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The true method of knowledge is experiment.
William Blake, 1788

What's New?

What's the latest medical and scientific info about bicycling?

Do you read the ad copy in the magazines to figure out what might be worth trying? Do you look to the pro athletes, who are sponsored, and figure that if they do it or use it, it must be great? Do you rely on coaches, some of whom receive kickbacks if you buy on their recommendation? Do you ask your friends? Or do you just spend your time, effort, or money and try everything yourself?

For most of us, it's a combination of all of the above, plus a little hope. And, unfortunately, that little hope is what lots of companies cash in on when they manage for example, to sell us plain old water at a couple of bucks a gallon or more.

There's another way—the scientific way. Looking at what studies or experiments really show. The scientific way is the best way to evaluate what works and what doesn't. The scientific method is better than opinion or guessing, but it's not foolproof. Good sport science studies are hard to come by. Worse, unfortunately, there is sometimes bad science.

A complete review of what makes good science isn't possible in this article, but here are a few examples of "science" problems.

Initially, only studies showing an effect tend to be published: Few publications are interested in reporting, for example, that Vitamin *X* doesn't cure cancer. Once something has been accepted as working, then it's fair game for challenge. So it's common for some substance or training method to burst on the scene for a few years, and then have its bubble burst—by being shown not to work or having undesirable side effects. Androstenediol, androstenedione, bee pollen, chromium, medium chain triglycerides, nasal dilators, and royal jelly are now out of favor.

An interested party pays for some studies. Peanuts were reported to help ballet dancers' performance (presumably by increasing deficient caloric intake) in a study paid for by a consulting company. A company I'd guess was representing a peanut company. Peanuts may well help calorically deficient ballet dancers, but so might Häagen-Dazs ice-cream or Pop-Tarts.

Worse, imagine a company that pays for ten studies from ten different sets of researchers and advertises only the findings, perhaps obtained by chance, that promote the company's products.

Some studies appear to provide important or new information but the wrong question is being asked or answered. A year ago the recovery drink R4 was shown to provide better recovery than Gatorade when 24 ounces of either was consumed between taxing exercise bouts. Sounds promising, doesn't it? But the R4 provided almost four times as many calories. Would a couple of donuts with the Gatorade have been as good?

A problem with sport science, unlike general medicine, is that studies tend to use small groups—fewer than 20 subjects. Small groups require relatively large differences to find statistical significance.

Studies often initially appear as abstracts. These present preliminary data, are often incomplete, are less subject to peer or other review, may be withdrawn, and are often cited in promotions by sponsoring commercial companies.

Keep in mind that it's common for studies to show apparently conflicting results. For example, over the years bicarbonate loading and caffeine have been accepted as improving human performance. Newer studies have questioned that conventional wisdom.

Each study often adds just a little piece to the puzzle. It's important not to put too much faith in any one study.

I've written similar articles for the past seven years. I've culled over 2,000 abstracts, reports and papers during the last year. Here's my synopsis and occasional spin on some of the published information on bicycle-related medicine and science that came out in 2001.

Each new paragraph represents a different study.

I've summarized studies from the past 7 years at the end of this article.

Nutrition

Calories

General nutrient mix: It is commonly accepted, perhaps erroneously, that most aerobic endurance athletes should consume a diet relatively high in carbohydrates—65% to 70% of total caloric intake.

Many find this approach simplistic, and say it is more important to ingest enough carb calories to replace those lost through exercise. This often amounts to the same thing, but reflects an approach to the reasoning underlying the simplification. For example, it's not that an athlete consuming 3,000 calories per day needs 65% of calories from carbohydrates; it's that 7-10 grams/kilogram/day (2,000 carb calories for a 132 pound athlete) are needed to replace those lost during exercise.

This reasoning is also based on the premise that high-intensity exercise uses more carbs than fats, so maintaining high carb levels is crucial to high-level training and performance.

Furthering the notion that the 65% to 70% concept is simplistic, studies this year showed that marathoners and soccer players were able to get the percentage right, but based on 7-10 grams/kilogram/day, less than 20% of men and women marathoners consumed enough carbs.

Some studies have shown that high-carb diets are important only prior to events, and that a relatively high-fat diet ending a couple of days before a race may confer an advantage.

Those who consume a low-carb, high-fat diet have been shown repeatedly to have more fat utilization during exercise. The fat appears to come from muscle stores of fat or circulating fat in the blood, rather than adipose stores. Dietary patterns (high carb vs. lower-carb, higher-fat) may not degrade training when training hours are low to moderate.

At mild-moderate exercise levels, the percentage contribution from carbs and fat is the same whether the legs or of the arms are exercising. At similar higher VO_2 max levels of exercise, arm exercise uses relatively more carbohydrate than leg exercise.

A high-fat diet did not prevent interval work in seven competitive cyclists, though perceived exertion was higher.

Keep in mind that unused carbs and proteins are converted to fat. A study of nine well-trained athletes confirmed that a diet high in carbs will result in lipogenesis (conversion to fat).

Swiss Olympic athletes, in sports as diverse as badminton to triathlon, were found to have a negative energy balance—especially women (77%). The study concluded that the women would lose 77 pounds per year based on their reporting. Since elite women athletes simply do not lose that much weight a year, either the study was flawed, women underreported their caloric intakes, or they make up for within-study deficiencies at other times during the year.

Vegetarian protein was associated with the same strength-improvement responses to resistance training as beef protein.

