Cardiovascular Drift during Training for Fitness in Patients with Metabolic Syndrome

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ABSTRACT

MORALES-PALOMO, F., M. RAMIREZ-JIMENEZ, J. F. ORTEGA, J. G. PALLARES, and R. MORA-RODRIGUEZ. Cardiovascular Drift during Training for Fitness in Patients with Metabolic Syndrome. *Med. Sci. Sports Exerc.*, Vol. 49, No. 3, pp. 00–00, 2017. **Purpose:** The health benefits of a training program are largely influenced by the exercise dose and intensity. We sought to determine whether during a training bout of continuous versus interval exercise the workload needs to be reduced to maintain the prescribed target HR. **Methods:** Fourteen obese ($31 \pm 4 \text{ kg} \cdot \text{m}^{-2}$) middle-age ($57 \pm 8 \text{ yr}$) individuals with metabolic syndrome, underwent two exercise training bouts matched by energy expenditure (i.e., $70 \pm 5 \text{ min}$ of continuous exercise [CE] or 45 min of interval exercise, high-intensity interval training [HIIT]). All subjects completed both trials in a randomized order. HR, power output (W), percent dehydration, intestinal and skin temperature (T_{INT} and T_{SK}), mean arterial pressure, cardiac output (CO), stroke volume (SV), and blood lactate concentration (La^-) were measured at the initial and latter stages of each trial to assess time-dependent drift. **Results:** During the HIIT trial, power output was lowered by $30 \pm 16 \text{ W}$ to maintain the target HR, whereas a $10 \pm 11 \text{ W}$ reduction was needed in the CE trial ($P < 0.05$). Energy expenditure, CO, and SV declined with exercise time only in the HIIT trial (15%, 10%, and 13%, respectively). During HIIT, percent dehydration, T_{INT} , and T_{SK} increased more than during the CE trial (all $P = 0.001$). Mean arterial pressure and La^- were higher in HIIT without time drift in any trial. **Conclusion:** Our findings suggests that although CE results in mild power output reductions to maintain target HR, the increasingly popular HIIT results in significant reductions in power output, energy expenditure, and CO (21%, 15%, and 10%, respectively). HIIT based on target HR may result in lower than expected training adaptations because of workload adjustments to avoid HR drift. **Key Words:** HEART RATE DRIFT, AEROBIC TRAINING, FITNESS, EXERCISE PRESCRIPTION, ENERGY EXPENDITURE, METABOLIC SYNDROME

HR is a good index of exercise intensity up to levels close to maximum oxygen uptake ($\dot{V}\text{O}_{2\text{max}}$) (16). The reliable lineal relationship of HR and exercise intensity and the availability of telemetric HR monitors have flourished the use of HR in training sessions. Thus, for endurance sports, the prescription of training loads is often based on the attainment and maintenance of a target HR (21). Detractors of monitoring exercise intensity by means of target HR argue that cardiovascular training adaptations (i.e., reductions in HR) require periodic readjustments of target HR values. However, data in endurance cyclists reveal that as training adaptations ensued, so does the workload to elicit the target HR. The progressive increase in workload to elicit the

target HR complies with the progressive overload training principle. This implies that a single pretraining determination of target HR (e.g., $90\% \text{ HR}_{\text{max}} = 153 \text{ bpm}$ for an individual) is sufficient to prescribe training for the duration of a entire training program (23). Athletic training can be simplified not only by adjusting workloads based on target HR but also by training for improving fitness and health (39). In the HERITAGE family study with participants of a wide range in age, initial fitness level, and responses to training, the HR at a given percent of $\dot{V}\text{O}_{2\text{max}}$ was unaltered after 20 wk of a training program.

The other concern regarding the use of target HR to monitor exercise intensity is the occurrence of a common exercise phenomenon known as cardiovascular drift (i.e., CDV drift). CDV drift is the progressive increase in HR and the concomitant reduction in stroke volume (SV) that occur during prolonged fixed-load aerobic submaximal exercise (35,36). The increases in HR during prolonged exercise, despite maintained workload, disrupt the single correspondence between HR and workload. CDV drift leaves exercise administrators with two choices, either to reduce the workload to maintain the target HR or to maintain the workload allowing HR to migrate above the HR target. To our knowledge, the consequences for training adaptations of each strategy have not been fully addressed in the scientific literature.

