The Effect of 10-s Maximal Sprints Performed Prior to and Immediately Following Moderate Intensity Exercise on Glucoregulation of Individuals with Type 1 Diabetes

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THE EFFECT OF 10-S MAXIMAL SPRINTS PERFORMED PRIOR TO AND IMMEDIATELY FOLLOWING MODERATE INTENSITY EXERCISE ON GLUCOREGULATION OF INDIVIDUALS WITH TYPE 1 DIABETES

By

Jennifer Maher Raeburn

A DISSERTATION

Submitted to the Faculty of the University of Miami in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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THE EFFECT OF 10-S MAXIMAL SPRINTS PERFORMED PRIOR TO AND IMMEDIATELY FOLLOWING MODERATE INTENSITY EXERCISE ON GLUCOREGULATION OF INDIVIDUALS WITH TYPE 1 DIABETES

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**Objective:** To examine the efficacy of a 10-s maximal sprint performed immediately prior to and following a 40-min, moderate-intensity bout of exercise, as a means of maintaining plasma glucose concentration during both exercise and 120 min of recovery in those with type 1 diabetes mellitus (T1DM). **Research Design and Methods:** Seven moderately active males with T1DM performed a continuous graded exercise test on a cycle ergometer to determine peak power output ($W_{\text{peak}}$). Subjects then reported to the laboratory on two separate occasions after an overnight 8-h fast and either rested (CON) or performed a 10-s maximal effort sprint (150% $W_{\text{peak}}$) immediately prior to and again immediately following (SP) a 40-min bout of steady-state exercise (55% of $W_{\text{peak}}$, ~70% $VO_{2\text{peak}}$) on a cycle ergometer. Trials were performed in a randomized and counterbalanced order. **Results:** Plasma glucose concentration decreased during exercise in CON and was significantly lower than baseline at 40 min of exercise (-2.5 ± 0.9 mM, $p < 0.05$) and throughout recovery. While plasma glucose concentration tended to decrease during exercise in the SP trial (-0.9 ± 1.2 mM), values were never significantly different than baseline. Plasma glucose concentration did not change from the end of exercise throughout recovery in either CON or SP. Plasma lactate concentration increased significantly from baseline to end of exercise in both CON and SP and was significantly higher in SP than CON (~1.5 mM, $p < 0.05$) throughout exercise and 15 min into
recovery. Plasma epinephrine concentration increased significantly (5- to 8-fold, \( p < 0.05 \)) from rest to exercise and there were no differences between conditions. **Conclusions:** A brief maximal sprint attenuated the decline in plasma glucose concentration during moderate intensity exercise, but plasma glucose concentration did not change from the end of exercise throughout recovery in either CON or SP. The protective effects of the brief maximal sprint before exercise appear to be attributable more to the increased availability of plasma lactate than a potentiation of the catecholamine response. Brief maximal sprints may aid individuals with uncomplicated TIDM to better maintain normoglycemia during exercise and gain the greatest benefits from regular aerobic exercise.
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Chapter 1

Introduction

Physical activity has been shown to improve insulin sensitivity, aid in glycemic control and weight management, reduce blood pressure (BP), improve metabolic profile and dyslipidemia, and improve overall quality of life in individuals with type 1 diabetes mellitus T1DM (1-3). Despite these clear benefits, the most common and dangerous consequence of exercise for those with T1DM is hypoglycemia both during and up to 17 h post-exercise (4).

Reducing the prandial insulin dose in anticipation of imminent exercise is effective in minimizing exercise-induced hypoglycemia and most closely mimics the normal physiological response of insulin to exercise in non-diabetic individuals. (5). However, the precise degree of insulin dose reduction remains in question as recommendations have varied anywhere from 10-40% (6), 10-50% (7), 50-75% (8), and 50-90% (9). Adjustments of insulin dosage require planning and thus are not helpful for spontaneous bouts of exercise. This leaves many individuals with T1DM employing a “learning by trial and error” strategy (10), often relying on additional caloric intake to prevent or treat hypoglycemia during or immediately following exercise.