Net protein breakdown/synthesis was balanced whether runners regularly consumed a high-protein diet or not; however there was more breakdown and synthesis in the moderate-protein group. One possible interpretation, and the one proposed by the study authors, funded by the National Cattlemen's Beef Association (NCBA), was that high-protein intake may reduce the demand for protein metabolism during exercise.

The NCBA sponsored another study that showed that high-protein intake in runners lowers post-run protein breakdown, but provides no benefit in protein utilization.

Another NCBA funded study showed that a high protein diet did not change hydration status of endurance runners—although the kidneys had to work harder.

Those who exercise more than a few hours at a time may have increased needs for protein. A study showed that during six hours of exercise protein breakdown products are three times higher during the last four hours than they are during the first two.

Some of us exercise to lose weight. The total amount of work performed, not the intensity, was found to predict 24-hour energy cost. That is to say that the same amount of work performed more quickly results in the same consumption of energy as the same total work performed slowly. Men were found to use more carbs at rest than women.

Pre-event nutrition: Simple carbs 30 minutes prior to exercise may increase insulin levels and reduce blood sugar. Some feel this may worsen performance. However, performance was not lower in a study this year.

Performance was better, though not significantly so, in a study of swimmers who ingested carb solution 30 minutes before exercise, even though insulin levels were higher and blood sugar levels were lower immediately before exercise began. Performance was better by almost two minutes when the solution was ingested just five minutes before exercise, though still not significantly—possibly because the number of subjects and statistical power of the study was too small.

In another study, neither glucose nor energy bars were associated with a hypoglycemic response.

During-event nutrition: Intake of carbs during a two-hour ergometer test increased performance and reduced fatigue.

Intake of carbs at 20 and 40 minutes into a 60-minute test enhanced the contribution of plasma glucose oxidation to total carb oxidation compared to water.

Carb drink supplementation during a 15-kilometer run resulted in 3-minute time improvements in women. Again, this improvement was not statistically significant, possibly because of too few subjects and not enough study power.

Gels and carb solutions both help maintain blood sugar levels during exercise. However the gel was less palatable and associated with more gastrointestinal distress.

Protein-carb solutions were shown to increase insulin levels more than equally-caloric carb-alone solutions. Effect on exercise was not studied.

Ultramarathoners commonly ingest too few calories and too little fluids. This was associated with documented decreases in cognitive function at the 2000 Iditasport race.

Post-event nutrition: Ingested glucose was shown to reach the blood stream more quickly 30 minutes after exercise than a day later in one study, but not in another. There was a suggestion that fructose, rather than glucose, is preferentially used by the liver to replace glycogen stores.

Protein and carb solutions post exercise resulted in greater muscle uptake of protein than either protein or carb alone. However the groups did not consume equally-caloric solutions.

We've all heard of carb loading and the glycogen window; few of us have heard of the lipid window. Perhaps this is because glycogen (stored carbs in muscle) was easier to study and was studied first. Now fat replacement after exercise has been shown to effectively restore intramyocellular lipids (fat in muscle cells) using water-suppressed nuclear magnetic resonance spectroscopic imaging.

Hydration

It is generally recommended that athletes consume enough fluids to replace sweat and urine losses during training and events. Few do.

Experienced runners replaced only 30% of an almost 2 liter (quart) loss in a 10-mile run. They underestimated their sweat loss by 46% and fluid intake by 15%.

Replacing sweat fluid losses with an equal volume of ingested fluid is insufficient to compensate for sweat losses because urine losses continue. (Studies show that 50% to 100% more fluid is required, depending upon simultaneous sodium ingestion).

Fluid loss was about 1.5 liters (quarts) during two cool (approximately 63° F) 25-mile time trials and warm-ups in which subjects drank as usual.

Perhaps traditional sports science advice is wrong about hydration and performance. More than 20% of both boys and girls lost more than 2% of body weight during a triathlon consisting of an 800 meter swim, 30-kilometer bike, and 8-kilometer run. Performance was better in the more dehydrated athletes.

One-hour cycle time-trial performance was not improved by hydration during the event.

Subjects drank more of a sports drink than plain water when the two were offered separately, and didn't drink more total fluid when given both, in a study funded by Gatorade.

Subjects preferred a sports drink with added sodium, although the level was too low to provide appreciable sodium replacement.

Urine color was found to be reliably correlated with percent dehydration during a 30-mile mountain bike race that followed a pre-exercise hyperhydration protocol.

Sweat sodium values over three collections in the same athletes were shown to vary about 20% using a standard technique.

Temperature of equal volumes of ingested water did not affect fatigue. This is not to say that the fluid temperature is not important. Athletes generally drink more when fluids are chilled.

Vitamins and Minerals

In general, studies over the last few years have found that third-world athletes often have major nutritional intake deficiencies. Industrialized-nation athletes are frequently found to have knowledge deficiencies, but their intakes are better. In athletes without nutritional deficiencies, nutritional supplements do not exhibit an ergogenic effect.

Weight-controlled athletes are often voluntarily calorically deficient (starved).

Though Canadian Olympic athletes had no known nutritional deficiencies, 62% took vitamin supplements.

US college wrestlers widely use supplements. Almost 40% take creatine, 30% protein powders, 5%

androstenedione, 15% caffeine, and 5% ephedrine. Some supplements are banned by the NCAA.

This year a study showed that physical fitness in men is correlated with vitamin usage: In a study of almost 2,000 males at the Cooper Institute in Dallas, Texas, fitter men take more supplements. This does not imply that vitamins help fitness. Rather it may suggest that fit men are advertising targets.

