Ephedrine and It's Effect on Weight Loss?

The Dilemma

It is dilemma that affects the world over, its scope nothing short of the earth's 25,000 mile circumference. However, in certain cultures it is a more significant issue than in others. Nevertheless, it can affect every aspect of our lives, driving many even to suicide. Few, if any, are naturally invincible to its hidden wrath. This invisible, yet potent dilemma is obesity, or simply weight control.

In countries, such as the United States, weight control is a common, yet, dire issue. Especially, in a society where thin is in, but for many, so are fatty foods and infrequent exercise, there is a huge and growing demand for quick, easy schemes to lose weight. However, the true importance of being overweight, is often misconstrued. For the majority, being overweight is frightening because of it's social ramifications, while the many important health risks are often overlooked. According to the Department of Health and Human Services, being overweight is a risk factor for heart disease, stroke, diabetes, and several types of cancer. Thus, the weight loss business has skyrocketed over the past decade, becoming a multi-billion dollar industry. Despite the seemingly countless 'magical' diet schemes available to the public, a product and/or method has yet to emerge which allows for quick, easy and physically safe weight-loss. One chemical in particular, however, has showed increasingly promising signs regarding this issue. The chemical is ephedrine.

Ephedrine and It's Uses

Derived from the Chinese plant ma huang, ephedra or better known as ephedrine, is found both naturally and synthetically in various dietary supplements, over the counter herbal stimulants, prescription cold and flu remedies, asthmatic aid products, as well as several illicit drugs. Ephedra has been used for over two thousand years to treat "bronchial asthma cold and flu, chills, lack of perspiration, headache, nasal congestion, aching joints and bones, cough and wheezing and edema. In Western terms, ma-huang is considered to have diaphoretic, diuretic, central nervous system stimulating and antiasthmatic activity. The stem (herb) of ephedra contains a number of active compounds, including small amounts of an essential oil, and most important, one or two percent alkaloids composed mainly of ephedrine and pseudoephedrine, with ephedrine ranging from thirty to ninety percent depending on the source."

Alone, ephedrine is a very powerful amphetamine-like compound. However, as "Mark Blumenthal editor of HerbalGram and executive director of the American Botanical Council, was quoted...as saying that he has used the stems and twigs of the Chinese herb ma-huang as a cold remedy for twenty years. He pointed out that the effects of ephedrine, a stimulant alkaloid in ma-huang should not be confused with the whole herb itself. This is a good example of how the effects of a whole herb and its isolated constituents must be considered separately. One should not confuse ephedrine and pseudoephedrine with ephedra, just like one shouldn't confuse pure caffeine with coffee." [http://www.smartbasic.com/glos.herbs/ephedra.html](http://www.smartbasic.com/glos.herbs/ephedra.html) It's Side Effects "The
Ephedrine's Effects on Weight Loss

Despite its many potentially harmful side effects, ephedrine is for the most part, dangerous only if abused. Nevertheless, it offers a variety of positive qualities in terms of its beneficial effects on particular aspects of the mind and body. One of its more significant qualities is its potential effect on weight loss. Ephedrine has the unique ability to stimulate thermogenesis in the human body. It works by, essentially, speeding up the heart rate, thus inducing a faster metabolism. "To lose body fat, you must burn more energy than you eat so that your body has to draw upon the fuel stored in fat cells. The only way to lose weight is to increase the amount of fuel you burn, decrease the amount you consume, or do both at the same time. The rate at which you can lose weight is limited by how fast the body burns energy." (Is there any Magic?)

Over the past three or four years there has been a flurry of studies regarding ephedrine and its current and potential effects on weight loss. For the most part, these particular studies are conducted on laboratory rats under strictly supervised conditions.

"Ephedra is sometimes combined with other stimulants like caffeine or ginseng. Phenylpropanolamine is a related compound that is sold over the counter, often in combination with caffeine, as a weight loss aid.... These stimulants are effective aids in inducing small to moderate weight losses. Animal studies suggest that they work by both reducing appetite and by stimulating fat metabolism (Wellman & Sellars, 1986). When taken at the recommended dosages, they often lead to few adverse symptoms or side effects."