While continuous, moderate intensity exercise bouts are associated with decreases in plasma glucose concentration in those with T1DM, high intensity exercise often has the opposite effect (4). Recently a number of studies have reported that brief intermittent high intensity exercise bouts can attenuate the usual drop in plasma glucose concentration both during (11-15) as well as after (15; 16) moderate intensity exercise in those with T1DM. This is likely attributable to the stimulation of metabolic and hormonal responses,
such as increased catecholamines, that stimulate hepatic glucose production and inhibit insulin-mediated glucose uptake (14).

Additional research suggests that adding a 10-s bout of maximal sprint immediately before or after moderate intensity exercise can counter the rapid fall in post-exercise plasma glucose concentration often seen in T1DM individuals without the need for pre-exercise dietary or insulin adjustments (11; 12). These 10-s bouts are associated with elevated levels of counterregulatory hormones (catecholamines, growth hormone, cortisol) and lactate, thought to contribute to the stabilization in glycemia post-exercise. The advantage of this approach is that a broad recommendation of incorporating brief sprints prior to and/or at the end of aerobic exercise may be effective in reducing the risk of hypoglycemia in those with T1DM. This might supplement or replace highly specific and individualized insulin dose and nutritional recommendations that require additional testing and trial and error for hypoglycemia prevention. However, the exercise bouts used in these previous studies consisted of a duration (20 min) and intensity (40% VO$_{2\text{max}}$) of activity that might not pose as great a risk for hypoglycemia, and would generally be considered insufficient to attain optimal cardiovascular benefits.

The purpose of the proposed study was to examine the efficacy of 10-s maximal sprints performed immediately prior to and following a 40-min, moderate-intensity (55% of $W_{\text{peak}}$, ~70% VO$_{2\text{peak}}$) bout of aerobic exercise, as a means of maintaining plasma glucose concentration stable during both exercise and 120 min of recovery in those with T1DM. We hypothesized that performing a pre-exercise 10-s maximal sprint would attenuate the decline in plasma glucose concentration during 40 min of moderate intensity exercise compared to a control condition in those with T1DM. Additionally, we
hypothesized that the combined effects of performing 10-s maximal sprints prior to and immediately after exercise would attenuate the decline in plasma glucose concentration during 120 min of recovery compared to a control condition in those with T1DM.
Chapter 2

Research Design and Methods

Subjects

Seven moderately active males (age 31.1 ± 2.7 years, height 175.5 ± 2.3 cm, weight 78.8 ± 4.1 kg, body composition 20.2 ± 1.8% fat, BMI 26.5 ± 1.2 kg/m^2) with T1DM (duration of disease > 5 yr) were recruited from the University of Miami and surrounding communities. All participants had HbA1c levels < 9% and had no evidence of advanced vascular complications, such as heart disease, nephropathy, retinopathy, or neuropathy. Six subjects were treated with a subcutaneous insulin infusion pump and one was on a multiple injection regimen. Subjects were screened using PAR-Q and health history questionnaires for health issues that could impact exercise performance or safety during the trials. The procedures and risks were thoroughly explained to the subjects and their written, voluntary, informed consent was obtained.

General experimental design

Following screening, subjects underwent a peak aerobic capacity (VO_{2peak}) test. Subsequently, subjects performed two experimental exercise trials in a randomized and counterbalanced order.

Screening

Subjects completed one screening appointment at baseline for which they were instructed to arrive at the laboratory well rested (no heavy exercise for 24 h prior) and normally hydrated (500 ml of water within 1 h of testing). They were instructed to consume their normal pre-exercise meal and insulin dose. Timing of the meal and insulin was left to the subject’s discretion and was consumed on average 45 min (range of 45-90
min) prior to the testing. Subjects completed PAR-Q and health history questionnaires, body fat percentage was determined with a three-site skin fold test, and heart rate (HR), BP and plasma glucose concentration were measured at rest prior to the VO$_{2peak}$ test.

