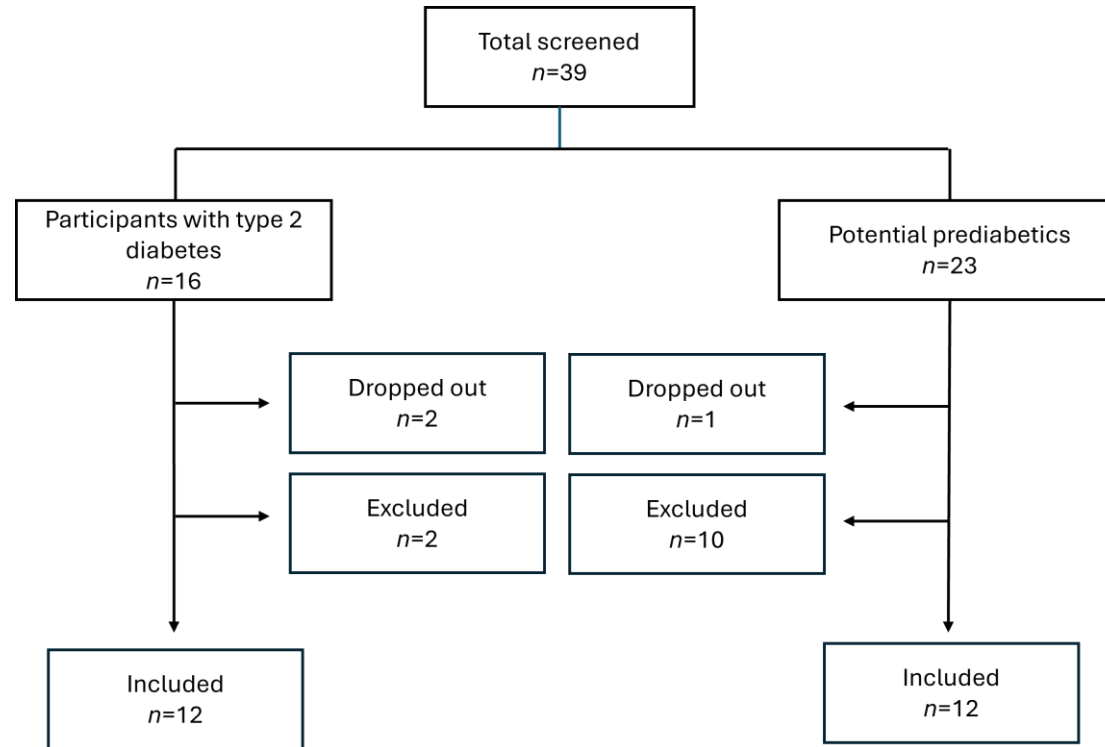
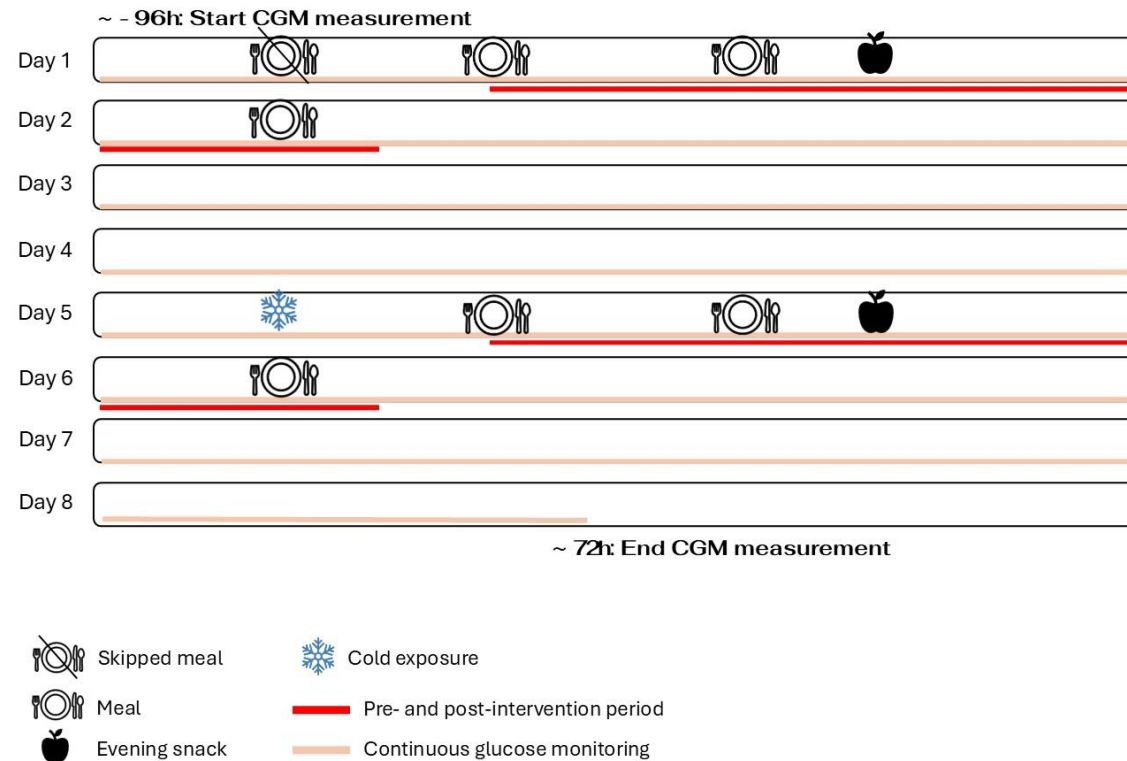


