Sex-Related Glycemic and Cardiovascular Responses After Continuous and Interval Aerobic Sessions in Patients With Type 1 Diabetes: A Randomized Crossover Study

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We aimed to investigate sex-related glycemic and cardiovascular responses after intensity- (moderate) and duration- (30 minutes) matched interval aerobic exercise (IAE) and continuous (CAE) aerobic exercise sessions in patients with type 1 diabetes mellitus (T1DM). A total of 19 volunteers (10 women) participated in 2 randomized and crossover sessions (1:1). Heart rate, systolic and diastolic blood pressure, double product, and blood glucose (BG) levels were measured before (PRE), immediately after (POST-0), and 20 minutes after (POST-20) each session. The rates of perceived exertion (RPE) and enjoyment levels (ELs) were assessed after each session. Generalized estimating equations were used to analyze the data (condition × time × sex). Regarding sex-related changes, men showed BG reductions at POST-0 and POST-20 after CAE (Δ: −3.7 and −3.7 mmol/L, respectively) and only at POST-0 after IAE (Δ: −1.6 mmol/L), with 1 episode of hypoglycemia occurring in the latter group. In contrast, women showed reduced BG values only after CAE at both time points (Δ: −1.4 and −1.7 mmol/L) compared with PRE values. The decrease in BG levels at both time points was higher for men after CAE than IAE. Cardiovascular responses, RPEs, and ELs were similar between exercise sessions, except for blood pressure, which showed higher values in men. In conclusion, lower BG levels were observed after CAE, with greater reductions in men. Similar cardiovascular, RPE, and EL responses were found across sexes and sessions. Consideration of sex-specific recommendations may be warranted when prescribing aerobic exercise, particularly, for men with irregular physical activity levels.

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Type 1 diabetes mellitus (T1DM) is a chronic disease that usually appears at young ages and increases glycemic levels. Without adequate management, it may induce high risks of developing cardiovascular complications and mortality.[1,2] T1DM management involves exogenous insulin application (multiple daily injections or continuous subcutaneous insulin infusion), healthy eating, and exercise.[1,2] Several types of exercises have been recommended as nondrug alternatives in the treatment of T1DM. Physical efforts should be performed for at least 30 minutes per session (≥5 times per week with moderate to vigorous intensity). Aerobic exercise, in particular, is crucial because a single session could change glycemic levels (e.g., reducing capillary blood glucose [CBG]) and cardiovascular parameters (e.g., reducing exaggerated resting heart rate, systolic blood pressure, and double product[1,3−5]).

Cross-sectional exercise studies with patients with T1DM and aerobic exercise have examined different intensities (moderate to vigorous efforts), durations (∼ 14 to 90 min), sample sizes (∼ 5 to 12 participants per group/condition), ages (children, adolescents, and young adults), comparisons(single aerobic type, continuous vs intermittent, interval vs interval videogame, or interval vs strength), and physical activity level (active, irregularly active, and sedentary) and most of them have focused on glycemic or cardiovascular responses.[4−10] These studies have applied specific comparisons of interval aerobic exercise (IAE) and continuous aerobic exercise (CAE) over these variables by sex when prescribed with similarly matched intensity and duration.

Moreover, the male and female metabolism could be influenced by sex-related factors such as hormones, epigenetic modifications, physical activity level, and type of exercise.[7,9,11−13] Recent studies examining sex-related responses after exercise in patients with T1DM confirm a

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higher risk of hypoglycemia in men than women after strength (anerobic) sessions.[14] However, after moderate-intensity interval aerobic sessions compared with strength sessions, young adult men showed lower CBG than irregularly active women.[9] Interestingly, a single moderate-intensity continuous aerobic session in men showed no differences compared with women in terms of blood glucose (BG) levels; however, men exhibited a tendency toward higher carbohydrate oxidation.[6]

Although studies continue to refine our understanding of the appropriate volumes and intensities of exercise for health and treating metabolic disease,[2,11,13] it remains unclear whether sex differences influence BG and cardiovascular responses after intensity- and duration-matched IAE and CAE sessions in irregularly active patients with T1DM.[15] Therefore, this randomized crossover study aimed to investigate sex-related glycemic and cardiovascular responses after intensity- (moderate) and duration- (30 minutes) matched IAE and CAE sessions in adults with T1DM who have irregular physical activity levels. We hypothesize that compared with women, men will present lower BG levels after continuous exercise with higher cardiovascular response during or immediately after the session and exhibit greater reductions in cardiovascular responses after the sessions.