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In one study conducted on endurance-trained young individuals during exercise in the heat (35°C), HR was maintained at its target during the 45 min that the trial lasted (43). To keep HR constant, power output had to be lowered 37% (from 157 to 98 W). $\dot{V}O_2$ declined by 24% because of the reduced metabolic demand from the lowered workload. Cardiac output (CO) declined by 20% and SV by 21%. Thus, in this stressful environment, training by HR target could result in unplanned reductions in energy expenditure and cardiac work and possibly a delay in the metabolic and cardiovascular adaptations sought with training.

In the field of fitness programs to promote health, the existence of CDV drift has not been established. Mikus et al. (25) examined the effects of maintaining the target HR that elicited 50% of $\dot{V}O_{2max}$ in a large group of postmenopausal women with overweight ($n = 326$). The purpose of the study was to determine whether workload reductions were required to maintain the target HR. They analyzed approximately 13,000 training sessions and concluded that in this population, they rarely have to reduce exercise intensity to maintain HR constant (i.e., only 1–4 bpm drift). However, the training was conducted in a low thermal strain environment (i.e., 20°C with fans and water available *ad libitum*) under a low metabolic demand (i.e., CE at 50% $\dot{V}O_{2max}$).

High-intensity interval training (HIIT), a training mode originally used to improve athletic performance, has been quickly embraced in health fitness programs for being less time consuming and tedious than aerobic continuous training while producing similar health benefits. Although shorter, this training modality involves repeated short periods (30 s [24]; to 4 min [20]) of high-intensity exercise, which could lead to accumulated fatigue, transient hyperthermia, and sympathetic heart stimulation leading to CDV drift. To our knowledge, no study has addressed the cardiovascular and metabolic consequences of maintaining target HR during either a continuous moderate-intensity prolonged training bout in comparison with an HIIT session geared both to improve health status of the participants. In this study, we perform such experiment in overweight patients with metabolic syndrome enrolled in a health fitness exercise program. We did a full assessment of possible physiological variables linked to CDV drift (i.e., dehydration, SV, core and skin temperature, blood pressure [BP], and blood lactate) that could account for HR drift during these two exercise training modes. Our hypothesis is that when using HIIT exercise bouts, workload may need to be reduced to maintain the target HR. The lowering of workload during HIIT bouts could deter the expected health related training adaptations.

METHODS

Participants. Fourteen middle-age (57 ± 8 yr) obese subjects ($n = 11$ males and $n = 3$ females) with a body mass index of $31 \pm 4 \text{ kg}\cdot\text{m}^{-2}$ (Table 1) and with metabolic syndrome completed this study. Metabolic syndrome was defined as the

TABLE 1. Anthropometric and cardiometabolic variables.

	Pretest
Age and body composition	
Male/female	11/3
Age (yr)	57 ± 8
BMI ($\text{kg}\cdot\text{m}^{-2}$)	31 ± 4
Fat (%)	32 ± 8
Fitness parameters	
$\dot{V}O_{2peak}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	30.2 ± 8.1
PO_{peak} (W)	225 ± 60
HR_{peak} (bpm)	167 ± 12

Results as presented as mean $\pm$ SD.

presence of three of the following five risk factors: elevated waist circumference, elevated BP, elevated fasting blood glucose, elevated triglycerides, or reduced HDL-C (1). Subjects were familiar with cycling as exercise mode because they were tested 2 months into a stationary cycling exercise program with a frequency of 3 d $\cdot\text{wk}^{-1}$ (24–28 sessions completed). Exclusion criteria included the use of medication known to affect HR response (i.e., beta blockers and Ca^{2+} antagonist), untreated thyroid, cardiovascular or renal disease, or any condition associated with exercise intolerance. All subjects provided written, witnessed, informed consent of the protocol approved by the Virgen de la Salud Hospital's Ethics Committee in accordance with the world medical association Declaration of Helsinki.

