High Intensity Interval Training vs. Continuous Cardio Training:
Battle of the Aerobic Titans

By Len Kravitz, Ph.D. and Micah Zuhl, M.S., lkravitz@unm.edu, www.drlenkravitz.com

I. Brief history of high intensity interval training (HIIT) history

A. Hannes Kolehmainen, 1912; Olympic Champion from Finland, Gold medal in 5,000m and 10,000m; world record in 3,000m; used interval training (5-10 repetitions, 1000m or 3min 5sec, 19km/hr or 11.78mph, recovery not known)

B. Pavoo Nurmi, 1920-1930; Olympic Champion from Finland, won 9 Gold medals in 1,500m, 3,000m, 5,000m, 10,000m, and Steeplechase; used interval training (6 repetitions, 400m, 24km/hr or 14.88mph, did this workout within 10km-24km (6-15mile) runs, introduced short intervals)

C. Emil Zatopek, 1950's; 1952 Olympics won 5,000m, 10,000m, and Marathon; (up to 100 repetitions, 400m, 20km/hr or 12.4mph, 200m recovery)

D. First scientific publication on HIIT in 1959 by Reiundell and Roskamm

E. Saltin, B. and Astand, P., 1960. Swedish physiologist who began intense study of interval training. Introduced intervals as % of VO_2max (30min, 15sec runs, 15sec rest, 100% speed of VO2max intensity)

F. Edward L. Fox, 1967. Interval training for military purpose; compared the physiological response for a recovery run or passive complete rest; suggested to alternate the work intervals with rest, rather than running; felt it restores phosphocreatine reserves better; scientists later suggest otherwise

G. Metabolic adaptations, 1970's. Researchers around world begin study of metabolic adaptations of interval training. Muscle enzymes of interest include ATPase, creatine kinase, adenylate kinase. Jonas Bergstrom and introduction of biopsy needle made metabolic research a viable science.

H. Coaches use HIIT in 1980's. Sebastian Coe was trained by his father Peter, who was very inspired by scientific methods. He performed aerobic and anaerobic interval training as well as circuit training for strength and power improvement. Seb Coe was an 800m to 1500m runner who won four Olympic medals.

I. Said Aouita in 1980's. The great middle-distance runner (who held World records for the 1500m, 2,000m, 3,000m, and 5,000m); he won the 5,000m at the 1984 Summer Olympics. Intervals with different speeds.

J. Grete Waitz in 1980's. Nine-time winner of New York Marathon. Two world records in the 3,000m and World Champion in the marathon in 1983. She utilized a combination of Fartlek, short intervals, long intervals, tempo training and distance runs.

K. HIIT in 2000 to 2012. More sport application (tennis, handball, soccer, rugby, American football, etc.). Clinical application (COPD, cardiac patients, diabetes). Molecular research focused on solving questions on metabolism and bioenergetic effects of HIIT.

II. Brief history of continuous cardiovascular exercise

A. Phidippides in 490 B.C. What is called the Marathon today gets its name from the 280-mile distance he covered in 3-4 days from Athens to Sparta and then back to Marathon. He was sent to gain the help of the Spartans against the attack of the Persian army in Marathon.

B. Marathon at Olympic Games. Marathon changes to 26 miles in 1908. After 16 yrs., in 1924 the Marathon was established at 26.2 miles. Run in Paris Olympics in 1924 for the first time. Albin Stenroos from Finland was the Men's Olympic Marathon Champion on July 13, 1924. His time was 2:41:23.

C. Women's Marathon at the Olympic Games. The women's Marathon was introduced in the 1984 Summer Olympics (in Los Angeles, CA, USA). It was won by Joan Benoit of the USA. Time 2:24:52.

III. Cardiovascular physiology 101: Key terms

A. Maximal oxygen consumption (VO_2max): The maximal rate of consumption, distribution and utilization of oxygen in ml oxygen/kg/min.

