Supplemental Material

Circadian rhythm phase shifts caused by timed exercise vary with chronotype

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Table S1. Baseline characteristics of study participants by sex and exercise group

	Morning Exercise		Evening Exercise	
Variable[A]	**Male (N=8)**	**Female (N=18)**	**Male (N=8)**	**Female (N=18)**
Age	21.88 ± 1.49	26.06 ± 1.52	23.63 ± 1.70	23.78 ± 1.19
Body Mass (kg)	73.99 ± 3.65	63.53 ± 3.57	73.10 ± 3.81	67.31 ± 2.79
Height (cm)	171.69 ± 2.11	163.32 ± 1.22	175.54 ± 1.88	164.74 ± 1.95
BMI (kg/m^2)	25.05 ± 0.93	23.71 ± 1.17	23.70 ± 1.06	24.94 ± 1.14
Sleep and Circadian Measures				
Circadian Phase Shift (h)	0.46 ± 0.42	0.53 ± 0.25	0.25 ± 0.29	0.02 ± 0.21
Baseline DLMO (hh:mm)	22:20 ± 00:27	21:38 ± 00:20	22:33 ± 00:39	22:35 ± 00:19
MEQ Baseline Score	52.38 ± 2.78	50.89 ± 2.32	50.75 ± 2.38	45.22 ± 2.40
Mid-Sleep Exercise Days (hh:mm)*	3:43 ± 00:23	3:14 ± 00:16	4:38 ± 00:20	4:58 ± 00:17
Sleep Fragmentation Index (%)*	27.80 ± 1.91	23.58 ± 1.41	25.96 ± 3.47	26.82 ± 2.16
Anthropometric and Body Composition				
Waist Circumference (cm)	80.76 ± 1.63	72.92 ± 2.35	80.33 ± 3.02	76.37 ± 2.55
Abdominal Circumference (cm)	85.26 ± 1.50	81.51 ± 2.96	85.63 ± 3.86	85.52 ± 2.70
Hip Circumference (cm)	99.79 ± 2.52	99.63 ± 2.47	99.30 ± 2.64	101.79 ± 2.20
Body Fat Percentage (%)	27.88 ± 1.63	32.54 ± 2.19	24.90 ± 3.10	35.81 ± 1.74
Fat Mass (kg)	20.12 ± 1.86	21.37 ± 2.62	18.30 ± 3.01	24.05 ± 2.05
Fat Free Mass (kg)	51.41 ± 1.83	41.52 ± 1.59	52.61 ± 1.86	41.36 ± 1.16
Mineral-free Lean Mass (kg)	48.84 ± 1.78	39.21 ± 1.51	50.02 ± 1.75	39.08 ± 1.09
Cardiorespiratory Fitness				
VO_{2peak} ($mL*kg^{-1}*min^{-1}$)	46.38 ± 2.1	35.59 ± 1.47	44.30 ± 2.83	33.25 ± 1.55
Environmental Conditions				
Civil Daylength (h)	13.13 ± 0.70	12.81 ± 0.30	12.51 ± 0.39	12.91 ± 0.38

[A]Data are Means ± SEM

*N is reduced by 7 total participants.

Table S2. Characteristics of study participants by sex

Variable[A]	Male (N=16)	Female (N=36)	p-value[B]
Age	22.75 ± 1.12	24.92 ± 0.97	0.19
Body Mass (kg)	73.54 ± 2.55	65.42 ± 2.26	0.04
Height (cm)	173.61 ± 1.45	164.03 ± 1.14	<0.01
BMI (kg/m^2)	24.37 ± 0.70	24.32 ± 0.81	0.97
Sleep and Circadian Measures			
Circadian Phase Shift (h)	0.36 ± 0.25	0.27 ± 0.17	0.79
Baseline DLMO (hh:mm)	22:26 ± 00:23	22:06 ± 00:14	0.45
Post-exercise DLMO (hh:mm)	22:05 ± 00:18	21:50 ± 00:15	0.57
MEQ Baseline Score	51.56 ± 1.78	48.06 ± 1.71	0.22
Mid-Sleep Exercise Days (hh:mm)*	4:15 ± 00:17	4:01 ± 00:15	0.60
Sleep Fragmentation Index (%)*	26.73 ± 2.11	25.05 ± 1.26	0.50
Anthropometric and Body Composition			
Waist Circumference (cm)	80.54 ± 1.66	74.65 ± 1.73	0.04
Abdominal Circumference (cm)	85.44 ± 2.00	83.51 ± 2.01	0.56
Hip Circumference (cm)	99.54 ± 1.77	100.71 ± 1.64	0.67
Body Fat Percentage (%)	26.39 ± 1.74	34.18 ± 1.41	<0.01
Fat Mass (kg)	19.21 ± 1.73	22.71 ± 1.65	0.21
Fat Free Mass (kg)	52.01 ± 1.27	41.44 ± 0.97	<0.01
Mineral-free Lean Mass (kg)	49.43 ± 1.21	39.14 ± 0.92	<0.01
Cardiorespiratory Fitness			
VO_{2Peak} ($mL*kg^{-1}*min^{-1}$)	45.41 ± 1.70	34.45 ± 1.07	<0.01
Environmental Conditions			
Civil Daylength (h)	12.82 ± 0.40	12.86 ± 0.24	0.93

[A]Data are Means ± SEM. [B]Participant characteristics for the males and females were compared using independent sample *t*-tests

*N is reduced by 7 total participants.

