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Implementation of a Novel Cyclic Exercise Protocol in Healthy Women

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Traditional exercise regimens are based on maintaining a prolonged increase in heart rate, followed by a single recovery period. The authors tested the efficacy of a cyclic exercise protocol designed to generate a series of parabolic-like waves of cardioacceleration (lasting ≤1 minute) followed by recovery to a steady state. In an observational study, they studied the effects of this type of cyclic regimen, consisting of four to seven cycles per session, in a group of healthy women (n=10; 32–58 years). Cardiorespiratory fitness, autonomic function, and quality of life were assessed before and after 8 weeks of exercise, performed three days per week. Observations were an increase in peak Vo_2 ($p<0.001$) and the ventilatory breakpoint ($p<0.001$), a decrease in resting diastolic blood pressure ($p<0.05$), an increase in heart rate variability during paced breathing ($p<0.05$), as well as a trend toward increased general positive affect ($p<0.06$). The authors conclude that even very short (8-week) implementation of a cyclic exercise protocol involving ≤66 minutes of exercise per month may have beneficial effects. Further studies are indicated to compare cyclic and traditional exercise protocols, both in healthy subjects and in selected patient groups. (Am J Med Sports. 2002;4: 135–141, 151)

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Traditional aerobic exercise regimens are based on increasing heart rate (HR) to a target range determined by age and fitness and maintaining that level of activity for a sustained period, followed by a "cool-down" phase. Another approach to training, particularly among athletes, employs interval-type protocols in which there is typically a preset, alternating sequence of exercise and rest periods.

In contrast to these conventional routines, we investigated the implementation of a "cyclic" exercise protocol designed to train not only the activation (arousal) phase, but also the relaxation (recovery) phase of exercise in a wave-like or pulsatile fashion. The physiologic importance of "training recovery" is derived from the concept that recovery itself is a dynamic process, mediated primarily by the parasympathetic nervous system.[1] Therefore, training recovery as well as activation may result in greater neuroautonomic plasticity, which, in turn, may enhance healthy function.[1]

The cycle protocol described here is tailored to measurements of an individual's HR during very short (≤1 minute) periods of exercise, followed by variable periods of relaxation to a steady state. This preliminary observational study assessed the effects of a short (8-week) course of cyclic exercise on selected measures of cardiovascular fitness and subjective perception of psychological well-being in healthy adult women.

Methods

SUBJECTS. Subjects were recruited from the nursing staff of Hunterdon Medical Center (Flemington, NJ). Candidates aged 20–70 years were eligible unless their history revealed any of the following: smoking, chronic disease, chronic drug or medication use, musculoskeletal limitations to exercise, or participation in a structured exercise program. Each subject signed informed consent forms approved by the Columbia University and Hunterdon Institutional Review Boards prior to enrollment.

STUDY DESIGN. Participants underwent a baseline evaluation within 1 week prior to an 8-week cyclic exercise regimen and then again within 1 week after completing the program. The evaluation consisted of a maximal oxygen consumption (Vo_2) test, measurement of HR variability (HRV) during controlled respiration, and a standard questionnaire to assess subjective sense of well-being. Prior to beginning the exercise regimen, a baseline cycles test (described below) was used to determine each subject's exercise prescription. The cycles test was repeated after the 8-week training period.