Methods

This study was approved by the local ethics committee (National Health Council #6.103.597/2023), registered with the Brazilian Randomized Clinical Trial (#RBR-57T7VB), and adhered to the Declaration of Helsinki principles. Participants were informed of the study's benefits and risks and signed an institutionally approved informed consent form. The study is a randomized crossover trial comparing 2 exercise protocols (continuous and interval) matched for intensity and duration. Data were collected before (PRE), immediately after (POST-0), and 20 minutes (POST-20) after exercise sessions. Participants completed the International Physical Activity Questionnaire (short form), anthropometric measurements, and cardiorespiratory fitness tests. They were then randomly allocated (based on arrival order) to 2 crossover sessions, starting with either interval or continuous exercise, with a 48- to 196-hour gap between the sessions.

The participants were recruited through advertisements and flyers on social networks, television, word-of-mouth on a university health campus, a regional diabetes association, and through the "Exercise as Daily Sugar" project offered by the Department of Physical Education. The following inclusion criteria were applied: (1) female and male patients with T1DM aged between 20 and 45 years, (2) using multiple daily insulin doses or continuous subcutaneous insulin infusion, (3) irregularly active or sedentary adults with T1DM, (4) experienced aerobic treadmill exercise before the study, and (5) without medical restrictions for exercising or any micro or macrovascular complication that may be exacerbated by participating in the research. Figure 1 shows a flow diagram of the participants' recruitment.

A previous sample size calculation was estimated using the G*Power 3.1.9 software,[16] with $\alpha = 0.05$, power $(1-\beta) = 0.80$, and a moderate effect size (ES) ($\eta^2 = 0.8$). Therefore, a minimum of 6 participants per sex was required, considering 2 experimental sessions and 3 repeated measures (PRE, POST-0, and POST-20) for a generalized estimation equation—a sample size commonly used in T1DM studies.[6,9]

Physical activity levels were assessed using self-referential questionnaire (International Physical Activity Questionnaire short form), as used in previous studies with patients with T1DM.[17,18] Height (meters) and body mass (kilograms) were recorded using a stadiometer/digital scale (LD-1050, Lider, Brazil) accurate to the nearest 0.01 m and 0.1 kg, respectively. Body perimeters were assessed using an anthropometric tape (TR-4010, Sanny, Brazil) and skinfold measurements (biceps, triceps, subscapular, chest, axillary, iliac supra, abdominal, leg, and calf) were taken using an adipometer (Clinical, Sanny, Brazil). All measures were performed by a single evaluator using standardized techniques.

The 30-minute duration was selected based on recommendations[1,3] and aimed to avoid the need for carbohydrate supplementation to correct hypoglycemia, in contrast to findings from previous studies.[4,6] Similar intensity levels were chosen to enable precise comparisons between IAE and CAE prescriptions, unlike studies that examined various exercise protocols.[5,8,9,13] These 2 aerobic exercise

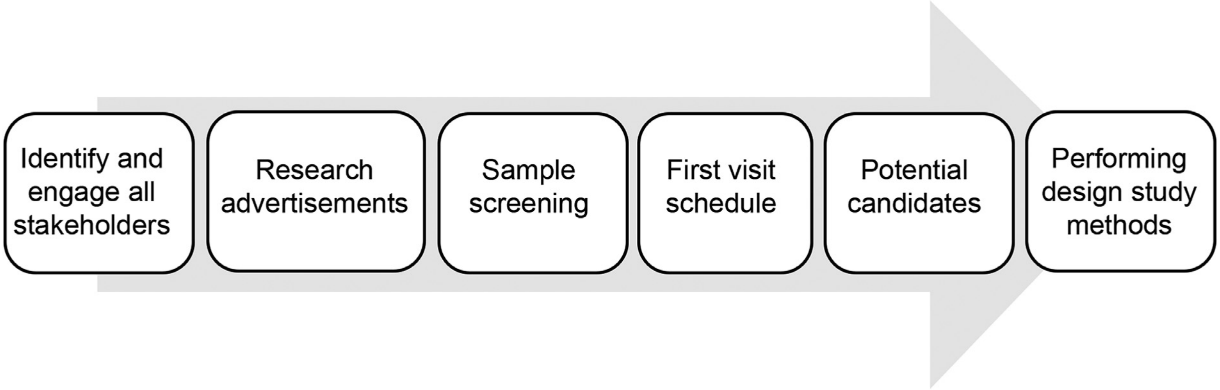

Figure 1. Flow diagram of the participants' recruitment.

sessions were also selected because of their common inclusion in typical beginner training programs conducted in gyms or parks, aligning with real-world application.