A continuous progressive exercise test to volitional exhaustion on an electromagnetically braked cycle ergometer (Monark 829e, Vansbro, Sweden) was used to determine VO$_{2peak}$ and peak exercise capacity (W$_{peak}$). Data from this test was used to set the workload for the experimental trials at 55% W$_{peak}$. Subjects began cycling at 50 W and the workload was increased by 50 W increments every 2 min until 150 W and then by 30 W increments every 2 min until exhaustion. Expired respiratory gases were collected continuously and analyzed with an online open-circuit metabolic cart (Encore Vmax 29c, CareFusion, San Diego, CA). Heart rate, stroke volume (SV) and cardiac output (Q) were measured continuously with a noninvasive impedance cardiography device (PhysioFlow PF05 L1, Manitec Biomedical, Macharen, France). The PhysioFlow device emits a low-amperage (3.6 mA), high frequency (75 KHz), alternating electrical signal between two sets of electrodes. One set was placed on the supraclavicular fossa on the left side of the neck; the other set on the middle of the back at the level of the xiphoid process. SV was calculated from the measurement of changes in transthoracic electrical impedance during the cardiac cycle while simultaneous measurements of ECG activity (V1 and V6) allowed for the HR measurement, and therefore, the calculation of Q. When compared to the direct Fick method at rest and during submaximal and maximal incremental exercise, the PhysioFlow device has been shown to be very reliable ($r = 0.95$, mean difference for Q of 0.009 L/min) with clinically acceptable accuracy ($r = 0.85 - 0.94$, mean difference for Q of 0.07 - 0.58 L/min) (17). The coefficient of variations for
SV and Q from the PhysioFlow across repeated cycle ergometer VO_{2peak} tests in healthy, trained men was reported to be 3.6 and 3.4%, respectively (18). Rating of perceived exertion (RPE), BP, and finger stick plasma glucose concentration (Freestyle Blood Glucose Monitoring System, Abbot, Abbot Park, IL) were assessed at the end of each 2-min stage and during recovery. Subjects were asked to remain in the laboratory until their HR and BP values returned to within 15% of baseline values

**Experimental exercise trials.**

Subjects completed a total of two experimental exercise trials, consisting of a control trial (CON) and a sprint trial (SP) that were administered in a randomized and counterbalanced order at least one week apart. Subjects were asked to limit exercise for 48 h prior to each trial and were asked to refrain from caffeine and alcohol for 36 h prior to each trial. For 24 h prior to the first experimental exercise trial subjects were instructed to record their diet and were asked to repeat this diet and their prandial insulin protocol before the second exercise trial. Subjects were instructed to arrive to the laboratory following an 8-h fast. Subjects were provided with instructions to ensure that their finger stick plasma glucose concentrations were within an appropriate range for exercise (5.6-13.9 mM, 100-250 mg/dl). An indwelling catheter was placed in the antecubital fossa by a licensed phlebotomist for venous blood sampling at rest and during exercise and recovery. Electrodes were placed on the chest, neck and back for the measurement of cardiovascular hemodynamics by noninvasive impedance cardiography as described in Screening. Blood pressure, HR, and finger stick plasma glucose concentration were measured at rest before the steady state exercise bout.
All experimental exercise trials consisted of 5 min of warm up at 50 W. Subjects then either rested (CON) or performed a 10-s maximal sprint (150% W\text{peak}) immediately prior to and again immediately following (SP) a 40-min bout of steady-state exercise at 55% W\text{peak} on an electromagnetically braked cycle ergometer. Subjects began cycling while the workload was adjusted in the first 5 min until a workload that elicited 55% of W\text{peak} was reached. Subjects remained at this workload for the remainder of the 40-min test. Cardiovascular hemodynamics (HR, SV, Q), RPE, and respiratory measures were assessed between minutes 15-20 (steady state 1, SS\textsubscript{1}) and 35-40 (steady state 2, SS\textsubscript{2}). After 120 min of recovery, subjects were instructed to eat and to take 50% of their usual prandial insulin dose.

**Blood sampling**

Venous blood from the arm (10 ml) was sampled at rest, immediately after the sprint (in the SP trial), every 10 min during the exercise bout, and then at 0, 5, 10, 15, 30, 50, 75, 100 and 120 min of recovery. A small portion of this sample was used to obtain immediate plasma glucose values at each time point (Freestyle Blood Glucose Monitoring System, Abbot, Abbot Park, IL) and trials were to be terminated if values dropped below 3.9 mM (70 mg/dl).

Blood samples were centrifuged at 4\degree C and 3000 rpm for 15 min (5804 R, Eppendorf) and the supernatant was transferred via transfer pipettes into 1.5 mL microtubes, and frozen at -80\degree C (VWR 5700 U LT Freezer, Bristol, CT) until analysis.