Table S3. Characteristics of participants that withdrew from the study

Subject ID	Sex	Reason	MEQ Score	MEQ Category*
Randomized to Morning Exercise Group				
23	Female	Unforeseen schedule conflict	63	Moderate morning type
31	Female	Schedule conflict/transportation	47	Neither type
36	Female	Unwilling to forgo beginning a personal training regime	73	Definite morning type
45	Female	Unwilling to complete DLMO	57	Neither type
52	Female	Separate commitment that required exercise training outside of study protocol	56	Neither type
72	Female	Time constraints	50	Neither type
Randomized to Evening Exercise Group				
16	Male	Academic/personal issues	55	Neither type
24	Female	Unwilling to refrain from additional exercise outside of study protocol	44	Neither type
30	Male	Family event/emergency	45	Neither type
44	Female	Personal issues	40	Moderate evening type
57	Female	Unforeseen schedule conflict	61	Moderate morning type

*The categories for the Morningness-Eveningness Questionnaire (MEQ) were from (1)

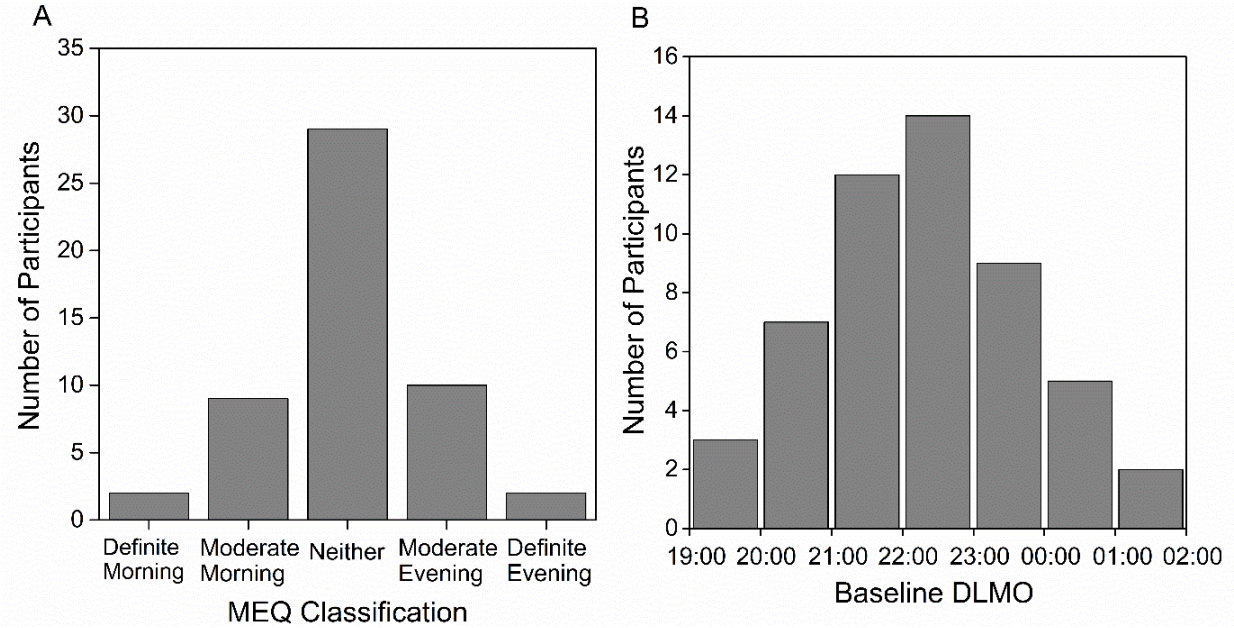
Table S4. Estimated Phase Shift Difference for Evening vs. Morning Exercise Group

		Mean Phase Shift Difference	Standard Error	*p*-value
Model 1	(Unadjusted)	-0.42	0.27	0.13
Model 2	Adjusted for baseline DLMO	-0.64	0.25	0.01
Model 3	Adjusted for baseline MEQ score	-0.49	0.28	0.08
Model 4	Adjusted for baseline DLMO and baseline MEQ score	-0.62	0.26	0.02
Model 5	Adjusted for midsleep on exercise days	-0.53	0.36	0.15
Model 6	Adjusted for sex	-0.42	0.28	0.13

Table S5. Effect of earlier and later chronotypes on estimated phase shift difference*

Baseline DLMO group	Exercise Group	Mean	Standard Error	Mean Phase Shift Difference	*p*-value
Earlier Chronotypes	Morning	0.49	0.25	-0.90	0.02
	Evening	-0.41	0.29		
Later Chronotypes	Morning	0.54	0.29	-0.08	0.83
	Evening	0.46	0.25		

*Results adjusted for baseline DLMO



Supplemental Figure S1. Chronotype was normally distributed among our study participants. Young sedentary adults completed a MEQ questionnaire at the consent session (A) and the DLMO assay 1-9 days later (B) to objectively assess circadian phase at baseline (prior to the exercise intervention).

Supplemental Reference

1. Horne JA, and Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol.* 1976;4(2):97-110.