1993 issue of the International Journal of Obesity and Related Metabolic Disorders states, "The purpose of the present study was to establish the effectiveness of ephedrine and/or theophylline on alimentary obesity...It also seems suitable for establishing whether thermogenic drugs affect the activity of plasma and adipose tissue lipoprotein lipase. This enzyme is known as a 'metabolic gatekeeper' and may play a key role in the pathophysiology of obesity."

According to a similar study in the November 1992 issue of Metabolism: Clinical and Experimental, "Although in acceptable doses, the thermogenic effects of these methylxanthines seem to be too mild for obesity therapy, current interest focuses on their ability to potentiate the thermogenic effect of ephedrine-a sympathomimetic with both anorectic and thermogenic properties-which has been shown to enhance weight loss in diet-restricted patients. The interaction between ephedrine and caffeine on whole-body thermogenesis has now been confirmed in man, and combinations of these drugs have been shown to be safe and more effective than either ephedrine or caffeine alone in facilitating weight loss."
The Real Problem with Ephedrine

The real problem with ephedrine is directly related to its powerful side effects and the fact that products containing ephedrine are easily obtained and sold with "little federal oversight." A published report dated October 12, 1995 reveals that the FDA is just beginning to make an attempt at "stringently" regulating the drug. "Prompted by growing concern that these (dietary supplement) products contain enough ephedrine to cause serious and sometimes fatal heart and nervous system side effects,...the advisory committee on Wednesday began reviewing research into about 100 ephedrine-containing supplements, to help the FDA decide how far to go in regulating them. A key question is whether certain people could be warned that they are at particular risk or if the substance is too dangerous to stay on the market." The same report stated that "more than 330 Americans have suffered side effects from ephedrine-containing products, including 12 deaths." A more recent article dated August 28, 1996, states that more than 800 have suffered serious side effects and 17 have died because of ephedrine related complications.

Conclusion

In short, ephedrine has shown promising signs in terms of its generally positive effects on the human body, especially on the reduction of fat and body weight. Studies have shown that ephedrine is most effective as a weight loss stimulant when used in conjunction with other drugs, such as caffeine. Research has also shown that is is virtually impossible to achieve weight loss without a healthy diet and regular exercise. Therefore, it seems that the optimal solution to lose weight must involve the proper combination of diet, exercise, and drug interaction. Ephedrine may hold the key to fill in for the drug portion of the equation, but as with practically all drugs, there are risks involved. Whether ephedrine is too dangerous to be sold in over the counter products, is still under debate. Ephedrine does have great potential, yet is it worth the risks?
SPEEDING RECOVERY FROM EXERCISE

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KEY POINTS

■ To hasten recovery after exhaustive exercise, athletes should continue exercising for 10-20 minutes at progressively lower intensities to speed the removal of lactic acid from the muscles and blood. Stretching of all major muscle groups should follow this activity.

■ Athletes should begin consuming fluids and carbohydrate immediately after exercise to help the body replace fluids lost in sweat and to replenish muscle glycogen stores.

■ Research indicates that a 70 kg (154 lb) athlete should consume 50-150 grams of carbohydrate (200-600 calories) within the first two hours following exercise to optimize the replacement of muscle glycogen stores.

■ As little as six grams of protein (more is not better) may accelerate protein synthesis in the muscles following exercise. Expensive protein powders and amino-acid supplements are no more effective than normal foods (e.g., meat, fish, eggs) at providing the necessary amino acids.

■ It is important to replace both water and electrolytes (especially sodium) during and following exercise to minimize dehydration, to stabilize blood volume, and to avoid muscle cramps.

■ Although there are exceptions, athletes generally require at least 7-8 hours of sleep each night to perform at their best.

INTRODUCTION

A high school tennis player has just finished a grueling three-hour singles match and has only two hours to get ready to play for the doubles championship. Should she simply concentrate on resting for those two hours, or should she be most concerned about refilling her carbohydrate stores and body fluids?

A power lifter completes a tough two-hour training session and must compete for the national title in three days. Should he stop lifting completely until the day of the meet? What should he be eating? Are there supplements he should take to speed his recovery?

During morning competition, an age-group swimmer competes in three preliminary races and qualifies for the evening finals in each. What should she do in the intervening six hours to assure peak performance in the evening events?