CYCLIC EXERCISE PROTOCOL. *Overview.* The cyclic exercise protocol was designed to generate a series of parabolic-like waves of cardiovascular exercise and recovery.[2] A single cycle consisted of a short (≤1 minute) burst of exercise followed by a period of cardiovascular recovery. Subjects were taught to use a specific relaxation response[3] to standardize and facilitate the recovery period. This type of meditative response has been shown to acutely augment parasympathetic nervous system activity[4] and thus may potentiate the increase in parasympathetic nervous system activity during recovery. Cycles were performed consecutively in sets of four to seven and at specific times of the day. The study was designed such that cycles to be performed in the afternoon required more exertion than those in morning sessions. This design was motivated by the findings that work performance typically increases in the afternoon.[5-7] The exercise phase of the cycles consisted of jogging in place on a trampoline. Two of the subjects complained of knee pain during the trampoline exercise. After the first week of training, one of these subjects instead performed her cycles training on an exercise bicycle (Schwinn Airdyne, Boulder, CO), while the other alternated between the trampoline and bicycle. Five-second averaged HRs were monitored and recorded continuously using a Polar NV HR monitor watch and chest strap (Polar Electro Inc., Woodbury, NY) and then downloaded to a computer. Subjects began a prescribed course of cyclic exercise three times weekly for 8 weeks, monitored by a trainer. After the 8 weeks of cycles training, the subjects performed another cycles exercise test.

Cycles Testing. Subjects were requested to refrain from caffeine and meals for 3 hours prior to testing. Upon arrival, subjects were briefed on the five-cycle baseline exercise test protocol, familiarized with the equipment, and instructed in the relaxation response.[3] During this first cycle of the testing phase, subjects were asked to exercise at an easy pace (3 on the 10-point Borg scale[8]) until the HR stabilized (defined as varying ± three beats over 15 seconds), which always occurred in less than 1 minute of exertion. The subject then stopped the exercise, took a deep breath, sat down, and began initiating the recovery phase of the cycle, including the relaxation response. When the subject had recovered, again defined as a stable HR (± three beats over 15 seconds), the subject again took a deep breath and held it for 5 seconds. The deep breath further enhances the HR recovery (Figure 1) via a vagally mediated effect.[9] The subjects performed cycles two, three, and four in a similar manner but increased the level of exertion with each successive cycle. Cycle five, which was used to determine the peak HR for the subsequent sessions, consisted of a very vigorous, brief exertion (9 on the 10-point Borg Scale), continued until the HR

Table I. Cyclic Exercise Protocol: Overview

Week	Time of Day	HR Ranges (Peak HR)	Cycle Set Day 1 Monday	Cycle Set Day 2 Wednesday	Cycle Set Day 3 Friday
1	6 a.m.–9 a.m.	60%–92%	7 Cycles	6 Cycles	5 Cycles
2	6 a.m.–9 a.m.	65%–93%	7 Cycles	6 Cycles	5 Cycles
3	9 a.m.–noon	70%–97%	5 Cycles	5 Cycles	4 Cycles
4	3 p.m.–6 p.m.	75%–100%	6 Cycles	5 Cycles	5 Cycles

Peak heart rate (HR) as determined from the baseline cycles exercise test plateaued or the subject completed 1 minute of exertion. The subjects then began the final recovery cycle. The trainer measured the subject's blood pressure 5 minutes after the peak HR was reached and again 10 minutes later ("recovery blood pressure"). A sample of a five-cycle baseline test is shown in Figure 1.

Exercise Training. Once the baseline cycles testing was completed, the subjects began a regimen consisting of four to seven consecutive cycles per day, three days per week for 8 weeks (Table I). A trainer tracked the participants as they moved through the same type of exercise-recovery cycles described above. Target HRs for each cycle were calculated as percentages of the peak HR determined from the baseline session described above. The target HRs for each cycle began at the low end of the range and progressively increased in a step-wise, incremental fashion to the high end of the range (Table I). An example of the actual exercise prescription for one of the subjects (whose baseline exercise test is shown in Figure 1) is shown in Table II. During cycles that required high HRs, all subjects exercising on the trampoline used hand weights (2–3 pounds) to assist in reaching HR targets within the allotted 60 seconds. Each subject's individual exercise protocol was assessed after 4 weeks of exercise. If a subject had exceeded her target HR on the final cycle of the final session by more than five beats per minute, she was moved into the next higher range of exercise HRs for the second month. If not, she repeated the same exercise protocol for the second month.

