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Physiological characterization of a simulated kettlebell routine in experienced kettlebell athletes

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ABSTRACT

Kettlebell as a sport has gained recognition worldwide. We characterized the physiological responses induced by a simulated kettlebell competition routine in experienced kettlebell athletes ($n = 26$) in a two-group, pre-post plus short-term follow-up, non-randomized experiment. The experimental group (EXP) included 13 kettlebell athletes, while the control group (CON) consisted of 13 individuals with prior recreational exposure to kettlebell activities. EXP performed a 10-minute-long, long-cycle kettlebell routine, whereas CON engaged in seated rest. Cardiovascular and neuromuscular outcomes were measured at rest, after warm-up, during exercise, at 0 (immediately post), 5 and 15 min into recovery. Group-by-time interactions revealed that the 10-minute-long, long-cycle kettlebell routine increased ($P < 0.05$) the levels of all outcomes (*e.g.* heart rate, blood pressure, blood lactate) (range of effect sizes: −0.9–8.9) with many

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outcomes remaining well above baseline at 5 and 15 min into recovery. A notable exception was a lack of change in maximal squat strength. Kettlebell experience and mass correlated with changes in oxygen uptake (ΔVO_2) and in ventilation (ΔVT) ($r = -0.70$, 0.64, -0.87, and 0.73, respectively, $P < 0.05$) in EXP. Kettlebell routine evoked significant changes in all physiological variables (respiratory and cardiovascular), out of which the heart rate (HR), diastolic blood pressure (DBP), rate pressure product (RPP), and blood lactate (BL) outlasted the routine for at least 15 min. Future studies should longitudinally examine physiological responses to kettlebell training throughout a season. Long-cycle kettlebell routine adds to the repertoire of evidence-based exercise options for high-intensity exercise.

KEYWORDS

long cycle, cardiovascular responses, oxygen uptake, strength, blood lactate

INTRODUCTION

From the 17th century, when it was used as counterweight to measure crops at farmers' markets in Russia, exercising with a kettlebell has gained enormous popularity as a strength and conditioning device in the realm of 21st century fitness. Practitioners now have the option to join the World Kettlebell Sport Federation, the International Kettlebell Marathon Federation, the International Union of Kettlebell Lifting (accommodating participants from 65 countries), the Kettlebell Sport World League, and clubs [1]. Kettlebell lifting is attractive to fitness practitioners because it provides a full-body workout in a short time and at a low cost [2]. Kettlebell training as an adjuvant has now reached gymnastics [3], clinical practice [4], aging research [5, 6], ballet training [7], weightlifting [6, 8, 9], military training [10], track and field training [11], mental health and sleep treatment [12]. Kettlebell protocols have also been characterized in the context of cardiovascular [2, 13], neuromechanical load [14–17], hormonal changes [18], fatigue [19], and the process of learning the kettlebell swing as a skill [20, 21].

While the various kettlebell federations organize competitions at an international level, there is a paucity of data characterizing cardiovascular responses to a 10-minute-long, simulated long-cycle kettlebell competition (continuously performing clean and jerks, as many repetitions as possible in 10 min) in athletes who participate in such competitions. The competitive kettlebell exercise is completely different from other kettlebell routines used in fitness and conditioning in terms of implement size, weight, and execution. Its main and unique specificity is that about 30–57% of an athlete's body weight (Table 1) as resistance is lifted continuously in a 10-min interval until complete failure. This exercise routine seems unique in terms of intensity and duration, dissimilar to other anaerobic sports activities. Therefore it is expected to elicit a high cardiovascular load, as oxygen uptake has been described to exceed 80% of maximal oxygen uptake and heart rate also to near 100% of the age-predicted heart rate maximum [2]. Because strength-endurance adaptations can be substantial following kettlebell training in previously sedentary individuals [3, 5, 9, 12, 18], it is reasonable to expect that a long-cycle kettlebell routine in individuals with years of kettlebell lifting experience would also reach high, near maximal levels, but while using a much heavier implement. We also hypothesized that kettlebell experience, in terms of years of practicing and the mass of the kettlebell implement, would be associated with the cardiovascular responses to a 10-minute-long, long-cycle kettlebell routine.

Table 1. Participant and kettlebell characteristics

Variable	EXP, *n* = 13 males			CON, *n* = 13 males		
	Mean	±SD	Range	Mean	±SD	Range
Age, y	39.1	9.39	26–53	41.0	4.14	35–49
Height, m	1.79	0.05	1.7–1.9	1.82	0.07	1.7–1.9
Mass, kg	85.3	8.45	71–103	92.2	11.27	75–110
BMI, $kg \cdot m^{-2}$	26.6	2.81	22–31	27.8	2.48	23–32
Kettlebell history, y	4.6	3.77	0.5–11	5.8	3.17	0.5–12
Kettlebell mass, kg[a]	30.2	3.87	24–40			
Kettlebell mass/body mass, %[a]	35.8	6.97	30–57			
Number of lifts[a]	81.4	20.50	60–125			
Exercise duration, min[a]	10.0	0.00	0–0			

EXP: experimental group; CON: control group; y: years; m: meter; BMI: body mass index; a: data relative to the 10-minute-long, long-cycle kettlebell exercise routine only in EXP.

