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Impaired whole-body heat loss in Type I diabetes during exercise in the heat: a cause for concern?

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Tweet: "Researchers from @HEPRU_uOttawa suggest impairments in whole-body heat loss in #type1diabetes during #exercise in the heat may pose a health concern" *(Figure 1 in its entirety or panel D would best complement this tweet. Since panel D does not contain the legend, we can provide a separate file with legend included if required)*

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To the Editor: Regular exercise is recommended for type 1 diabetes management[1], although exercise in hot conditions may pose a health concern[2]. This is primarily because even patients without neuropathy display impaired cutaneous vasodilation[3] and sweating[4], especially during vigorous exercise[5], which may increase dry-heat gain by reducing blood-borne heat delivery to the skin and attenuate evaporative-heat loss. The resulting reductions in total-heat loss (dry ± evaporative-heat exchange) can elevate heat-illness risk by exacerbating body heat storage and the subsequent increase in body core temperature[6]. However, since those investigators measured cutaneous vasodilation and sweating at only a handful of small surfaces (~1-3 cm^2) on the body[4, 5, 7], it remains unclear whether such impairments translate into clinically meaningful decrements in whole-body total-heat loss (*i.e.*, from all body surfaces). We therefore used our unique direct air calorimeter (the gold standard method for measuring whole-body heat exchange)[8] to examine the effects of type 1 diabetes on whole-body total-heat loss and body heat storage for the first time during light, moderate and vigorous exercise in the heat.

Following written informed consent, 28 habitually active young adults (aged 18-37 years) with (10 males, 4 females) and without (10 males, 4 females; control) type 1 diabetes matched for age, aerobic fitness and body morphology participated in an experimental trial approved by the University of Ottawa Research Ethics Board. Type 1 diabetes participants had been diagnosed for ≥5 years, had an HbA1c of 6.2-9.2% (44-77 mmol/mol), and no diagnosed diabetes-related complications. Participants were instructed to arrive well hydrated, having followed their normal insulin therapy (type 1 diabetes; pump: n=8; injections: n=6), having eaten their usual breakfast and having abstained from exercise, alcohol, caffeine and anti-inflammatory drugs for >24 hours.

After confirming euhydration (urine specific gravity: <1.025), participants entered the direct calorimeter (35°C, relative humidity ~20%; humidex 36°C) wearing shorts, sleeveless top (females) and sandals. Participants completed 30-min seated rest and three, 30-min bouts of semi-recumbent cycling at metabolic heat production rates of 200 (light), 250 (moderate), and 300 W/m^2 (vigorous), each followed by 30-min recovery. These work rates represented ~37, 47 and 56% of peak aerobic power and ensured the heat load was matched between groups. Indirect calorimetry (Moxus system, AEI Technologies, TX, USA) was used to derive metabolic heat production (metabolic rate - external work). The direct calorimeter measured whole-body dry- and evaporative-heat exchange[8]. Body core temperature was measured via the esophagus (n=9 per group) or rectum (n=5 per group) using a Mon-a-therm Temperature Probe (Mallinckrodt Medical, MO, USA). Blood samples were drawn from an indwelling catheter during the final five minutes of rest and each exercise period in type 1 diabetes (n=14) and control participants (n=12), and analyzed for blood glucose concentrations (mmol/L) by an external laboratory (Dynacare, Ottawa, ON, Canada).

Data are reported as means over the final five minutes of rest and each exercise period. Body heat storage (kJ) during each exercise period represents the temporal summation of total-heat loss (dry ± evaporative-heat exchange) and metabolic heat production. Body core temperature changes from rest were normalized to 37ºC to account for baseline variation. Data were analysed using a two-way, mixed-model ANOVA (Prism 8, GraphPad, CA, USA) with factors of group (type 1 diabetes, control) and time (rest, light, moderate, vigorous). *Post-hoc* between-group comparisons were carried out using unpaired two-tailed t-tests ($\alpha=0.05$ for all comparisons). Based on previously reported type 1 diabetes-related reductions in sweating[5], ≥13 participants per group were required to detect between-group differences of similar effect size with 80% statistical power. Our analysis (n=14 per group) was therefore adequately powered.