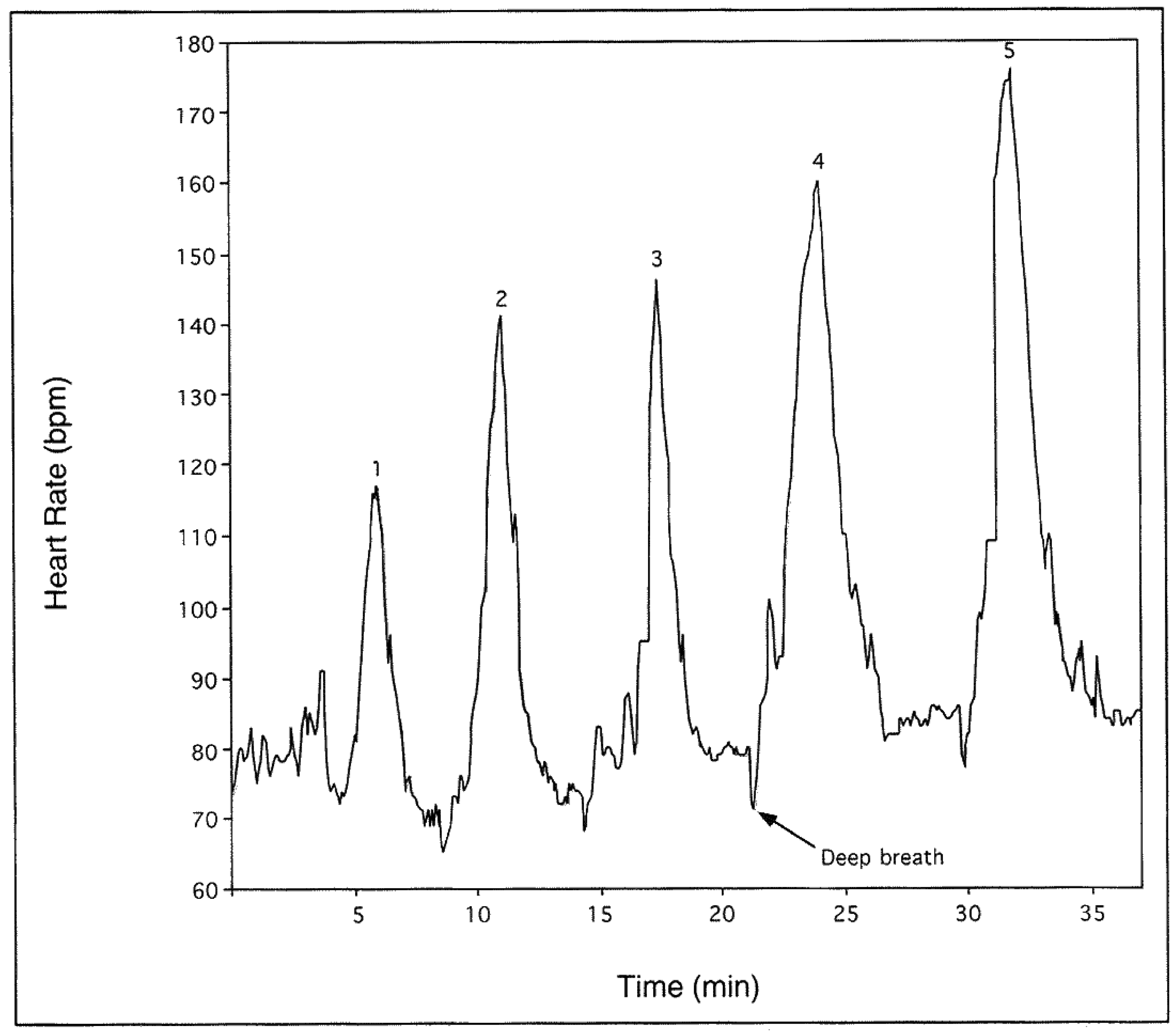

Figure 1. A representative set of five cycles performed during the baseline cycles testing. Peak heart rates achieved were 117, 141, 146, 160, and 176 beats per minute (bpm) for cycles 1 through 5, respectively. After each cycle, the subject recovered by sitting quietly and performing the relaxation response. After the heart rate achieved a steady state, the subject took a 5-second deep breath and then began the next cycle. As seen on the graph (arrow), deep breathing was associated with a further lowering of heart rate during recovery.