The purpose of the present study was to characterize the cardiovascular and neuromuscular responses induced by a simulated kettlebell competition routine in experienced kettlebell athletes.

MATERIALS AND METHODS

Participants

Athletes (*n* = 26 males) were non-randomly assigned to an experimental group (EXP) and a control group (CON). Members of EXP were competitive kettlebell athletes (*n* = 13) who travelled from the Kecskemét Kettlebell Sports Club to the university campus in Pécs, Hungary, where the experiment was conducted. Their weekly training load was 10.2 hours. Inclusion criteria for the EXP group were male gender, age higher than 23 years, and at least half year of kettlebell training history. Exclusion criteria were any cardiovascular and/or metabolic disorders or any recent musculoskeletal injury or pain. Participants reported that they were free of pre-existing medical conditions. Two participants in EXP had the highest level of kettlebell qualification, i.e., Master of Sport. Members of CON (*n* = 13) also had recreational but non-competitive kettlebell experiences. Their weekly training load was 4.5 hours. Most participants (*n* = 22) pursued non-competitive sports in addition to kettlebell, including one or two of the following activities: swimming, boxing, running, CrossFit, cycling, aikido, judo, karate, kickboxing, Thai boxing, martial arts, weightlifting, track and field, cross country running, mountain biking, freediving, basketball, team handball, futsal, football, ice hockey, and rugby.

Each participant was informed of the experimental procedure, and written informed consent was obtained from each participant before the experiment. The study was conducted according to the Declaration of Helsinki and was approved by the University Ethics Committee (protocol number: 7961-PTE2019).

Participants were requested to maintain their normal diet before the experiment. Stimulants such as caffeine, taurine, arginine, and citrulline malate were prohibited within 24 h before the tests.

Study design

Each participant was measured on one occasion on one day, starting at 8 am and finishing over a 2-hour-long period. Figure 1 shows the study design. The two groups were measured on selected tests at baseline (Test 1), after warm-up (Test 2), 0 (immediately) (Test 3), 5 (Test 4), and 15 min (Test 5) after the 10-minute-long intervention [22, 23]. The intervention for EXP consisted of a 10-minute-long, long-cycle kettlebell routine. The intervention for CON was seated rest [24]. Because the laboratory environment and the measurements were highly unusual for the participants, we implemented a no-intervention control group to ascertain the stability of the measurements and determine the net physiological effects of the kettlebell routine on the outcomes.

Warm-up

The warm-up differed between the two groups because of the content and demand of the interventions. The warm-up in EXP corresponded to pre-competition warm-up and consisted of 25 min of calisthenics, stretching, and sport-specific exercises with the kettlebell implement.

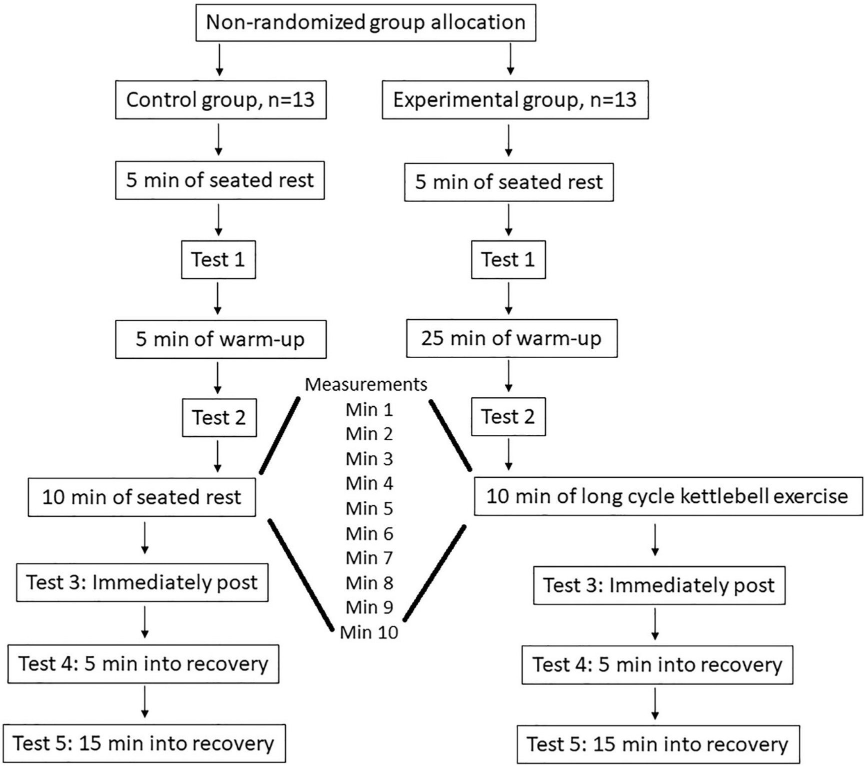

Fig. 1. The design and time course of the Tests

CON warmed up by cycling for 5 min before the maximal isometric squat test (see section "Warm-up" and Fig. 1).