**Hormone and metabolite analyses**

Glucose, lactate, nonesterified fatty acids (NEFA) and glycerol were assayed by spectrophotometry in duplicate with a Multiskan Spectrum microplate reader (Thermo
Fischer Scientific, Waltham, MA) using commercially available kits. Plasma glucose was analyzed using a hexokinase enzymatic kit (Sigma-Aldrich, St. Louis, MO) while plasma lactate was measured using a lactate oxidase enzymatic kit (Trinity Biotech, Wicklow, Ireland). Serum NEFA levels were measured using an enzymatic colorimetric kit (Wako Pure Chemical Industries, Osaka, Japan) while serum glycerol was measured using a glycerol kinase enzymatic kit (Sigma-Aldrich, St. Louis, MO). Plasma insulin was measured using enzyme-linked immunosorbent assay (ELISA) kits (Kamiya Biomedical, Seattle, WA). Plasma catecholamine levels were determined using an enzyme-linked immunosorbent assay kit (Rocky Mountain Diagnostics, Inc., Colorado Springs, CO).

**Whole body carbohydrate and lipid oxidation**

Substrate oxidation rates were derived from respiratory data averaged over minutes 15-20 and 35-40 of the 40 min cycling bout. The proportion of energy expenditure (EE) derived from carbohydrate (CHO) and fat, and the rates of whole body CHO and fat oxidation rates were calculated using stoichiometric equations assuming that nitrogen excretion was negligible due to the subjects being diet and body mass stable (19):

\[
\text{%EE from CHO} = \frac{[(\text{RER} - 0.71)/0.29] \times 100}{\text{Whole body CHO oxidation (g/minute)}}
\]

\[
\text{Whole body CHO oxidation (g/minute)} = \frac{[(\text{EE from CHO} \times \text{VO}_2) \times 5.05 \text{ kcal/l} \text{O}_2]}{4.2\text{kcal/g CHO}}
\]

\[
\text{Whole body fat oxidation (g/minute)} = \frac{[(\text{EE from fat} \times \text{VO}_2) \times 4.7 \text{ kcal/l} \text{O}_2]}{9\text{kcal/g lipid}}
\]

where \( \text{VO}_2 \) is expressed in l/min.
**Statistics**

All data are expressed as means ± SE. The significance of within- and between-subjects differences was analyzed using a repeated measures two-way ANOVA followed by post hoc analyses using the Least Significant Difference test using SPSS 19.0 software. Significance was set *a priori* at alpha < 0.05.
Chapter 3

Results

Oxygen consumption and cardiovascular hemodynamics during peak exercise

Subjects had a VO$_{2peak}$ of 48.8 ± 2.4 ml/kg/min, placing them in 80-85$^{th}$ percentile for their age range and gender according to ACSM guidelines (Table 1) (20). Maximal oxygen consumption occurred at 260 W and ∼94% of age-predicted maximum HR.

Cardiovascular hemodynamics during steady-state exercise

Heart rate and Q significantly increased from SS$_1$ to SS$_2$ in both conditions (Table 2). However, there were no hemodynamic differences between CON and SP trials. Average steady state exercise HR and Q values were ∼84 and 72% of maximal values, respectively.

Oxygen consumption and whole body substrate oxidation rates during steady-state exercise

In both CON and SP trials, subjects exercised at an average VO$_2$ of 2.7 L/min or ∼70% of VO$_{2peak}$ (Table 2). RER decreased significantly from SS$_1$ to SS$_2$ in the CON trial. The contribution of CHO to total energy expenditure significantly decreased while that of fat significantly increased in the CON trial (Table 2).

Metabolite and hormone responses

Plasma glucose concentration during exercise in CON decreased significantly at 30 and 40 min of exercise and throughout recovery compared to baseline (Fig. 1A). While plasma glucose concentration tended to decrease during exercise in the SP trial, values were never significantly different than at baseline. None of the subjects in either trial experienced hypoglycemia, defined as a plasma glucose value of 3.9 mM (70 mg/dl) or lower, leading to premature trial termination. Examination of the change in plasma
glucose also shows a significant decrease at 30 and 40 min of exercise and throughout recovery in CON (Fig. 1B). Plasma lactate concentration increased significantly from baseline in both CON and SP trials during exercise and remained elevated 30 min into recovery (Fig. 2). However, plasma lactate concentrations in SP were significantly higher than CON throughout exercise and 15 min into recovery. Serum NEFA were similar in both trials with a significant decrease from baseline to early exercise (min 5-10) and a recovery to resting levels later in exercise (Fig. 3). In recovery, serum NEFA initially increased sharply and were significantly greater than baseline at 75-120 min in CON trial only. The concentration of serum NEFA at the end of recovery was significantly lower in SP than CON. Serum glycerol concentrations steadily increased during exercise from baseline in both CON and SP trials and remained significantly higher than rest in the CON trial only (Fig. 4).