MAXIMAL CARDIOPULMONARY EXERCISE TEST. Peak V_{O_2} was measured by an incremental exercise test on a treadmill. Expired gas analysis of each breath was performed continuously during the test with a Sensormedics Vmax 29 (Yorba Linda, CA) metabolic cart. During the test, the work rate increased as a ramp or step function; treadmill protocol choice was made based on each subject's fitness level as determined by a pretest questionnaire. Peak V_{O_2} was defined as the highest V_{O_2} averaged over 20 seconds achieved during the final minute of exercise. V_{O_2} at the ventilatory breakpoint (VB) was identified using the V-slope method.[10] VB could be determined in nine of the 10 subjects. Subjects' HRs were compared at 3 minutes and 6 minutes into both the pre- and post-training exercise tests to study the effect of exercise training on submaximal HR. Each subject performed the same protocol on her pre- and post-test.

HR VARIABILITY. Studies were performed in a quiet room. The electrocardiogram (EKG) was monitored on an oscilloscope and continuously recorded using a digital acquisition analysis program (Gould Ponemah version 1.21, Valley View, OH). The subjects were allowed to acclimate to the environment while breathing spontaneously. Subjects were then asked to breathe for 7 minutes at a rate of 12 breaths per minute with the aid of a light box. A 6.5-minute window at the start of paced breathing was selected for analysis, this being the longest data length common to all subjects. The mean and standard deviation of the R-R intervals (SDNN) over this window were calculated. Spectral powers were calculated for total power (0–0.40 Hz), low-frequency power (0.04–0.15 Hz), and high-frequency power (0.15–0.40 Hz), using the Lomb periodogram technique for unevenly sampled data.[11]

PSYCHOLOGICAL MEASUREMENTS. The 38-item Mental Health Inventory (MHI)[12] was used to measure changes in psychological status. The MHI includes six subscales—Anxiety, Depression, Loss of Behavioral/Emotional Control, General Positive Affect, Emotional Ties, and Life Satisfaction; two global scales—Psychologic Distress and Psychologic Well-Being; and an overall Mental Health Index. For each item, subjects rated the frequency or intensity of a psychological symptom during the previous month. All items except two used a six-point response scale; two of the items used five-point response scales.

STATISTICAL ANALYSES. Comparisons of HR, HRV, and fitness measures at baseline and after 8 weeks of

HR cycle training were analyzed using the Student *t* test for paired observations. In order to use parametric statistics, which require near-normal distributions, HRV data were transformed to their natural logarithms. Systolic and diastolic blood pressure (SBP and DBP) (recorded at the time of the cycles exercise test) at rest and during recovery, before and after cycles training, were compared using a two-way repeated measures analysis of variance. The Wilcoxon signed rank test was used to determine pre- and postprogram differences on all scales of the MHI. Statistical significance is defined as $p<0.05$.

Table II. Exercise prescription for a subject who achieved a peak heart rate (HR) of 176 beats/min on her baseline cycles test. The numbers listed below are the HR goals for each cycle.

Monday	Wednesday	Friday
Week 1 — 6 A.M.–9 A.M.		
107	111	115
125	131	134
137	149	148
147	5-Minute break	153
5-Minute break	145	160
143	153	
151	158	
156		
Week 2 — 6 A.M.–9 A.M.		
112	116	120
130	136	139
142	154	153
152	5-Minute break	158
5-Minute break	150	165
148	158	
156	163	
161		
Week 3 — 9 A.M.–NOON		
123	126	129
144	147	152
152	155	160
161	164	170
167	169	
Week 4 — 3 P.M.–6 P.M.		
132	135	138
147	150	154
155	162	162
168	167	167
159	172	175
169		

The time windows indicate the hours during the day in which exercise sessions were conducted.