Measurements

Handgrip (administered at Tests 2,3,5): In a standing position maximal grip strength was determined for each hand using three trials per hand with a special electronic hand dynamometer (Deyard EH101; OEM by Camry LLC, El Monte, CA, USA), separated by 40–60s of rest. The highest peak value was included in the analyses [25]. In all cases, the right hand was the dominant one, whereas the left was the non-dominant.

Maximal isometric squat (Tests 2,3,5): Participants stood on a force platform (Tenzi, Pilisvörösvár, Hungary) in a squat rack with 90° of knee flexion and pressed upward against the fixed weightlifting bar. Warm-up consisted of one effort at 80% of what each athlete perceived as the maximum (maximal voluntary isometric force, MVC). Participants were verbally encouraged to press against the fixed bar with a maximal effort for 5s. Peak vertical ground reaction force was identified from the force-time curves to represent maximal squat strength, normalized for body mass [26]. There was one MVC trial for each participant.

Oxygen uptake and heart rate (HR): We measured oxygen uptake during the 10-minute-long, long-cycle kettlebell exercise using a portable, breath-by-breath mobile spiroergometer (MetaMax®3B, CORTEX Biophysik GmbH, Leipzig, Germany). Heart rate was also monitored during the 10-min exercise routine and Tests 3–5 using the POLAR® H7 (Bluetooth) (Polar Electro Oy, Kempele, Finland) transmitter. Following the manufacturer's guidelines, the spiroergometer system was turned on at least 30 min before measurements to reach a stable operating temperature. The flow sensor was calibrated using a CORTEX-calibration pump (3L), and the gas analyzers were calibrated using reference gases. Respiratory volume was measured using a bidirectional digital turbine and the concentrations of O_2 and CO_2 were determined by an electrochemical cell and infrared analyzers. These cardiorespiratory data were telemetrically transmitted in real-time to a computer by Bluetooth and offline analyzed by the MetaSoft®-Studio 5.8.3 software [27].

Blood lactate (Tests 1–5): Fingertip capillary blood was analyzed for lactate using a portable lactate analyzer (Lactate Scout+, Leipzig, Germany). The tip of the ring finger was cleaned with alcohol spray and pricked. The initial blood drop was wiped away with a cotton ball. The fingertip was squeezed to obtain a fresh blood drop, which was retained for analysis [28].

Rate of perceived exertion (RPE) (Tests 2, 3): We used the 6–20 Borg scale during warm-up and the long-cycle kettlebell exercise to determine self-reported levels of exertion [29].

Heart rate (HR) (Tests 1, 2) and blood pressure (Tests 1–5): HR and blood pressure were measured while seated, with the cuff of a digital automatic blood pressure monitor (Omron M10-IT, Kyoto, Japan) placed on the left arm, which was positioned at heart level [30].

Rate Pressure Product (RPP) (Tests 1–5): It is a marker of cardiac function. It is the product of systolic blood pressure (SBP) and HR ($\text{mmHg} \times \text{b}\cdot\text{min}^{-1}$)/1,000 [31]. The RPP value estimates the workload on the heart and reflects the hemodynamic stress during exercise or other activities. A typical resting RPP might fall within the range of

7.0–9.0 mmHg·bpm·10^{-3}. During exercise, the RPP naturally increases in tandem with HR and blood pressure. The exact range during exercise can vary widely based on individual factors. However, values in the range of 20.0–25.0 mmHg·bpm·10^{-3} might be considered normal for a healthy individual engaging in moderate exercise. Higher values could be expected during more intense activities [31].

Interventions

Participants of EXP started the 10-min-long-cycle kettlebell exercise with each kettlebell in the rack position at the chest, elbows pointing outward, and legs straight. From the rack position, athletes pressed the kettlebells in a smooth and continuous motion overhead, where the kettlebells remain still with elbows fully extended. The trunk, head, and arms align in a straight line, called the fixation position. The athlete then lowers the kettlebells to the starting (rack) position and executes the swing part of the routine either between or outside the legs. Following the swing, the athlete lifts the kettlebell back up to the rack position. A combination of the pull-up (clean) and the jerk (pressing the implement overhead) forms a repetitive cycle known as the long cycle. In the selection of the kettlebell weight, we followed the regulations given by the Hungarian Kettlebell Sport Federation), i. e. athletes can freely select in a range of 12–32 kg, with 2-kg increments. Note that the 10-min-long cycle kettlebell exercise is performed with two hands, holding two kettlebells at the same time, doubling the load. Members of CON sat on a chair and rested for 10 min (Fig. 1).