Plasma epinephrine concentration increased significantly from baseline to exercise in both CON and SP trials and decreased to resting values within 20 min of recovery, with no differences noted between conditions (Fig. 5A). Despite trends of norepinephrine concentration increasing from baseline during exercise, it did not reach statistical significance in either trial (Fig. 5B). No significant changes were noted for plasma insulin concentrations (Fig. 6).
Chapter 4

Discussion

The purpose of this study was to examine the efficacy of 10-s maximal sprints performed immediately prior to and following a 40-min, moderate-intensity bout of exercise, as a means of maintaining plasma glucose concentration during both exercise and 120 min of recovery in individuals with T1DM. Our hypotheses were partially supported in that performing a 10-s sprint prior to exercise attenuated the decline in plasma glucose concentration during exercise compared to CON. However, surprisingly the SP condition provided no benefit compared to CON during recovery where plasma glucose concentration remained unchanged in both conditions. These results build on those previously published (11; 12) to provide valuable information regarding the conditions in which the use of brief maximal sprints may aid those with T1DM to better maintain normoglycemia and gain the greatest benefits from regular aerobic exercise.

While previous investigators chose to study individuals with T1DM ~120 min following a bolus insulin dose to cover breakfast (11-14), we tested our subjects under fasting conditions 8 h after their last meal and insulin dose. Despite these methodological differences, the baseline plasma glucose concentrations of our subjects under CON and SP conditions (11.6 ± 1.4 and 10.4 ± 0.8 mM, respectively; Fig. 1A) were similar to those of previous studies (~11 mM) (11-14). However, the 2.5 ± 0.9 mM decline in plasma glucose concentration during exercise in CON (Fig. 1B) was less than that of previous studies (~3-4 mM) (12; 13). This is an interesting observation given the higher intensity (70% vs. 40% VO2peak) and duration (40 vs. 20-30 min) of the exercise bout in our study that resulted in a heavy reliance on carbohydrate (65-75% of EE, Table 2) and has been
shown to require a significant contribution of plasma glucose (~12-14% of EE) (21; 22).
The previous work at 40% VO2peak was below the typical crossover point for whole body fuel partitioning during exercise (23) and as such likely resulted in a greater reliance on fat than carbohydrate. The finding that subjects in this study achieved plasma lactate concentrations of 5-7 mM during exercise (Fig. 2) compared to 1-2 mM in previous studies (11-15; 24) reflects the difference in exercise intensity. The most likely explanation for the smaller decline in plasma glucose concentration despite higher exercise intensity and duration is related to the difference in serum insulin concentration between studies. Our study was performed under fasting conditions with basal insulin concentrations (~7-11 pM before and during exercise, Fig. 6) while the previous studies were conducted around peak post-bolus insulin concentrations (~250 pM) (12; 13). It is quite possible that the additive effects of hyperinsulinemia and muscle contraction in these studies resulted in greater rates of glucose uptake and a more pronounced drop in plasma glucose concentration than found in our study.

Performing the 10-s maximal sprint before exercise attenuated the decline in plasma glucose concentration during exercise compared to CON (Fig. 1B). This protective effect of brief maximal sprints has been attributed to the alteration of counter-regulatory hormones, especially catecholamines (11-15). Catecholamines are potent stimulators of hepatic glucose production during exercise. When T1DM subjects perform sprints intermittently during moderate intensity exercise, catecholamines may be in part responsible for a sharper rise in glucose rate of appearance. Previous studies have found the 14- to 18-fold increase in catecholamines during intense exercise (> 80% VO2max and maximal effort sprints) to elicit a 7- to 8-fold increase in glucose production via hepatic
glycogenolysis (4; 25). Prior to our study, a single 10-s maximal sprint before exercise was found to have no beneficial effect on plasma glucose concentration during a subsequent 20-min exercise bout at 40% VO$_{2\text{peak}}$ (12). The discrepancy in these findings between our study and Bussau et al. (12) is once again likely to be due to differences in insulin concentrations during activity. Specifically, the hyperinsulinemic state of the subjects in the trial by Bussau et al. (12) prior to exercise may have countered the ability of the sprint-induced increase in catecholamine concentration to increase hepatic glucose production.

