grade-, topic-, and year-specific effects was 0.24 (95% CI, −0.90 to 1.39]). Adjusting for socioeconomic status, the difference was 0.45 (95% CI, −0.58 to 1.49) (**Table 2** and **Figure 1**).

Sensitivity and Subgroup Analyses of the Primary Outcome

In the case-sibling analysis (Figure 1), 7344 test scores were identified, of which 2966 were from children with diabetes (n = 1257 children) and 4378 were from siblings without diabetes (n = 1606 children). Children with diabetes had slightly

Figure 1. Mean Test Score Difference Between Children With and Without Type 1 Diabetes—Linear Model

Subgroup	Mean Score Difference (95% CI)
Children with diabetes vs diabetes-free children, all tests	
Diabetes	0.24 (-0.90 to 1.39)
Adjusted for SES	0.45 (-0.58 to 1.49)
Children with diabetes vs diabetes-free siblings, all tests	
Case-sibling	0.32 (-0.92 to 1.57)
Adjusted for SES	-0.03 (-1.30 to 1.23)
Children with diabetes vs diabetes-free children, by subject	
Reading, grade 2	-0.37 (-3.58 to 2.84)
Adjusted for SES	0.44 (-1.59 to 2.47)
Reading, grade 4	2.08 (-0.42 to 4.59)
Adjusted for SES	1.89 (0.09 to 3.68)
Reading, grade 6	0.78 (-1.29 to 2.85)
Adjusted for SES	0.73 (-0.90 to 2.36)
Reading, grade 8	-0.71 (-2.61 to 1.19)
Adjusted for SES	-0.50 (-2.03 to 1.04)
Math, grade 3	0.03 (-2.66 to 2.73)
Adjusted for SES	0.78 (-1.13 to 2.69)
Math, grade 6	0.46 (-1.55 to 2.47)
Adjusted for SES	0.05 (-1.58 to 1.68)



For top and bottom panels, n = 608 655 children and n = 1 561 770 test scores (n = 1878 children with diabetes and n = 4234 test scores). For center panel, n = 2863 children and n = 7344 test scores (n = 1257 children with diabetes and n = 2966 test scores). All models are adjusted for grade-, topic-, and year-specific effects (bottom panel is only adjusted for year-specific effects). In models adjusted for socioeconomic status (SES), adjustment was made for sex of child, immigration status, birth order, number of siblings, living with both parents, maternal/paternal educational attainment, maternal/paternal income, maternal/paternal diabetes status, and zip code.

higher raw mean test scores than their siblings (56.43 vs 55.03; difference, 1.40 [95% CI, 0.20 to 2.60]), but this difference was insignificant in both linear models (adjusted for grade-, topic-, and year-specific effects, 0.32 [95% CI, −0.92 to 1.57]; additionally adjusted for socioeconomic status, −0.03 [95% CI, −1.30 to 1.23]).

In the analysis of differences in test scores between children with and without diabetes separately by topic and grade (Figure 1), only reading in fourth grade with adjustment for socioeconomic status showed a significant difference (1.89 [95% CI, 0.09 to 3.68]; higher scores for children with diabetes).

When comparing test scores in subgroups of children with diabetes with test scores of children without diabetes (**Figure 2**), having an HbA_{1c} level greater than 7.5% (n = 1155 children, n = 2354 test scores) was associated with lower test scores (mean, 53.84 vs 56.11; difference, −2.26 [95% CI, −3.27 to −1.26]), but the association was not statistically significant in the linear model adjusted for socioeconomic status (difference, −1.06 [95% CI, −2.37 to 0.25]). Having an HbA_{1c} level greater than 8.6% (n = 472 children, n = 867 test scores) was associated with lower scores (mean, 49.95 vs 56.11; difference, −6.15 [95% CI, −7.80 to −4.50]), and the difference was statistically significant in the linear model with adjustment for socioeconomic status (difference, −2.47 [95% CI, −4.50 to −0.45]). In the statistical tests for interaction between subgroups of children with diabetes (separately compared with children without diabetes), there was a statistically significant difference between subgroups with HbA_{1c} levels greater than 7.5% vs 7.5% or lower and HbA_{1c} levels greater than 8.6% vs 8.6% or lower ($P < .001$ for both subgroups, both with and without adjustment).