All sports medicine professionals, coaches, and athletes have been faced with questions about how best to recover from one bout of exercise and prepare for the next. There are many myths and half-truths about the best approaches to recovery, and there is far more published science on optimal preparation for exercise than on how best to recover from exercise. Therefore, we asked a group of experts who have scientific and/or practical experience in dealing with recovery to help us better understand the recovery process and how to enhance it.

Brad Arnett, head strength and conditioning coach at the University of Arizona in Tucson, works primarily with the football and basketball teams but also has experience working with athletes in a variety of other sports. Dan Benardot is Associate Dean for Research for the College of Health and Human Sciences and co-directs the Laboratory for Elite Athlete Performance at Georgia State University. He was national team nutritionist for USAGymnastics from 1991-1997 and has authored Nutrition for Serious Athletes (Human Kinetics) plus numerous articles in sports nutrition. Ron Maughan is an internationally acclaimed expert in the physiology, biochemistry, and nutrition of exercise performance. He has published extensively on these topics in the scientific literature. Brent Steuerwald has been a varsity high school football coach for 43 years. In 1995 the National High School Athletic Coaches Association named him National Coach of the Year in Football. He works with the National Football League in developing educational programs to improve football coaching across the nation. Fred Tedeschi is the
head athletic trainer with the Chicago Bulls. He previously held similar positions with the University of California, Berkeley, and with Vanderbilt University, and he was also an assistant athletic trainer with the San Francisco 49ers for seven years.

“Recovery” may have different meanings, depending on the sport in question and on other factors. How do you define “recovery” in the sport settings with which you are most familiar?

Benardot: Recovery is the process the athlete goes through to return to a state of performance readiness. Recovery involves a restoration of nutrient and energy stores, a return to normal physiological function, a lessening of muscle soreness, and the disappearance of the psychological symptoms (irritability, disorientation, inability to concentrate) associated with extreme fatigue. Regardless of whether the athletes I work with are figure skaters, gymnasts, marathon runners, tennis players, or hockey players, the goal is to get the athlete ready to compete again or to make certain the next practice session enhances performance potential. There is no question that athletes who train or compete without fully recovering from a prior competition or training session will not train or compete at their best.

Maughan: I agree with Dr. Benardot that recovery must involve both physical and mental restoration. In training, this allows the quality of the workout to be maintained while minimizing the risk of chronic fatigue, illness, and injury. In competition, it means being able to take part in the next round or event and to perform at the same or at a higher level.

What types of “cool-down” activities do you recommend that athletes perform immediately following a session of intense training or competition that lasts 1-2 hours?

Steuerwald: Immediately following any training session or competition, athletes should “taper down” their exercise to a lower level of intensity. This should include non-sport-specific physical activity (e.g., jogging or swimming a different stroke) that gradually decreases in intensity over the duration of the cool-down. Following this, athletes should stretch all major muscle groups. If competition is to resume shortly, athletes should be encouraged to remain warm and mildly active.

Tedeschi: Athletes should ramp up into any exercise activity and ramp down after activity, regardless of the duration of the exercise. As Coach Steuerwald indicated, cooling down should consist of submaximal exercise followed by a stretching regimen. In addition, as the last component of cooling down after exercise, athletes should consume carbohydrates to enhance replenishment of carbohydrate stores.

Maughan: After a hard workout, 10-20 minutes of gentle exercise can speed removal of lactic acid from the muscles and promote recovery. If another competition will follow soon, restoration of fluid balance and replenishment of glycogen stores are priorities, so there should be time for fluids and/or food immediately after finishing exercise but before beginning the cool-down activity. I agree with the other participants that stretching should also occur following the cool-down exercise.

Benardot: I would like to expand on Dr. Maughan’s emphasis on replenishing fluids and carbohydrate stores. Because intense physical activity is likely to lead to a severe depletion of carbohydrate stores (glycogen) and to dehydration, two main goals following intense exercise should be to replace this fuel in addition to the fluid and electrolytes that were lost in sweat. Drinking fluids is also important to return blood volume and total body water to pre-exercise levels. A note of caution: Athletes who must compete again in a relatively short period of time must be careful to not consume such a large amount of food and fluid that a large portion of it remains in the stomach at the start of the next event. These athletes should focus on smaller amounts of foods and drinks containing glucose, sucrose, or maltodextrins—carbohydrates that can quickly leave the stomach and become absorbed. The athlete who won’t exercise again for another 24-hours can be more liberal with the type and amount of carbohydrate and fluid consumed.