B. Heart rate max (HRmax), maximal HR. The highest heart rate one can achieve during graded exercise. Many estimations: 208-(0.7xAge), 220-Age, 206.9-(0.67xAge)

C. Stroke volume (SV): Blood pumped beat by each heart ventricle. Average at rest from 70ml-80ml each beat.

D. Cardiac output: (CO)=HRxSV. Resting CO: 75beat/min x 70ml/beat = 5.2L/min
Exercise CO: 180beat/min x 120ml/beat = 22L/min

E. Peak power: The maximal power output measured in watts. Typically performed on a cycle ergometer.

F. Exercise intensity in HIIT: A percentage of maximal effort. Examples are 95% of VO_2max (VO_2max x .95); 85% Peak Power (Peak Power x .85); 75% HRmax (HRmax x .75)
G. HIIT Intervals: The exercise intervals are the work bouts of exercise that range from 5sec to 8min. The rest interval is the recovery between exercise intervals and can be quite variable.
H. Work/Rest Ratio. Scientists and coaches look at the relationship of the exercise interval and rest interval. An exercise interval of 1min and a rest interval of 4min is a Work/Rest ration of 1-to-4. An exercise interval of 5min and a rest interval of 5min is a Work/Rest ratio of 1-to-1.
I. E.P.O.C. represents the Excess Post-Exercise Oxygen Consumption (called the 'exercise after burn'). Factors that E.P.O.C. include creatine phosphate (CrP) replenishment, metabolism of lactate, temperature recovery, hormones recovery. The oxygen consumed to bring physiological variables (above) to pre-exercise. Research shows that HIIT programs have very high E.P.O.C. Kravitz 'blender' explanation 'Why'.
J. Capillary density: a proliferation of capillaries in skeletal muscle (5-15% increase)

IV. Cardiovascular physiology 101: Key concepts
A. Overview of heart as it sits in the thoracic cavity
B. Overview of heart pumping blood through the pulmonary and systemic circuits
C. The heart is really two independent pump systems that work simultaneously together. Blood moves along a pressure gradient (higher to lower pressure). It is the pressure that causes the heart valves to open.
D. Video overview of cardiac cycle. Children's Hospital of Philadelphia (www.chop.edu)
E. View of actual myocardium comparison of right and left ventricle. Overview of sinoatrial (SA) node.
F. Heart rate influenced by medulla oblongata. This is the cardiovascular control system
G. Sympathetic nervous system increases HR and blood pressure. Parasympathetic nervous system inhibits HR and blood pressure. With exercise there is a large increase of sympathetic activity accompanied by a decrease in the parasympathetic systems inhibiting mechanisms.
H. HR adaptations with chronic exercise. HR in trained individuals will be lower as compared to untrained persons. This is because trained individuals have much GREAT stroke volume adaptations to exercise.
I. EDV represents end-diastolic volume (describing the filling of the ventricles)
J. ESV represents end-systolic volume (describing blood left in ventricles after ejection)
K. EDV – SV = ESV; EDV - ESV = SV; ESV + SV = EDV
L. EDV (is diastole, also called preload); SV (is systole; afterload describes the pressure that the chambers of the heart must generate in order to eject blood out of the heart).
M. SV, in untrained persons ranges from 40-60% of VO_2max; however, it is much higher in trained persons
N. During exercise, the vascular compliance or elasticity of vesicles increases (in healthy persons) thus less mean arterial pressure. This really helps to enhance SV during exercise in trained persons.
O. Contractility affects SV as well. During exercise the peripheral muscles contract harder, thus increasing venous return-EDV-heart stretch-and SV
P. Contractility of the heart increases too. The heart is a muscle and during CV exercise it contracts harder.
Q. Summary of benefits of CV responses and adaptations to HIIT and endurance training: increased heart size (thickening of cardiac muscle), increased heart contractility, increased cardiac output, enlarged ventricle volume, decreased resting heart rate, decrease submaximal exercise heart rate, increased venous blood return to the heart, improved aerobic capacity in healthy persons and those with cardiovascular disease, lowered resting blood pressure (when elevated), improved stroke volume, increased VO_2max

V. Metabolic adaptations
A. Where is fat completely oxidized in cells? Mitochondrion (think of it as a fat burning fireplace)
B. With cardiovascular and HIIT training mitochondrial density increases: the mitochondria get 35% bigger and can reproduce up 15-50% more
C. Metabolic model diagram: In this model calcium–calmodulin kinase (CaMK) and adenosine monophosphate kinase (AMPK) are signaling pathways that activate peroxisome proliferator-activated receptor-g coactivator-1α (PGC-1α). PGC-1α is like a "master switch'' that is believed to be involved in promoting the development of the skeletal muscle function (increase in fat oxidation, increase in GLUT4 and glycogen, increase in mitochondrial density, increase in slow-twitch muscle fibers oxidative capacity.