Diabetic ketoacidosis at onset (n = 336 children, n = 755 test scores), diabetes onset at age younger than 6 years (n = 564 children, n = 1391 test scores), and diabetes duration longer than 4 years (n = 799 children, n = 1659 test scores) were not associated with significantly different test scores compared with the children without diabetes (Figure 2). In the statistical tests for interaction between subgroups with diabetic ketoacidosis at onset vs no diabetic ketoacidosis at onset (separately compared with children without diabetes), there was a statistically significant difference without adjustment ($P = .01$) but not with adjustment ($P = .13$). The tests for interaction between children with diabetes onset at age younger than 6 years vs 6 years or older ($P = .77$ without adjustment; $P = .81$ with adjustment) and children with diabetes duration longer than 4 years vs 4 years or less ($P = .89$ without adjustment; $P = .72$ with adjustment) did not reach statistical significance.

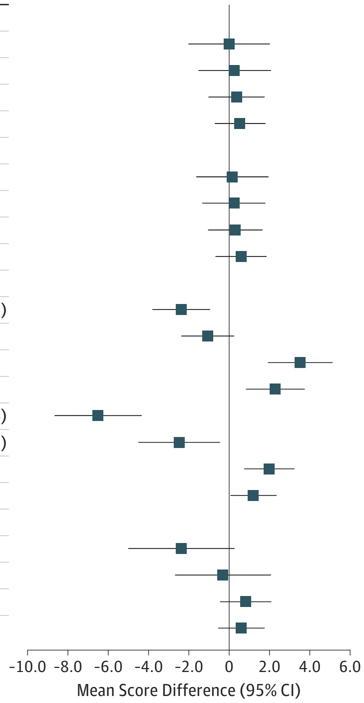
Secondary Outcomes

Among children with diabetes, levels of HbA_{1c} and indicators for severe hypoglycemia and hospitalizations for diabetic ketoacidosis could be assigned to 87% of the test score observations (n = 3684 from n = 1729 children with diabetes). Mean HbA_{1c} level was 7.9% (SD, 1.1%). HbA_{1c} level was significantly higher when the test score was missing (8.3% vs 7.9%; difference, 0.4% [95% CI, 0.3 to 0.6]).

The unadjusted kernel-weighted test scores for children with diabetes and HbA_{1c} levels less than 8% were higher than the population mean (**Figure 3**A). Conversely, test scores for children with HbA_{1c} levels in the range 8% to 11% were lower than the population mean. Adjusting for socioeconomic status attenuated the association between HbA_{1c} level and test scores. Test scores from children with mean HbA_{1c} levels less than 7.5% were slightly above the population mean. In contrast, test scores were lower than the population mean among children with HbA_{1c} levels ranging from 8.5% to 9.5% (Figure 3B).

Figure 2. Mean Test Score Differences Between Subgroups of Children With vs Without Type 1 Diabetes—Linear Model

Subgroup	Mean Score Difference (95% CI)
Onset age, y	
<6	0.00 (-2.02 to 2.02)
Adjusted for SES	0.27 (-1.52 to 2.07)
≥6	0.36 (-1.02 to 1.75)
Adjusted for SES	0.54 (-0.72 to 1.80)
Diabetes duration, y	
>4	0.15 (-1.63 to 1.94)
Adjusted for SES	0.24 (-1.33 to 1.80)
≤4	0.30 (-1.33 to 1.80)
Adjusted for SES	0.59 (-0.67 to 1.85)
HbA_{1c}, %	
>7.5	-2.38 (-3.81 to -0.95)
Adjusted for SES	-1.06 (-2.37 to 0.25)
≤7.5	3.53 (1.93 to 5.13)
Adjusted for SES	2.29 (0.83 to 3.75)
>8.6	-6.50 (-8.65 to -4.34)
Adjusted for SES	-2.47 (-4.50 to -0.45)
≤8.6	1.99 (0.74 to 3.23)
Adjusted for SES	1.20 (0.06 to 2.34)
DKA	
DKA at diabetes onset	-2.37 (-5.00 to 0.26)
Adjusted for SES	-0.31 (-2.69 to 2.06)
No DKA at diabetes onset	0.81 (-0.46 to 2.08)
Adjusted for SES	0.61 (-0.54 to 1.76)