Do you advise athletes to consume carbohydrate foods to speed recovery?

Arnett: I recommend that athletes consume a high-glycemic blend of maltodextrins, dextrose (glucose), and sucrose to speed recovery. Assuming no further competition or strenuous training for at least 24 hours, an athlete whose lean body mass is 200 pounds (91 kg) should begin consuming about 160 grams of carbohydrate and 60 grams of protein immediately following a workout and finish consuming these nutrients within the next couple of hours.

Maughan: Carbohydrate is an absolute must. The amount and type of carbohydrate will depend on the circumstances, but there are advantages to a liquid form when the athlete does not feel like eating immediately after exercise. If the athlete has roughly 24 hours to recover, the usual recommendation for a 154-pound (70-kg) athlete is at least 50-150 grams of carbohydrate within two hours immediately following exercise. We try to help the athlete by identifying food portions that will give this amount of carbohydrate. For example, you need about 200 grams of pasta to get 50 grams of carbohydrate, but you can also get 50 grams of carbohydrate from about 80 grams of raisins or about 700 ml (24 oz) of a sports drink. Athletes are more likely to have a candy bar and a sports drink than potatoes or pasta in their sports bags, so there needs to be an immediate fueling option followed by a focus on carbohydrate foods at the first visit to the dining table.

Benardot: Sure, carbohydrate is crucial, but vitamins, minerals, and energy substrates (protein, carbohydrate, and fat) all play important roles in optimal nutrition. A monotonous emphasis on any single nutrient or energy substrate may disturb the relationships among these nutrients and make it difficult for the athlete to achieve an optimal nutritional state. So carbohydrate should not be the exclusive focus of our attention as a strategy for speeding recovery.

Foods that contain a high proportion of carbohydrates, but also some protein and a small amount of fat, are suitable for encouraging recovery. The amounts needed depend on the size of athlete, the degree of carbohydrate depletion, and the severity of fluid loss. For smaller athletes who have multiple competitions within a day, I might recommend a 200-250 calorie (1 MJ) energy bar or other snack containing mainly carbohydrate, along with 12 to 16 ounces (350-475 ml) of a sports drink to wash it down. This amount of food would increase proportionately with the size of the athlete and the situation. I encourage athletes who are finished for the day to consume 250-400 calories (1-1.8 MJ) of foods high in carbohydrates (pretzels, bread, fruit) with
How can athletes optimize their stores of body fluids to help speed recovery from exercise? Is hydration important only in hot environments, or should those participating in winter sports be concerned, too?

Benardot: Physical activity, regardless of the environmental condition, causes an increase in body heat production and, therefore, a loss of sweat, which can lead to dehydration. Novice skiers are often surprised when they find that their clothes are soaked in sweat, even though the air temperature is bitterly cold. The ideal strategy is to maintain fluid balance during the event to avoid dehydration. Sweat losses may exceed the athlete’s capacity to adequately replace fluids, particularly in hot environments, so paying special attention to fluid consumption at every opportunity reduces the risk that water loss may induce premature fatigue. As a goal, the athlete should drink as much as is tolerable as often as possible during the event, and then enough following the event to return body weight to its pre-event weight. Carbohydrates in fluids have the effect of improving rates of fluid absorption by the intestines (a 6-7% carbohydrate solution is considered best), and the carbohydrates also help to replenish the muscle glycogen used during the exercise.

Maughan: Fluid replacement is a key issue. Athletes should begin the recovery process during training or competition by drinking fluids to minimize the fluid deficit that is incurred. Replacement of fluids after exercise should be based on need. You can tell how much sweat was lost by weighing yourself before and after a workout. We know that you should drink about 1.5 liters (50 oz) of fluid for every kilogram (2.2 lbs) of weight loss, and we also know that you won’t rehydrate effectively unless you also replace the salts lost in sweat. Some winter sports athletes actually lose more fluid than those competing in warm environments because the insulation provided by winter clothing can reduce heat loss and thus promote sweating. Even in a game like soccer, with limited clothing, sweat rates can be high on a winter day.