Metabolic heat production (Figure 1A) and dry-heat loss (Figure 1B) did not differ between groups. However, evaporative-heat loss was attenuated in type 1 diabetes relative to control during vigorous exercise ($p=0.03$) (Figure 1C). Total-heat loss was also lower in type 1 diabetes during moderate ($p=0.04$) and vigorous exercise ($p=0.01$) (Figure 1D). Consequently, type 1 diabetes displayed higher body heat storage during moderate ($p=0.03$) and vigorous exercise ($p=0.02$) (Figure 1E) and a higher body core temperature during vigorous exercise relative to control ($p=0.03$) (Figure 1F). Blood glucose was higher in type 1 diabetes relative to control throughout (all $p<0.01$) (Figure 1G), albeit a greater reduction from rest occurred in type 1 diabetes during exercise (all $p<0.05$) (Figure 1H).

Observations from this experiment indicate that relative to their matched controls, young patients with type 1 diabetes without clinically-evident neuropathy display similar whole-body dry-heat exchange, but impaired whole-body evaporative-heat loss during exercise, perhaps due to attenuated sweat gland innervation[7]. This impairment worsened with increasing exercise intensity, resulting in a mean reduction in total-heat loss of ~10% and a subsequent mean increase in body heat storage of ~35% in type 1 diabetes during moderate and vigorous exercise. Importantly, this increase in body heat storage represented a between-group difference in body temperature change equivalent to ~0.5°C per hour (assuming a body mass of 70 kg with a specific heat capacity of 3.47 kj kg^{-1} $°C^{-1}$), which could elevate heat-illness risk and result in heat stroke during exercise of longer duration and/or in hotter conditions[6]. Further, while blood glucose was elevated throughout exercise in type 1 diabetes, one might expect greater reductions in heat loss and even higher body heat storage in individuals with less well-controlled diabetes and/or diabetic neuropathy[2].

Together, our findings provide two key outcomes that advance understanding of thermoregulation in type 1 diabetes. First, although type 1 diabetes has been shown to attenuate cutaneous blood flow[3], those reductions do not appear to modify whole-body dry-heat exchange, irrespective of the exercise-induced heat load. Second, a lowered rate of sweat secretion in type 1 diabetes[4, 5] can cause reductions in whole-body evaporative-heat loss that result in clinically meaningful increases in body heat storage, albeit only during moderate-to-vigorous exercise. While there is a need for larger confirmatory studies, ideally over a broader range of environmental conditions (*e.g.*, hot-humid conditions, higher air flow, others), we suggest that exercise in the heat may pose a health concern that requires consideration in clinical guidelines for exercise management in type 1 diabetes.

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DUALITY OF INTEREST

No conflict of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

S.R.N. and G.P.K. conceptualized and designed the research; M.P.P. performed data collection. S.R.N. performed statistical analysis, prepared figures and drafted manuscript; S.R.N., G.P.K., J.E.Y. and R.J.S. interpreted results; all authors edited, revised and approved the final version. G.P.K. is the guarantor of this work and, as such, had full access to all the data and takes responsibility for the integrity of the data and the accuracy of the data analysis. Data are available on request from the corresponding author.