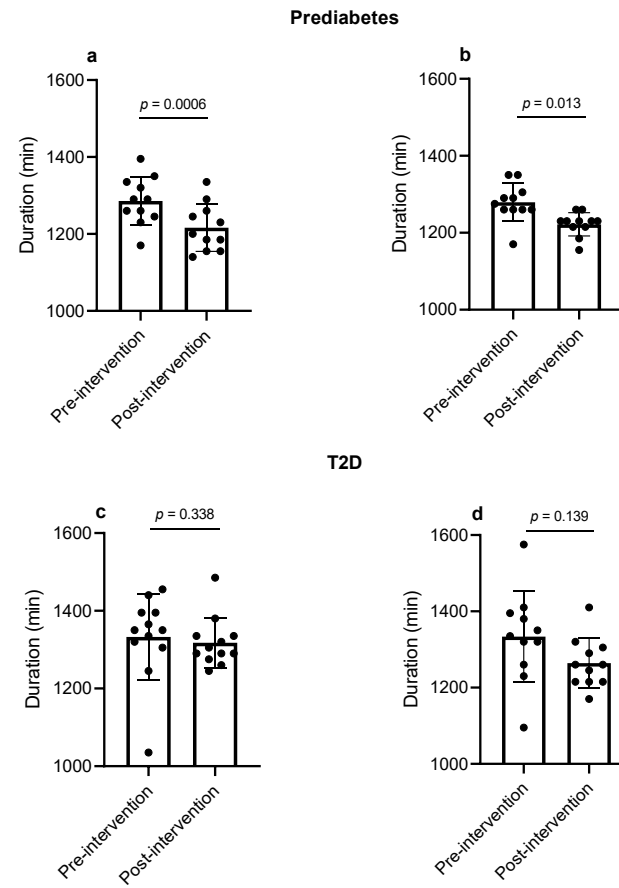
Electronic supplementary material



ESM Figure 1. Inclusion chart.