In this study, peak plasma epinephrine and norepinephrine levels during exercise (2 and 8 nM, respectively; Figs. 5A and 5B) were similar to values reported at 65% VO$_{2\text{peak}}$ in non-diabetic subjects (~1.6 and 10.9 nM, respectively) (26), but appeared higher than those reported in individuals with T1DM exercising at 40% VO$_{2\text{peak}}$ following a 10-s maximal sprint (~0.15 and 6.5 nM, respectively) (12). While plasma epinephrine concentrations rose significantly during exercise in both conditions they tended to be higher during exercise in SP than CON, although this difference never reached statistical significance (Fig. 5A). While the role of elevated catecholamine levels in glucoregulation is generally recognized, it is likely not the only mechanism. Other counter-regulatory hormones such as glucagon, cortisol, and growth hormone have been investigated, but in most cases do not appear to play major roles in the preservation of plasma glucose following maximal sprints in those with T1DM (11; 12; 15). However, maximal sprints result in large increases in plasma lactate concentration that may aid in gluoregulation both by increasing hepatic glucose production and reducing plasma glucose uptake by skeletal muscle and other highly oxidative tissues. Plasma lactate
concentration increased above resting in both trials during exercise, however it was significantly higher in SP than CON throughout most of exercise and into early recovery (Fig. 2). Elevated plasma lactate levels may contribute to the stabilization of plasma glucose concentration by providing an important gluconeogenic precursor, especially under the fasting conditions, such as this study. The relative contribution of gluconeogenesis to hepatic glucose production during exercise is small (~10-25% of hepatic glucose production) (27; 28), however, evidence suggests that it may be higher in individuals with T1DM (29). Nonetheless, this is likely not the only explanation. Plasma lactate is also a highly oxidizable substrate and when its concentration was increased above control via infusion during moderate intensity exercise, it resulted in an increase in plasma lactate oxidation and the sparing of plasma glucose (30). The pre-exercise sprint in our study raised plasma lactate concentrations above the levels seen in the CON group during exercise, and to the same extent as those observed with the lactate infusion (30) and, therefore, may have aided in the preservation of plasma glucose during exercise by providing an alternate fuel source and reducing the uptake and oxidation of plasma glucose.

Previous research has demonstrated that a 10-s maximal sprint performed either before or after a 20-min bout of exercise at 40% VO_{2peak} is associated with better preservation of plasma glucose during recovery compared to control (11; 12; 31; 32). As during exercise, the benefits of the brief maximal sprints have been attributed to an enhancement in hepatic glucose production by higher concentrations of plasma catecholamines and lactate (11-15) Interestingly, plasma glucose maintenance during recovery from brief maximal sprints is also associated with a rapid decline in whole body
plasma glucose uptake (15; 32). The exact mechanism of this finding is not clear (15; 32), but may be due to catecholamine-induced inhibition of sarcolemmal glucose transport (33; 34). We were surprised to see that plasma glucose was preserved during recovery in not only SP, but also for CON. (Fig. 1B). We feel that this is due to the nearly equal catecholamine responses between the CON and SP conditions, basal insulinemia in both conditions and the reduced importance of higher plasma lactate concentrations in recovery than during exercise. As mentioned previously, the higher exercise intensity of our study (~70% VO$_{2peak}$) resulted in higher plasma catecholamine concentrations during exercise in CON and SP than in previous studies at 40% VO$_{2peak}$ (11; 12), thereby potentially resulting in enhanced hepatic glucose production and inhibition of plasma glucose uptake during exercise recovery in both CON and SP conditions. Previous work has shown that when T1DM subjects perform intense exercise (12.8 ± 0.3 min at 89-98% VO$_{2peak}$) it results in significant and prolonged (> 2 h) hyperglycemia during recovery when accompanied by basal insulinemic conditions (35). While previous studies performed under hyperinsulinemic conditions may have promoted further drops in plasma glucose concentration during recovery (12), the basal insulinemic conditions of the current study likely promoted the preservation of plasma glucose concentration in both CON and SP. While the higher plasma lactate concentration during exercise in the SP condition, compared to CON, contributed an alternate highly oxidizable fuel source, this likely provided little advantage during recovery when the turnover and therefore demand of plasma glucose is very low compared to exercise (36; 37).