The interval aerobic session involved alternating 1-minute intervals at 40% and 60% of estimated maximal oxygen consumption (VO_{2max}) on a treadmill, as per previous studies.[5,9,13] The CAE was performed at 50% of VO_{2max}, consistent with other research.[6,13] After the test, participants were assigned to their first session.

The 12-minute test was conducted on a sports court to estimate the VO_{2max}, in accordance with recommendations and previous studies involving patients with T1DM.[9,19,20] The VO_{2max} value (ml/kg/min) was then divided by 3.5 ml/kg/min to convert it to metabolic equivalent for the task (MET) units.[3,9] Considering 1 MET equals 1 km/h, the MET result was multiplied by the prescribed intensities (40%, 50%, and 60%) to determine the absolute speeds (km/h) for the aerobic sessions.[3,9,21] Before the 30-minute aerobic sessions, volunteers performed a 3-minute warm-up of their 40% VO_{2max}.

CBG levels were assessed using capillary samples using a handheld glucose meter (Accu-Check Active, Roche, Switzerland), in conjunction with a lancet device, disposable test strips, and lancets (Accu-Check Softclix, Roche), following established guidelines and previous studies.[1,4,9] All capillary samples were taken at PRE, POST-0, and POST-20 while participants were seated, and they were instructed to remain still during the assessments.

Heart rate (HR) was measured using an HR monitor (Polar FT4, Polar Electro, Finland) throughout all experimental sessions. Systolic blood pressure (SBP) diastolic blood pressure (DBP) were measured on the left arm using a blood pressure monitor (Omron HEM 7122, Omron, Japan). All cardiovascular measures were taken at PRE, POST-0, and POST-20 in a seated position. Participants were instructed to remain motionless and refrain from speaking or sleeping during measurements. Double product (DP) was calculated as the product of HR and SBP (beats per minute × mm Hg) during the same periods, providing insights into cardiac workload and myocardial oxygen demand. HR values were recorded to characterize session intensity.[5,9]

RPE were self-reported using the Borg scale (6 to 20 points[22,23]), which is commonly used to subjectively assess exercise intensity, encompassing muscular, cardiovascular (tachycardia/bradycardia), and respiratory (hyperventilation) effort. RPE was defined as "How tired did your body feel while you were exercising aerobically, considering your perception of cardiorespiratory and skeletal muscle exertion?"[22] Enjoyment level (EL) was evaluated using a paper-and-pencil adaptation of a 100-mm visual analog scale, ranging from 0 (very boring) to 100 (very enjoyable[9,23,24]).

Before each session, volunteers rested comfortably in a chair for 10 minutes to measure HR, SBP, DBP, and CBG. Subsequently, the young T1DM volunteers underwent the prescribed aerobic exercise session. Immediately after the exercise session (POST-0), volunteers returned to the chair for another measurement of HR, SBP, DBP, and CBG and rates of perceived exertion (RPEs) and EL. Measurements of HR, SBP, DBP, and CBG were repeated at POST-20. All sessions were scheduled between 04:00 A.M. to 07:00 P.M., with participants advised to reduce their insulin dose by approximately 50% before their last presession meal.[1] Participants were instructed (1) to maintain their usual daily nutrition, sleep patterns, and habits; (2) to refrain from alcohol or other stimulants; (3) to avoid moderate to vigorous physical activities 24 hours before the crossover aerobic sessions; and (4) to promptly report any factors that could affect their physical or cognitive performance (e.g., injuries and emotional issues). In the event of any issue potentially introducing methodologic bias, the exercise session was rescheduled.