For no diabetes, n = 606 777 children and n = 1 557 536 test scores; for diabetes onset at younger than 6 years, n = 564 children and n = 1391 test scores; diabetes onset at 6 years or older, n = 1314 children and n = 2843 test scores; diabetes duration greater than 4 years, n = 799 children and n = 1659 test scores; diabetes duration 4 years or less, n = 1324 children and n = 2575 test scores; hemoglobin A_{1c} (HbA_{1c}) level greater than 7.5%, n = 1155 children and n = 2354 test scores; HbA_{1c} level 7.5% or less, n = 728 children and n = 1330 test scores; HbA_{1c} level greater than 8.6%, n = 472 children and n = 867 test scores; HbA_{1c} level 8.6% or less, n = 1388 children and n = 2817 test scores; diabetic ketoacidosis (DKA) at onset, n = 336 children and n = 755 test scores; no DKA at onset, n = 1542 children and n = 3479 test scores. All models are adjusted for grade-, topic-, and year-specific effects. In models adjusted for socioeconomic status (SES), adjustment was made for sex of child, immigration status, birth order, number of siblings, living with both parents, maternal/paternal educational attainment, maternal/paternal income, maternal/paternal diabetes status, and zip code.

The unadjusted linear model (Figure 3A) showed that each 1% increase in HbA_{1c} level was associated with a 3.48-point lower test score (95% CI, −4.32 to −2.64). The corresponding coefficient from the adjusted model (Figure 3B) was −1.59 (95% CI, −2.53 to −0.66).

Experiencing at least 1 episode of diabetic ketoacidosis within the past 3 years was associated with lower test scores (50.80 vs 56.91; difference, −6.11 [95% CI, −10.15 to −2.07]). This association was not statistically significant when controlling for HbA_{1c} level, socioeconomic status, or both (eTable 1 in the Supplement). No association was found between having experienced at least 1 episode of severe hypoglycemia and test scores (eTable 1 in the Supplement).

All outcomes and analyses were repeated for math and reading test scores separately (eTables 1 and 2 and eFigures 1-5 in the Supplement). The results were similar to those for the pooled test score.

Missing Values

To address the potential of the increased propensity to miss a test among children with diabetes, all missing test scores were replaced with 1 (assuming that children who missed a test performed worst of all). Children with diabetes scored slightly lower (53.08 vs 54.02; difference, −0.94 [95% CI, −1.76 to −0.13]). The difference was not statistically significant in adjusted models (linear model, −1.05 [95% CI, −2.21 to 0.12]; with adjustment for socioeconomic status, −0.88 [95% CI, −1.94 to 0.17]).

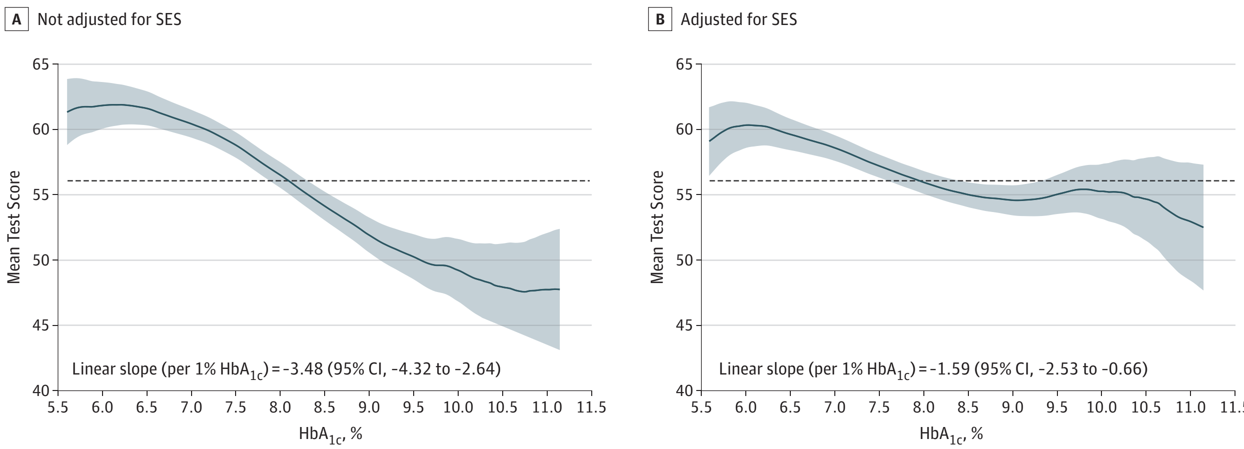
To investigate the importance of missing HbA_{1c} values among children with diabetes, pooled test score means were compared. Mean test score was 55.38 when HbA_{1c} values were missing and 56.74 when values were available (difference, −1.35 [95% CI, −3.71 to 1.00]).