Tedeschi: I agree that appropriate hydration is important in any climate. An ideal or near ideal state of hydration can be achieved through a regimen of drinking before and during exercise, and drinking after exercise in amounts sufficient to replace any lost weight during exercise. In addition, ample research has demonstrated that a sports drink like Gatorade is superior to plain water for optimizing the stores of body fluids.

Steuerwald: I’m happy to jump on this “hydration-in-all-environments” bandwagon. In my experience, if athletes practice drinking during training sessions, they can learn to tolerate the consumption of greater fluid volumes during exercise and thereby reduce the incidence of serious dehydration.

Are electrolytes important in speeding recovery from exercise? If so, which ones?

Maughan: Electrolyte replacement is crucial. Salts act like a sponge, holding fluid in the body. If you drink a large volume of plain water, the body thinks that it is over-hydrated because the water dilutes the concentrations of sodium and other dissolved substances in the blood. This switches off thirst and switches on the kidneys to increase urine output. Sodium is the most important electrolyte as it is the one lost in sweat in the greatest amounts, and that’s why it is added to sports drinks.

Benardot: There are other minerals in sweat, including magnesium, but the amounts lost are insignificant compared to sodium and potassium. Sodium in fluids is particularly important because, as Dr. Maughan said, sodium drives the desire to drink (a good thing), and the sodium also helps to maintain blood volume. The maintenance of blood volume is considered to be vital to sustaining athletic performance.

Steuerwald: I, too, am firmly convinced that sodium and potassium replacement is important in speeding recovery from exercise. Athletes can replace these electrolytes by consuming sports drinks, fruits, vegetables, and other foods and beverages rich in sodium and potassium.

Tedeschi: In addition to its beneficial effects on maintaining body fluids, replacement of sodium and potassium can also help prevent muscle cramps during and after exercise. To be sure they are replacing lost electrolytes, I tell athletes to use sports drinks that contain sodium, eat ample fruits and green leafy vegetables, and lightly salt their food.

How important are protein supplements and/or other dietary supplements as aids to rapid recovery?

Arnett: A recent report by Blomstrand and Saltin suggests that branched-chain amino acids (leucine, isoleucine, and valine) may have a protein sparing effect in muscles following exercise. I also recommend that athletes take glutamine following exercise to speed recovery.

Maughan: The evidence now emerging suggests that there may be benefits from taking protein immediately after exercise to help the process of building and repairing muscles. The aim of training is to remodel the muscles and other tissues. This means we are breaking down some of the older proteins and making newer ones. At present, the timing and amount of protein that will be optimal is not clear, but early research indicates that very small amounts of protein may be effective; for example, six grams of protein are just as effective as larger amounts at stimulating protein synthesis after exercise. The research evidence I have seen does not support Coach Arnett’s earlier suggestion that an athlete might need 60 grams of protein during recovery. Moreover, the best research shows that consuming individual amino acids, including branched-chain amino acids and glutamine, provides no advantage over proteins. Finally, given that carbohydrate is also needed during recovery, a sandwich with ham, cheese, or tuna, together with a drink, may be an effective option as a recovery “supplement.”

Benardot: The only supplement I recommend is Vitamin E, an antioxidant that may help athletes reduce the oxidative stress and tissue damage associated with exercise. I agree that a small amount of protein may be useful in aiding muscle recovery, but many athletes consume excessive quantities of proteins or amino acids. It is likely that most, if not all, of any benefit derived from consuming large amounts of protein (more than 1.5 grams of protein per kilogram (2.2 lbs) of body weight) and/or amino acids can be attributed to the role these supplements play in helping the athletes meet their caloric needs rather than their pro-
tein needs.

Tedeschi: I am not convinced of the need for protein or amino acid supplementation. If athletes eat calorically sufficient diets, they most likely are getting more than enough protein and amino acids. I believe the real benefit of foods for speeding recovery lies in carbohydrate feeding.

Steuerwald: Fred and I have similar views on this issue. I do not encourage the use of any supplements to aid recovery. There are many foods and drinks that can naturally replace nutrients that are lost through training and competition.

How important is adequate sleep in optimizing recovery from exercise? How much sleep do you think most athletes should get?

