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Research Article

Physiological and perceptual responses to sprint interval exercise using arm versus leg cycling ergometry

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A R T I C L E I N F O

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A B S T R A C T

Increases in power output and maximal oxygen consumption ($\dot{V}O_2$max) occur in response to sprint interval exercise (SIE), but common use of "all-out" intensities presents a barrier for many adults. Furthermore, lower-body SIE is not feasible for all adults. We compared physiological and perceptual responses to supramaximal, but "non-all-out" SIE between leg and arm cycling exercise. Twenty-four active adults (mean ± *SD* age: [25 ± 7] y; cycling $\dot{V}O_2$max: [39 ± 7] $mL \cdot kg^{-1} \cdot min^{-1}$) performed incremental exercise using leg (LCE) and arm cycle ergometry (ACE) to determine $\dot{V}O_2$max and maximal work capacity (Wmax). Subsequently, they performed four 20 s bouts of SIE at 130% Wmax on the LCE or ACE at cadence = 120–130 rev/min, with 2 min recovery between intervals. Gas exchange data, heart rate (HR), blood lactate concentration (BLa), rating of perceived exertion (RPE), and affective valence were acquired. Data showed significantly lower ($p < 0.001$) absolute mean ([1.24 ± 0.31] $L \cdot min^{-1}$ vs. [1.59 ± 0.34] $L \cdot min^{-1}$; $d = 1.08$) and peak $\dot{V}O_2$ ([1.79 ± 0.48] $L \cdot min^{-1}$ vs. [2.10 ± 0.44] $L \cdot min^{-1}$; $d = 0.70$) with ACE versus LCE. However, ACE elicited significantly higher ($p < 0.001$) relative mean ([62% ± 9%] $\dot{V}O_2$max vs. [57% ± 7%] $\dot{V}O_2$max, $d = 0.63$) and peak $\dot{V}O_2$ ([88% ± 10%] $\dot{V}O_2$max vs. [75% ± 10%] $\dot{V}O_2$max, $d = 1.33$). Post-exercise BLa was significantly higher ([7.0 ± 1.7] mM vs. [5.7 ± 1.5] mM, $p = 0.024$, $d = 0.83$) for LCE versus ACE. There was no significant effect of modality on RPE or affective valence ($p > 0.42$), and lowest affective valence recorded (2.0 ± 1.8) was considered "good to fairly good". Data show that non "all-out" ACE elicits lower absolute but higher relative HR and $\dot{V}O_2$ compared to LCE. Less aversive perceptual responses could make this non-all-out modality feasible for inactive adults.

1. Introduction

Sprint interval exercise (SIE) consists of brief (5–30 seconds [s]), repeated, and exhaustive efforts at intensities greater than that associated with maximal oxygen consumption ($\dot{V}O_2$max) or maximal work capacity (Wmax) separated by low intensity or resting recovery.[1] Although there are various iterations of SIE, the most widely used protocols require completion of 4–6 Wingate tests,[2,3] 10 s cycling sprints at 170%Wmax,[4] or two or three 20 s sprints within a 10-minute (min) session (reduced-exertion high-intensity training; REHIT).[5–7] One unique attribute of SIE is the low training volume (1–3 min) compared to high intensity interval exercise (10–16 min) or moderate intensity continuous exercise (20–60 min). It is likely that generation of extremely high work rates characteristic of SIE is critical to resultant training-induced increases in $\dot{V}O_2$max,[2,3,8] insulin sensitivity,[9] fat oxidation,[2,3] and oxidative capacity[3,10] despite the extremely low training volume.

Nevertheless, SIE requires "all-out" efforts characterized by attainment of maximal cadence and in turn, power outputs higher than that associated with $\dot{V}O_2$max, which may be undesirable in inactive adults. In some cases, SIE can elicit extreme fatigue, hyperventilation, nausea, and dizziness[2] which may reduce its widespread application in this population. In fact, Hardcastle et al.[11] stated that SIE is inappropriate for the typical inactive adult as it may be perceived as too arduous which would lead to feelings of displeasure and in turn, low adherence.[12] Nevertheless, data show that pleasure: displeasure remains positive (average affective

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List of abbreviations

ACE	arm cycling ergometry
ATP	adenosine triphosphate
b/min	beats per minute
B-HAD	3-hydroxyacyl-CoA dehyderogenase
BLa	blood lactate concentration
BMI	body mass index
COmax	maximal cardiac output
FT	fast twitch
h	hours
HIIT	high intensity interval training
HR	heart rate
HRmax	maximal heart rate
h/wk	hours per week
$kg \cdot m^{-2}$	kilograms per meter squared
LCE	leg cycling ergometry
min	minutes
PACES	physical activity enjoyment scale
rev/min	revolutions per minute
RPE	rating of perceived exertion
REHIT	reduced exertion high intensity training
RER	respiratory exchange ratio
s	seconds
SIE	sprint interval exercise
ST	slow twitch
$\dot{V}CO_2$	carbon dioxide production
$\dot{V}_E$	ventilation
$\dot{V}O_2max$	maximal oxygen consumption
$\dot{V}O_2$	oxygen uptake
W	watts
Wmax	maximal workload
W/min	watts per minute
y	years

valence ~ 1.0–1.5) in less fit adults who engage in relatively low-volume SIE.[5,13] In a recent systematic review and meta-analysis, Hu et al.[14] revealed that low-volume SIE protocols using shorter sprints and lower number of efforts induced more positive affective responses, suggesting the feasibility of SIE in adults.

Several approaches exist to reduce the metabolic perturbation of vigorous exercise including SIE. One option is to reduce sprint duration. In young adults, Islam et al.[15] compared physiological responses to work-matched bouts of treadmill-based SIE requiring durations of 5 s, 15 s, and 30 s using a 1:8 ratio of work:recovery. Compared to the longer durations, $\dot{V}O_2$ and energy expenditure were significantly higher with the 5 s sprints which was attendant with greater intention to engage in this protocol and more positive affective valence,[16] emphasizing the importance of brief sprint durations to augment the tolerability of SIE. In addition, Vollaard and Metcalfe[17] revealed that fewer number (2–3) and shorter intervals (10 s or 20 s) provide similar health benefits as the traditional 30 s Wingate-based SIE regimen.