A study of Norwegian medical personnel and coaches found that almost half recommend vitamin supplements to their athletes; three-quarters felt deficiencies in knowledge indicated a need for more athlete education.

High school students were found to benefit from a nutritional and sports supplement program.

Wrestlers were found to have educational deficiencies especially regarding safe weight loss methods and nutritional supplements.

Brazilian male soccer players were found to have important nutritional knowledge deficiencies.

More than two-thirds of Brazilian college judo athletes were deficient in B vitamins, vitamin C, and calcium.

One-third of Brazilian tennis athletes were deficient in thiamin, riboflavin, and niacin even though 70% of them reportedly use supplements.

One half of German rock climbers failed to meet dietary recommendations for athletes. Norwegian women soccer players had good overall nutrition but deficient nutrition strategies for competition.

Several elite female distance runners had iron deficiency in a study of 32 elite distance runners conducted over two years.

Ergogenics

Performance-enhancing substances and devices.

Should these be banned? Should one be allowed to take something to make one stronger or go faster? It's not a black and white issue, and not a question that I'll discuss here. But many researchers look at these substances.

Supplements are used by over 90% of athletes in some sports. Intakes are higher in men than in women. In high school and college, progressively more athletes use supplements as academic class (freshman through senior) advances. The most popular supplements are vitamins and minerals, creatine, and protein powders.

Many studies of athletes have shown that they have important deficiencies in knowledge about supplements. In the case of vitamins and minerals, intakes over 10 times the US Recommended Daily Allowances (RDA) are common. As I point out in my book *Bicycling Medicine*, studies have shown that such excessive RDA intakes are more likely to hurt, rather than help, performance.

Supplements, unlike drugs, do not have to be proven to be safe and effective before they are marketed. There are no governmental regulatory processes unless a substance is shown to be dangerous. The US Food and Drug Administration issued warnings over the last few years about a number of supplements, marketed as sleep aids, aphrodisiacs, and muscle builders that have caused at lease three deaths and hundreds of severe reactions. Some of the brand names include Revitalize Plus, Serenity, Enliven, GHRE, SomatoPro, NRG3, Thunder Nectar, and Weight Belt Cleaner. The diet-pill company Metabolife was sued for its (legal, unregulated) use of ephedrine in its products—a substance linked to seizures, brain damage, stroke, and as many as 17 deaths.

A study two years ago found that in one high school about 20% of male and 1% of female athletes used performance enhancing substances. When asked whether they would take such substances if they would guarantee a college scholarship but take 20 years off of their lives, 6% said “yes.”

A sample of competitive bodybuilders found that supplement levels were so high as to place the group at high risk for specific nutrient toxicities.

Substance abuse among high school athletes was found to be higher than for the general high school population. More than one-fifth of the athletes reported having been drunk and 25% having been drinking and driving in the last month.

5-methyl-7-methoxyisoflavone-treated subjects had a decrease in percent body fat in a study that also found placebo-treated healthy, resistance-trained men who maintained consistent training and dietary habits significantly increased their percent body fat. Why percent fat increased in the placebo group when diet and exercise were supposedly constant was not explained.

A proprietary *amino acid supplement* was found to reduce some hormonal changes normally associated with overtraining in a study sponsored by the manufacturer.

Anabolic Steroids. A 39-page document summarizing studies of anabolic-androgenic steroids in basketball, biathlon, rowing, weight lifting, and track and field in the former Soviet Union was revealed in the West this year.

4-androstenediol topically was found to elevate blood testosterone levels.

Androstenedione was not effective in raising total testosterone levels in males aged 40-48 years.

Androstenedione again was shown to convert to estrogens (“female hormones”) and cause estrogenization (“feminization”).

Clenbuterol is an asthma-like drug thought to have anabolic effects. It is a relatively commonly-used banned substance. A study in horses showed that chronic use may worsen aerobic performance and recovery.

Norandrostenedione and *norandrostenediol* in moderate doses had no effect on body composition or strength.

Testosterone was found to increase muscle strength, power and endurance, but not aerobic capacity, in a dose-dependant fashion. An upper limit of benefit was not found. Caution: Anabolic steroids are banned in most sports and side effects of are well-known, including risk of cardiovascular disease.

Antidepressants (selective serotonin reuptake inhibitors) are thought to possibly improve athletic performance by reducing negative hormonal consequences of overtraining. A study examining one-time use prior to exercise found no change in 90-minute time-trial performance.

*Asthma medication*s. *Formoterol* had no effect on cycling performance in non asthmatics.

Bovine colostrum (the early milk-like product of new cow mothers) is an expensive and controversial supplement used by Australian Institute of Sport cyclists, among others. A study this year found that supplementation did not increase human growth hormone or insulin-like growth factor.

Caffeine has been touted as an ergogenic aid—however the mechanism by which it helps is not certain. Some reports have suggested it helps glycogen use; others suggest that it improves the function of the central nervous system.

Several caffeine protocols were studied and reported this year. In 30-minute time trialing cyclists, both 6 mg/kg caffeine one hour before exercise as well as ingestion of 5 mL/kg Coca-Cola at 10 and 20 minutes during exercise helped performance by about 3%.

Caffeine resulted in what turned out to be a poor pacing strategy in a 100-kilometer cycling test of anaerobic and aerobic performance. Riders began too quickly; they later faded. Caffeine effect on blood pressure and heart rate was less during aerobic work than during resistance training.

L-Carnitine supplementation reduced some measures of oxidative stress in response to exercise in a study paid for by a biotech company that manufactures it.