Benardot: Getting sufficient sleep is just as important a part of training as practicing the skills of the sport, lifting weights, or improving endurance. Clearly, muscles that have worked so hard in training to get bigger or stronger need adequate rest to rebuild themselves in a way that can help the athlete perform better. I don’t know any hard working athlete who needs less than seven hours of sleep each day, and most athletes could probably do better with eight hours. With all of the time demands on many athletes, getting enough sleep won’t happen by accident. It must be a planned part of the training schedule.

Maughan: Some people survive and even thrive on much less sleep than do others, so I don’t think blanket recommendations are a good idea. Individual athletes should determine their own needs. I believe that if we listen to our own bodies, we won’t go far wrong. Routine is important to many athletes, but experience suggests that missing a few hours because of a late night the day before an event may not necessarily do much harm, so athletes should not worry if travel or other factors cause disruptions.

Tedeschi: One of the signs of overtraining is sleep difficulty. Given the time devoted to team travel and other commitments in athletics, it is often difficult to get the necessary rest. I advocate at least 8-10 hours of sleep to enhance recovery from exercise.

SUGGESTED ADDITIONAL READING:


RAPID RECOVERY AFTER A WORKOUT OR COMPETITION

Training sessions and competitions can make you feel totally exhausted. If you don’t recover properly, you will not be ready to perform well during the next training period or competition. A failure to recover adequately can eventually lead to overtraining and staleness. What is optimal recovery? All of your body systems should be returned to the state they were in before exercise. You want to rid your muscles of lactic acid and other waste products, replenish all the energy sources you used to fuel your exercise, fill up your body fluid reservoirs, minimize any muscle or joint damage resulting from exercise, and re-energize your brain cells. Here are some recovery tips that will help you feel more energetic and ready to take on the world.

Don’t Lie Down on the Job
After exhaustive exercise, don’t stop and rest immediately. You can speed up the removal of lactic acid from your muscles by continuing to exercise at a low intensity for 10-20 minutes. This cool-down exercise can help reduce the feelings of stiffness that you may experience after a workout and is especially important if your next round of competition is only a few hours away.

Stretch Mostly After Exercise, Not Before
Stretch your major muscle groups after your cool-down exercise to get the maximal benefits of stretching. If you stretch your muscles, tendons, and ligaments too aggressively before beginning your exercise, you risk damaging those tissues. Rather, wait until the tissues are warmed up by exercise, and you can perform better stretches that will minimize muscle soreness and may help prevent future muscle pulls and other injuries.

Fuel Up Fast
The muscles are primed for quick restoration of their carbohydrate fuel reserves (glycogen) immediately after exercise, so don’t wait to start eating foods and drinking beverages rich in carbohydrate. Pretzels, fresh fruits, energy bars, sports drinks, and even jellybeans all contain lots of carbohydrate.

Carbohydrate is Best, But Some Protein Can’t Hurt
During strenuous exercise, some proteins in the muscles are broken down. For faster buildup of muscle proteins during recovery, include a small amount of protein in your food intake. To combine both carbohydrate and protein, try a ham or tuna sandwich. Most energy bars contain ample carbohydrate and protein to get your muscles on the road to recovery. So do foods like milk, cheese, eggs, and nutrition shakes.

Fill Up Your Tank
Body fluids are lost in sweat, and quickly replacing that fluid is crucial. Fluids are needed to maintain your blood volume so you can deliver oxygen and fuel to your muscles. Moreover, without enough fluids, you can’t sweat to help keep your body temperature at safe levels. You should top off your body fluids by drinking an hour or so before exercise, try to replace as much sweat loss as you can during exercise, and replace any body weight lost during exercise by drinking while you are recovering.

Salt is Super
When you sweat, your body loses both water and electrolytes (mostly salt—sodium chloride—and some potassium). If you drink only plain water during exercise and recovery, you will have difficulty replacing your body fluids rapidly because much of the water will pass through your kidneys to become urine. You must replace the salt along with the water to counteract dehydration. Especially if you will compete again in a few hours, consider using sports drinks during recovery for fast replacement of water, salt, and carbohydrate. Also, make sure you put some extra salt on your foods at mealtime, particularly if you are prone to cramping.