Practical Implications

Previous recommendations for the prevention of exercise-induced hypoglycemia are extremely varied based on differences in the individual’s insulin regimen and metabolic responses to physical activity. Insulin dose reduction recommendations range from 10-90% (6-9) and must be considered in conjunction with the amount and timing of carbohydrate consumption before exercise as well as the type, intensity and duration of the exercise bout. Finding the combination of these factors that results in optimal maintenance of plasma glucose during exercise and recovery requires a great degree of individual experimentation. Our findings support a simple and effective recommendation that young individuals with uncomplicated TIDM should incorporate a 10-s maximal sprint at the end of their normal warm-up to reduce the risk of hypoglycemia during moderate-intensity exercise. Furthermore, exercise, when planned, could take place when plasma insulin concentrations are in the basal state, to further mitigate the risk of immediate post-exercise hypoglycemia. This might occur in the morning before breakfast, or at least 4-5 hours after the last bolus of rapid-acting insulin. Future work will have to determine whether this approach is improved by performing more than one pre-exercise 10-s maximal sprint and whether the pre-exercise sprint remains effective with longer bouts of exercise and the carbohydrate feedings before and during exercise that are required to complete them.

Limitations

This study was limited by the performance of the exercise trials under fasting conditions. We felt this was necessary to reduce the confounding effects of variable plasma glucose and insulin concentrations before exercise, but fully realize that this
experimental control came at the cost of reduced generalizability in that some individuals with TIDM would typically perform exercise in a fed state. Of note, is that the expected decrease in plasma glucose following exercise was mitigated in both control and experimental groups by exercising under conditions of basal only insulin concentrations. Additionally, while the size of the subject pool of the current study ($n = 7$) is similar to those of similar studies of those with TIDM ($n = 7-8$) (11-14), it may have been insufficient to detect some of the small effects of maximal sprints on metabolite and hormone responses. Finally, although the fitness level of the subjects was similar, the mode of exercise that the individuals were accustomed to (running or biking) varied. Most of our subjects were cyclists or triathletes who were familiar with cycling, but the few that were strictly runners found the cycling task to be more difficult than they had expected.

**Conclusions**

The primary finding of this study was that a 10-s maximal sprint performed prior to a 40-min, moderate-intensity exercise bout attenuated the decline in plasma glucose concentration during exercise compared to CON. Surprisingly, the SP condition provided no benefit compared to CON during recovery where plasma glucose concentration remained unchanged in both conditions, possibly reflecting the low (basal) insulin concentrations surrounding the physical activity. The protective effects of the brief maximal sprint before exercise appear to be more attributable to the increased availability of plasma lactate than a potentiation of the catecholamine response. These results indicated that this might be a viable option for individuals with TIDM who wish to safely enjoy the benefits of regular physical activity. Further research of this kind is needed to
identify if differences in exercise intensity and duration will alter the effectiveness of the sprints and if they are equally effective across individuals with TIDM of varied levels of aerobic fitness.
REFERENCES


Table 1. Mean oxygen consumption and cardiovascular hemodynamics during peak exercise

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$VO_2\text{peak}$, ml/kg/min</td>
<td>$48.8 \pm 2.4$</td>
</tr>
<tr>
<td>$W_{\text{peak}}$, W</td>
<td>$260 \pm 17$</td>
</tr>
<tr>
<td>$HR_{\text{peak}}$, beats/min</td>
<td>$177 \pm 3$</td>
</tr>
<tr>
<td>$SV_{\text{peak}}$, ml/beat</td>
<td>$120 \pm 2$</td>
</tr>
<tr>
<td>$Q_{\text{peak}}$, L/min</td>
<td>$22.1 \pm 2.2$</td>
</tr>
</tbody>
</table>

Values are mean ± SE; $n = 7$.