Preliminary testing. Peak aerobic capacity ($\dot{V}O_{2peak}$) was assessed on an electronically braked cycle ergometer (Ergoselect 200; Ergoline, Germany) during graded exercise testing using indirect calorimetry (Quark b²; Cosmed, Italy) with 12-lead ECG monitoring (Quark T12, Cosmed). After 3 min of warm-up at 30 W for women and 50 W for men, workload was increased every minute (15 W women and 20 W men) until volitional exhaustion. Participants met or exceeded the criteria that indicated maximal effort with RPE ≥ 17 , RER ≥ 1.1 , and HR $\geq 85\%$ of the maximal age predicted (2). The highest HR value obtained during the test was considered HR_{peak} . Maximal power output values (PO_{peak}) and $\dot{V}O_{2peak}$ are shown in Table 1.

Experimental design. A repeated-measures crossover randomized design was used in which all subjects completed two trials, each one with a different exercise mode. In one occasion, subjects completed 45 min of high-intensity aerobic interval exercise (HIIT) consisting on pedaling for 10-min as warm-up (70% HR_{peak}) followed by 5×4 -min intervals at 90% of HR_{peak} interspersed with a 3-min active recovery (70% HR_{peak}). In another occasion, subjects completed 70 ± 5 min of CE test at 60% HR_{peak} . Exercise duration for the CE was individually calculated to result in similar energy expenditure than when performing the HIIT bout (45 min) for that subject. In turn, the energy to be expended during HIIT was estimated from the individual linear relationship between workload and $\dot{V}O_2$ from the initial graded exercise test. We recommend subjects to maintain a similar pedaling cadence in both trials (60–70 rpm). During exercise, HR was monitored every 5 s (Accurex coded; Polar, Kempele, Finland) by a researcher and workload adjusted to reach the desired target HR.

Experimental protocol. Tests were conducted at least 72 h after the last training bout, with subjects refraining from

consumption of any stimulant that may have altered their cardiovascular response to exercise during the 24 h before exercise (alcohol, tobacco, coffee, tea, or herbal extracts). At least 72 h separated both trials. Each subject was tested in the morning at the same time of day to minimize the effects of circadian rhythm in HR and core temperature (22). Four hours before arriving at the laboratory, participants ingested a telemetric thermistor pill (CorTemp™, HQ, Inc., Palmetto, FL) to allow us to measure intestinal temperature (T_{INT}) during exercise. Two hours before arrival to the laboratory, subjects ingested a light breakfast (330 mL fruit milkshake and a pastry for a total of 624 kcal and 68 g of carbohydrate). Upon arrival to the laboratory, subjects voided and nude body weight was recorded (Mettler Toledo Hawk, Columbus, OH). Urine-specific gravity (U_{SG}) was measured to confirm euhydration ($U_{SG} < 1.020$ [37]). Then subjects dressed with shorts and a T-shirt and were instrumented with three ECG adhesive electrodes and an HR chest band to allow measurements of BP (Tango™; Suntech Medical Inc., Morrisville, NC) and HR (Accurex coded, Polar). Next subjects laid on a stretcher, and four temperature thermistors were attached to their skin to calculate average skin temperature (T_{SK}). Data between trials were compared at the beginning (INIT) and at the end (FINAL)

of each protocol. Comparison times were chosen where accumulated energy expenditure was similar (i.e., isocaloric comparison) between trials. Thus, INIT comparison took place between 20 and 25 min of CE and between 10 and 17 min of HIIT. FINAL comparison took place between 60 and 65 min of CE and between 38 and 45 min of HIIT (Fig. 1). Measurements during HIIT were taken as the weighted mean value of the high-intensity bout (4 min at 90% HR_{peak}) and after the recovery bout (3 min at 70% HR_{peak}). At the end of each exercise trial, subjects towed dry, and nude weight was measured again.

Metabolic measurements. During data collection periods (INIT and FINAL), O_2 consumption ($\dot{V}O_2$) and CO_2 production ($\dot{V}CO_2$) were continuously measured using indirect calorimetry (Quark b2, Cosmed) and values averaged. Energy expenditure was calculated from these data using Brouwer equations (3). At the beginning of each collecting period, a capillary blood sample was obtained by a finger prick in the right hand. The lactic acid concentration was analyzed using a hand held analyzer (Lactate Pro, Arkray, Japan).