ESM Figure 2. Overview of one study period. Study period begins approximately 96 hours before the respective cold exposure session (at ~09:00). On day 1 subject are instructed to skip breakfast to replicate the cold exposure day and are provided standardised lunch, dinner, evening snack and breakfast the following morning. The pre-intervention time window begins with lunch on day 1 and ends 2 hours following breakfast on day 2. Participants are exposed to cold in the morning of Day 5 (in the fasted state). One hour after cold exposure participants are provided standardised lunch. Post-intervention time window starts with lunch after cold exposure and ends 2 hours following breakfast on day 6.



ESM Figure 3. Duration of the pre- and post-intervention meal-to-meal time windows in *Prediabetes* group (a: ‘Mild’ period and b: ‘Moderate’ period) and *type 2 diabetes* group (c: ‘Mild’ period and d: ‘Moderate’ period).

ESM Table 1. Overview of medications used by participants. Other medications include medications in the following categories: antihistamine (x1), methylfenidaat (x1), osteopenia (x1), blood thinners (x1), prostate (x1), corticosteroid (x1), gastrointestinal (x1), thyroid-regulating (x1), serotonin-reuptake inhibitor (x3).

		Prediabetes group (<i>n</i>=12)	Type 2 diabetes group (<i>n</i>=12)
Glucose lowering treatment	Metformin only	NA	<i>n</i> =6
	Metformin + sulfonylurea agent and/or GLP-1 agonist	NA	<i>n</i> =4
	Diet only	NA	<i>n</i> =2
Antihypertensive medications		<i>n</i> =2	<i>n</i> =8
Cholesterol-lowering medications		<i>n</i> =1	<i>n</i> =7
Other medications		<i>n</i> =7	<i>n</i> =7

ESM Table 2. Caloric intake over the ± 24 h meal-to-meal period before and after moderate and mild cold exposure for the respective study group. Values are expressed in MJ and % for total intake and macronutrient composition, respectively. Differences are assessed with a paired t-test or non-parametric equivalent. Data are presented as mean $\pm$ SD. Statistical significance was deemed as $p < 0.05$.

	Mild cold			Moderate cold		
Prediabetes group	Pre	Post	<i>p</i>	Pre	Post	<i>p</i>
Total intake (MJ)	11.9 $\pm$ 3.2	12.2 $\pm$ 3.2	0.117	11.8 $\pm$ 3.2	12.0 $\pm$ 3.2	0.282
Fat (%)	32.6 $\pm$ 1.4	32.5 $\pm$ 1.2	0.506	32.6 $\pm$ 1.3	32.4 $\pm$ 0.9	0.661
Carbohydrate (%)	49.1 $\pm$ 1.6	49.08 $\pm$ 1.4	0.901	49.1 $\pm$ 1.5	49.2 $\pm$ 1.2	0.610
Protein (%)	14.1 $\pm$ 0.4	14.4 $\pm$ 0.5	0.976	14.4 $\pm$ 0.5	14.4 $\pm$ 0.5	0.809
Type 2 diabetes group	Pre	Post	<i>p</i>	Pre	Post	<i>p</i>
Total intake (MJ)	10.6 $\pm$ 2.6	10.6 $\pm$ 2.3	0.974	11.0 $\pm$ 2.3	10.5 $\pm$ 3.0	0.436
Fat (%)	33.9 $\pm$ 2.5	34.3 $\pm$ 2.3	0.535	34.2 $\pm$ 1.7	33.4 $\pm$ 3.0	0.283
Carbohydrate (%)	46.5 $\pm$ 5.4	47.8 $\pm$ 2.2	0.625	46.8 $\pm$ 4.6	48.3 $\pm$ 2.9	0.625
Protein (%)	15.0 $\pm$ 2.0	14.4 $\pm$ 1.0	0.221	15.0 $\pm$ 1.8	14.6 $\pm$ 1.1	0.846

ESM Table 3. Overview of physical activity levels over the ± 24 -hour meal-to-meal period before and after moderate and mild cold exposure in the respective study group. Differences are assessed with a paired t-test or non-parametric equivalent. Data are presented as mean $\pm$ SD. Statistical significance deemed as $p < 0.05$.