High-volume training appears more likely to operate through the CaMK pathway and HIIT appears more likely to signal via the AMPK pathway.

VI. HIIT and CV Conditioning programs: Special suggestion: to prevent overuse and overtraining, complete programs on different modes of exercise

1) TRACK (OR TREADMILL) HITT

Warm-up: Light 10min run
Interval: 800meter runs at approximately 90% of maximal heart rate
16-17 on 6-20 ratings of perceived exertion scale (RPE scale) which is 'Hard to Very Hard"
Each 800meter interval should be timed
Rest Interval: Light jog or walk for same amount of time it took to run each 800meter
Work/Rest ratio: 1-to-1 ratio. The time for the interval (800meter) and rest interval should be the same
Frequency: Try to complete 4 repetitions
Modify: The distance of the interval can be adjusted from 200meter to 1000meter. Vary length of the rest interval.
Adapted from Musa, D.I., et al. (2009). The effect of a high-intensity interval training program on high-density lipoprotein cholesterol in young men. Journal of Strength and Conditioning Research, 23(2), 587-592.

2) HILL TRAINING HITT

Warm-up: 10min of light jogging
Interval: Set treadmill incline at 5%-8% grade and speed at 3 mph. During each interval increase speed to 5 mph – 6.5 mph, while keeping grade at 5%. The length of the interval should be 1min.
Rest Interval: Self-selected speed. Do not adjust incline.
Work/Rest Ratio: 1-to-2 ratio. The work interval is 1min and the rest interval is 2min
Frequency: 3-6 intervals
Cool Down: 5 – 10min of easy jogging
Comments: This is a hill running interval session. Modify incline, running speed, interval length, and rest interval.
Adapted from Seiler, S., and Hetlelid, K.J. (2005). The impact of rest duration on work intensity and RPE during interval training. Medicine & Science in Sports & Exercise, 37(9), 1601-1607.

3) COMBINATION HITT AND CV CONDITIONING

Warm-up: 10min of light exercise
Interval: 30seconds of sprinting (any mode)
Rest Interval: 30second rest
Work/Rest Ratio: 1-to-1 ratio. The work interval is 30seconds and the rest interval is 30seconds
Frequency: Preformed continuously for 20-30min
Note: After completion of interval session perform a 20-30min slow jog or walk at 50% HRmax
Modify: Complete on multiple modes (cycling, elliptical training, running, rowing, stair stepping, etc.)
Adapted from Seiler, S., and Hetlelid, K.J. (2005). The impact of rest duration on work intensity and RPE during interval training. Medicine & Science in Sports & Exercise, 37(9), 1601-1607.

4) STEP-WISE INTERVAL TRAINING

Protocol: Start at a relatively easy workload (cardiovascular warm-up) for 5min of exercise and then increase intensity about 10-15 percent. At the end of each subsequent 4min exercise stage increase the work load about 10-15 percent for the first 4min training period. This program can be halted when a particular intensity level is reached or a specific duration is attained. Try completing step-wise UP and step-wise DOWN sequence.
Intensity: The initial work intensity should be about an RPE of 11. Then, depending on the means of increasing the intensity on the mode (i.e., speed, grade, stride, etc) increase the intensity roughly 1 RPE with each subsequent 4min stage (i.e., program starts at an RPE of 11; after 4min the intensity becomes a 12; after 4min the intensity becomes a 13; after 4min and intensity becomes a 14. Do until a specific time/intensity is attained.
Duration: Duration should follow ACSM (2006) guidelines, which recommend 20-60min
Adapted from Jacobs and Sjodin (1985). Relationship of ergometer-specific VO_2max and muscle enzymes to blood lactate during submaximal exercise. British Journal of Sports Medicine, 19, 77-80.