Anthropometric and clinical characteristics demonstrated normal distribution according to the Shapiro−Wilk test and were compared between sexes using independent Student's *t* tests. Interactions between aerobic exercise conditions and sex for intensity measures (RPE and %HRmax) and ELs were analyzed using generalized linear mixed models (GLMMs) with a normal distribution assumption, identity link function, and robust estimator. The Satterthwaite approximation method was used for degrees of freedom. Model selection for GLMM was based on minimizing the Akaike corrected information criterion to determine the best overall fit.

Primary outcomes (HR, SBP, DBP, DP, and CBG) were analyzed for exercise type (interval vs continuous), time points (PRE, POST-0, and POST-20), and their interactions by sex using generalized estimating equations (GEEs). The GEE used an unstructured working correlation matrix with a robust estimator, gamma distribution, and log link function. Model selection for GEE was based on minimizing the quasi-likelihood under the independence model criterion. Main effects were assessed using Wald's chi-square statistic and pairwise comparisons were conducted using sequential Sidak post hoc tests. Normality of raw residuals for GLMM and GEE models was confirmed through *Q-Q* plots, indicating suitability for analysis. Statistical analyses were performed using IBM SPSS Statistics 23.0 (IBM), with significance set at $p \leq 0.05$. The ES for primary responses in the repeated measures design was computed between PRE and POST-0 and POST-20 using the formula by Morris and DeShon[25]:

$$d = \frac{(POST\text{-}0 \text{ or } POST\text{-}20) - PRE}{SD_{PRE}} \times \frac{1}{\sqrt{2(1-r)}}$$

and interpreted as trivial for $d < 0.20$, small for d ranging 0.20 to 0.59, moderate for d ranging 0.60 to 1.19, large for d ranging 1.20 to 1.99, very large for d ranging 2.00 to 3.99, and almost perfect for $d \geq 4.0$.

Results

Briefly, 29 patients with T1DM were initially recruited, with 19 (10 women) completing the 2 randomized crossover aerobic sessions. Exclusions were primarily because of failure to meet the inclusion criteria (n = 4) or declining participation (n = 6). Anthropometric, clinical, and insulin delivery characteristics of the patients with T1DM who completed all crossover aerobic sessions are listed in

Table 1
Anthropometric, clinical, and insulin delivery characteristics by total (n = 19) and sex

	Total (n=19)	Female (n=10)	Male (n=9)	*p*
Anthropometric				
BMI (kg/m^2)	26.5 ± 4.7	25.6 ± 4.9	27.4 ± 4.5	0.437
Skinfolds (sum)	208.5 ± 82.2	204.8 ± 73.6	216.0 ± 94.7	0.858
Clinical				
Age (years)	30.4 ± 6.9	32.1 ± 7.6	29.0 ± 5.7	0.285
Duration of T1DM (years)	10.1 ± 6.0	8.3 ± 6.4	13.0 ± 4.6	0.167
HbA_{1C} (%)	8.1 ± 1.3	7.9 ± 1.2	8.4 ± 1.4	0.402
VO_{2max} (mL/kg/min)	33.1 ± 5.1	30.6 ± 4.0	36.9 ± 4.9	**0.028***
Insulin Delivery				
Multiple daily injections (n)	18	8	10	-
Continuous insulin infusion (n)	1	1	0	-
Basal insulin (Type)	-	NPH (5), Glargine (4) and Degludeca (1)	NPH (1), Glargine (7) and Degludeca (1)	-
Bolus insulin (Type)	-	Aspart (2), Humalog (2), Apidra (1), Regular (3), and Humulin (1)	Aspart (1), Humalog (4), Apidra (2), Regular (1) and Novorapid (1)	-
Basal Insulin (Unit)	-	29.4 ± 9.3	35.3 ± 5.4	0.103
Bolus insulin (Unit)	-	13.6 ± 6.2	15.5 ±5.9	0.853

BMI = body mass index; HbA_{1C} = glycated hemoglobin; NPH = neutral protamine Hagedorn; VO_{2max} = maximal oxygen consumption estimated.
A single male and female use only basal insulin.
Data expressed as mean ± standard deviation.

Table 1. Significant differences by sex were observed only in VO_{2max} ($p < 0.05$).

Regarding Table 2, no significant sex × session interaction effects were observed for RPE, EL, or relative intensity ($p > 0.05$).