Creatine. For the last few years creatine has been one of the hottest ergogenic aids. Over the years, the consensus has been that it will not help aerobic performance activities such as most bicycling events. It may or may not work for sports with repeated anaerobic efforts such as track bicycling.

Creatine is not without potential side effects. Studies have suggested that:

- Creatine may be a problem in the heat—it may be related to cramping and injury. Some studies show this, others don’t.
- It may increase blood pressure.
- It may increase compartment pressure. Pressure within a confined space may reduce blood flow.
- Creatine seems to increase body weight—probably not good for climbers.
- It may increase the risk of dehydration.
- It may cause upset stomach.
- It may cause muscle strain.
- It may cause kidney and liver damage.

Studies this year also showed that creatine:

- Helped maintain testosterone levels, and prevented an increase in uric acid.
- Improved performance for 15-second bicycle intervals.
- Did not adversely affect heat regulation, although BUN (blood urea nitrogen, a waste product of protein metabolism) was higher in the creatine group.
- Ingestion with glucose may improve creatine’s effect.
- Did not change vertical jump, anaerobic speed, peak power, fatigue, or blood lactates.
- Helped competitive squash players improve drill times.
- Improved female performance more than male performance in a fatigue test of knee-extension exercise.
- Use was found in 53% of Division IA football and 54% of Division I baseball players. Improved peak torque production during 50 consecutive maximal knee extensions.

- Did not alter mean or peak power output during four 45-second supramaximal cycling bouts.
- Improved some measures of swimming performance in 50- and 100-yard sprints.
- Was not associated with kidney or liver damage in a 21-months study.
- Was more likely to be helpful in younger than in older subjects.
- Had minimal strength effects in female baseball players.
- Increased compartment pressure.
- Combined with resistance training improved bone mass in a group of older men more than resistance training alone.

Cycle summary: Creatine may or may not help track sprinters. It probably won't help anybody else.

Nasal dilators (Breathe-Right) had no effect in three more studies this year.

Omega-3 and *medium-chain triglycerides* had similar interactions with strength training in promoting body weight changes and muscle hypertrophy.

Oxygenated water. One study this year showed that oxygenated water benefited highly-trained cyclists. Whether there can possibly be any help from this product is doubtful. As one physician put it:

"We need to know just two numbers: the solubility of oxygen in water and the oxygen requirements of players. Well, one liter of tap water contains about eight milligrams of dissolved oxygen. Four times that, which the company claims, would be about 32 milligrams. A trained athlete playing hard will use something like 130 milligrams every second. To get only a one percent boost, therefore, players would have to chug one liter of oxygenated water every 25 seconds. The technical term for this is drowning."

Ribose improved sprint performance in a group of cyclists, in a study that was probably supported by the manufacturer.

Sodium phosphate no effect on anaerobic or aerobic cycling performance.

Equipment

A talking heart-rate monitor was shown to be a valid and reliable instrument in a study funded by the manufacturer.

There was a fad a couple of decades ago: Male cyclists wore pantyhose to improve performance. A study this year showed that compressive garments improved some track events in a study supported by the manufacturer.

A commercially-available body fat scale resembling a typical bathroom scale was found to give higher body fat estimates and have greater variability than underwater weighing, skin fold, or bioelectrical methods.

Cotton shirts resulted in more heat stress than running bare-chested or in nylon in a group of men.

An altitude tent was found to result in 88% relative humidity. Baseline relative humidity was not reported.

A hydroweave vest cooled with tap water reduced sweat loss, resulted in lower core body temperature, and reduced perceived exertion in a one hour cycle-ergometer study performed in a lab.

Magnets did not change heart rate, skin temperature, blood pressure, oxygen consumption, or ventilation in a study of 11 women.

Physiology

Physiology—Aging

The age-related decline in masters performance of 78 triathletes appeared linear from ages 20 though 60 and was present in bicycling, swimming, and running.

When compared with age alone, age plus training time was not found to be a better predictor of finish time between 10-year age groups of masters triathletes. However, overall the groups trained about the same number of hours.

Physiology—Blood

Those who exercise have more total (oxygen-carrying) hemoglobin than those who do not. High-altitude residents have more total hemoglobin than those at sea-level. Athletes who reside at altitude have the most—60% more than non athletes at sea level.

Athletes with high training volumes increase blood volume during the training year, mostly as a response to an increasing plasma. The German professional cyclists studied also increased red-blood cell volume.

A previous study suggested that running at altitude might produce more of a stimulus for clot formation via increased thrombin production than running at sea-level. Increased thrombin was not demonstrated in a study reported this year.

Women participating in Ore-Ida confirmed what has been previously shown about blood parameters in men: hemoglobin and hematocrit decrease during stage races.

Incremental exercise is associated with an incremental increase in blood potassium and an exponential increase in blood hydrogen ion.

Lactate levels at maximal lactate steady state (MLSS) were found to vary between 1.5 and 6.3 millimoles in a group of twelve trained men.

Some of the increase in blood lactate at high exertion levels relates to decreased processing by the liver as hepatic blood flow decreases.

Physiology—Blood Vessels

Artery size increases in response to training. This is a regional rather than general response to training, as shown by a study of one-legged cycling. Only blood vessels supplying the trained leg increased in size.

Arteriolar dilation effects of running were confined to trained (leg) muscles. Untrained (arm) muscles showed no changes.

Physiology—Bone

Elite female triathletes had the same bone mineral density as non-athletes in weight bearing bones. The triathletes' non weight-bearing bones had reduced density. Three of the eight triathletes studied had either bulimia or risk behavior associated with eating disorders.