$VO_2\text{peak}$, peak exercise capacity; $W_{\text{peak}}$, peak exercise workload; $HR_{\text{peak}}$, peak heart rate; $SV_{\text{peak}}$, peak stroke volume; $Q_{\text{peak}}$, peak cardiac output.
Table 2. Cardiovascular hemodynamics, oxygen consumption, respiratory gas exchange and whole body substrate use during steady state exercise

<table>
<thead>
<tr>
<th>Variable</th>
<th>CON SS1</th>
<th>CON SS2</th>
<th>SP SS1</th>
<th>SP SS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR, beats/min</td>
<td>142 ± 4</td>
<td>150 ± 4*</td>
<td>146 ± 4</td>
<td>155 ± 4*</td>
</tr>
<tr>
<td>SV, ml/beat</td>
<td>112 ± 7</td>
<td>114 ± 8</td>
<td>104 ± 4</td>
<td>104 ± 4</td>
</tr>
<tr>
<td>Q, L/min</td>
<td>15.8 ± 0.8</td>
<td>17.0 ± 1.1*</td>
<td>15.1 ± 0.6</td>
<td>16.1 ± 0.7*</td>
</tr>
<tr>
<td>VO₂, L/min</td>
<td>2.7 ± 0.2</td>
<td>2.7 ± 0.1</td>
<td>2.6 ± 0.2</td>
<td>2.7 ± 0.2</td>
</tr>
<tr>
<td>VCO₂, L/min</td>
<td>2.5 ± 0.1</td>
<td>2.4 ± 0.1</td>
<td>2.4 ± 0.1</td>
<td>2.4 ± 0.1</td>
</tr>
<tr>
<td>RER</td>
<td>0.93 ± 0.02</td>
<td>0.90 ± 0.02*</td>
<td>0.92 ± 0.02</td>
<td>0.90 ± 0.02</td>
</tr>
</tbody>
</table>

CHO Oxidation
(g/min)        | 2.36 ± 0.18 | 2.04 ± 0.17* | 2.26 ± 0.23 | 2.08 ± 0.12 |
%EE            | 75.1 ± 7.3 | 64.9 ± 7.0* | 73.5 ± 7.9 | 64.9 ± 5.4 |

Lipid Oxidation
(g/min)        | 0.38 ± 0.13 | 0.52 ± 0.13* | 0.39 ± 0.14 | 0.53 ± 0.12* |
%EE            | 24.9 ± 7.3 | 35.1 ± 7.0* | 26.5 ± 7.9 | 35.7 ± 5.3 |

Values are mean ± SE; \( n = 7 \).
CON, control trial; SP, sprint trial; SS₁, steady state exercise minutes 15-20; SS₂, steady state exercise minutes 35-40; HR, heart rate; SV, stroke volume; Q, cardiac output; VO₂, oxygen consumption; VCO₂, carbon dioxide production; RER, respiratory exchange ratio; %EE, percent energy expenditure
*Significantly different from SS₁ under the same condition (\( p < 0.05 \)).
Values are mean ± SE; n = 7. *Significantly different from rest (CON trial) (p < 0.05).
†Significantly different from rest (SP trial) (p < 0.05).
Values are mean ± SE; n = 7. Change in plasma glucose concentration is expressed relative to rest (time point zero). *Significantly different from rest (CON trial) (p < 0.05). †Significantly different from rest (SP trial) (p < 0.05).
Values are mean ± SE; n = 7. *Significantly different from rest (CON trial) (p < 0.05).
†Significantly different from rest (SP trial) (p < 0.05). ‡Significantly different from
CON at same time point (p < 0.05).
Values are mean ± SE; n = 7. NEFA, non-esterified fatty acid. *Significantly different from rest (CON trial) (p < 0.05). †Significantly different from rest (SP trial) (p < 0.05). ‡Significantly different from CON at same time point (p < 0.05).
Values are mean ± SE; n = 7. *Significantly different from rest (CON trial) (p < 0.05).
‡Significantly different from CON at same time point (p < 0.05).

4.
Values are mean ± SE; n = 7. *Significantly different from rest (CON trial) (p < 0.05).
†Significantly different from rest (SP trial) (p < 0.05).
Values are mean ± SE; n = 7. *Significantly different from rest (CON trial) (p < 0.05). †Significantly different from rest (SP trial) (p < 0.05).
Values are mean ± SE; n = 7.