Results

DESCRIPTIVE DATA. Eleven subjects were recruited for this study. One of the subjects developed nausea and emesis in response to cycles testing during the first set of cycles. This subject did not continue with the prescribed exercise program. The baseline characteristics of the 10 subjects who completed the protocol are shown in Table III. The peak Vo_2 levels of the subjects are consistent with those of untrained healthy women.

MAXIMAL CARDIOPULMONARY EXERCISE TEST. Results of treadmill testing at baseline and after completion of the training are shown in Table IV. Peak Vo_2 increased by 14.8% ($p<0.0001$). As seen in Figure 2, nine of the 10 subjects improved their peak Vo_2. Vo_2 at the ventilatory breakpoint also increased significantly ($p<0.003$) after training.

CYCLES TESTING. The peak HR achieved during cycles testing averaged 99% of the peak HR achieved on the maximal treadmill test. Training was not associated with a change in resting SBP (125±14 vs. 124±14 mm Hg) or postexercise recovery SBP (123±15 vs. 125±15 mm Hg). DBP was significantly lower after training in both the pre-exercise resting (79.4±8.4 vs. 73.2±7.9 mm Hg) and postexercise recovery states (73.8±14.8 vs. 68.4±10.2 mm Hg; $p<0.009$). In addition, DBP decreased approximately 5 mm Hg from resting to recovery phases ($p<0.04$) in both the trained and untrained states.

HR AND HRV. After 8 weeks of exercise, despite no significant change in mean resting HR, a reduction in mean HR at submaximal workloads was observed. At 3 minutes into the postexercise tests, mean HR was 2.4±3.5 beats/min lower than it had been on the pretests ($p<0.06$); at 6 minutes, mean HR was 4.7±5.5 beats/min lower ($p<0.03$). There was also a small but significant increase in HRV after training (Table V). Broadband measures of HRV, such as the SD of normal R-R intervals (SDNN) and the natural logarithm total power, increased ($p<0.05$). In high-frequncy power, a measure of vagally mediated R-R variability, increased 9.1% ($p<0.05$) when measured during paced breathing.

PSYCHOLOGICAL MEASUREMENTS. There was a trend toward a decrease in anxiety and an increase in general positive affect, psychological well-being, and overall mental health index after 8 weeks of cycles training (Table VI).

Discussion

This observational study is of interest from two perspectives. First, we demonstrated the feasibility of implementing a type of cyclic exercise protocol. This new approach is attractive because the three-times-per-week sessions are brief, reproduce the activation-recovery waves of many forms of spontaneous, vigorous physiologic activity, and consist of individually tailored exercise parameters. Second, we found that a short (8-week) course of this protocol in healthy adult women is associated with evidence of enhanced cardiorespiratory fitness and autonomic function, as well as subjective assessment of quality of life.

CARDIOPULMONARY FITNESS. Increases in peak Vo_2 generally range from 15%–20% following traditional short-term endurance training programs.[13] The increase in peak Vo_2 (Table IV) observed in this 8-week study is consistent with these reports. The cycles training program protocol described here, however, more closely resembles interval (or intermittent) training than continuous training, since cyclic training involves repeated bouts of high-intensity exercise of short duration separated by rest periods (or relief intervals). Although the effects of interval training have primarily been studied in young, healthy subjects and highly-trained male athletes,[14–16] a few studies have examined the effects of interval training on exercise capacity in sedentary women,[17] in patients after coronary bypass surgery,[18] and even in patients with left ventricular dysfunction.[19] Burke et al.[17] demonstrated that a 7-week interval training performed at 85%–95% of Vo_2 resulted in a 5% increase in peak Vo_2 and a 19% increase in VB in active, young women. Meyer et al.[19] demonstrated that peak Vo_2 increased significantly (from 12.2 to 14.6 mL/kg/min) after only 5 weeks of a moderate-intensity interval training program performed for 15 minutes five times a week in patients with chronic heart failure. Thus, increases in peak Vo_2 and VB can be attained with interval training in less than 8 weeks.