Bone mass is acutely dynamic according to a study of seven Hawaii Ironman athletes (men and women) who lost an average of 37 grams (over one ounces) of bone mass during the course of the event.

Moderate running was not associated with an increased risk of osteoarthritis compared with walking.

Physiology—Fat

Exercising to help lose weight? Intermittent, more intense aerobic exercise resulted in greater weight loss than continuous exercise in a group of previously sedentary adults.

Physiology—Heart

For the same power output, heart rates are higher at faster cadences. This is due in part to reduced vagal tone.

At rest or during exercise under constant load, heart rate is known to vary slightly. This variability is a marker of cardiac health and was found to increase in response to aerobic training.

Heart-rate variability has two components—low frequency and high frequency. The high-frequency heart-rate variability continues to occur during exercise, the low-frequency variability does not.

Stroke volume is the amount of blood ejected from the heart with each beat. The amount ejected at near maximal heart rates has long been thought to decrease, since the heart has less time to fill with new blood with each beat, and so has less blood to eject. A study this year found slightly decreases in stroke volume at high heart rates in untrained subjects, a leveling off in trained collegiate athletes, and an increase without tapering in elite runners. Two other studies of moderately-trained subjects found an increase in stroke volume during high-load exercise. One study specifically found that the increase occurs whether supine or upright. Two markers of myocardial infarction (cardiac troponin and CK-MB) may rise during 10-kilometer running of relatively untrained subjects, without other evidence of an actual heart attack.

A preliminary study suggested that the loss of periods in athletic women may be associated with premature cardiovascular disease.

Physiology—Hormones

Testosterone and cortisol levels decrease in elite road cyclists during three week stage races.

Physiology—Lung

More than 60% of South African Olympic athletes at the Olympic Games in Sydney were found to have air-born allergies.

The high rates of exercise-induced bronchospasm (EIB) in ice-sport athletes may be related to indoor pollutants, possibly those produced by Zamboni's ice-resurfacing machines. High rates of EIB are present in both men and women.

Exercise induced bronchoconstriction is identified in some patients by eucapnic voluntary hyperpnea (inhaling air with a roughly 5% carbon dioxide content).

A study supported by the US Olympic Committee found that standard "first line" asthma medications such as albuterol may be only marginally effective in controlling airways dysfunction in athletes.

A heat-exchange mask was helpful in reducing EIB during cold-weather exposure in a study funded by the manufacturer.

At high power outputs, elite athletes desaturate their blood. The demand of the muscles to use oxygen exceeds the lung's ability to transfer oxygen to hemoglobin. The presence of extravascular lung fluid has been proposed as a cause, and a pharmacologic treatment proposed to improve this. Both nedocromil and diphenhydramine were shown to improve oxygen saturation in one study. Nedocromil was confirmed to help in another study.

Physiology—Mouth vs. Nose Breathing

Nasal ventilation appeared to have a maximal rate of 30 to 40 liters per minute, while maximal mouth ventilation is more than 100 liters per minutes. Nonathlete male volunteers given the option to breath through their mouth or nose decreased the percentage contribution of nasal ventilation to total ventilation from 81%to 26% during a maximal exercise test.

Physiology—Muscle

Is lactic acidosis ever a problem? Although scientists have measured blood lactate for years, some evidence suggests that other acids are responsible for muscle acidosis, not lactic acid per se.

A number of studies over the years have shown that stretching before exercise can worsen performance. A study this year found that the number of hamstring strength endurance repetitions was reduced from 15 to 12 in a group of 26 athletes following a hamstring and calf stretching routine.

Carnosine may be an important determinant of high intensity exercise performance, possibly due to physicochemical buffering in muscle.

Ultrasound following contusion did not improve the recovery of muscle-fiber cross-sectional area.

Physiology—Women

It has been suggested that as distance increases, women perform better relative to men. A review of best performance times in running over the last 25 years showed no such trend. Men generally had 10% to 12% faster times regardless of distance.

Blood glucose levels are lower during exercise in women using oral contraceptives than non-users, and oral glucose ingestion at the onset of prolonged submaximal exercise did not change this difference.

Glucose flux was found to be related to exercise intensity but not menstrual cycle in one study this year. Another study found that menstrual cycle did influence relative fat and carbohydrate use during exercise.

Resistance training did not improve bone mineralization over biphosphonate therapy alone.

Testing

Every year sports scientists and physiologists report on a variety of testing methods that attempt to define and document easily-performed, reliable and valid methods of predicting performance. Many studies reported here will be of more interest to coaches than athletes.

Evaluating training, ergogenic, equipment or other factors in athletics requires knowledge of an individual's normal variation in racing times (standard error of measurement). In professional cyclists, this was less than 1% in races as diverse as one-kilometer track races and in road races up to 294 kilometers.

Reliability of knee extension peak torque testing, testing at a variety of velocities, was low—especially in women.

A 5-minute running test was shown to have value in predicting VO_2 max.

A 10-minute bicycling test at 100 watts used heart rate, perceived exertion, and recovery heart rate to predict VO_2 and heart rate at ventilatory threshold.

The 12-minute YMCA submaximal bicycle test and 6-minute Astrand-Rhyming submaximal bicycle tests were shown to overestimate VO_2 max.

Overall, the YMCA ergometer test better predicted VO_2 max of a group of subjects than single-stage treadmill or bench-stepping tests, though all tests were inaccurate in predicting individual VO2.

For power levels over 200 watts, an equation was developed to predict the oxygen cost of exercise in milliliters per minute of bicycle ergometry. The equation is: $VO_2 = 11.1 \times$ watts output + 679 ml/min.