Cardiovascular measurements. During the collection periods, BP was measured in the left arm (Tango™, Suntech Medical Inc.) in duplicate. Mean arterial pressure (MAP) was

FIGURE 1—Experimental design.

calculated as $MAP = [(SBP - DBP)/2] + DBP$. HR (RS 400, Polar) was averaged over the collection periods for each trial. In each measurement period, CO was measured in duplicate using the rebreathing technique (Innocor™; Innovision, Odense, Denmark). In brief, participants rebreathed a gas mixture of nitrous oxide (0.5%) and sulfur hexafluoride (0.1%) in oxygen, diluted with atmospheric air, from an anesthesia bag of size 3–6 L, depending on the participant's predicted vital capacity (33). SV was calculated by dividing the CO between HR. Systemic vascular resistance (SVR) was calculated by the following formula: $MAP/CO \times 80$, where 80 is a conversion factor to $\text{dynes} \cdot \text{s}^{-1} \cdot \text{cm}^{-5}$.

Thermoregulatory measurement. Whole-body percent dehydration was calculated by subtracting pre- from postexercise nude body mass and dividing by preexercise body weight. None of the participants urinated or ingested fluids during exercise, and thus no corrections were needed for these factors. Mean skin temperature (T_{SK}) was calculated using the formula of Ramanathan (34):

$$T_{SK} = 0.3(T_1 + T_2) + 0.2(T_3 + T_4),$$

where T_1 , T_2 , T_3 , and T_4 are temperatures measured at the chest, deltoid, thigh, and calf skin, respectively. Mean body temperature (T_B) was calculated from T_{INT} and T_{SK} with the formula of Colin et al. (7):

$$T_B = 0.87T_{INT} + 0.13T_{SK}.$$

Statistical analysis. Normality was evaluated by the Shapiro–Wilk test. Data collected overtime (INIT and FINAL) was analyzed using a two-way (treatment-by-time) repeated-measures ANOVA. After a significant F -test, pairwise differences were identified using Tukey's significance (HDS) *post hoc* procedure. Cohen's formula for effect size (ES [6]) was used, and the results were based on the following criteria: >0.70 large effect, 0.30 – 0.69 moderate effect, and ≤ 0.30 small effect. Pearson product-moment correlation coefficient was used to establish associations between the reductions in power output and other variables in the HIIT trial. All analyses were performed with the Statistical Package for the Social Sciences version 21 (SPSS Inc., Chicago, IL). Data presented as mean $\pm$ SD. Statistical significance level was set at $P \leq 0.05$.

RESULTS

There were no significant different responses to any of the two exercise protocols between genders, and thus data were analyzed as a group ($n = 14$). In Figure 1, a layout of the two experimental trials is depicted. Because of the differences in exercise intensity between trials (lower in CE than HIIT), exercise time was extended in the CE trial to take measurements at comparable energy expenditure.

Experimental manipulation. During the HIIT trial, we were successful on clamping HR (controlled variable) to 90% of HR_{peak} and 70% HR_{peak} . During CE, HR target remained clamped during the full trial (Fig. 2A). By design,

FIGURE 2—HR (% maximum) (A) and power output (B) during a bout of CE or HIIT equaled by total energy expenditure (~460 kcal). Data are presented as mean $\pm$ SD for 14 middle-age metabolic syndrome subjects. *Significant difference from the first time point for that trial ($P < 0.05$).

HR and workloads were different between trials with higher values in the HIIT than CE trial ($P = 0.001$; Figs. 2A and B). To maintain the target HR during the HIIT trial, researchers ought to reduce exercise workload by 30 ± 16 W in the HIIT trial (143 ± 35 to 113 ± 27 W, $ES = 0.96$, $P = 0.001$) and by 10 ± 11 W in the CE trial (71 ± 36 to 61 ± 31 W, $ES = 0.31$, $P = 0.003$). The magnitude of reduction in workload was larger in the HIIT than that in the CE trial (insert of Fig. 2B).