Table 3 lists the acute cardiovascular responses to IAE and CAE sessions. Concerning HR, a main effect was found for time (chi-square = 94.9, $p < 0.001$). Briefly, for female and male patients with T1DM, the HR at POST-0 after the interval session was higher than PRE and POST-0 at the same session. Only for male patients with T1DM, HR at POST-0 was higher in continuous sessions than PRE values ($p < 0.001$). Regarding SBP, a main effect was found for time (chi-square = 31.4, $p < 0.001$) and condition × time × sex interaction (chi-square = 13.9, $p = 0.016$). SBP at POST-0 after the interval was higher than POST-20 at the same session, with sex differences than PRE, POST-0, and POST-20 for interval and continuous female values. SBP at POST-0 after the continuous presented similar sex differences when POST-0 was higher than PRE and POST-0 for interval and continuous female values. DBP presented no main effect for condition, sex, time, and their interactions ($p > 0.05$). For DP, a main effect was found for time (chi-square = 49.5, $p < 0.001$). For male patients with T1DM, POST-0 after the interval session was higher than PRE and POST-0 at the same session.

Regarding glycemic responses, a main effect was found for time (chi-square = 76.9, $p < 0.001$) (Figure 2) and condition × sex × time interaction (chi-square = 18.4, $p = 0.002$) (Figure 3). For time (Figure 2), a significant reduction of CBG levels only at POST-0 (ES: 0.9, Δ: 1.5 mmol/L and 26.8 mg/100 ml) after the interval session and at POST-0 (ES: 1.0, Δ: 2.5 mmol/L and 45.8 mg/100 ml) and POST-20 (ES: 1.0, Δ: 2.7 mmol/L and 49.1 mg/100 ml) after continuous aerobic session for the grouped analysis (n = 19). Moderate CBG ES was found.

Regarding sex-glycemic responses (Figure 3), the interval session induced a significant reduction of CBG levels only at POST-0 for men compared with PRE values (ES: 0.9, Δ: 1.6 mmol/L and 28.7 mg/100 ml, $p = 0.020$), whereas CAE decreased CBG at POST-0 (ES: 1.0, Δ: 3.7 mmol/L and 66.1 mg/100 ml, $p = 0.020$) and at POST-20 (ES: 1.0, Δ: 3.7 mmol/L and 66.9 mg/100 ml, $p = 0.020$) compared with their respective PRE values. For women,

Table 2
Intensity control and descriptive variables in each aerobic session by sex (n = 19)

Variables	Sex	Aerobic Exercise Sessions		
		Interval	Continuous	*p*
HR_{max} (%)	Male	71 ± 4	65 ± 7	0.879
	Female	64 ± 4	60 ± 6	
RPE (6-20 points)	Male	10 ± 1	10 ± 1	0.569
	Female	10 ± 1	10 ± 1	
EL (0-10 points)	Male	7 ± 1	7 ± 1	0.495
	Female	6 ± 1	7 ± 1	
Descriptive data		n / unit	n / unit	
Bolus insulin before until 4h previous exercise (Unit)	Male	2 / 10	1 / 5	-
	Female	1 / 6	1 / 6	
Volunteers who need CHO		n / g	n / g	
Pre exercise	Male	2 / 5	0 / 0	-
	Female	3 / 10	2 / 10	
During exercise	Male	0 / 0	0 / 0	-
	Female	0 / 0	0 / 0	
After exercise	Male	0 / 0	0 / 0	-
	Female	0 / 0	0 / 0	
Twenty min after exercise	Male	0 / 0	0 / 0	-
	Female	0 / 0	0 / 0	
Hypoglycemia episodes after exercise (n)	Male	0	1	-
	Female	0	0	

CHO = carbohydrate; EL = enjoyment level; HR_{max} = maximal heart rate; RPE = rate of perceived exertion.
Data expressed as mean ± standard error of the mean (SE).