With conventional interval training protocols, exercise and rest parameters are based on pre-established values (such as running at a designated speed for a specific time interval), and the duration of rest is expressed as a ratio of exercise time to recovery time. In contrast, cycles training involves an individual prescription based on the physiologic parameter of HR. The intensity of the exercise intervals is determined by the subject's HR response to maximal exertion, similar to the way intensity of exercise can be prescribed from a maximal exercise test. However, in the case of cycles training, each exercise burst lasts until HR reaches a target value based on the individual's maximum HR. Each recovery period then lasts until the HR decelerates to a stable value. The achievement of an HR nadir after each cycle contrasts with traditional exercise regimens that do not incorporate such individualized periods of steady-state HR recovery. Thus, the entire protocol can be individually tailored to each subject's physiology, as shown in the example in Table II. Whether these fuller relaxation periods that follow pulsatile bursts of activation during cyclic exercise actually facilitate salutary physiologic responses, such as enhanced vagal recovery, requires further evaluation.

BLOOD PRESSURE RESPONSE. Aerobic exercise results in small reductions in resting SBP and DBP among normotensive adults.[20] In this study of healthy

Table III. Subject Characteristics (n=10)

	Mean±SD	Range
Age (years)	47.3± 7.3	32–58
Height (m)	1.67± 0.08	1.52–1.78
Weight (kg)	76.6± 12.6	55–96
Body mass index (kg/m ^{2})	27.2± 3.4	21–34
Vo_2 peak (mL/min $^{-1}$)	1882± 311	1606–2561
Vo_2 peak (mL/min $^{-1}$/kg $^{-1}$)	24.8± 3.6	20.1–30.4
% Pred Vo_{2max}	92.8± 10.0	73–110

Vo_2=oxygen consumption; % Pred Vo_{2max}=percent predicted maximal oxygen consumption, using the prediction equations from Wasserman et al.[10]