An additional element that can be modified to reduce the physiological response to SIE is to not require "all-out" efforts which should attenuate the level of fatigue experienced by participants. Although all SIE is characterized by supramaximal sprints, this includes exercise intensities ranging from just above Wmax to several-fold higher intensities achieved in all-out sprints (e.g., ~350% of $\dot{V}O_2$max).[18] Bayati et al.[19] revealed similar increases in $\dot{V}O_2$max and Wmax in response to 12 sessions of "all-out" SIT (30 s Wingate tests) compared to a higher volume of 30 s efforts at 125%Wmax, which would suggest that the level of effort maintained during supramaximal sprints does not affect the chronic response. To our knowledge, no study has examined acute physiological and perceptual responses to SIE characterized by intervals which are supramaximal, but not all-out.

The majority of studies employing SIE used leg cycle ergometry (LCE),[2,3,10,19] although some have employed treadmill sprinting.[16,20,21] One disadvantage of cycling-based SIE is that it leads to lightheadedness, leg pain, and nausea and in turn, displeasure.[11] Furthermore, LCE is not feasible for all individuals e.g. most people with spinal cord injury.[22] An alternative modality to LCE is arm cycle ergometry (ACE) which has been widely implemented in persons with heart disease[23] and spinal cord injury[24] to improve physical fitness and function. Price et al.[25] reported higher peak and mean power output, yet no difference in heart rate or respiratory exchange ratio, between the Wingate test performed using LCE versus ACE. In adults, Zinner et al.[26] reported that six sessions of SIE using ACE and LCE increased upper-body $\dot{V}O_2$max slightly more than that of the legs despite less work being performed during ACE. However, little is known about the acute physiological response to non "all-out" SIE performed using ACE and how this may compare to LCE. At a given submaximal or maximal absolute work rate, ACE elicits higher HR and $\dot{V}O_2$ versus LCE due to use of a smaller exercising muscle mass and the lower efficiency of arm cycling.[27]

The aim of the present study was to compare physiological and perceptual responses to SIE between LCE and ACE characterized by supramaximal, but non-all-out efforts. Reducing the effort attendant with SIE may attenuate blood lactate accumulation, enhance perceptual responses, and in turn, make it more feasible for the majority of adults who are insufficiently active and likely intolerant of "all-out" efforts. We hypothesize that supramaximal, but non-all-out ACE will be associated with less aversive perceptual responses, but considering the lower active muscle mass and higher contribution of type 2 muscle fibers, will present a lower absolute and relative cardiopulmonary response compared to LCE.

2. Material and methods

2.1. *Experimental design and subjects*

This repeated measures, crossover study examined differences in various outcomes between brief bouts of SIE characterized by different active muscle mass. Participants initially underwent incremental exercise to exhaustion to determine Wmax and $\dot{V}O_2$max on both the leg and arm cycle ergometer. On the second visit, they completed a familiarization trial comprising two bouts of SIE on both exercise modes. For the final two sessions, order of assignment to ACE or LCE was randomized, and a minimum of 48 hours (h) separated each visit, which were held at the same time of day (08:00 to 13:00) within participants. Physiological and perceptual responses were acquired during the sessions. All participants were asked to be well-rested, hydrated, and refrain from intense exercise for 36 h prior to all sessions. A study flow diagram is shown in Fig. 1.

Recreationally-active men ($n = 15$) and women ($n = 9$) were recruited by word-of-mouth. Inclusion criteria included age 18–50 y, healthy, non-obese, non-smoker, participation in 150 min/wk of moderate or 75 min/wk of vigorous exercise, and no joint issues which would be worsened by upper- or lower-body sprint cycling.

2.2. *Ethical approval*

Participants provided written informed consent, and study

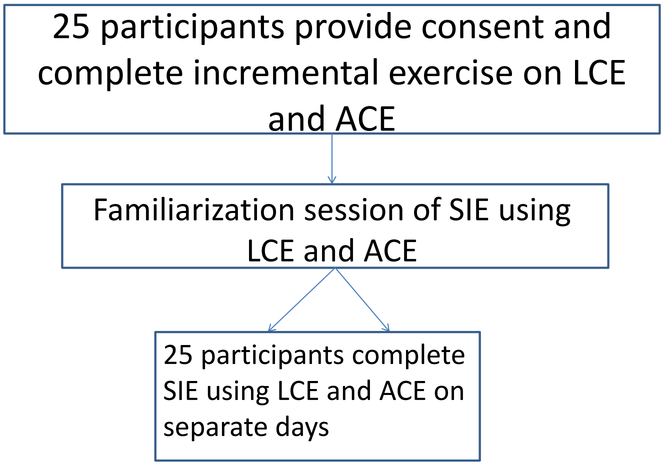

Fig. 1. Study Flow Diagram. LCE = leg cycling ergometry; ACE = arm cycling ergometry; SIE = sprint interval exercise.

experimental procedures were reviewed and approved by the Institutional Review Board at CSU—San Marcos (Protocol 1876593-1). The study was conducted in accordance with the Declaration of Helsinki.

2.3. *Testing of maximal oxygen uptake*

Initially, height and body mass were determined and used to calculate body mass index (BMI). Subsequently, skinfold measurements were performed at chest, abdomen, and thigh for men and triceps, suprailiac, and thigh for women.[28,29] to determine percent body fat from body density.[30] Then, participants completed incremental exercise to volitional exhaustion on both an electrically-braked cycle ergometer (Velotron RacerMate, Quark, SD) and arm cycle ergometer (Lode Angio, Groningen, Netherlands). Order of assignment to LCE versus ACE incremental test was randomized and separated by a 30 min recovery period.[31] Our preliminary data in four active men and women show similar values of Wmax (difference $\leq$ 4 W) and $\dot{V}O_2$max (difference $\leq$ 2.5%) when these tests are performed on separate days or separated by 30 min as performed in the present study. Graded exercise on the ACE began with a 2 min warm up at 7 W after which power output was increased in a ramp-like manner by 8, 15, or 20 Watt/min (W/min) until volitional exhaustion which occurred when pedal cadence was below 50 rev/min.[32] The pedal crank was aligned to the height of the shoulder joint and there was a small degree of elbow flexion. Participants were seated, required to keep their feet shoulder width apart, and encouraged to use their lower body, since lower body restriction reduces $\dot{V}O_2$max and power output during ACE.[33]

Incremental exercise using LCE began with a 2 min warm up at 40–70 W. Power output was subsequently increased in a ramp-like manner by 20–35 W/min until volitional exhaustion which was determined by pedal cadence below 50 rev/min. Different work rate increments were used across participants to account for differences in sex, body size, and fitness level and to ensure duration of incremental exercise between 8 and 12 min. Throughout exercise, heart rate (HR) was assessed continuously via telemetry (Polar, Woodbury, NY), and gas exchange data ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, and respiratory exchange ratio [RER]) were acquired at 10 s increments using a metabolic cart (ParvoMedics True One, Sandy, UT), which was calibrated prior to testing according to manufacturer guidelines.