Statistical analyses

Variables were checked and met the test for normality using the Shapiro-Wilk test. The main analysis was a Group (EXP, CON) by Time (2, 3, or 5 time points) analysis of variance with repeated measures on Time followed by a Tukey's post-hoc test. The strength of an effect was quantified by partial eta squared (${}_{p}\eta^2$) with values 0.01, 0.06, and 0.14 demarking the levels of small, medium, and large effects. We further qualified within-group changes by Hedges's effect size, g (small: 0.2; medium: 0.5; large: ≥ 0.8). Association among variables was determined by Spearman's rank correlation. In the correlation analyses, three outliers (more than 2.0 standard deviations away from the mean) were excluded. The level of significance was set at $P < 0.05$.

RESULTS

Overall, the 26 participants' age, height, body mass, and body mass index were 40.0 years (±7.18), 1.81 cm (±0.06), 88.8 kg (±10.37), and 27.2 kg·m^{-2} (±2.68), respectively. Table 1 shows that the two groups did not differ in age, height, body mass, body mass index, and kettlebell history (all $P > 0.05$).

Table 2 shows the cardiovascular changes induced by the 10-minute-long, long-cycle kettlebell routine. Before the intervention at baseline, the two groups did not differ in the outcomes (all $P > 0.05$) except for the levels of blood lactate ($P = 0.038$). Except for right grip and squat strength, the group-by-time interaction was significant ($P < 0.05$) and reported below with the

Table 2. Cardiovascular characteristics of kettlebell exercise

Variable		Rest		Warm-up		IP		5 min		15 min	
		X	±SD	X	±SD	X	±SD	X	±SD	X	±SD
RPE, score	EXP	–	–	10.1^{a}	1.26	$17.2^{a,c}$	1.83	–	–	–	–
	CON	–	–	7.5	0.66	6.5	0.78	–	–	–	–
HR, $b \cdot min^{-1}$	EXP	69.8	8.82	$87.9^{a,b}$	6.45	$169.7^{a,b,c}$	12.29	$132.6^{a,b,c}$	14.65	$108.8^{a,b,c}$	8.15
	CON	65.9	9.38	73.6^{b}	14.10	71.9	10.14	70.8	12.53	71.4	9.01
SBP, mmHg	EXP	128.1	11.64	154.4^{b}	12.65	$153.1^{a,b}$	13.30	134.1^{b}	11.41	125.8	8.93
	CON	133.2	12.12	147.9^{b}	8.25	138.8	12.17	139.1	14.99	133.7	11.81
DBP, mmHg	EXP	82.7	5.50	85.8	5.88	87.1	10.97	$80.9^{a,c}$	8.27	$77.2^{a,b,c}$	5.75
	CON	84.1	7.55	87.0	6.92	88.2	8.22	86.5	7.47	85.8	7.84
RPP, $mmHg \cdot bpm \cdot 10^{-3}$	EXP	8.9	1.02	$13.6^{a,b}$	1.75	$26.0^{a,b,c}$	2.99	$17.8^{a,b,c}$	2.34	$13.7^{a,b}$	1.41
	CON	8.7	1.53	10.5^{b}	1.73	10.0^{b}	1.83	9.9	2.26	9.6	1.56
BL, $mmol \cdot L^{-1}$	EXP	1.7^{a}	0.38	$2.3^{a,b}$	0.60	$9.7^{a,b,c}$	3.09	$9.2^{a,b}$	2.36	$7.0^{a,b,c}$	2.19
	CON	1.3	0.52	1.7	0.73	1.6	0.48	1.9^{b}	0.48	2.0^{b}	0.65
Non-dominant HG, kg	EXP	–	–	54.1	5.28	$49.0^{a,b}$	7.20	–	–	$50.6^{a,b}$	5.36
	CON	–	–	54.3	8.23	54.1	7.30	–	–	53.4	8.25
Dominant HG, kg	EXP	–	–	57.3	4.07	52.4	4.84	–	–	52.8	6.15
	CON	–	–	58.8	7.44	56.0	7.81	–	–	58.2	10.90
Squat MVC, N	EXP	–	–	1,464	254	1,461	202	–	–	1,417	244
	CON	–	–	1,437	198	1,466	161	–	–	1,501	138

Values are mean (X) and ±SD. EXP: experimental group; CON: control group; Warm-up: values after warm-up as described in the Methods section; IP: immediately post the 10-minute-long, long-cycle kettlebell routine; 5 and 10 min: 5 and 10 min after the end of 10-minute-long, long-cycle kettlebell routine; RPE: rate of perceived exertion (20 points maximum); HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; RPP: rate pressure product; BL: blood lactate; HG: handgrip; MVC: maximal voluntary isometric force; a: $P < 0.05$ between the two groups; b: $P < 0.05$ relative to baseline within group; c: $P < 0.05$ relative to the previous value within group. The text in the Results section, corresponding to Table 2, shows the detailed statistical analyses.

relevant Tukey's post-hoc test and Hedges g effect sizes (g). CON remained stable and unchanged in the outcomes.