In models in which test scores from children with diabetes onset near the date of the test (within 6 months) were discarded, results were unchanged (n = 558 test scores; difference adjusted for grade-, topic-, and year-specific effects, 0.43 [95% CI, −0.75 to 1.61]; with additional adjustment for socioeconomic status, 0.62 [95% CI, −0.44 to 1.69]).

Discussion

In this population-based cohort study, there was no statistically significant difference in pooled reading and math test scores between children with and without diabetes. The

Figure 3. Local Kernel–Weighted Mean of Test Score on HbA_{1c} Level Among Children With Type 1 Diabetes (n = 1729 Children [3684 Test Scores])



Local kernel-weighted mean of test score on hemoglobin A_{1c} (HbA_{1c}) measure. Shaded areas indicate 95% CIs; dashed lines indicate population mean test scores. The lowest and highest 1% of the HbA_{1c} distribution is not shown. Panel B is adjusted for sex of child, immigration status, birth order, number of siblings, living with both parents, maternal/paternal educational attainment, maternal/paternal income, maternal/paternal diabetes status, zip code residence, and diabetes duration. Kernel-weighted mean adjustment was performed by obtaining the residuals from a linear projection of test scores on the socioeconomic covariates (y-axis) and the residuals from a linear projection of HbA_{1c} values on the socioeconomic covariates (x-axis).[23] The linear slope coefficient stems from a linear regression model for test scores with and without adjusting for covariates. SES indicates socioeconomic status.

estimated difference was small and statistically insignificant. Among children with diabetes, a statistically significant (linear) association between test scores and diabetes control (assessed by HbA_{1c} level) was found.

A key question is whether the tests measure school performance. Previous research[18] has demonstrated that test scores predict 48% to 51% of the variation in ninth-grade math and Danish examination grades.

The main finding of no statisticially significant difference in test scores contrasts with the findings of some previous studies.[3-7] However, most existing studies are based on small, nonrandom samples of individuals with diabetes matched to random controls. Closest to this study is the study by Persson et al,[6] which found small negative effects of diabetes on school grades for the population of Swedish children with diabetes born in the 1970s. Besides school grades (potentially) measuring more dimensions than test performance, most of the children in the current study were born after the turn of the millennium. It is possible that advances in treatment modalities over recent decades (64% of children with diabetes in this study used an insulin pump) have improved not only gaps in mortality and morbidity[1,24] between individuals with diabetes and the overall population but also have improved gaps in school performance. This study also documented that it is important to adjust for confounders such as socioeconomic status when assessing the association between diabetes control and test scores or school performance.

While demonstrating a negative association between poor glycemic control and test scores, the results showed that children reaching the treatment target (HbA1c level <7.5%) scored higher than the population mean. While no conclusive evidence can be provided from an observational study, one interpretation could be that the parents of children with diabetes direct more of their resources toward the affected child, giving rise to both better school performance and better metabolic control. This might happen to a lesser extent among children with poor diabetes control. A second interpretation could be that being able to maintain good glycemic control and school performance is confounded by ability (cognitive and noncognitive skills), which is correlated with socioeconomic status.

Limitations

The study has several limitations. First, there was a higher proportion of missing test scores for children with diabetes. However, the sensitivity analysis showed that setting all missing test scores to 1 did not change the results. Second, Denmark has considerable diabetes awareness and good medical and social care by international standards, and hence the findings may not apply to other countries. It is possible that the gaps in test performance are larger in countries where access to health care is associated with socioeconomic status. Third, in this study tests were performed after short disease duration (mean, 4.5 years), and diabetic complications usually manifest after a longer duration. However, no association was found after limiting to children with longer disease duration. Further, even though diabetic ketoacidosis at onset (or later) may directly affect cognitive skills, no association with test scores was found.

Conclusions

Among Danish public schoolchildren, there was no significant difference in standardized reading and mathematics test scores of children with type 1 diabetes compared with test scores of children without diabetes.

ARTICLE INFORMATION

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Author Contributions: Dr Skipper had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Skipper, Gaulke, Eriksen, Svensson.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Skipper, Gaulke, Eriksen, Fabrin Nielsen.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Skipper, Fabrin Nielsen, Svensson.
Obtained funding: Skipper, Svensson.
Administrative, technical, or material support: Skipper, Svensson.
Supervision: Skipper, Svensson.

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