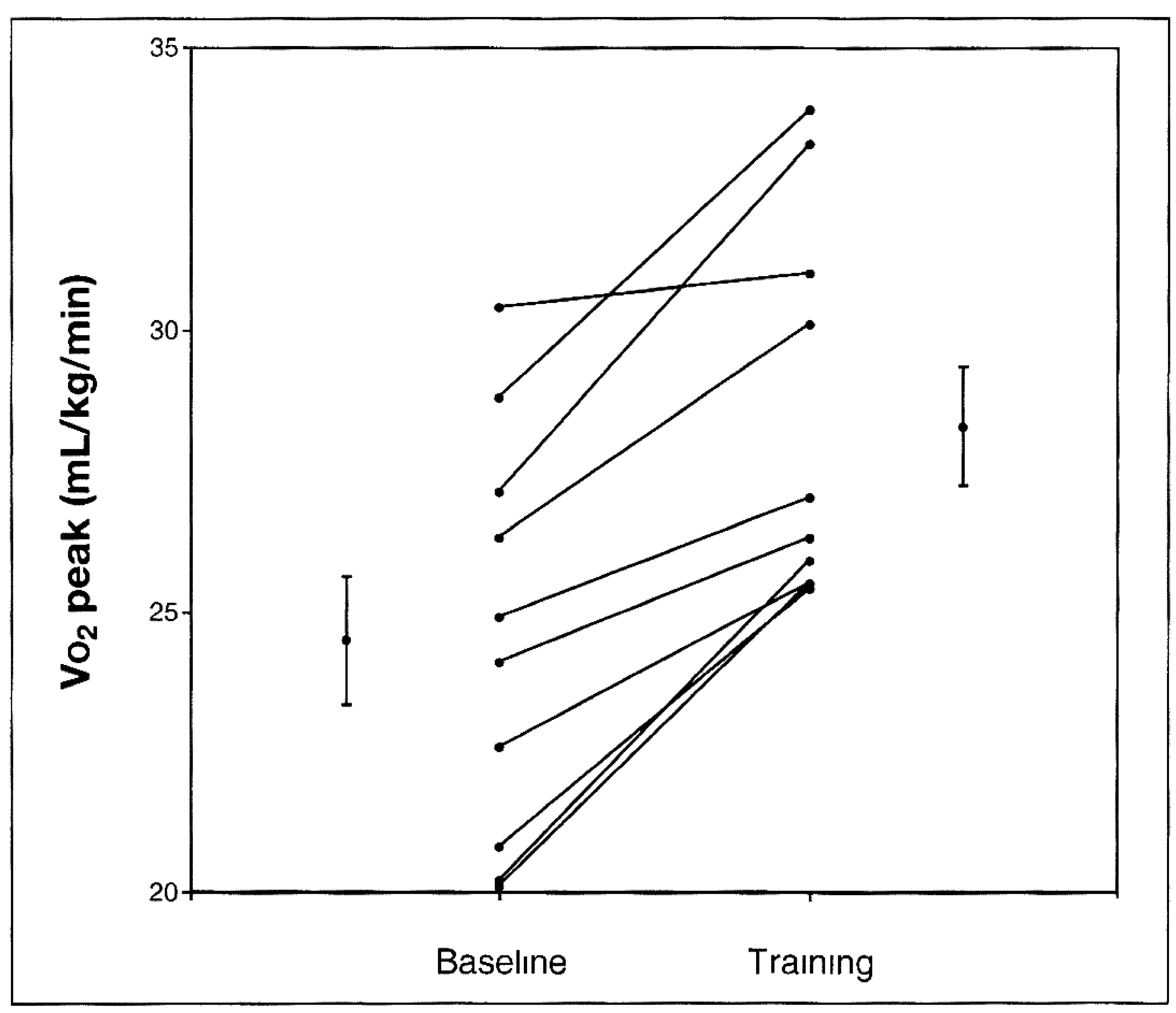

Figure 2. Individual values for peak oxygen consumption (Vo_2 peak) at baseline and after cycles training

Table IV. Cardiopulmonary Exercise Results Before and After Cycles Training

	Pretraining	Post-Training	*p* Value
Weight (kg)	76.6± 13.6	76.7± 13.2	<0.85
Peak Vo_2 (mL/min^{-1})	1882±311	2161±361	<0.0001
Peak Vo_2 (mL/min^{-1}/kg^{-1})	24.8±3.6	28.3±3.3	<0.0001
Peak Vo_2 (% pred max)	93±11	108±10	<0.0002
Peak HR (beats/min)	170.2±7.5	174.4±11.4	<0.14
Peak RER	1.08±0.07	1.06±0.03	< 0.30
Vo_2 at VB (mL/kg/min)	15.1±2.4	17.1±2.4	<0.0003
Vo_2 at VB (% peak)	60±8	60±9	<0.86

Vo_2=oxygen consumption, % Pred Vo_{2max}=percent predicted maximal oxygen consumption, using the prediction equations from Wasserman et al.[10]; HR=heart rate; RER=respiratory exchange ratio; VB=ventilatory breakpoint

Table V. Heart Rate Variability

Paced Breathing	Pretraining	Post-Training	*p* Value
Average R-R interval (msec)	839± 147	864± 151	<0.30
HR (beats/min)	73.6± 13.9	71.5± 13.6	<0.30
SDNN (msec)	40.3± 20.6	49.2± 26.9	<0.04
Ln total power (0–0.4 Hz) (msec^2)	7.12± 1.08	7.53± 1.13	<0.05
Ln LF power (0.04–0.15 Hz) (msec^2)	5.23± 1.104	5.49± 090	<0.17
Ln HF power (0.15–0.40 Hz) (msec^2)	5.95± 1.56	6.47± 1.54	<0.05

HR=heart rate; SDNN=standard deviation of normal R-R intervals; Ln=natural logarithm; LF=low-frequency; HF=high-frequency

women, resting SBP was not altered by cycles training but resting DBP was approximately 5 mm Hg lower after training. The mechanism underlying this small but statistically significant effect is unknown, but is most likely related to a fall in peripheral resistance.