The validity of traditional ramped max power tests in determining VO_2 max was questioned in a study that showed higher VO_2 values in a computerized race simulation.

Two minutes of recovery following a max ramped test and subsequent remeasuring of VO_2 shows higher VO_2 max values in runners, but not cyclists.

Determining VO_2 max from 10-second gas exchange samples overestimates VO_2 max. 30-second or longer duration samples were suggested.

VO_2 plateaus were detected in 80% of 20 subjects during VO_2 max tests in which computer-assisted continuous signal processing techniques were used to measure slope.

Another study confirmed the presence of VO_2 plateaus, as long as sampling intervals less than 15 seconds were used for 11-breath moving average VO2.

The American College of Sports Medicine has published two formulas for estimating VO_2 from power levels. Both equations were found to overestimate VO_2.

Power measured during cycle Wingates is less than measured by the Bosco 30-second jump test.

Testing maximal power output with the force-velocity test was shown to be reliable both in children and in adults.

The Karvonen heart rate reserve formula is sometimes used to estimate heart rate associated with a given VO_2 max. In a study of 663 subjects, it was found to overestimate corresponding heart rates.

The single-day Palmer protocol was shown to be reliable and valid in the estimation of maximal lactate steady-state in two studies. The interpretation of the meaning of MLSS is another matter entirely.

There was no relationship between perceived and actual treadmill fitness in a sample of 40 type-A adults evaluated for the risk of coronary artery disease.

A study of fatigue in cycling showed that about one-third of the increase in motor-unit recruitment during fatigue was due to the lower cadence associated with fatigue rather than muscle-unit recruitment per se.

Wingates that do not consider flywheel and other mechanical inertias (which they traditionally ignore) underestimate power generation.

Athletes commonly report that perceived exertion relative to workload is lower in a competitive situation. A study that looked at the magnitude of this reduction found it to be about 2 points on a 15-point scale near the beginning of a running race.

Perceived exertion is lower at slow cadence when power output is low; it is higher at slow cadence when power output is high. This confirms what we know to be true in the real world: recreational riders have lower cadences than racers.

Perceived exertion level during a ramped power test depends not only on the absolute workload, but also on the time spent at each stage.

Men did not differ from women in rating perceived exertion during running or cycling.

Aerobic dance subjects who rated their exertion were more accurate at predicting their work intensity than those who took their heart rates manually when compared with recorded, but not subject-observed heart rates.

Prolonged lactate release after roughly 7-minute intervals was related to percent slow-twitch fibers.

In another study, maximum lactate steady state levels were also related to percent slow-twitch fibers, possibly because fast-twitch fibers are able to better buffer lactic acid.

Hormonal, neuromuscular, and psychological indicators of overtraining overlap with those of appropriate training. They can be influenced by training before a drop in performance occurs.

A group of runners was able to complete a 30-minute run at blood lactates between 4 and 5 millimoles per liter. Whether they would have been able to complete the run at higher levels was not determined.

Ventilatory and lactate thresholds were lower at altitude (1,388 meters/4,678 feet) than at sea level.

Peak watts and watts at lactate threshold were better predictors of 90-minute cycle performance than VO_2 max.

There was no correlation between placing and anaerobic power in seven professional BMX racers. Technical skill and race experience were proposed to account for differences in race success.

Heart rate correlated with energy expenditure and substrate utilization (carb or fat used for energy) in running; less so in cycling.

VO_2 reserve (the difference between VO_2 max and VO_2 at rest) is increasingly being used in the sport science community. One study this year suggested that exercise at 30% of VO_2 reserve for unfit and 45% VO_2 reserve for moderately fit adults is effective in improving aerobic capacity.

Heart rate increases predate increases in oxygen consumption during exercise.

Sleeping heart rate was found to be quite variable and rarely related to training load in four middle- and long-distance runners studied over an entire competitive season.

Gender specific equations have been developed that estimate carbohydrate, fat, and total energy expenditure based on body weight, aerobic fitness, and heart rate.

Blood and urine tests for recombinant (synthetic) EPO (rEPO) have been developed. The blood test for rEPO was shown to be positive for about 40% of athletes training at altitude camps. The urine test cleared all of abuse. The blood test is less expensive, and can screen for the results of fluctuating EPO levels. The urine test uncovers recent rEPO use.

Hydration changes percent body fat as determined by bioelectric impedance and to a lesser extent, near-infrared interactance. Skinfold testing remains reliable.

Bioelectrical impedance and dual energy X-ray absorptiometry were worse at assessing percent body fat than underwater weighing and skinfolds.

Training/Racing

A group of sampled sprint triathletes from the Tin-man Triathlon were found to train about 14 hours per week, including 4 miles of swimming, 125 miles biking and 25 miles of running.

Arm exercise prior to leg exercise was found to shorten the time to leg exercise exhaustion when compared with no arm exercise.

As core temperature rises, VO_2 max decreases.

Stand or sit while climbing? A study of thirteen trained cyclists found that position made no difference in cycling economy (power produced per liter of oxygen consumed). Cadence was higher while seated.

Triathletes required greater oxygen uptakes following cycling at cadences of roughly 80, 85, and 90 than at 72 rpm.

Should hand cyclists use cranks that are synchronous or asynchronous (think swimming butterfly vs. crawl). A study found that at low-power outputs, synchronous hand cycling was associated with less physiological demand—lower oxygen uptake and reduced heart rate.