$\dot{V}O_2$max was identified as the mean of the two highest 10 s values at exercise termination. Workload (in Watts) at volitional fatigue was identified as Wmax and used to determine the exercise intensities of subsequent SIE bouts. To verify attainment of $\dot{V}O_2$max, the following criteria were used: change in $\dot{V}O_2 < 0.15$ L min^{-1} at $\dot{V}O_2$max and RER $>$ 1.10.[34,35]

2.4. *Familiarization session*

Most participants had no experience with SIE, so a familiarization session on both ergometers was performed. After a 3 min warm-up at 20% Wmax, participants completed two 20 s bouts of SIE at the required cadence separated by 2 min of active recovery at 20% Wmax. They completed a 5 min passive recovery, then performed two SIE bouts on the other modality, whose order was randomized across participants. Perceptual responses and HR were acquired pre-exercise, immediately after each sprint, and halfway into recovery between sprints.

2.5. *Completion of sprint interval exercise*

SIE sessions began with a 3 min warm up at 20% Wmax succeeded by four 20 s sprints at 130% Wmax at a cadence between 120 and 130 rev/min, which was closely monitored during each interval. This cadence was selected for two reasons. First, pilot testing revealed that young adults can attain peak cadences during ACE exceeding 150 rev/min. In addition, prior work from our lab employing SIE on the cycle ergometer shows that men and women can achieve peak cadences $\geq$ 180 rev/min.[2,5] Approximately 5 s before each sprint, participants were required to increase pedal cadence so by the start of the interval, they were pedaling at the desired cadence which is when resistance was applied to the ergometer. Intervals were interspersed by 2 min recovery at 20% Wmax. This protocol was chosen as "all-out" SIE protocols comprising fewer sprint repetitions and shorter durations[5,9] generate significant improvements in cardiorespiratory fitness[6] yet elicit more positive affective responses.[13,14] This power output is appropriate for nonathletic adults, elicits significant BLa (~12 mM),[36] and the 1:6 work:rest ratio is adequate to promote recovery. Gas exchange data and HR were acquired every 10 s throughout exercise. Values from each interval were determined as the two 10 s values during exercise and first value in recovery, due to the lag in HR and $\dot{V}O_2$ during SIE.[37] Recovery values were calculated from the last 60 s of recovery (6 values). Mean $\dot{V}O_2$, $\dot{V}_E$, RER, and HR were identified as the average value from the session (9 min and 20 s), not including the warm-up. Peak values were determined as the average of any three consecutive 10 s values recorded during the session.

2.6. *Assessment of perceptual responses and blood lactate concentration*

Prior to exercise, participants were seated and read specific instructions pertaining to what each scale represented. The Borg 6–20 RPE scale was used to measure perceived exertion in response to exercise.[38] To communicate the meaning of the RPE scale, participants were instructed to report their exertion according to their level of fatigue, breathing, and HR.[38] Affective valence (assessed using the 11-point Feeling Scale, rating from +5 very good to −5 very bad including 0)[39] was described by reciting the following text: *While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable; whereas, others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise*. Participants were instructed to respond to each scale according to their perception at that moment, and their score was repeated back to them before being recorded. These measures were acquired pre-exercise, at the end of the warm-up, immediately on completion of each interval and 1 min into each recovery period. Five min post-exercise, participants were administered the 18-item Physical Activity Enjoyment Scale[40] (PACES) to assess their enjoyment of each session. This scale is widely employed in similar studies analyzing how acute exercise mediates enjoyment measured post-exercise.[32,36,41,42] Blood samples were acquired pre-, midway (after interval 2), and 3 min post-exercise to assess changes in blood lactate concentration (BLa). Participants remained seated and after the fingertip was cleaned with a damp towel, dried, and then the first drop of blood wiped away, a 0.7 μl blood sample was taken using a lancet (Owen Mumford Inc., Marietta, GA) and portable monitor (Lactate Plus, Sports Research Group, New Rochelle, NY).

2.7. *Consideration of dietary intake*

To reduce the potential effects of dietary changes on study outcomes, participants were asked to complete a 36 h food diary before their first SIE session. This was submitted to the investigators who advised participants to replicate this pattern before the final SIE session, which was done in all participants.

2.8. *Data analysis*

Data are reported as means ± standard deviation (*SD*) and were analyzed using SPSS Version 27 (IBM, NY). We determined the normality of data distributions using the Shapiro-Wilks test. To identify differences in our outcome measures between modalities, two-way repeated measures ANOVA was used, with two levels for modality, and three (BLa) or eight levels (gas exchange data, HR, RPE, and affective valence) for time. If a significant *F* ratio was obtained, Tukey's post hoc test was used to identify differences between means. The Greenhouse-Geisser correction was used if the sphericity assumption was violated. Paired *t*-test was used to assess differences in enjoyment and mean/peak and maximal variables between arm and leg cycling. Cohen's *d* was used as a measure of effect size, with a small, medium, and large effect equal to 0.2, 0.5, and 0.8, respectively.[43] G Power[44] was used to confirm that a sample size of nine per condition is adequate to detect a change in $\dot{V}O_2$ equal to 0.20 L min^{-1} across modalities, a difference shown in a prior study comparing these modalities.[31] Although our study was not adequately powered to detect differences between men and women, sex was used as a between-subjects variable in these analyses. Independent *t*-test was used to identify significant differences in peak and mean outcomes between men and women. Statistical significance was set at $p < 0.05$.