	Mild cold			Moderate cold		
Prediabetes group	Pre	Post	<i>p</i>	Pre	Post	<i>p</i>
Time sitting/lying (h)	18.3 $\pm$ 0.4	17.8 $\pm$ 0.5	0.444	18.1 $\pm$ 0.3	17.5 $\pm$ 0.3	0.085
Time standing (h)	3.2 $\pm$ 0.2	2.7 $\pm$ 0.2	0.083	3.2 $\pm$ 0.3	2.6 $\pm$ 0.2	0.180
Time stepping (h)	1.1 $\pm$ 0.2	0.9 $\pm$ 0.1	0.338	1.0 $\pm$ 0.1	0.9 $\pm$ 0.1	0.424
Type 2 diabetes group	Pre	Post	<i>p</i>	Pre	Post	<i>p</i>
Time sitting/lying (h)	19.5 $\pm$ 0.8	18.9 $\pm$ 0.6	0.202	18.9 $\pm$ 0.7	17.7 $\pm$ 0.6	0.055
Time standing (h)	2.4 $\pm$ 0.4	2.7 $\pm$ 0.4	0.578	2.9 $\pm$ 0.4	2.9 $\pm$ 0.5	0.924
Time stepping (h)	1.4 $\pm$ 0.2	1.6 $\pm$ 0.2	0.540	1.3 $\pm$ 0.1	1.4 $\pm$ 0.2	0.783

ESM Table 4. Plasma concentration of substrates at baseline, at the onset of final 1 hour of cold exposure ($T=0$) and the end of final 1-hour of cold exposure ($T=60$). Data are presented as mean $\pm$ SD. Repeated measured ANOVA or its non-parametric equivalent was used to test for change over time (time effect presented in the last column for each substrate), with a post-hoc test with Bonferroni or Dunn's correction for multiple testing to determine differences between time points. Statistical differences were denoted as * $p<0.05$, ** $p<0.01$, *** $p<0.001$ vs. respective baseline.

		Group Prediabetes				Group T2D			
		Baseline	$T = 0$	$T = 60$	p	Baseline	$T = 0$	$T = 60$	p
Glucose (mmol/l)	Mild	5.8 $\pm$ 0.5	5.5 $\pm$ 0.3	5.3 $\pm$ 0.2*	0.03	8.2 $\pm$ 2.0	7.4 $\pm$ 1.5	7.0 $\pm$ 1.2***	<0.001
	Moderate	5.7 $\pm$ 0.5	5.3 $\pm$ 0.3	5.3 $\pm$ 0.3*	0.02	8.2 $\pm$ 1.6	7.0 $\pm$ 1.1***	6.7 $\pm$ 0.8***	<0.001
Insulin (pmol/l)	Mild	123.6 $\pm$ 111.7	88.8 $\pm$ 72.1	79.0 $\pm$ 63.7*	0.02	75.5 $\pm$ 43.2	61.8 $\pm$ 47.2	46.1 $\pm$ 34.3**	0.003
	Moderate	96.5 $\pm$ 98.4	76.3 $\pm$ 73.2	68.3 $\pm$ 69.9**	0.006	88.1 $\pm$ 60.4	51.2 $\pm$ 27.2*	45.9 $\pm$ 34.5*	0.01
NEFA (mmol/l)	Mild	0.470 $\pm$ 0.139	0.555 $\pm$ 0.196	0.658 $\pm$ 0.160**	0.001	0.486 $\pm$ 0.141	0.543 $\pm$ 0.204	0.625 $\pm$ 0.217**	0.002
	Moderate	0.448 $\pm$ 0.076	0.627 $\pm$ 0.146***	0.734 $\pm$ 0.140***	<0.001	0.452 $\pm$ 0.164	0.520 $\pm$ 0.155	0.683 $\pm$ 0.230**	0.001
TG (mmol/l)	Mild	1.9 $\pm$ 0.4	2.3 $\pm$ 0.4***	2.4 $\pm$ 0.4***	<0.001	1.8 $\pm$ 0.9	2.1 $\pm$ 1.1*	2.2 $\pm$ 1.2***	<0.001
	Moderate	1.7 $\pm$ 0.6	2.2 $\pm$ 0.7***	2.2 $\pm$ 0.7***	<0.001	1.6 $\pm$ 0.5	2.0 $\pm$ 0.7**	2.1 $\pm$ 0.7***	<0.001
Glycerol (μ mol/l)	Mild	101.3 $\pm$ 35.1	130.5 $\pm$ 69.5	150.0 $\pm$ 52.8*	0.01	65.1 $\pm$ 17.0	93.6 $\pm$ 31.9**	107.8 $\pm$ 38.0****	0.001
	Moderate	75.7 $\pm$ 14.5	146.7 $\pm$ 59.8	192.7 $\pm$ 74.7***	<0.001	57.3 $\pm$ 13.5	105.0 $\pm$ 39.2**	128.9 $\pm$ 53.8****	<0.001