The interaction showed that the 10-minute-long, long-cycle kettlebell routine increased RPE by 7 (±2.51) units (interaction: $F = 216.1$, $P < 0.001$, ${}_{p}\eta^2 = 0.835$). HR recorded at the 5-time points increased (interaction: $F = 148.9$, $P = 0.001$, ${}_{p}\eta^2 = 0.876$) and reached 169.6 (±12.29) b min^{-1} peak during the 10-min exercise routine, an increase of 99.8 (±16.45, $g = 8.9$) b min^{-1} relative to baseline. Compared with baseline, HR remained still elevated by 62.8 (±17.17) b min^{-1} immediately ($P < 0.001$, $g = 5.0$) and by 39.0 (±12.57) b min^{-1} 15 min after exercise ($P < 0.001$, $g = 4.4$). Systolic blood pressure (SBP) increased (interaction: $F = 6.5$, $P = 0.001$, ${}_{p}\eta^2 = 0.236$) already after warm-up by 26 units ($P < 0.001$, $g = 2.1$), did not increase further immediately after exercise and returned to baseline at 15 min post-exercise. Diastolic blood pressure increased (interaction: $F = 2.9$, $P = 0.030$, ${}_{p}\eta^2 = 0.119$) moderately by 4.4 (±9.37) units ($P = 0.020$, $g = 0.5$) and decreased by 5.5 (±9.39, $P = 0.033$, $g = -0.9$) units at 15 min after exercise. Rate pressure product (RPP) increased (interaction: $F = 118.5$, $P = 0.001$, ${}_{p}\eta^2 = 0.849$) and peaked at 26.0 (±2.99) units during the 10-min exercise routine, an increase of 17.1 (±3.14, $P < 0.001$, $g = 7.3$) relative to baseline. Compared with baseline, RPP remained still elevated by 8.9 (±2.02) units immediately ($P < 0.001$, $g = 4.7$) and by 4.8 (±1.65) units 15 min after exercise ($P < 0.001$, $g = 3.7$). Blood lactate increased (interaction: $F = 56.3$, $P = 0.001$, ${}_{p}\eta^2 = 0.710$) after exercise by 7.9 (±3.27, $g = 3.5$) units and remained elevated at 5 min by 7.5 (±2.50, $g = 4.3$) and at 15 min by 5.2 units (±2.36, $g = 3.2$). Left hand grip (HG) decreased (interaction: $F = 3.7$, $P = 0.031$, ${}_{p}\eta^2 = 0.135$) by 5.0 kg after exercise (±6.15, $P < 0.001$, $g = -0.8$) and remained depressed by 3.4 kg (±2.24, $P = 0.042$, $g = -0.6$) at 15 min after exercise. Right hand grip (HG) strength showed no group-by-time interaction ($F = 1.8$, $P = 0.183$, ${}_{p}\eta^2 = 0.068$) but the Time main effect ($F = 7.1$, $P = 0.002$, ${}_{p}\eta^2 = 0.230$) showed a decrease of 3.8 (±3.77) and 2.5 (±5.47, both $P < 0.029$) immediately and 15 min after the interventions. There were no changes in squat strength (MVC) in either group at any time points.

Table 3 shows the cardiorespiratory data recorded during the 10-minute-long interventions. HR monotonically increased (interaction: $F = 16.8$, $P < 0.001$, ${}_{p}\eta^2 = 0.433$) by 21 (±8.85) b min^{-1}, or 13% (±6.49) reaching 185 b min^{-1} ($P < 0.001$, $g = 2.2$) during the kettlebell routine. Mass-normalized oxygen uptake increased (interaction: $F = 16.4$, $P < 0.001$, ${}_{p}\eta^2 = 0.451$) by 7.6 units (±3.89, $g = 3.9$) or 29.0% (±15.10) by the 10th minute of the kettlebell routine. The remaining eight variables (VO_2, $VO_2 \cdot HR^{-1}$, $VE \cdot {VO_2}^{-1}$, $VE \cdot {VCO_2}^{-1}$, RER, VE, VT, BF) revealed a similar pattern of changes during the 10-minute-long kettlebell routine with stability in these outcomes in CON.

Correlation analyses revealed that practice experience (i.e., number of years training) correlated with changes in VO_2 ($r = -0.70$, $P = 0.023$) (Fig. 2), VT ($r = 0.64$, $P = 0.045$), and VE ($r = 0.59$, $P = 0.045$), but did not correlate with HR ($r = -0.49$, $P = 0.11$) induced by the 10-minute-long routine. The mass of the implement also correlated with changes in HR ($r = -0.70$, $P = 0.012$), VO_2 ($r = -0.87$, $P = 0.001$), VE ($r = 0.72$, $P = 0.009$), and VT ($r = 0.73$, $P = 0.017$) (Fig. 3).