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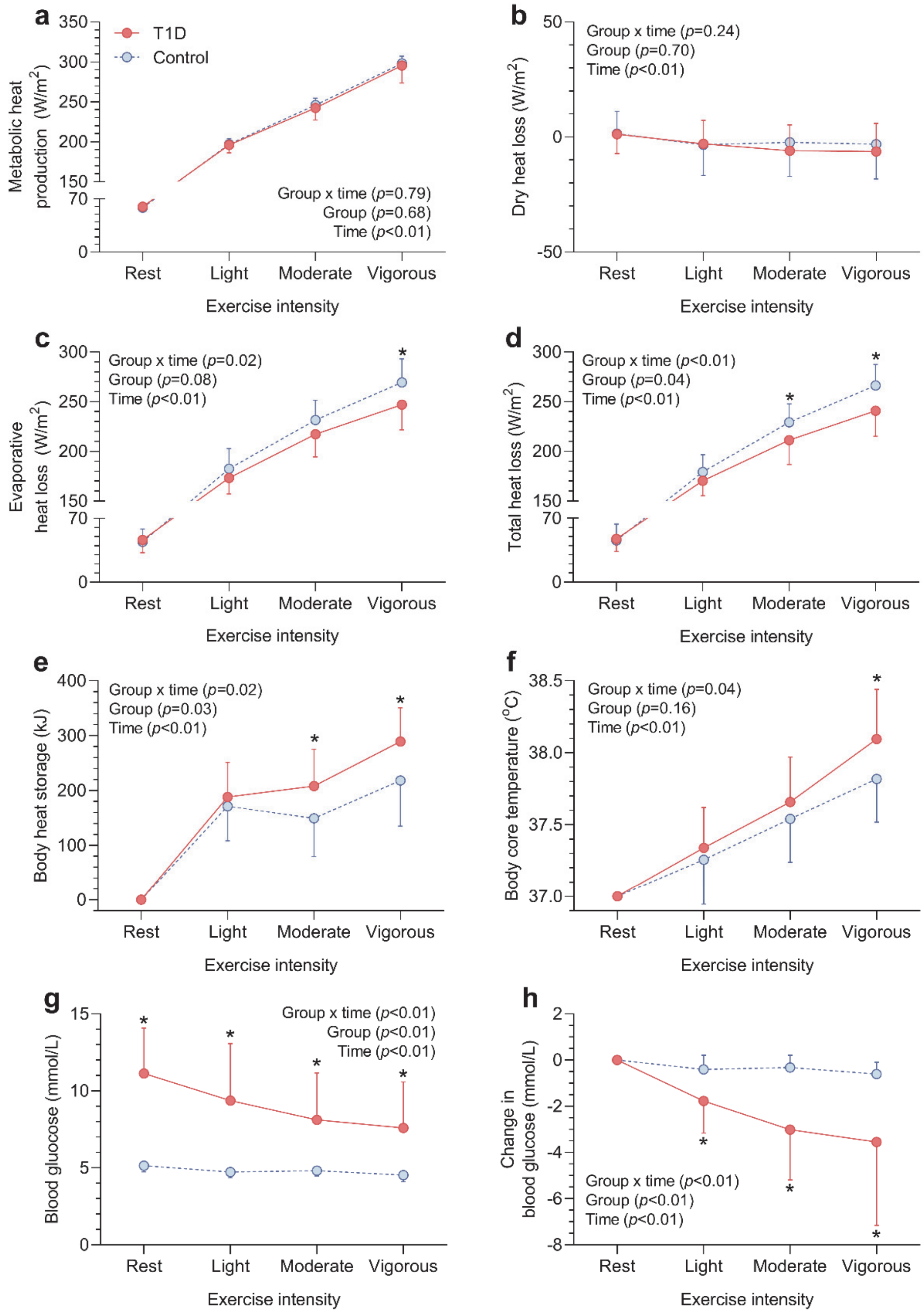
FIGURE CAPTION

Figure 1: Metabolic heat production (A) as well as dry- (B), evaporative- (C) and total-heat loss (D), body heat storage (E), body core temperature (F), blood glucose (G) and the change in blood glucose (H) during 30 min of rest and light, moderate and vigorous exercise in dry-heat (35°C, 20% relative humidity). Data are means (±SD) of the final five minutes of rest and exercise in patients with (10 males, 4 females; T1D) and without (10 males, 4 females; control) type 1 diabetes. Negative values for dry-heat loss denote heat gain from the environment. Significantly different from control (*; $p<0.05$).

FIGURE 1.


a
T1D
Control
Metabolic heat production (W/m2)
Group x time (p=0.79)
Group (p=0.68)
Time (p<0.01)
Exercise intensity
Rest
Light
Moderate
Vigorous
b
Dry heat loss (W/m2)
Group x time (p=0.24)
Group (p=0.70)
Time (p<0.01)
c
Evaporative heat loss (W/m2)
Group x time (p=0.02)
Group (p=0.08)
Time (p<0.01)
d
Total heat loss (W/m2)
Group x time (p<0.01)
Group (p=0.04)
Time (p<0.01)
e
Body heat storage (kJ)
Group x time (p=0.02)
Group (p=0.03)
Time (p<0.01)
f
Body core temperature (°C)
Group x time (p=0.04)
Group (p=0.16)
Time (p<0.01)
g
Blood glucose (mmol/L)
Group x time (p<0.01)
Group (p<0.01)
Time (p<0.01)
h
Change in blood glucose (mmol/L)
Group x time (p<0.01)
Group (p<0.01)
Time (p<0.01)