Recumbent cycling results in a lower heart rate for a given workload. For the same perceived exertion, cyclists perform more work when upright.

The metabolic cost of cycling is related to power output and pedal speed (related to muscle shortening velocity), but not directly to crank length nor pedaling rate.

The use of Powercranks® during 6 weeks of training reduced energy expenditure during a 1-hour submaximal ride performed with standard cranks.

Respiratory muscles use up to 20% of energy and can fatigue at high work rates. Respiratory muscle training improved breathing endurance, but not VO_2 max or endurance-exercise time in collegiate distance runners.

Training/Racing—Heart Rate Monitoring

Seven weeks of roughly four walks per week of 30 minutes at a moderately-brisk walking pace reduced exercising heart rate 12 beats per minute for the same walking speed.

Do heart rate monitors help typical fitness club members improve fitness? Not in a study of 76 new recruits to the Cooper Fitness Clinic.

Morning and evening resting heart rates were lower, and nighttime urinary catecholamines higher, in a group of endurance athletes who, during a 4-week camp, increased training volume from 8 to 40 hours per week.

Training/Racing—Hypoxia/Altitude

Training low and resting high is an accepted strategy for improving performance at sea-level.

Altitude induces favorable physiologic changes, while training at sea-level allows more intense work. Maximal work and VO_2 max is less at altitudes as little as a few thousand feet.

Interval training performed at altitude at the same blood lactate levels results in similar hormonal and metabolic stressors in variables such as glucose, cortisol, and growth hormone. But the absolute workload is lower.

Hypoxia (reduced oxygen) studies have been especially popular over the last few years as hypobaric (reduced pressure) chambers and hypoxic (normobaric or normal-pressure, reduced oxygen content) tents, both of which simulate altitude, have become commercially available.

One motivation has been to increase red blood cells—through a “safe and legal” method of increasing natural EPO.

Athletes and coaches should be aware that such devices are not proven safe. With the passage of time, it might be found that the use of such devices is associated with a number of problems. The following scenario has *not* been shown, but is offered to suggest restraint: Consider that reduced oxygen might stimulate new blood vessel formation. This could be good. Or it could be very bad if new blood vessels so formed in the brain are weak blood vessels, prone to rupture, and leave athletes prone to strokes. Again, this has *not* been shown. It may be a mistake for athletes to sleep at 14,000 feet in altitude tents until safety has been shown. And this may never be possible.

EPO response to natural altitude can be predicted by 24 hours of artificial exposure to hypobaric hypoxia.

A study designed to determine the optimal resting altitude found that sea-level VO_2 max improved as resting altitude increased up to roughly 2,000 meters (6,740 feet); 2,500 meters (8,425 feet) was not better; 2,800 meters (9,436 feet) was worse.

Of 9 women and 14 men who lived at 2,100 meters (7,077 feet) and trained at sea-level, all the women and 9 out of the 14 men improved performance. Females increased their VO_2 max by 8.0%. Males increased by 4.7%; this includes the five non responders. Men, not women, lost body fat and gained muscle mass. Some, not all, of the improvement was explained by increase in red blood cells.

Performance improvement of 1.5% through the use of altitude tents was found in a study of 21 competitive middle-distance runners. Improvement was not related to hematocrit, which did not show a change.

This was confirmed in a 15-day study of athletes at 2,750 meters (9,268 feet), who increased maximal average power output in a 4-minute test.

Strength endurance improved in both a group trained at sea-level and a group trained at normobaric hypoxia. The amount of improvement and change in leg muscle cross-sectional area was about the same.

Rapid weight loss is known to be associated with negative mood. High altitude exposure is also known to cause negative mood changes and weight loss. A study examining these factors found that decreasing caloric consumption at altitude did not further worsen mood changes associated with altitude exposure.

Altitude exposure may alter the gene expression of some muscle fiber types, a suggestion from a rat study.

Training/Racing—Intervals

High-intensity training at running velocities corresponding to VO_2 max for 60% of the duration that VO_2 max could be sustained were effective in improving running performance; when interval run times were 70%, performance did not improve.

Five-second bouts of high intensity training over 7 weeks improved anaerobic alactic (without lactic acid production) power, but not anaerobic lactic power, in a group of varsity athletes.

Training/Racing—Music

Studies over the years have looked at whether music changes exercise performance. In general, most studies have found no effect. Subjects who listened to music described as "percussive sonic driving >200 beat per minute" before exercise began exercise with higher heart rates, blood pressure, and respiration rates than those who listened to quiet music. There were marginal or no differences in exercise-testing performance. In another music study, tempo and rhythm aspects of music seem to help 10-kilometer cycling times by 10 to 34 seconds and reduced perceived exertion. Most of the benefit occurred during the first third of the time trial.

Training/Racing—Psychology

Why do we exercise? Extrinsic motivation (attractiveness/success, social comparison, tangible rewards) and intrinsic (enjoyment, achievement, pressure, choice) were found to correlate with exercise behavior. Women were more intrinsically motivated than men.

Training/Racing—Strength

How often should strength training be performed? A study of subjects between the ages of 60 and 70 found that both two and three times a week training improved strength. Overall, twice-a-week training provided as much benefit. Some muscle groups were improved more with twice-a-week training; some more with three-times-a-week training.

How much recovery is needed from strength training? In a study of 10 recreationally experienced men, after an extensive exercise session, only 4 were sufficiently recovered by 2 days to perform again at the same level; 7 were recovered by 3 days; and 8 by 4 days.

Which is better? Two reps at 90% of one-rep max vs. two sets of eight reps at 65%, 70%, and 75% of one-rep maximum. There was no difference in strength gains, though the two-rep approach took significantly less time.