Table 3. Cardiorespiratory data were recorded during the 10-minute-long kettlebell routine

Variable		Time, min									
		1	2	3	4	5	6	7	8	9	10
HR, $b \cdot min^{-1}$	EXP	164	170	173	175	177	179	181	182	184	185
		11.66	10.24	9.36	8.07	8.23	7.90	7.60	7.94	6.94	6.46
	CON	71	73	73	71	74	72	74	75	75	77
		11.54	12.59	13.00	9.35	12.23	9.75	12.82	12.53	13.63	12.90
VO_2, $L \cdot min^{-1}$	EXP	2.32	2.49	2.60	2.52	2.57	2.58	2.45	2.58	2.56	2.89
		0.16	0.28	0.24	0.22	0.33	0.24	0.15	0.29	0.29	0.34
	CON	0.43	0.42	0.42	0.43	0.40	0.41	0.41	0.40	0.41	0.48
		0.05	0.06	0.05	0.03	0.06	0.06	0.04	0.03	0.03	0.07
$VO_2 \cdot kg^{-1}$, $mL \cdot min^{-1} \cdot kg^{-1}$	EXP	26.3	29.1	30.4	29.5	29.6	30.1	29.3	30.5	31.1	35.1
		1.77	2.76	2.36	2.16	2.89	1.93	2.82	3.73	5.00	2.48
	CON	4.92	4.65	4.67	4.80	4.45	4.58	4.64	4.48	4.71	5.25
		0.40	0.37	0.29	0.41	0.31	0.45	0.33	0.35	0.50	0.60
$VO_2 \cdot HR^{-1}$, $mL \cdot b^{-1}$	EXP	14.65	14.99	15.47	14.75	14.77	14.78	13.82	14.24	14.73	15.93
		1.64	2.20	2.18	1.91	2.28	2.08	1.48	1.85	2.67	2.22
	CON	6.47	6.20	6.08	6.19	5.86	5.98	5.93	5.66	5.96	6.45
		1.16	1.36	1.34	1.20	1.47	1.35	1.22	1.20	1.33	1.44
$VE \cdot {VO_2}^{-1}$	EXP	23.3	26.6	28.5	30.7	31.5	33.3	34.9	35.3	37.3	37.7
		2.14	4.22	4.25	5.30	5.98	6.33	6.44	7.37	7.78	8.21
	CON	24.8	24.6	24.5	24.2	24.9	24.5	24.4	24.9	23.7	25.1
		2.33	2.67	2.90	1.90	2.20	2.39	2.43	2.67	1.35	2.41
$VE \cdot {VCO_2}^{-1}$	EXP	27.4	27.9	28.4	29.4	29.8	30.7	31.7	32.0	33.3	33.0
		1.45	3.09	3.07	3.73	4.14	4.28	4.47	5.19	5.49	5.67
	CON	29.6	29.4	29.4	29.2	29.8	29.4	29.7	30.0	29.2	29.8
		2.51	3.09	3.25	2.41	2.71	2.87	2.90	2.95	2.46	2.88
RER	EXP	0.85	0.95	1.00	1.04	1.05	1.08	1.09	1.10	1.10	1.13
		0.03	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06
	CON	0.84	0.84	0.84	0.83	0.84	0.83	0.82	0.83	0.82	0.84
		0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.02	0.03	0.05
VE, $L \cdot min^{-1}$	EXP	63.0	75.2	84.3	88.2	92.8	96.9	100.6	106.6	112.8	122.5

(continued)

Table 3. Continued

					Time, min						
Variable		1	2	3	4	5	6	7	8	9	10
		11.93	17.02	17.42	17.71	21.52	21.63	21.64	25.37	25.34	24.14
	CON	12.9	12.4	12.3	12.5	12.2	12.3	12.5	12.0	12.0	14.6
		2.34	2.26	1.77	1.50	2.08	2.22	2.00	1.13	1.12	2.46
VT, L	EXP	1.71	1.89	1.94	1.96	1.94	1.97	1.98	1.99	2.01	2.15
		0.23	0.22	0.20	0.16	0.18	0.18	0.24	0.23	0.30	0.14
	CON	1.09	1.02	0.92	0.98	0.92	0.93	0.82	0.85	0.83	0.87
		0.29	0.21	0.11	0.16	0.20	0.21	0.13	0.10	0.18	0.11
BF, breaths $\cdot$ min^{-1}	EXP	34.6	37.7	41.6	41.1	45.3	48.0	49.1	51.3	55.1	57.4
		6.99	8.89	9.55	6.85	8.82	10.18	11.46	12.25	11.61	10.10
	CON	13.4	13.5	14.0	13.8	14.8	14.8	16.0	15.8	15.7	16.8
		3.72	3.03	2.99	2.66	2.95	2.85	2.76	2.57	3.30	1.52