Metabolic measurement. As design, energy expended (kcal accumulated) was similar in HIIT and CE at the first time comparison (i.e., INIT; 175 ± 32 vs 158 ± 43 kcal) and at the last comparison (i.e., FINAL; 485 ± 88 vs 436 ± 125 kcal; Fig. 3B). Accordingly, with the higher exercise intensity during HIIT, the rate of energy expenditure ($\text{kcal} \cdot \text{min}^{-1}$) was higher during HIIT than during the CE trial ($P < 0.001$; Fig. 3A). The rate of energy expenditure was maintained from INIT to FINAL in the CE trial (6.3 ± 1.7 to 6.3 ± 1.7 $\text{kcal} \cdot \text{min}^{-1}$,

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ES = 0.008, $P = 0.934$; Fig. 3A). However, because of the 30-W reduction in workload during HIIT, there was a reduction in the rate of energy expenditure from INIT to FINAL (12.2 ± 2.3 to 10.4 ± 1.9 kcal·min⁻¹, ES = 0.86, $P = 0.001$; Fig. 3B). Capillary blood lactate was higher during HIIT than during CE at the beginning (i.e., INIT 11 ± 4 vs 5 ± 4 mmol·L⁻¹, respectively, $P = 0.029$) and end of the trials (i.e., FINAL 12 ± 4 vs 3 ± 1 mmol·L⁻¹, respectively, $P = 0.012$). With exercise time, blood lactate remained at similar concentrations in both trials (no time drift effect).

Cardiovascular measurement. There was no difference in CO among trials either in the beginning (INIT; $P = 0.102$) or end of the trials (FINAL; $P = 0.799$). Only during HIIT was CO reduced from beginning to the end of exercise (12.6 ± 2.9 INIT to 11.4 ± 3.0 L·min⁻¹ FINAL; $P = 0.003$, ES = 0.41). In the CE trial, CO was maintained during the entire trial (11.2 ± 3.9 INIT to 11.5 ± 2.7 L·min⁻¹ FINAL; $P = 0.658$, ES = 0.11; Fig. 5A). SV was lower in the HIIT trial than that in the CE at the beginning and end of exercise ($P = 0.037$ and 0.001 , respectively). With time of exercise, SV was reduced in the HIIT trial (INIT 99 ± 23 to 82 ± 20 mL·b⁻¹ FINAL; $P = 0.001$, ES = 0.64), whereas during the CE trial, SV was maintained (INIT 115 ± 37 to 118 ± 26 mL·b⁻¹ FINAL; $P = 0.071$, ES = 0.773; Fig. 5B). MAP was lower in CE than HIIT ($P = 0.001$; Fig. 5C). Time of exercise did not affect BP that was maintained from INIT to FINAL in the HIIT (127 ± 12 to 124 ± 17 mm Hg, $P = 0.426$, ES = 0.20) and CE trials (97 ± 7 to 98 ± 9 mm Hg, $P = 0.250$, ES = 0.18; Fig. 5C). When we calculated systemic vascular resistance (i.e., MAP/CO), values were similar between trials with a tendency to increase with time of exercise in HIIT (1.1 ± 1.7) and to decrease in CE (-0.7 ± 2.9).