5) CONTINUOUS INTERVAL TRAINING

Warm-up 5-10min of light exercise
4-8 continuous endurance intervals
Each interval is 4min followed by a 4min low-intensity rest (12min/mile)
Each successive interval is at a faster pace: Let's look at an example
1) 10min/mile
2) 9:30min/mile

3) 9:00min/mile
4) 8:30min/mile
5) 8:00min/mile
Complete on multiple modes
Adapted from Akubat, I. et al. (2011) Intermittent exercise alters the heart rate-blood lactate relationship used for calculating the training impulse (TRIMP) in team sport players. Journal of Science and Medicine in Sport / Sports Medicine Australia,14(3), 249-53.

6) METABOLIC BASE TRAINING
Warm-up: 5-10min
Protocol: Perform continuous submaximal aerobic exercise on the selected mode
Intensity: Intensity is 65% of VO_2peak which would be about a 14 RPE (Somewhat Hard)
Duration: Duration is 40-60min of sustained cardiorespiratory exercise
Called metabolic base training because it increases mitochondrial density
Adapted from Burgomaster, K. et al. (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. Journal of Applied Physiology, 586(1), 151-160.

7) MAXIMAL LACTATE THRESHOLD TRAINING
Warm-up: 5-10min of light-to-moderate intensity exercise
Protocol: Continuous aerobic exercise at 70-85% VO_2max (14-17 RPE or Somewhat Hard to Hard)
Duration: 30-60min on any mode: Also referred to as Maximal Steady State Training
Adapted from Smith, J. and McNaughton, L. (1993). The effects of intensity on excess post-exercise oxygen consumption and energy expenditure of moderately trained men and women. European Journal of Applied Physiology, 67, 420-425.

8) CONTINUOUS CV TRAINING WITH TWO BIG EFFORTS
Warm-up:10min of light exercise
Workout: A low to moderate intensity 30-50min continuous run at 60% - 70% heart rate max.
At any time during the workout (beginning, middle or end) perform two Maximal Speed Efforts lasting 2min.
Modify: Complete on multiple modes
Adapted from Smith et al. (2003).Optimising high-intensity treadmill training using the running speed at maximal O_2 uptake and the time for which this can be maintained. European Journal of Applied Physiology, 89(3-4), v337-343.

9) THE THREE 1-MILE WORKOUT
Warm-up: 5min of light jogging
Workout: Workout is three 1-mile bouts with a 5-minute active rest between each mile. The first mile should be at fast pace (record time). The second mile should be at slower pace and intensity than the first mile. The goal of the final mile is to complete it in the same time as the first mile.
Interval: one-mile
Rest Interval: 5min of low intensity running between mile bouts
Modify: Any mode of exercise can be substituted for running
Babineau et al. (1997). Physiological response of 5/1 intermittent aerobic exercise and its relationship to 5km endurance performance. International Journal of Sports Medicine,18(1), 13-19.

QUESTIONS AND FABULOUS FEATS
Q: How many times per week can HIIT be completed?
A: Research says that three times per week may produce the best results while limiting injury. Interval training is very demanding and it is important to be fully recovered between sessions.
Fabulous Feats: The official International Association of Athletics Federations world Marathon record for men is 2:03:59, set by Haile Gebrselassie of Ethiopia. The women's record holder in the marathon is Paula Radcliffe of the United Kingdom in a time of 2:15:25.
Q: If a client has been inactive for several months is it safe to start an exercise program with HIIT?
A: There should be a careful progression of activity when re-starting any exercise program. Beginning with HIIT may increase the chance for injury and muscle soreness. A better approach would be to start with continuous aerobic exercise at a low intensity level. Once able to run for 30min at a moderate intensity he/she can then progress slowly into interval training.
More Fabulous Feats: The longest certified road race in the world is the 3,100 mile Self-Transcendance Race in NYC. The longest bicycle race is the Tour d'Afrique, which is 12,000 km (7500 miles) and 120 days traveling from Cairo, Egypt to Cape Town, South Africa. One of the longest swims ever was recorded by Martin Strel in 2009. The Slovenian man swam the length of the Amazon River (3,272 miles) in 66 days.
Final Quiz: Which program do you feel is superior in the following cardiovascular and metabolic adaptations: Stroke volume_____, heart contractility_____, cardiac muscle growth_____, maximal aerobic capacity (VO_2max)_____, mitochondrial density_____, capillary density_____, fat burning_____, glycolytic enzymes_____, E.P.O.C. (Excess post-exercise oxygen consumption energy expenditure)_____