3. Results

3.1. *Comparison of maximal data between LCE and ACE*

Our participants' demographic data (mean ± *SD*) were as follows: age (25 ± 7) y; body fat, (16% ± 6%); body mass index: (25 ± 4) kg·m^{-2}; physical activity: (6 ± 3) h/wk; LCE $\dot{V}O_2$max: (39 ± 7) mL·kg^{-1}·min^{-1}.

Table 1

Comparison of data from $\dot{V}O_2$max testing between leg and arm cycling ergometry (mean ± *SD*).

Parameter	LCE	ACE	*p* value	Cohen's *d*
$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	39.4 ± 7.4	27.1 ± 4.7	< 0.001	2.0
$\dot{V}O_2$max (L·min^{-1})	2.9 ± 0.7	2.0 ± 0.5	< 0.001	1.5
PPO (W)	272.1 ± 57.4	132.5 ± 36.7	< 0.001	3.0
HRmax (b/min)	184.4 ± 10.0	178.0 ± 14.4	0.001	0.6
RERmax	1.26 ± 0.09	1.23 ± 0.09	0.027	0.3
$\dot{V}_E$max (L·min^{-1})	121.6 ± 31.7	90.7 ± 24.3	< 0.001	1.1
BLa (mM)	11.0 ± 1.9	9.7 ± 2.3	0.002	0.7
Duration (min)	8.9 ± 1.2	8.8 ± 1.5	0.76	0.1
RPE (6–20)	16.5 ± 2.2	15.3 ± 3.4	0.10	0.4
Affect (+5 to −5)	0.7 ± 2.7	0.2 ± 2.4	0.42	0.2

$\dot{V}O_2$max = maximal oxygen uptake; PPO = peak power output; HR = heart rate; RER = respiratory exchange ratio; $\dot{V}_E$ = ventilation; BLa = blood lactate concentration; RPE = rating of perceived exertion.

As expected, $\dot{V}O_2$max, Wmax, and $\dot{V}_E$ were significantly higher in response to LCE, as was maximal RER, BLa, and HR (Table 1). The relative $\dot{V}O_2$max values obtained from LCE classify our participants as having average cardiorespiratory fitness ($\dot{V}O_2$max = [31–42] mL·kg^{-1}·min^{-1}) according to Kaminsky et al.[45] ACE-derived $\dot{V}O_2$max was 69% of the mean value from LCE, which supports prior data,[32,46] although this varied from 52% to 91% across participants.

3.2. *Familiarization session*

This session elicited peak HR equal to (85.7% ± 5.6%) HRmax and (85.8% ± 6.0%) HRmax for LCE and ACE, and peak RPE and affective valence equal to (10.4 ± 2.3) vs. (10.3 ± 2.7) and (2.9 ± 1.3) vs. (3.2 ± 1.3), respectively.

3.3. *Comparison of gas exchange data and heart rate between sprint interval exercise using LCE and ACE*

Results showed no significant mode × time interaction ($p = 0.51$) for $\dot{V}O_2$ although there was a main effect of time and mode ($p < 0.001$). Compared to rest, $\dot{V}O_2$ increased six-fold during bout 4 in LCE ([0.33 ± 0.10] L·min^{-1} vs. [1.87 ± 0.34] L·min^{-1}, $d = 6.1$) and five-fold in response to ACE ([0.30 ± 0.05] L·min^{-1} vs. [1.58 ± 0.45] L·min^{-1}, $d = 4.6$) (Fig. 2). At all timepoints, LCE exhibited higher $\dot{V}O_2$ than ACE ($d =$ 0.74–1.30). Ventilation showed a main effect of time and mode ($p <$ 0.001) but no mode × time interaction ($p = 0.83$). With exception of $\dot{V}_E$ obtained in recovery after bouts 3 and 4, all exercise values were different from each other ($p < 0.05$, $d =$ 0.34–1.36). Post hoc analyses showed that $\dot{V}_E$ was higher in response to LCE versus ACE at all time points ($d =$ 0.44–1.02). Resting RER was equal to (0.88 ± 0.08) and (0.89 ± 0.08) prior to LCE and ACE and significantly increased during the session ($p < 0.001$), yet there was no mode × time interaction ($p = 0.11$) or effect of mode ($p = 0.24$). Recovery RER values were significantly higher ($p < 0.001$, $d =$ 0.44–3.74) than those recorded in response to exercise and peaked after bout 2 ([1.33 ± 0.15] and [1.40 ± 0.14] for LCE and ACE). Results showed that HR increased during SIE ($p < 0.001$) and there was a significant effect of mode ($p < 0.001$) and mode × time interaction ($p = 0.007$). All values recorded during exercise were different ($p < 0.05$) from each other with exception of the value from bout 1 and HR recorded during recovery from bouts 3 and 4.

3.4. *Comparison of mean and peak responses between LCE and ACE*

Mean $\dot{V}O_2$ (L·min^{-1}) and HR (b/min) were significantly higher ($p <$ 0.001) in response to LCE versus ACE, as were peak $\dot{V}O_2$ ($p < 0.001$) and HR ($p = 0.01$). Data also revealed higher mean $\dot{V}_E$ ($p < 0.001$) and peak $\dot{V}_E$ (L·min^{-1}) ($p = 0.008$) on the LCE. Results showed that LCE elicited higher relative mean ($p = 0.04$), but not peak %HRmax ($p = 0.71$) compared to ACE. Other data revealed that ACE elicited higher mean ($p = 0.02$) and peak % $\dot{V}O_2$max ($p < 0.001$) as well as higher relative mean ($p = 0.048$) and peak % $\dot{V}_E$max ($p = 0.017$). Table 2 reveals differences in these outcomes between modalities.

3.5. *Comparison of blood lactate concentration between LCE and ACE*

Blood lactate concentration increased during SIE (main effect, $p <$ 0.001) and there was a mode × time interaction ($p = 0.047$) (Fig. 3a). Post hoc analyses revealed that BLa after bout 2 was higher in response to LCE compared to ACE ($d = 0.83$).