Table 3
Acute cardiovascular responses before and after (post-0 and post-20 minutes) the aerobic sessions of T1DM patients by sex (n = 19)

Variable	Time	Sex	Aerobic Exercise Sessions	
			Interval	Continuous
HR (bpm)	PRE-	Male	84 (4)	87 (4)
		Female	89 (3)	87 (4)
	POST-0	Male	107 (4)[*]	105 (5)[*]
		Female	107 (5)[*]	100 (5)
	POST-20	Male	86 (3)[†]	88 (3)
		Female	88 (3)[†]	84 (3)
SBP (mmHg)	PRE-	Male	132 (3)	127 (5)
		Female	116 (3)	115 (3)
	POST-0	Male	133 (3)[‡,§,¶]	132 (4) [‡,§]
		Female	116 (3)	117 (4)
	POST-20	Male	122 (2) b	124 (3)
		Female	116 (4)	113 (3)
DBP (mmHg)	PRE-	Male	88 (3)	86 (5)
		Female	82 (3)	80 (3)
	POST-0	Male	89 (3)	89 (4)
		Female	83 (3)	80 (3)
	POST-20	Male	84 (5)	88 (4)
		Female	83 (3)	80 (3)
DP (bpm × mmHg)	PRE-	Male	11769 (624)	11004 (518)
		Female	10326 (541)	9916 (464)
	POST-0	Male	14798 (512)[*]	13867 (792)
		Female	12475 (755)	11636 (774)
	POST-20	Male	11035 (429) [†]	10937 (602)
		Female	10214 (512)	9604 (516)

[*] Difference from PRE for the same sex and exercise session.
[†] Difference from POST-0 at the same sex and exercise session.
[‡] Difference from PRE for the other sex and both sessions.
[§] Difference from POST-0 for other sex and both sessions.
[¶] Difference from POST-20 at the same sex and both sessions.
Data expressed as mean ± standard error of the mean (SE).

CBG was decreased only after continuous at POST-0 (ES: 0.8, Δ: 1.4 mmol/L and 25.6 mg/100 ml, p = 0.036) and POST-20 (ES: 0.9, Δ: 1.7 mmol/L and 31.3 mg/100 ml, p = 0.003). Finally, CAE for men was statistically different at POST-0 (ES: 1.0, Δ: 4.5 mmol/L and 81.8 mg/100 ml, p <0.001) and POST-20 (ES: 1.0, Δ: 4.6 mmol/L and 82.6 mg/100 ml, p = 0.002) compared with the PRE values of IAE. Moderate CBG ES was found.

Discussion

This study aimed to investigate sex-related glycemic and cardiovascular responses after IAE and CAE sessions in irregularly active patients with T1DM. We hypothesized that (1) men would exhibit lower BG after continuous exercise, with a higher cardiovascular response during/immediately after the session, and (2) men would show greater cardiovascular reductions after the sessions. Our hypotheses were partly confirmed. First, men exhibited more reduced CBG levels POST-0 for interval and continuous aerobic sessions and POST-20 after CAE, resulting in a hypoglycemic episode. Second, in women, the CBG levels were reduced at POST-0 and POST-20 after CAE compared with PRE without causing hypoglycemic episodes. Third, HR, DBP, and DP presented similar responses for both sexes, with only SPB showing sex differences in these interval and continuous aerobic sessions. Finally, the RPEs, ELs, and relative intensity during the sessions were also similar, regardless of sex and exercise conditions.

In this study, the CBG-grouped analysis showed lower values after CAE in adults with T1DM exhibiting irregular physical activity and metabolic control (glycated hemoglobin: 8.1±1.3%). This phenomenon was also verified in adults with T1DM with very good metabolic control (glycated hemoglobin: 6.6±0.8%), where the greatest decrease in glucose occurred after continuous exercise, followed by in IAE in a real-world study of at-home exercises.[13] In addition to metabolic control and exercise type, sex is defined as one of the factors influencing glucose changes in patients with T1DM.[9,13,15]

In sex-related responses, our study observed that men exhibited reduced CBG levels after POST-0 for interval and higher decreases after continuous at POST-0 and POST-20 compared with continuous and interval PRE values, causing a hypoglycemia episode. In addition, CBG was reduced in both points only after CAE in women compared with PRE values, without causing hypoglycemic episodes.