Force production, not work per se, was found to be related to perceived exertion. Perceived exertion in cycling was less with an easier gear and faster cadence than it was at the same speed with a harder gear at a slower cadence.

The one-rep max (maximum load that can be lifted) is about 25% greater when movements are performed quickly than when they are performed slowly.

How long should recovery intervals be for 90% one-rep max lifts? One- and two-minute recoveries were shown to be too short. Three, four, and five minutes recoveries were equally helpful.

In young men, concentric contractions elevate testosterone and lactate levels more than eccentric exercise. Squat training improved running economy in soccer players.

Training/Racing—Stretching

Stretching before or after aerobic exercise improved flexibility about the same amount.

The technique of proprioceptive neuromuscular facilitation (PNF) is a technique involving contraction and then relaxation of muscle. It was more effective in increasing range of motion and was more effective when performed three times for 10 seconds, than when performed for any other combination of one two or four times and 20, 30, or 60 seconds.

A study of runners found that those with better trunk flexibility had better running economy.

Training/Racing—Warm-up, Pacing

A warm-up that included five 10-second sprints resulted in an improved 2-minute Kayak ergometer performance when compared with a steady-state warm-up.

Should triathletes have a specific cycling strategy before a 10 kilometer run? A study that compared steady cycling with cycling at ± 20% and ± 40% steady-state power found subsequent 10-kilometer run performance unchanged. Blood lactates were significantly higher during the cycle time trial that varied power output 40%.

Active recovery, compared with passive recovery, allowed more total work and improved performance of 30-second intervals.

Delayed Onset Muscle Soreness (DOMS)

Researchers spend a lot of time investigating this problem because sore muscles—sore especially from eccentric exercise (muscle fibers lengthening while under tension)—prevent high-level performance in athletes.

A study showed that when matched for strength, women experience more muscle fatigue than men, though not more soreness, following eccentric exercise.

DOMS may result in a loss of range of motion, decrease in strength, swelling, structural damage, and an increase in the release of muscle enzymes.

Confirming previous research, once exercise causing DOMS takes place, further similar exercise does not worsen soreness or damage, though total work is generally only about two thirds. A study this year showed that new tissue stabilization and synthesis may be more important than tissue destruction.

Pressure pain was more correlated with decreased performance than resting muscle soreness.

Neither warm-up (whether passive heat or active concentric exercise) nor before-exercise cooling reduced DOMS.

Vitamin C reduced soreness, but not measures of muscle damage in one study. In another study, the findings were reversed: no change in soreness but measures of muscle damage decreased.

Neither ibuprofen nor bromelain reduced pain or muscle dysfunction.

In two separate studies, Vicoprofen (hydrocodone and ibuprofen) improved performance, but not measures of muscle damage after eccentric exercise.

One study found that protease supplementation reduced muscle soreness following downhill running.

A manufacturer-supported study found that L-Carnitine reduced muscle soreness.

Electrical muscle stimulation did not change the markers of muscle injury after eccentric exercise.

Massage reduced the intensity of soreness, but not muscle dysfunction in one study. In another study, massage worsened muscle function. Hyperbaric oxygen exposure was not effective in treating DOMS.

Summary: Over the past few years studies have been inconclusive about the usefulness of almost all treatments studied for reducing DOMS. They have shown that anti-inflammatory medicines, massage, stretching, ice, or heat may or may not help. The effectiveness of placebo for DOMS makes meaningful investigation more difficult.

Prevention is key: When beginning new activities, ease into them. Don't start weight training, plyometrics, hill climbing, hard time trialing, intervals, or sprinting without base and transitional training. Allow the body time to adapt.

The Past 7 Years

This is the seventh annual review of the sports science literature I've performed. Here's some of what I've gleaned:

- Sport scientists understand a little about what they can measure, less about what they can't.
- High-carbohydrate diets in the few days before events may be helpful. The rest of the time, the need for high-carb diets is less certain.
- Consumption of up to 300 calories per hour during exercise improves performance.
- Glucose polymers (maltodextrins) can benefit performance.
- Almost all vitamin and mineral supplements have proved worthless for most athletes in industrialized countries.
- Increasing salt ingestion the day before and during multi-hour events in the heat may be helpful.
- Most athletes don't consume nearly enough fluids to replace their losses during events. Much of the time it doesn't affect performance.
- The vast majority of so-called performance-enhancing drugs don't.
- The live-high, train-low approach may confer modest benefits in athletic performance.

- Lightweight and aerodynamic bicycle equipment has improved time trial and other performance times.
- Despite decades of research, selecting optimal crank length and optimal cadence is more of an art than a science.
- Masters athletes are a lot fitter than textbooks predict.
- Compared with the marketing hype certainty of anti-oxidants, very little is known about exercise and immunity.
- We understand a lot about causing muscle soreness; we know little about treating it.
- Stretching before training and races may worsen performance.
- Athletes respond to training.
- Heart-rate monitors, lactate monitors, and power monitors don't improve fitness. It's the training they monitor that does.
- A variety of intervals, from 5 seconds to many minutes, provides significant benefits for aerobic endurance athletes.
- Recovery is as important as work.
- Most athletes are limited not so much by genetics but by inadequate training.

Conclusions

Knowledge is modestly incremental.

Key points: Hydrate. Have carbohydrates before, during, and after exercise. Be cautious about supplements, ergogenics, new techniques, and fads. Work on pacing during time trial type events.

If you want to have good luck, train.