3.6. *Psychological responses to LCE and ACE*

Fig. 3b–c documents changes in RPE and affective valence in response to SIE across modalities. There was a main effect of time as RPE increased

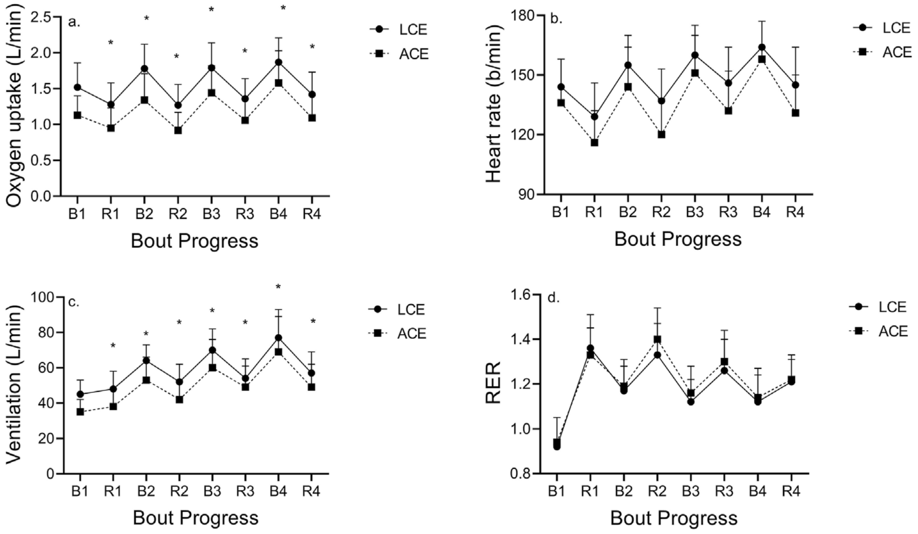

Fig. 2. Changes in (a) oxygen uptake, (b) heart rate, (c) ventilation, and (d) respiratory exchange ratio in response to sprint interval exercise (SIE) performed using leg cycling ergometry (LCE) and arm cycling ergometry (ACE). Data are mean ± *SD*; * = $p < 0.05$ between LCE and ACE.

Table 2
Comparison of mean and peak physiological responses during sprint interval exercise performed using leg and arm cycle ergometry (mean ± *SD*).

Parameter	LCE	Range	ACE	Range	*p* value	Cohen's *d*
Mean $\dot{V}O_2$ (L·min^{-1})	1.59 ± 0.34*	1.02–2.18	1.24 ± 0.31	0.64–1.83	< 0.001	1.08
Mean $\dot{V}O_2$ (% $\dot{V}O_2$max)	56.9 ± 7.2*	42–69	61.7 ± 8.6	50–84	0.015	0.63
Peak $\dot{V}O_2$ (L·min^{-1})	2.10 ± 0.44*	1.60–2.90	1.79 ± 0.48	0.94–2.78	< 0.001	0.70
Peak $\dot{V}O_2$ (% $\dot{V}O_2$max)	75.4 ± 9.7*	60–96	88.2 ± 10.4	68–110	< 0.001	1.33
Mean HR (b/min)	148 ± 15*	123–172	136 ± 16	112–173	< 0.001	0.81
Mean HR (%HRmax)	80.0 ± 6.4*	69–89	76.6 ± 6.1	66–90	0.038	0.58
Peak HR (b/min)	167 ± 13*	142–188	160 ± 17	133–188	0.014	0.49
Peak HR (%HRmax)	90.2 ± 5.0	81–98	90.0 ± 7.0	76–99	0.71	0
Mean $\dot{V}_E$ (L·min^{-1})	57 ± 10*	35–79	48 ± 12	20–78	< 0.001	0.83
Mean $\dot{V}_E$ (% $\dot{V}_E$max)	51 ± 10*	26–56	57 ± 14	40–90	0.047	0.50
Peak $\dot{V}_E$ (L·min^{-1})	80 ± 13*	46–111	67 ± 20	25–130	0.008	0.79
Peak $\dot{V}_E$ (% $\dot{V}_E$max)	71 ± 15*	48–102	81 ± 20	55–120	0.017	0.64
Mean RER	1.20 ± 0.11	1.04–1.38	1.21 ± 0.08	1.06–1.35	0.81	0.12
Peak RER	1.45 ± 0.16	1.21–1.84	1.47 ± 0.17	1.24–1.71	0.65	0.11

LCE – leg cycle ergometry; ACE = arm cycle ergometry; $\dot{V}O_2$ = oxygen uptake; HR = heart rate; $\dot{V}_E$ = ventilation; RER = respiratory exchange ratio; * = $p < 0.05$ versus ACE.

during SIE ($p < 0.001$) and peaked at values nearing 13 for both modalities, representing a "somewhat hard" level of exertion. RPE increased by approximately one unit with each successive interval and then declined by the same magnitude in recovery. Results showed no effect of mode ($p = 0.64$) or mode × time interaction ($p = 0.46$). Similar data were shown for affective valence, which significantly declined ($p < 0.001$) in response to SIE yet there was no main effect of mode ($p = 0.84$) or mode × time interaction ($p = 0.89$). The lowest value of affective valence was equal to (2.0 ± 1.8) and (1.8 ± 1.9) for LCE and ACE, respectively, which lies between "fairly good" and "good." There was no difference ($p = 0.97$, $d = 0.08$) in enjoyment between modalities ([102 ± 15] and [101 ± 18] for LCE and ACE, respectively).

3.7. Exploratory sex-based analyses

Data from baseline $\dot{V}O_2$max testing showed no difference in relative $\dot{V}O_2$max ($p = 0.34$ and 0.63 for LCE and ACE), HRmax ($p = 0.30$ and 0.36 for LCE and ACE), RERmax ($p = 0.51$ and 0.11 for LCE and ACE), or maximal BLa ($p = 0.14$ and 0.36 for LCE and ACE) between men and women, yet significant differences occurred in $\dot{V}_E$max for LCE ([132 ± 32] L·min^{-1} vs. [100 ± 18] L·min^{-1}, $p = 0.02$, $d = 1.2$) and ACE ([99 ± 20] L·min^{-1} vs. [73 ± 21] L·min^{-1}, $p = 0.01$, $d = 1.3$) for men versus women.