ESM Table 5. Multiple linear regression analyses outcome.

Variable	Estimate	Standard error	95% Confidence Interval	<i>p</i>
β1: Being a T2D patient	0.156	±0.281	-0.443 to 0.754	0.58
β2: Age (years)	0.028	±0.012	0.003 to 0.054	0.03
β3: Fat mass (kg)	-0.005	±0.010	-0.027 to 0.016	0.60
β4: Fat free mass (kg)	-0.005	±0.010	-0.026 to 0.016	0.61
β5: Fasting glucose (mmol/L)	-0.271	±0.071	-0.423 to -0.120	0.002
β6: ALT (U/L)	0.023	±0.009	0.005 to 0.041	0.02

ESM Table 6. Pairwise correlations between total body shivering activity (% maximum voluntary contraction [%MVC]) and changes in 24 h plasma glucose parameters (Δ = post–pre). Total body average %MVC represents the average across five assessed muscle groups. Lower Δ values indicate greater reductions in glucose parameters. Associations were tested using Pearson or Spearman correlations based on data normality (Shapiro–Wilk test), and corrected for multiple testing via the Hold–Sidak method. Statistical significance was set at $p < 0.05$.

	Total body MVC% (mild cold)			Total body MVC% (moderate cold)			Total body MVC% (mild and moderate cold combined)		
	<i>r</i>	95% CI	<i>p</i>	<i>r</i>	95% CI	<i>p</i>	<i>r</i>	95% CI	<i>p</i>
Δ 24-hour Glucose (mmol/L)	0.191	-0.241 to 0.559	0.945	0.237	-0.230 to 0.615	0.848	0.180	-0.127 to 0.456	0.761
Δ Fasting Glucose (mmol/L)	-0.056	-0.458 to 0.364	0.996	-0.191	-0.584 to 0.275	0.848	-0.168	-0.446 to 0.139	0.761
Δ Diurnal Glucose (mmol/L)	0.092	-0.333 to 0.486	0.996	0.475	0.041 to 0.758	0.215	0.284	-0.018 to 0.538	0.375
Δ Nocturnal Glucose (mmol/L)	0.068	-0.365 to 0.477	0.996	-0.216	-0.606 to 0.269	0.848	-0.087	-0.386 to 0.228	0.823
Δ Time in Range (4.4–7.2 mmol/L)	-0.096	-0.489 to 0.329	0.996	-0.024	-0.462 to 0.423	0.921	0.013	-0.288 to 0.312	0.932
Δ Time in High Glucose (7.3–9.9 mmol/L)	0.210	-0.234 to 0.581	0.944	-0.116	-0.531 to 0.344	0.860	-0.128	-0.413 to 0.179	0.798
Δ Time in Hyperglycaemia (>10.0 mmol/L)	-0.062	-0.473 to 0.371	0.996	0.445	-0.011 to 0.748	0.260	0.215	-0.101 to 0.491	0.666