Thermoregulatory measurement. Percent dehydration measured from body weight losses with exercise was larger in the HIIT than that in the CE trial ($0.85\% \pm 0.3\%$ vs $0.55\% \pm 0.2\%$, respectively, $P = 0.001$, ES = 1.15). At the beginning of exercise (i.e., INIT), there was no difference in intestinal temperature (T_{INT}) between trials. However, with exercise time, there was an increase in T_{INT} in the HIIT ($37.1^\circ\text{C} \pm 0.5^\circ\text{C}$ to $37.9^\circ\text{C} \pm 0.6^\circ\text{C}$, $P = 0.001$, ES = 1.53), whereas the increase during CE did not reach statistical difference ($36.9^\circ\text{C} \pm 0.3^\circ\text{C}$ to $37.2^\circ\text{C} \pm 0.6^\circ\text{C}$, $P = 0.06$) trials. The magnitude of increase was higher in the HIIT trial than that in the CE trial ($0.81^\circ\text{C} \pm 0.4^\circ\text{C}$ vs $0.38^\circ\text{C} \pm 0.4^\circ\text{C}$, $P = 0.003$, Fig. 5A). Skin temperature (T_{SK}) was higher in the HIIT than that in the CE trial at the beginning of exercise (INIT; $32.4^\circ\text{C} \pm 0.9^\circ\text{C}$ vs $31.6^\circ\text{C} \pm 0.9^\circ\text{C}$, $P < 0.001$; Fig. 5B). T_{SK} increased with time of exercise only during the HIIT trial ($32.4^\circ\text{C} \pm 0.9^\circ\text{C}$ to $33.7^\circ\text{C} \pm 0.6^\circ\text{C}$, $P < 0.001$, ES = 1.83; Fig. 5B), whereas no increase in T_{SK} was present with exercise time in the CE trial ($31.6^\circ\text{C} \pm 0.9^\circ\text{C}$ to $31.7^\circ\text{C} \pm 1.2^\circ\text{C}$, $P = 0.778$, ES = 0.06). Therefore, calculated body temperature (T_{B}) was higher in the HIIT than that in the CE trial at the beginning and end of the trials ($P = 0.006$). Although with exercise time T_{B} increased in both trials, the increase was larger in the HIIT than that in the CE trial ($0.87^\circ\text{C} \pm 0.4^\circ\text{C}$ to $0.33^\circ\text{C} \pm 0.4^\circ\text{C}$, $P < 0.001$; Fig. 5C).

Correlations. The reductions in power output during HIIT were correlated with the percent dehydration ($r = -0.528$, $P < 0.05$), but it did not reach statistical significance with the increases in T_{SK} ($r = 0.042$, $P = 0.881$), T_{INT} ($r = -0.193$, $P = 0.512$), or MAP ($r = -0.111$, $P = 0.705$).

DISCUSSION

We conducted this study to determine whether CDV drift and its main manifestation, HR drift, take place during exercise training to promote health in a sample of middle-age participants with obesity and metabolic syndrome (1). In most adult fitness facilities, calibrated ergometers are not available because of their elevated maintenance costs and calibration requirements. Exercise intensity is then typically prescribed based on HR as a proxy of workload on account of the linear relationship between these two physiological variables (16) during submaximal workloads. However, CDV drift upset this parallelism elevating HR for a given workload (21). Our goal in this study was to ascertain if workload ought to be reduced in exercise bouts typically used during a health promoting training program (continuous or interval exercise type) to maintain the prescribed target HR. Furthermore, if workload needs to be reduced to avoid CDV drift, we sought to determine the magnitude of this reduction to gauge the consequences for the metabolic and cardiorespiratory training stimulus. We should consider that one of the main reasons for subjects to enroll in a health-oriented exercise program is to increase energy expenditure and fat oxidation to incur in negative energy balance and promote body fat loss (19). We found that to maintain the HR target, workload ought to be reduced by 21% (i.e., 30 W) during a bout of intense interval exercise. Consequently, energy expenditure and CO were reduced during interval exercise (15% and 10%, respectively), curtailing the planned metabolic and cardiovascular training stimulus.

CDV drift is the topic of a fair amount of published studies and reviews (8,42). Most of these studies are geared to understand the mechanisms behind this physiological event (13,41) and its relationship with other physiological parameters (i.e., $\dot{V}\text{O}_{2\text{max}}$ [4,43]), dehydration (17), exercise mode (44), or with exercise performance (31). All the cited studies were conducted in young healthy endurance-trained individuals, whereas one study stands alone in exploring the incidence of CDV drift when exercising for health purposes. This study (25) conducted in a large sample of overweight postmenopausal women (i.e., $n = 326$, part of the larger DREW study) finds a very low incidence of CDV drift (<1%) when training for health. Exercise training intensity and duration in that study was in the lower end of the American College of Sports Medicine prudent recommendations for exercise in deconditioned adults (i.e., 30–90 min at 50% of $\dot{V}\text{O}_{2\text{peak}}$ [14]). However, in the last decade, the use of a training mode reserved for improving athletic performance (i.e., HIIT) has spread following the findings that HIIT elicits similar or larger health benefits than moderate CE mode in healthy sedentary (15,29) and obese patients with metabolic syndrome (26,40). Aware of

the increased use of HIIT for promoting health, we studied CDV drift not only during a constant exercise bout (70 min at 60% HR_{peak} , CE trial) but also during an isocaloric bout of HIIT (45 min at 70%–90% HR_{peak} , HIIT trial).