During LCE, significant differences were shown in mean HR ([142 ± 12] b/min vs. [159 ± 11] b/min, $p = 0.003$, $d = 1.5$; [78% ± 5%] vs. [85% ± 6%] HRmax, $p = 0.004$, $d = 1.6$) and peak HR ([163 ± 12] b/min vs. [174 ± 12] b/min, $p = 0.04$, $d = 1.0$; [88% ± 5%] vs. [93% ± 4%] HRmax, $p = 0.02$, $d = 1.1$), with significantly higher values recorded in women. There was no sex difference in mean ([56% ± 8%] $\dot{V}O_2$max vs. [58% ± 6%] $\dot{V}O_2$max, $p = 0.61$, $d = 0.3$) or peak $\dot{V}O_2$ ([73 ± 9] $\dot{V}O_2$max vs. [80% ± 10%] $\dot{V}O_2$max, $p = 0.10$, $d = 0.80$) expressed according to % $\dot{V}O_2$max, although men displayed higher absolute $\dot{V}O_2$ ($p < 0.002$, $d = 1.6$–2.2) which is attributed to their greater body mass. As far as $\dot{V}_E$, there was no difference in any outcome between men and women ($p = 0.11$–0.43) other than mean $\dot{V}_E$ which was significantly higher in men compared to women ([60 ± 9] L·min^{-1} vs. [51 ± 11] L·min^{-1}, $p = 0.03$, $d = 1.0$). There was no difference in mean ($p = 0.61$) or peak RER ($p = 0.11$) between men and women.

In response to ACE, there was no difference in mean HR when expressed in absolute ([133 ± 13] b/min vs. [144 ± 22] b/min, $p = 0.15$, $d = 0.70$) or relative terms ([76% ± 5%] vs. [79% ± 8%] HRmax, $p = 0.35$, $d = 0.5$). Similar lack of differences was shown for peak HR expressed in b/min ([156 ± 16] b/min vs. [169 ± 17] b/min, $p = 0.10$, $d = 0.8$) and %HRmax ([89% ± 8%] vs. [91% ± 5%] HRmax, $p = 0.41$, $d = 0.3$). Despite no difference in relative peak $\dot{V}O_2$ between men and women ([90% ± 11%] vs. [83% ± 9%], $p = 0.12$, $d = 0.7$), mean relative $\dot{V}O_2$

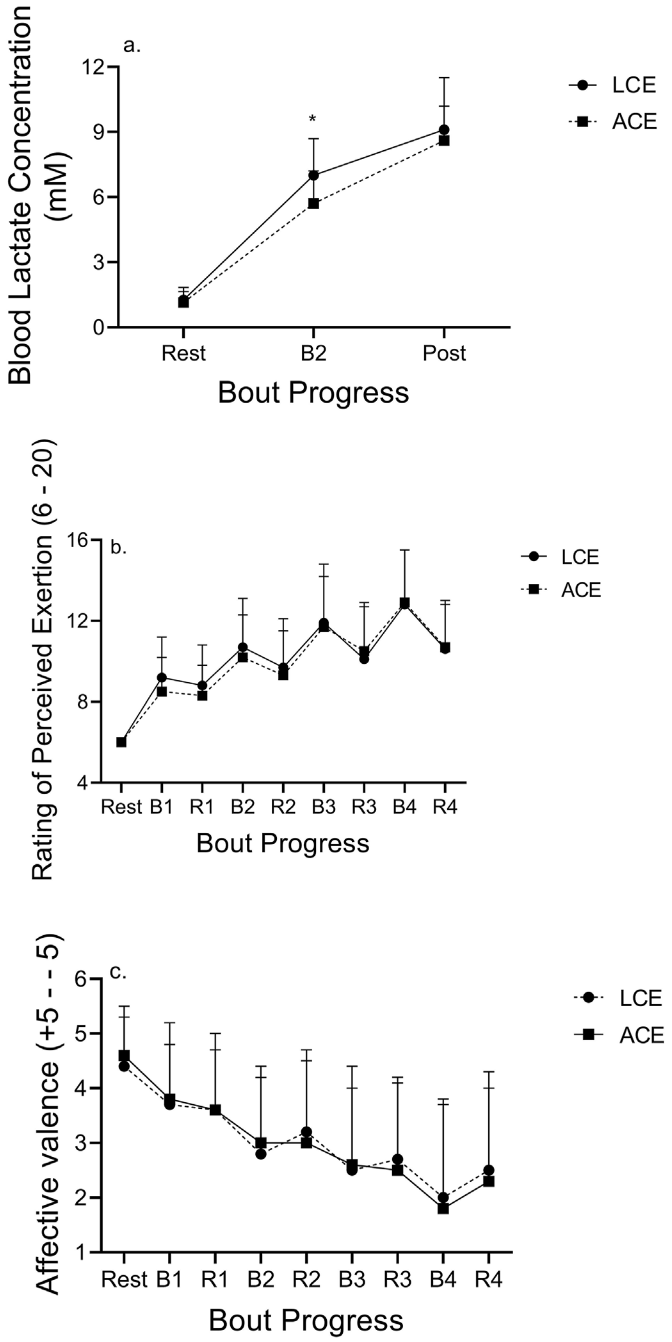

Fig. 3. Change in (a) blood lactate concentration, (b) rating of perceived exertion, and (c) affective valence in response to sprint interval exercise (SIE) performed using leg cycling ergometry (LCE) and arm cycling ergometry (ACE). Data are mean ± *SD*; * = $p < 0.05$ between LCE and ACE.

was higher in men compared to women ([64% ± 9%] $\dot{V}O_2$max vs. [56% ± 4%] $\dot{V}O_2$max, $p = 0.03$, $d = 0.7$) as was absolute $\dot{V}O_2$ ([1.38 ± 0.24] L·min^{-1} vs. [0.92 ± 0.22] L·min^{-1}, $p < 0.001$, $d = 2.0$ and [1.98 ± 0.41] L·min^{-1} vs. [1.38 ± 0.32] L·min^{-1}, $p = 0.002$, $d = 1.6$). Relative $\dot{V}_E$ was not different between men and women ([56% ± 12%] $\dot{V}_E$max vs. [58% ± 18%] $\dot{V}_E$max, $p = 0.80$, $d = 0.2$; [80% ± 20%] $\dot{V}_E$max vs. [82% ± 22%] $\dot{V}_E$max, $p = 0.80$, $d = 0.20$), although absolute $\dot{V}_E$ was higher in men compared to women ([52 ± 11] L·min^{-1} vs. [40 ± 11] L·min^{-1}, $p = 0.02$, $d = 1.1$; [75 ± 20] L·min^{-1} vs. [57 ± 17] L·min^{-1}, $p = 0.04$, $d = 1.0$). There was no difference in mean ($p = 0.44$) or peak RER ($p = 0.44$) between men and women. No interaction ($p = 0.43$) or main effect ($p = 0.07$) was shown for BLa or PACES ($p = -0.30$ and 0.59 for LCE and ACE) between men and women.