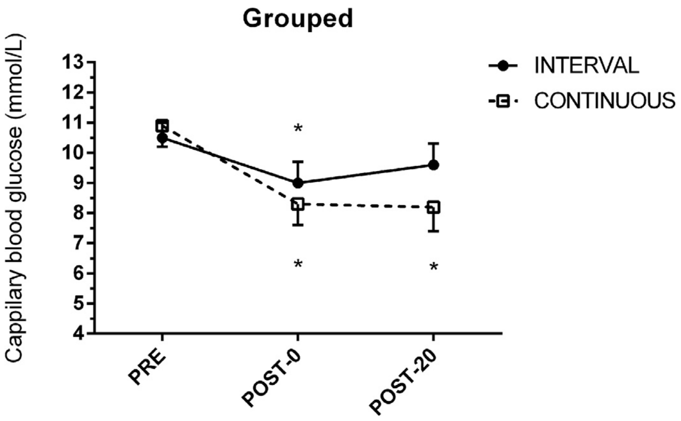

Figure 2. Acute glycemic responses of T1DM at rest (PRE), immediately after (POST-0), and 20 minutes after (POST-20) the interval and continuous aerobic exercise sessions (n = 19). Data are expressed as mean ± standard error of the mean. *Differed from their respective PRE values.

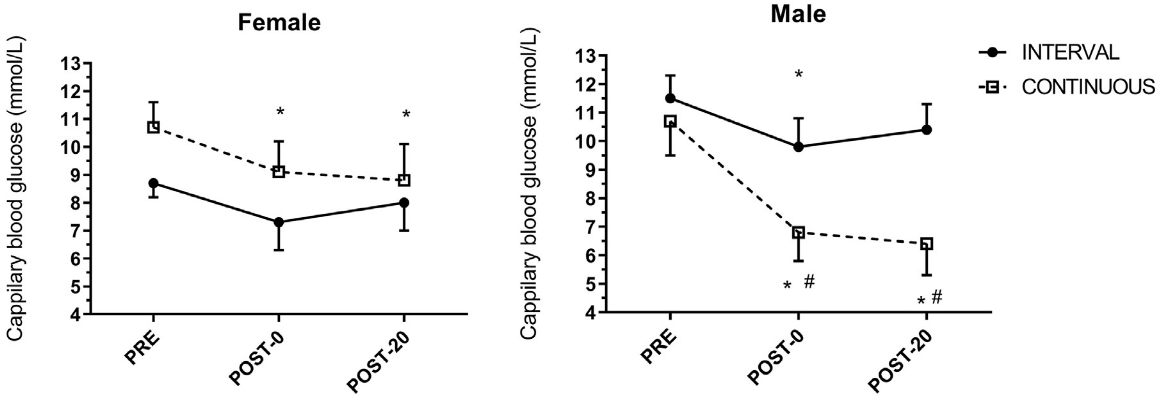

Figure 3. Acute glycemic responses of T1DM at rest (PRE), immediately (POST-0), and 20 minutes (POST-20) after interval and continuous aerobic exercise sessions by sex (n = 19). Data are expressed as mean ± standard error of the mean. *Differed from their respective PRE values. #Differed from PRE values at the other session.

Regarding patients with T1DM during moderate-intensity exercise, men rely mostly on plasma glucose, whereas women prioritize lipid oxidation for adenosine triphosphate resynthesis production. Women also seem to be better at conserving glycogen stores at 65% of VO_{2max}. These metabolic differences are important to avoid higher glucose decreases and cause hypoglycemia episodes.[15,26]

Paim da Cruz Carvalho et al[9] have found that men are more likely to experience higher CBG decreases after moderate-intensity IAE in physically inactive patients with T1DM. Our study observed no statistical decreases after IAE for women, whereas men exhibited a statistically significant presence of decreases. This response could be explained by increased growth hormone and estrogen levels, upregulating lipid oxidation pathways, and increasing sensibility to the lipolytic action of catecholamines in response to exercise.[6,15]

It is interesting to note and emphasize that our men with T1DM, after CAE, showed higher CBG decreases. These findings could be because men may demonstrate a greater respiratory exchange ratio and carbohydrate oxidation for adenosine triphosphate resynthesis production than women during aerobic exercise at the same relative exercise intensity[15,26] and present augmented counter-regulatory responses (increased gluconeogenesis).[15,27] Furthermore, considering the aerobic type, our results may support the idea that this counter-regulatory response could have attenuated possible decrease in CBG in IAE because of the nature of intervals, which was not observed after continuous exercise.[13]

We hypothesized that men would have higher cardiovascular response during and immediately after the session and higher cardiovascular reductions after the sessions. Our findings showed similar HR, DBP, and DP between sexes, with only SPB showing sex differences in the interval and continuous sessions. These responses align with previous studies that conducted IAE sessions in patients with T1DM.[5,9]