Despite the isocaloric matching of the exercise trials, blood lactate concentration, the rate of energy expenditure (Fig. 3A), MAP (Fig. 5C), and body temperatures (Fig. 5) were higher in the more intense trial (i.e., HIIT). Our data allow us to analyze how variables drifted with exercise duration in both trials. The exercise intensity during our CE trial (60% HR_{MAX} , 48% $\dot{\text{V}}\text{O}_{2\text{peak}}$) matches the one used by Mikus and coworkers (CE at 50% $\dot{\text{V}}\text{O}_{2\text{peak}}$ [25]). In our case, during the CE trial, to maintain the target HR, workload was slightly lowered during the last stages of exercise (i.e., 10 W at 60–70 min of exercise; Fig. 2B). The slight but significant reduction in workload did not affect $\dot{\text{V}}\text{O}_2$ or CO, and thus CDV drift had no incidence on the metabolic or cardiovascular demands of this training mode (i.e., continuous prolonged moderate intensity). By contrast, the marked reductions in workload during the 45 min of HIIT (i.e., 30 W) lowered $\dot{\text{V}}\text{O}_2$ and CO. Consequently, energy expenditure decreased approximately $2 \text{ kcal}\cdot\text{min}^{-1}$, and the heart pumped $1.2 \text{ L}\cdot\text{min}^{-1}$ less blood from the beginning to the end of the exercise bout (Figs. 3A and 4A). These numbers could seem negligible but when multiplied by a typical training program of 45 min per bout, three sessions per week during 16 wk (26), they amount to a relevant reduction in energy expenditure and cardiac work.

Results from the dose–response to exercise (i.e., DREW study) reveal that the improvements in cardiorespiratory fitness (i.e., $\dot{\text{V}}\text{O}_{2\text{max}}$) of a 6-month training program in overweight women are intimately linked to the energy expenditure induced by training (10). Increasing energy expenditure with exercise from 8 to $12 \text{ kcal}\cdot\text{kg}^{-1}\cdot\text{wk}^{-1}$ (50% increase) results in a 2.2% increase in $\dot{\text{V}}\text{O}_{2\text{max}}$. In this context, our finding of a 15% reduction in energy expenditure due to HR drift during HIIT may diminish the gains in cardiorespiratory fitness of a fitness program. However, renouncing to maintain target HR and leaving HR to drift up could result in overdue fatigue and reduce subject adherence to a training program (32). Even endurance-trained subjects volitionally lower their power output when performing in a hot environment to prevent undue HR drift (31). Thus, in our less conditioned population, even larger reductions in power output are expected to prevent HR drift. In our case, we can state that the expected benefits of a health-oriented HIIT program, with intensity controlled by target HR, should be rebated.

In young, healthy individuals, it is well established that exercising in a hot environment (35°C vs 20°C) reduces aerobic performance either when measured by time to exhaustion (30) or by self-selected intensity during a time trial (31). During submaximal exercise in a hot environment (i.e., 35°C [43]), the prevention of HR drift required an important reduction in power output that resulted in 24% lowering of oxygen consumption and energy expenditure, similarly to what we currently report with our obese, deconditioned subjects. We conducted our testing in a thermoneutral environment (24°C)

FIGURE 3—Energy expenditure rate (A) and accumulated energy expenditure (B) during a bout of CE or HIIT equaled by total energy expenditure. Data are presented as mean $\pm$ SD for 14 middle-age metabolic syndrome subjects. *Significant difference between the INIT and the FINAL time point for that trial ($P < 0.05$). †Significant difference between trials (HIIT vs CE; $P < 0.05$).

and monitored that participants were euhydrated ($U_{\text{SG}} < 1.020$) when starting the exercise bouts. Despite these favorable conditions to dissipate heat, during HIIT, a 21% reduction in power output was required to maintain HR. When we correlated the increases in temperature (i.e., T_{SK} , T_{INT} and T_{B}) during HIIT with the reductions in power output, no clear association emerged. However, the lowering of power output was significantly correlated with the percent dehydration. It seems then that the more subjects dehydrated (i.e., higher sweat rate), the more power output needed to be reduced to maintain HR. Profuse sweating during exercise lowers blood volume (17), which may signal baroreceptors to increase HR to maintain BP (i.e., Fig. 5C [35]). This suggests that heavy sweaters may be the ones lowering more power output and thus delaying training adaptations.