4. Discussion

This study compared physiological and perceptual responses to SIE performed using ACE and LCE. The results oppose our hypothesis since ACE elicits a lower absolute, but a higher relative cardiovascular response versus LCE, alongside a lower BLa response. No differences in RPE, affective valence, or post-exercise enjoyment were shown between modalities. In addition, our results support our hypothesis as affective valence remained positive on average and enjoyment was relatively high, suggesting that LCE and ACE involving four 20 s supramaximal, but not "all-out" sprints, do not elicit an aversive perceptual response in recreationally-active adults. Secondary analyses suggest unique responses to SIE between men and women, which merits additional study to determine if sex impacts the chronic adaptation to sprint interval training.

Although the exercise intensity used in the SIE protocols in this study was supramaximal, the brief nature of the sprints resulted in relative peak $\dot{V}O_2$ values of 75% (LCE) and 88% (ACE) of $\dot{V}O_2$max, and peak HR of 90% of HRmax for both LCE and ACE. These values are similar to the cardiovascular stress associated with "vigorous exercise" according to the American College of Sports Medicine.[47] These HR values are also comparable to prior studies using low-volume "all-out" SIE, despite a much lower intensity.[5,9] Nevertheless, contrary to our hypothesis, ACE exhibited significantly higher mean and peak % $\dot{V}O_2$max than LCE. Prior data[32] showed no difference in mean/peak $\dot{V}O_2$ or peak HR expressed as percentages of maximal values between HIIE (10 × 1 min at 75% PPO) performed using LCE and ACE, although mean HR was higher in response to LCE ([81% ± 5%] HRmax vs. [75% ± 7%] HRmax), which is similar to our data (Table 2).

One explanation of higher relative $\dot{V}O_2$ in response to ACE SIE is activation of accessory muscles, including the core and lower body, to assist the upper extremity in moving the pedal crank at high work rates. A secondary explanation of greater $\dot{V}O_2$ attendant with ACE SIE is incidence of a substantial $\dot{V}O_2$ slow component.[48] Compared to LCE, ACE is characterized by the use of a smaller muscle mass with a greater ratio of fast to slow twitch muscle fibers which leads to lower metabolic efficiency and higher $\dot{V}O_2$ at a given power output.[27,49] When performing ACE in the severe intensity domain characteristic of SIE, it is possible that this slow component is augmented due to marked recruitment of fast twitch (FT) fibers, greater ventilation (Table 2), and greater disturbance of acid-base balance, all leading to a greater $\dot{V}O_2$ cost and in turn, propensity for fatigue. In addition, adults with greater FT ratio in the vastus lateralis exhibit a greater slow component that those with a preponderance of slow twitch (ST) fibers,[48] which would suggest that any muscle group having a higher ratio of FT fibers such as the upper extremity should reveal a larger slow component during vigorous exercise. Finally, the greater relative $\dot{V}O_2$ with ACE could partly be related to differences between LCE versus ACE in the ramp test rather than the SIE sessions. However, as the $\dot{V}O_2$max values obtained in the ACE ramp test are in effect 'submaximal', probably not limited by central factors, and closer to the arm muscles' 'true' maximal ability to take up oxygen, it is even more remarkable that relative $\dot{V}O_2$ during SIE is higher compared to LCE.

Our data suggest that SIE completed on the ACE imposes a greater cardiorespiratory demand expressed as % $\dot{V}O_2$max than LCE (Table 2). Harvey et al.[50] required active men ($\dot{V}O_2$max not measured) to perform the 30 s Wingate test using LCE and ACE. Results showed a greater aerobic contribution towards ATP supply for LCE versus ACE (17% vs. 11%), which had a significantly higher glycolytic (60% vs. 47%) contribution. In contrast, Price et al.[25] in active men with $\dot{V}O_2$max equal to 34 mL·kg^{-1}·min^{-1} and 48 mL·kg^{-1}·min^{-1} on ACE and LCE showed a significantly higher aerobic contribution in response to the Wingate test performed with ACE compared to LCE (43% vs. 29%) which was consequent with a lower glycolytic contribution (39% vs. 68%). Nevertheless, in the latter study, a lower resistance was used (4% body mass vs. 5% body mass) which led to a significantly lower peak power output attained (6.9 W/kg vs. 9.8 W/kg) compared to the Harvey et al.[50] study. These methodological differences accompanied by discrepancies in calculation of the aerobic contribution likely mediate the different conclusions across studies.

Our data showing higher mean/peak % $\dot{V}O_2$max and % $\dot{V}_E$max in response to ACE corroborate prior work. Calbet et al.[51] demonstrated more substantial cardiovascular strain during incremental ACE versus LCE, potentially because the $\dot{V}O_2$ attained is closer to the true maximal amount that can be taken up by the upper body. However, LCE is limited by the ability of the cardiovascular system to deliver oxygen, which is not the case for ACE that is limited by peripheral factors. Zinner et al.[26] exhibited that six sessions of upper-body SIE in untrained men led to no difference in the increase in $\dot{V}O_2$max (9.8% vs. 6.1%, $p = 0.18$) than lower-body training, which was attendant with significant increases in Wingate-derived mean and peak power output and time trial performance. Their data also showed greater capillaries per fiber and a reduced oxygen deficit with upper-body training, suggesting that aerobic adaptations result from upper-body SIE, as repeatedly shown with LCE.[3,8,10] However, there was no significant change in muscle fiber type ratio or B-HAD activity in the upper body despite a significant increase in citrate synthase activity,[27] so the specific adaptations mediating the increase in $\dot{V}O_2$max with upper-body SIE remain elusive. Further study is needed to elucidate if adaptations exhibited with upper-body training are associated with improved health status, and if higher relative mean and peak $\dot{V}O_2$ attendant with upper-versus lower-body SIE leads to a different chronic response, as it is possible that these localized, peripheral adaptations do not extend to better whole-body cardiometabolic health.