Sleep Well
A good night’s sleep helps you get physically and mentally prepared for your next workout or competition. You can’t perform at your best when you are not alert and are unable to concentrate on your sport. Some athletes can get by for a day or two with inadequate sleep and still perform well, but poor sleep habits will eventually lead to poor performance. So try to get into a routine of at least 7-8 hours of sleep each night to ensure full recovery from your last training session or competition.

SUGGESTED ADDITIONAL READING:

Sports drinks aimed at enhancing endurance performance lasting several hours need to contain ~20 mM salt (sodium chloride) and ~10% carbohydrate in the form of glucose polymers and fructose. The salt and carbohydrate offset the losses of these substances caused by exercise. They also accelerate the uptake of water. Glucose polymers are used instead of glucose to keep the total osmotically active solute concentration (tonicity or osmolarity) of the drink below that of body fluids, because higher concentrations reduce the rate of emptying of the stomach and reduce the rate of uptake of water in the small intestine. KEYWORDS: carbohydrate, energy, hydration, nutrition, salt, water

Reprint pdf · Reprint doc · Commentary by Dave Rowlands

This article is an edited version of a literature review commissioned by a drink manufacturer on "the mechanisms… of water uptake in sports drinks of varying carbohydrate content and tonicity… Please explain how carbohydrates, electrolytes and tonicity affect water uptake and hydration in plain English." In our report we placed as much emphasis on the uptake of carbohydrate as of water, for the following reasons. First, in all but the hottest and most humid environments, exercise of duration and intensity sufficient to make dehydration an issue will also make supply of carbohydrate an issue. Secondly, getting the carbohydrate in is more of a challenge than getting the water in. Finally, we assumed that the drink is aimed at optimizing performance of elite endurance athletes and recreational multisport or ultraendurance athletes in competitions. For the mass market of less serious fitness enthusiasts, there is little need to worry about depletion of water, salt and carbohydrate during exercise. Indeed, fitness exercises can be performed without any concern for fluid and carbohydrate uptake.

We performed several searches with SportDiscus and Medline, but we got the best references by using Web of Science to find all the papers that cited a definitive paper by Rehrer et al. (1992). We found reviews by all the major researchers in the field (Brouns and Kovacs, 1997; Coyle, 2004; Jeukendrup, 2004; Jeukendrup et al., 2005; Maughan and Leiper, 1999; Rehrer, 2001).

There has been general agreement for the last decade that sports drinks need to contain salt (sodium chloride, NaCl) and carbohydrate (sugars) at concentrations of around 20 mM and 6% (6 g per 100 ml) respectively. The researchers also agree that at least some of the carbohydrate needs to be in the form or disaccharides (usually sucrose) or glucose polymers (malto-dextrins). In the last year or two Jeukendrup and colleagues have found a way to increase the rate of absorption of carbohydrate. This report is mainly a review of the reviews. The only original-research papers we read were the recent ones not covered by the reviews.

The issues with sports-drink composition are as follows…

**Exercise Depletes Water and Salt**

- Exercise results in loss of water and salt from the body via evaporation of water from the lungs and sweating of water and salt from the skin. For exercise of sufficient duration and intensity, the losses reduce the volume of blood available for the heart to pump to the muscles and skin. Reduction of blood flow to muscles implies less delivery of oxygen to the muscles, so endurance performance declines. Reduction of blood flow to the skin implies less elimination of heat from the body, so the risk of heart stroke (damage to cells and tissues from overheating) increases, especially in a hot or humid environment. The loss of water and salt may also reduce production of sweat, which will
also increase the risk of heat stroke. These effects become substantial for near-maximal exercise lasting an hour in a hot humid environment and two hours in a cool environment.

- In long hard events with excessive sweating, failure to replace the salt lost in sweat, combined with excessive consumption of water or drinks containing no salt, increases the risk of hyponatremia. In hyponatremia the blood becomes more dilute, and as a consequence excess water enters all cells and tissues in the body, including the brain. The brain therefore swells, and because it is encased almost completely by the skull, pressure builds up inside the skull and can reduce the flow of blood to the brain. On very rare occasions brain damage and death ensue.