Values are mean and ±SD; EXP: experimental group; CON: control group; HR: heart rate, VO_2: peak oxygen uptake; $VO_2 \cdot kg^{-1}$: relative oxygen consumption; $VO_2 \cdot HR^{-1}$: oxygen pulse; $VE \cdot {VO_2}^{-1}$: ventilatory equivalent for oxygen; $VE \cdot {VCO_2}^{-1}$: ventilatory equivalent for carbon dioxide; RER: respiratory exchange ratio; VE: minute ventilation; VT: tidal volume; BF: breathing frequency. The text in the Results section, corresponding to Table 3, shows the detailed statistical analyses.

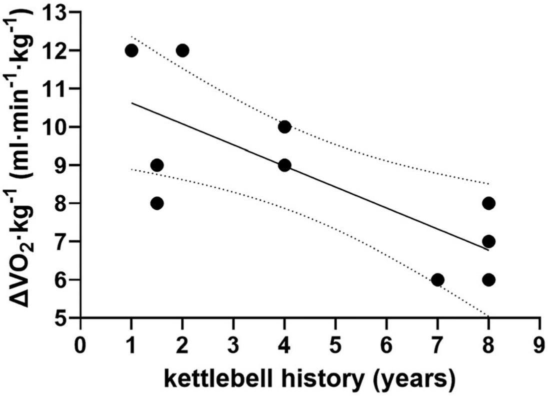

Fig. 2. Relationship between kettlebell history and change in oxygen uptake (ΔVO_2) computed as the difference between the 1st and the 10th minutes of the 10-minute-long, long-cycle kettlebell routine. The relationship is characterized by the equations $y = -0.47x + 10.8$ and $R^2 = 0.49$. Dotted lines denote 95% confidence bands

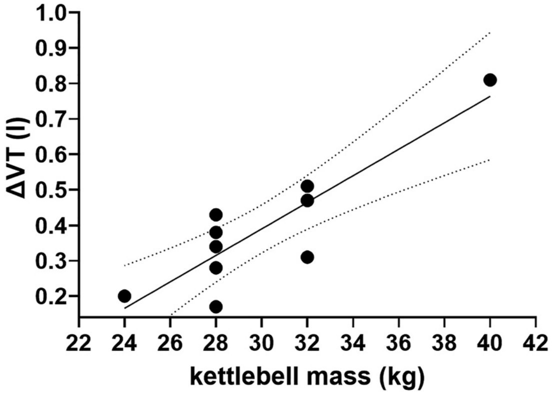

Fig. 3. Relationship between kettlebell mass and changes in ventilation (ΔVT) computed as the difference between the 1st and the 10th min of the 10-minute-long, long-cycle kettlebell routine. The relationship is characterized by the equations $y = 0.04x - 0.73$, $R^2 = 0.78$. Dotted lines denote 95% confidence bands

DISCUSSION

We characterized the physiological responses induced by a simulated kettlebell competition routine in experienced kettlebell athletes. We found that our kettlebell routine elicited higher changes in HR and blood lactate than in the study by Conti et al. [9] that, in most variables, outlasted the routine for at least 15 min. We also partially confirmed the hypotheses that kettlebell history in terms of years of practicing and the mass of the kettlebell implement would be associated with the cardiovascular responses to a 10-minute-long, long-cycle kettlebell routine. The two groups did not differ at baseline, and CON revealed the expected level of changes in the outcomes after warm-up and remained stable thereafter as well as during the 10-minute-long control (rest) period (Tables 2 and 3). The stability of the data in CON thus strengthens the reliability and fidelity of the kettlebell routine-induced cardiovascular changes. The CON data agree with the sporadic reliability data reported previously [32]. Participants in the two groups had ~5y of competitive kettlebell experience, with two participants performing at the international Master level with a kettlebell history of ~10y, using 40-kg and 32-kg kettlebells in the current experiment (Table 1). We thus extend the previously reported kettlebell data in sedentary individuals, gymnasts, ballet dancers, and healthy younger, and older individuals [3–7, 12, 20].