Our results show that peak RPE was equal to approximately 13 for both modalities, representing a ‘hard’ level of exertion. This value is lower than shown in studies using the REHIT protocol,[7] the Tabata protocol,[20] and higher volume all-out SIE.[20,36,37] The Wood et al.[37] study required active adults to perform eight 30 s intervals of LCE at 130% Wmax with 90 s recovery. Their peak HR (91%) is similar to that reported in the present study (90%, Table 2), so differences in HR do not explain the different RPE across studies. Nevertheless, participants underwent supramaximal “all-out” exercise with slightly longer interval durations and greater volume, likely augmenting the contribution of glycolysis contributing to higher BLa (~14 mM) and perceptions of fatigue, leading to a higher RPE. In the present study, the lack of difference in peak values of HR as well as BLa, two known mediators of RPE, likely led to similar RPE between LCE and ACE.

Similar to RPE, our results showed no effect of exercise modality on affective valence. RPE, enjoyment, and pre-exercise affective valence are associated with the change in affective valence during acute interval exercise,[52] so the lack of differences in these outcomes between modalities may partially explain this result. Our overall reduction in affective valence of ~ -2 units (i.e. ~ -0.5 units per sprint) is lower than what would be predicted based on results from a recent systematic review and meta-analysis showing that each additional “all-out” sprint in a SIE protocol elicits a ~1-unit decrease in affective valence.[13] This comparison supports our hypothesis that supramaximal but non-all-out SIE is perceived as less aversive compared with studies using all-out sprint protocols.[20,37] Furthermore, our end-exercise value represented “fairly good” affective valence, showing that a low-volume SIE protocol requiring non-all-out sprints does not elicit aversive responses. In addition, despite our bouts requiring intensities above that associated with Wmax, enjoyment was high and similar across modalities. Similar values (90–100) for enjoyment were shown in a recent study employing REHIT in adults with above and below average $\dot{V}O_2$max,[5] although our values are higher than those revealed in inactive adults performing SIE (PACES = 83).[41] Further study is merited to determine perceptual responses to similar SIE protocols in inactive adults and those with chronic disease to ascertain their feasibility as an alternative to aerobic exercise.

Our exploratory analysis demonstrates significantly higher HR in response to SIE on the cycle ergometer in women versus men. Although our study cannot identify the precise mechanism explaining this result, it may be related to the lower blood volume and left ventricular mass characteristic of women.[53] Hottenrott et al.[54] reported slower HR recovery to repeated Wingate tests in women versus men, and since our protocol involves 8 min of recovery and only 80 s of work, this may explain some of our results. Nevertheless, recent data showed no sex difference in the hemodynamic and cardiovascular response (expressed as % maximal cardiac output [COmax] and % $\dot{V}O_2$max) to three unique interval protocols performed on the cycle ergometer.[55] On the ACE, the only sex difference reported was mean % $\dot{V}O_2$max, which was higher in men compared to women. Potential explanations for this could be the greater upper-body muscle mass in men as well as their slower metabolic recovery to interval exercise versus women.[54] Additional investigations are needed which are adequately powered to discern potential sex differences in the physiological response to upper- and lower-body SIE.

This study has a few limitations. First, the participants included active, young, and non-obese adults naïve to SIE, so our data cannot be applied to inactive/obese populations or individuals who regularly perform these modalities. Second, our SIE protocol differed from those used in prior studies (e.g. multiple Wingate tests and Tabata), so our results are not entirely generalizable to studies using different SIE paradigms which have infinite permutations. Third, muscle fiber type differs between the upper and lower body[56] thus altering the $\dot{V}O_2$ and metabolic response to exercise, but this ratio was not determined in the present study. Fourth, despite preliminary data showing no difference in $\dot{V}O_2$max between ACE and LCE when performed on the same day versus separate days, it is possible that $\dot{V}O_2$max and Wmax may have been slightly underestimated in our participants. Fifth, additional study is needed to compare responses between “all-out” and non-all-out SIE using these modalities. Lastly, no consideration of menstrual phase was made, and it is possible that hormone fluctuations may slightly impact our results. Due to known differences in body composition between men and women, additional work is needed to elucidate potential discrepancies in the cardiometabolic response to upper-versus lower-body exercise between men and women. However, our study is strengthened by use of a large and heterogeneous sample, precise allocation of power output for all sessions, and use of a familiarization protocol which likely reduces learning effects and in turn augments the reliability of our data.

5. Conclusions

When performed regularly, SIE improves body composition and aerobic fitness yet requires a large degree of effort which can be unpleasant for many individuals. Our results show that supramaximal but non-all-out sprint interval exercise using the upper body is associated with lower absolute but greater relative cardiovascular demand versus lower body sprint interval exercise. In addition, affective valence was positive and post-exercise enjoyment was high. Clinicians may want to use low-volume SIE consisting of brief 20 s bouts that require non-all-out efforts to elicit more positive psychological responses than protocols requiring all-out sprints. In addition, upper-body sprint exercise leads to greater relative HR and $\dot{V}O_2$ versus leg cycling which may elicit a unique adaptive response.

Ethical approval

Participants provided written informed consent, and study experimental procedures were reviewed and approved by the Institutional Review Board at CSU—San Marcos (Protocol 1876593-1). The study was conducted in accordance with the Declaration of Helsinki.

Submission statement

All Authors have read and agree to this manuscript content. In addition, while this manuscript is being reviewed by this Journal, the manuscript will not be submitted elsewhere for review and publication.

CRediT authorship contribution statement

Todd A. Astorino: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shealin Pierce:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Formal analysis, Data curation. **Madisen B. Piva:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation. **Richard S. Metcalfe:** Writing – review & editing, Writing – original draft, Conceptualization. **Niels B.J. Vollaard:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2024.01.007.

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