HR DYNAMICS. Despite the relatively short period of exercise training, there was a reduction in submaximal exercise HRs consistent with a training effect, as well as modest increases in HRV. Several longitudinal training studies have demonstrated an increase in various parameters of HRV with training.[21-23] However, the mode of training implemented in these previous studies was continuous endurance exercise, and the duration of the training was usually greater than 6 months. One study[24] demonstrated increases in HRV after only 6 weeks of continuous, high-intensity training performed four times per week in young, healthy subjects. To our knowledge, there are no published studies that have specifically examined the effects of interval training on measures of HRV. Of interest, the increases in HRV observed in this study were not accompanied by a significant decrease in average HR. It is possible that the total amount of exercise performed during this 8-week program was insufficient to elicit changes in mean HR in this short time, while the emphasis on recovery training resulted in earlier changes in certain parameters of HRV.

PSYCHOLOGICAL MEASUREMENTS. Several studies have found that physical training is associated with increases in general well-being[25] and reductions in tension and perceived stress and anxiety[26] among subjects without mental health disorders, while other studies have reported limited[27] or no mental health benefits.[28] In this 8-week study, healthy adult women reported a trend toward an increase in positive affect and a decrease in anxiety based on a standard inventory of psychological function.

LIMITATIONS AND FUTURE DIRECTIONS. Previous studies[29,30] have suggested that sudden bursts of extremely vigorous exercise in healthy subjects may induce asymptomatic EKG evidence suggestive of ischemia. However, the physiologic and clinical implications of these findings remain uncertain.[31] In addition, mild to moderate exercise performed prior to the burst of very high-intensity exertion appears to reduce the ischemic response.[29] The protocol employed here incorporates a built-in warm-up phase

Table VI. Mental Health Inventory Before and After Cycles Training

Subscale	Pretraining Median (Min-Max)	Post-Training Median (Min-Max)	*P* Value
Anxiety	15.5 (12–23)	13.5 (10–24)	<0.08
Depression	6 (4-10)	5 (4–11)	<0.62
Loss of behavioral/emotional control	13 (10-16)	12 (10-18)	<0.67
General positive affect	45.5 (29-52)	50.5 (32–54)	<0.06
Emotional ties	10 (6–12)	10 (6-12)	<0.75
Life satisfaction	5 (4–6)	5 (3–6)	<0.65
Global Mental Health Scales			
Psychological distress	41.5 (30–50)	34 (26–59)	<0.17
Psychological well-being	66 (42-73)	71 (47–74)	<0.10
Mental Health Index	191 (161-209)	202.5 (154–214)	<0.10

during which subjects "ramp up" their HRs prior to the more vigorous cycles when they attain near maximal HRs (Figure 1). None of the subjects, all of whom had been screened with maximal exercise tests, complained of chest discomfort during the cycles protocol. However, one of the women was unable to complete the protocol because of recurrent nausea, as part of a probable vasovagal type response to the more intense bursts of exercise.

This preliminary observational study was designed to test the feasibility and efficacy of a new type of cyclic exercise in healthy subjects and not as a controlled comparison of different exercise regimens. However, our findings do create a basis for future investigations to determine whether cyclic exercise has specific advantages over more traditional aerobic or interval protocols with respect not only to cardiovascular fitness, but also to neuroautonomic dynamics and psychological well-being. The pulsatile, physiologically "tailored," and self-monitored nature of this protocol makes it particularly attractive for study in subjects who may have been excluded from, or noncompliant with, conventional exercise programs because of lack of stamina or motivation. ■

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Conflict of Interest: LifeWaves International holds patents on the kind of cyclic exercise program described in the study. Drs. Dardik, Reisman, and Hagberg are, at least in part, employees of that company. The results of this study are not an endorsement by the authors of any specific exercise program, or of any associated equipment.

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