Experiments using cardioselective beta-adrenergic blockade (β_1 blocker [13,41]) have attempted to dissociate the reduction in SV that concomitantly occurs with the elevations

FIGURE 4—CO (A), SV (B), and MAP (C) during a bout of CE or HIIT equaled by total energy expenditure. Data are presented as mean $\pm$ SD for 14 middle-age metabolic syndrome subjects. *Significant difference between the INIT and the FINAL time point for that trial ($P < 0.05$). †Significant difference between trials (HIIT vs CE; $P < 0.05$).

in HR during CDV drift. These studies revealed that the HR drift may be influenced by reduced central venous pressure signaling baroreceptors to increase HR (35) but also by

increased sinoatrial node temperature (18) and sympathetic cardiac stimulation (28). We observed that T_{SK} and T_{INT} were elevated in the HIIT in comparison with CE already at the first stages of exercise (i.e., INIT; Fig. 5A and B), which may explain the higher drive during the HIIT trial to increase HR and thus the larger reduction in power output needed to prevent it in comparison with the CE trial. On the other hand, the

FIGURE 5—Intestinal (A), skin (B), and body temperatures (C) during a bout of CE or HIIT equaled by total energy expenditure. Data are presented as mean $\pm$ SD for 14 middle-age metabolic syndrome subjects. *Significant difference between the INIT and the FINAL time point for that trial ($P < 0.05$). †Significant difference between trials (HIIT vs CE) at that time point ($P < 0.05$).

higher skin temperatures (i.e., index of a higher skin blood flow [9]) during HIIT versus CE may have resulted in a redistribution of blood volume peripherally, which together with the higher dehydration could have reduced central venous pressure increasing the drive for increase HR. Nevertheless, the reduction in workload during HIIT prevented cardiovascular strain and reduced CO and SV over time. SV reductions may limit the main cardiovascular adaptations to endurance training (i.e., increase in maximal SV), reducing the stimulus to enlarge end-diastolic volume (27).

It is known that SV plateaus at intensities more than 45% of $\dot{V}O_{2\text{peak}}$ (~55% HR_{MAX}) in sedentary subjects (5); thus, we expected similar SV in both trials because both exceed that intensity. To our surprise, SV during HIIT was lower than during CE trial (Fig. 5B). The technology we used for measuring CO (CO; inert gas rebreathing method; Innocor®) has been shown to be reliable (intraday CV = 4% [11]) and fast enough to provide measures even during short bouts of high-intensity exercise (12). However, it has also been shown to result in a lower value than the gold standard Fick method because of the recirculation of the inert gas into the pulmonary circulation (38). Thus, an underestimated value of CO obtained with this technology during the high bouts of HIIT could be responsible for the lower SV during that trial in comparison with the CE trial. Nevertheless, we sustain that

this underestimation in CO assessment remained constant during the entire HIIT trial and thus had no role on the reported reduction in CO from beginning to the end of the exercise.

In summary, in agreement with a previous report (25), we found that the traditional exercise bouts used to promote health (i.e., continuous moderate-intensity exercise) results in small power output reductions to maintain target HR, which do not reduce energy expenditure or CO during the workout. By contrast, an isocaloric bout of the increasingly popular HIIT results in significant reductions in power output, energy expenditure, and CO (21%, 15%, and 10%, respectively) to maintain the target HR. It could be speculated that exercise prescription based on HR target during HIIT will lower the expected training adaptations (metabolic and cardiovascular). However, allowing HR and relative metabolic intensity to rise over time may result in increased thermal and cardiovascular strain, leading to fatigue and subject attrition.

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