It was expected that adrenergic increase during and immediately after the aerobic sessions would cause changes in HR, DBP, and DP.[9,15,27] In our study, although there were no statistically significant differences over time × sex × condition, cardiovascular adjustment were observed in SBP after the interval and continuous sessions. For men, the enhanced SBP at POST-0 in both sessions was different from female values. These results could be explained by the present augmented catecholamine releases, which are higher for men.[15,27]

Moreover, an important aspect is that when intensity- and duration-matched aerobic sessions are performed by sex, the RPE, EL, and relative intensity are similar for irregularly physically active patients with T1DM. Similar values were seen after IAE compared by sex in a previous study.[9] Thus, using other control variables in this study can improve some aspects of information in clinical practice, independent of the aerobic type or sex of the patients with T1DM. These scale instruments (RPE and EL) are valid methods for monitoring internal aerobic load in patients with T1DM, offering a low-cost and easily understandable way to anchor their exercise intensity.[23,28,29]

Monitoring exercise intensity for patients with T1DM is important, particularly, because hypoglycemia is an important factor affecting exercise adherence. Recurrent hypoglycemic episodes can hinder patients from benefiting from exercise.[1,30] In our study, the 30-minute moderate-intensity sessions did not necessitate carbohydrate intake during the sessions and resulted in only a single hypoglycemic episode (3.7 mmol/L or 68 mg/100 ml) occurring 20 minutes after the continuous aerobic session in a male patient with T1DM (who was on multiple insulin doses without bolus insulin on board). Given the similar scale responses, we recommend that health professionals, families, and patients use these scales in the clinical practice of prescribing aerobic exercise for men and women with T1DM, with a cautionary note for men engaging in CAE.

Our present study has certain limitations. First, although our study provided volunteer groups by sex with similar anthropometric, clinical, and insulin delivery characteristics, evaluating the gas exchange ratio and hormone (counter-regulatory and adrenergic) levels during and after the sessions would provide more insights into understanding the mechanisms regarding glycemic and cardiovascular changes by sex.[6,11,12] Second, although the female volunteers performed the sessions during a nonmenstruation week, we did not specifically evaluate their menstrual cycle phase.[12] Third, although CBG is a widely used real-world measurement, it was used alongside continuous glucose monitoring in this study. In addition, although a previous study performed a 12-minute test for prescription,[9] the field test used for VO_{2max} estimation in our work represents a limitation. Finally, the limited sample size and the lack of assessment of muscle mass, which is an important metabolic organ for glycemic uptake, are notable limitations.[3,6,27] Future studies could use a larger sample size to provide more robust insights and to establish more reliable recommendations.

However, our work has achieved considerable external validity through the free-living environment because several researchers used strictly controlled conditions that cannot be applied to real-life situations. To the best of our knowledge, this study is the first to compare specific sex-related CBG and cardiovascular responses after intensity- and duration-matched interval and continuous aerobic sessions in adults with T1DM who have irregular metabolic and physical activity levels.

The practical application suggested by this study is that the prescription of aerobic exercise is dependent on sex. Depending on the pre-exercise BG, men could select either interval or CAE. For example, if starting the continuous session with lower CBG, there is a risk of a hypoglycemia episode. Conversely, the prescription of IAE and CAE for women can be the same because our findings did not show differences in BG between these types of exercise.

In conclusion, lower glycemic levels are observed after CAE, with greater reductions seen in men. Similar cardiovascular, RPE, and EL responses were found across sexes and sessions. Based on these glycemic findings, we strongly advise considering sex-specific recommendations when prescribing aerobic exercise for adults with T1DM who are irregularly active.

Declaration of competing interest

The authors have no competing interests to declare.

CRediT authorship contribution statement

Tamy Beatriz Freire de Sá Martins: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology. **Orlando Vieira Gomes:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology. **Pooya Soltani:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis. **Thalles Henrique Rodrigues Oliveira:** Writing – review & editing, Writing – original draft, Supervision. **Jorge Luiz de Brito-Gomes:** Writing – review & editing, Writing – original draft, Resources, Project administration, Formal analysis, Data curation, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2024.07.028.

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