The 10-minute-long, long-cycle kettlebell routine was high intensity; RPE was ~17/20, peak HR reached 185 $b \cdot min^{-1}$, similar to the age-predicted maximum of 181 (±9.39), and oxygen uptake was ~36 $mL \cdot min^{-1} \cdot kg^{-1}$, near the estimated maximum of 40 $mL \cdot min^{-1} \cdot kg^{-1}$ or ~90% of this estimated maximum [33] (Tables 2 and 3). These data are in line with one study reporting that a 10-minute-long kettlebell snatch routine with a 16-kg competition kettlebell elicited an oxygen uptake of ~38 $mL \cdot min^{-1} \cdot kg^{-1}$ (corresponding to 83% of maximal oxygen uptake) and 174 $b \cdot min^{-1}$ (corresponding to 98% of maximum heart rate) [2]. However, a major difference between the current study and this previous one is that the mass of the kettlebell our participants lifted ~80 times was ~30 kg (Table 1) vs. 16 kg (the exact number of lifts not reported) [2]. Comparable HR data are also available in another study, demonstrating that participants achieved 80–100% of maximum HR during a 10-min snatch test [34]. All other respiratory and cardiovascular function-related outcomes revealed very high values at the 10th minute of the routine. Indeed, critical measures after 15 min of recovery remained at levels substantially higher than baseline (Tables 2 and 3). For example, HR was ~39 $b \cdot min^{-1}$, rate pressure product was ~5 units, lactate was ~5 $mmol \cdot L^{-1}$ higher and handgrip strength was still ~5 kg below the baseline.

The high demand for the kettlebell routine employed in the present study might be related to the unstable nature of the implement, which is known to activate limb and core muscles to a greater extent than the same movement executed with a stable implement [14]. The high cardiovascular demand is further characterized by the associations between the physiological changes and kettlebell experience and the mass of the implement. For example, practice experience (i.e., number of years of training) correlated with changes in VO_2 (Fig. 2), VE, and VT induced by the 10-minute-long routine. The mass of the implement also correlated with changes in HR, VO_2, VE, and VT (Fig. 3). These cross-sectional data suggest that years of kettlebell training and the mass of the implement bring about robust cardiovascular adaptations that are comparable to many other exercise interventions [9, 12, 16]. These data extend and add to previous findings, characterizing the very high cardiovascular load imposed by a single, 10-minute-long, long-cycle kettlebell routine. Such an exercise stimulus thus provides an additional option for exercise practitioners to choose from the many available routines, including high-intensity interval training or HIIT, sprint interval training, stair climbing routines, and other exercise regimens to improve aerobic capacity, cardiovascular function, and ultimately health [35, 36].

A somewhat unexpected finding was a lack of change in maximal squat performance, which contrasts with the significant changes in all other measures (Tables 2 and 3). Squat performance was nearly numerically identical before and immediately after the kettlebell routine (Table 2). Because squat performance was stable and unchanged in CON, unreliability did not affect squat performance in EXP. A lack of reduction in squat performance after such a highly demanding

10-minute-long, long-cycle routine is strange because kettlebell training has been shown to improve leg power, vertical jump, and hamstring strength [37–40]. These activities involve the quadriceps, which we also tested with our squat test. However, biomechanical analyses comprising inverse dynamics of the kettlebell swing also revealed large hip extensor torques and power generation as well as trunk extensor, but not knee extensor torques [16, 19]. Without whole body motion analysis data, we can only speculate that our kettlebell athletes executed the kettlebell movement by adopting a 'pendulum' strategy, which might have spared the knee extensors from fatigue [41] instead of the 'hip-hinge style' style strategy used by recreational and fitness practitioners [16].

One limitation of the present study is a lack of maximal oxygen uptake measurement. Another limitation is the cross-sectional design instead of a longitudinal follow-up of kettlebell athletes through a season. Because we wished to ascertain the stability of our measures, we opted for a passive control group instead of an active comparator intervention group [2]. We also did not employ a low kettlebell skill group so that we could determine the effects of skill level on the cardiovascular responses to a long-cycle kettlebell routine. A practical application of the current results is that when kettlebell athletes use this routine as a training exercise, proper recovery is needed prior to the next training exercise to minimize the risk of injury.

CONCLUSIONS

The present study shows that a 10-minute-long, long-cycle kettlebell routine evoked very high levels of physiological responses that, in most measures, outlasted the routine for at least 15 min. Some of these changes were associated with kettlebell experience and the mass of the implement in athletes with ~5y of kettlebell competition experience. Long-cycle kettlebell routine adds to the repertoire of evidence-based exercise options for high-intensity exercise.

Statement for conflicts of interest: The authors state that they have no conflict of interest to declare.

Author contributions: Conceptualization and methodology: SZ.L, T.H, B.S, D.CS; investigation: SZ.L, A.K, B.S, H.K, D.CS, P.P, T.A; resources: M.V, T.A; writing-original draft preparation, SZ.L, T.H, M.V, T.A; writing-review and editing, SZ.L, T.H, M.V, T.A; prepared the tables and the figures: T.H, SZ.L, B.S, T.A; supervision: T.H, M.V, T.A; funding acquisition, M.V, T.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the University of Pécs (protocol number: 7961-PTE2019, approval date: 09.20.2019) for studies involving humans.

Informed consent statement: Informed consent was obtained from all subjects involved in the study.

Data availability statement: Data from this study can be accessed by contacting the corresponding author, T.A., by email at attam@gamma.ttk.pte.hu.

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