Exercise Depletes Carbohydrate
- Exercise results in loss of carbohydrate stored as glycogen in muscles and liver. After an hour of hard exercise, the loss contributes to the feeling of fatigue, either because the brain is affected by a fall in blood glucose concentration (via inability of the liver to maintain the concentration in the face of demand for glucose by muscle) or because the depletion of glycogen stored in muscle reduces the ability of muscle to do work. Performance therefore declines.

Drinks Can Offset These Depletions
- Drinks containing appropriate concentration of salt and appropriate types and concentrations of carbohydrate consumed at an appropriate rate can offset the losses when consumed before and during exercise and can therefore enhance performance.
- Research on what is appropriate is based on measurement of several variables: rate of emptying of the stomach, rate of uptake across the small intestine, rate of oxidation of ingested carbohydrate, and endurance performance.
- Salt and carbohydrate in a sports drink act synergistically to stimulate the uptake of water. That is, the uptake of water is more rapid than occurs with pure water, with water plus salt, or with water plus carbohydrate, even though the concentration gradient for absorption of water in the small intestine is reduced by adding salt and carbohydrate to the drink. The mechanism of the synergistic effect presumably involves opening of water channels in the wall of the small intestine.
- A sports drink can obviously speed full recovery of the losses post exercise. Fast recovery is an issue for athletes training hard every day, especially if they train twice a day.
- Nevertheless, it may be beneficial to perform some training sessions in a somewhat dehydrated state and/or to delay restoration of fluid after training. The body may then supercompensate by increasing blood volume above normal, which would benefit endurance performance. It may also be beneficial for longer endurance and ultraendurance athletes to perform some training sessions in a state of depleted carbohydrate stores, to produce supercompensation of those stores and/or to switch the body to greater use of fat rather than carbohydrate in such events. Research on this question is in progress in several laboratories.

With these issues in mind, we made the following recommendations for the optimum composition of a sport drink for use by endurance athletes in competitions lasting several hours.

- The concentration of salt is determined partly by the need to meet at least partly the expected rate of loss of salt in sweat.
- The concentration of carbohydrate is determined partly by the maximum rate of absorption from the gut. (The maximum rate that carbohydrate can be used to fuel exercise by aerobic and anaerobic processes is greater than the rate it can be absorbed.)
- The combined concentration of salt and carbohydrate is determined by the rate at which water needs to be consumed to replace losses, and the need to limit the inhibiting effect of high solute concentrations both on emptying of the stomach and on transport of water across the wall of the small intestine.
- All of the above are determined partly by the duration and intensity of the exercise and by the environmental conditions in which it is performed.
- A diagram summarizing the recent state of the art for exercise of durations up to 24 hours can be found in Rehrer (2001). She opted for 20 mM (1.2 g/L or 0.12% w/v) NaCl and 60 g/L (6% w/v) carbohydrate at
least partly in the form of glucose polymers for an expected consumption rate of 1.5 L/h in exercise lasting 2 hours, through to twice as much NaCl and half as much carbohydrate for half the expected rate of fluid intake in exercise lasting 24 hours.

- Recent research by Jeukendrup and colleagues indicates that the rate of absorption and oxidation of carbohydrate can be increased by using several kinds of carbohydrate, apparently because the rate of absorption of each kind of carbohydrate is limited by specific carriers in the wall of the small intestine.

- With glucose or glucose polymers alone, the maximum rate is ~1.0 g/min, but Jentjens et al. (2004) achieved a rate of 1.7 g/min when their subjects ingested a mixture of glucose+fructose+sucrose at the rate of 1.2+0.6+0.6 g/min, in a drink containing 20 mM NaCl. After an initial bolus of 600 ml, the drink was consumed at a rate of 600 ml/h. We have calculated that the drink was therefore 12% glucose, 6% fructose, and 6% sucrose, which is 4× the usual recommended total concentration of carbohydrate. We have also calculated that the osmolarity of the drink was 1215 mOsm, which is more than 4× the concentration of body fluids. There was no indication of the effects of this drink on water absorption, but presumably it was strongly impaired.

- In a more recent study, Wallis et al. (2005) achieved a rate of absorption/oxidation of carbohydrate of 1.5 g/min with a more realistic drink consisting of 7.5% maltodextrins and 3.75% fructose (total carbohydrate 11.25%). After an initial bolus of 600 ml, the drink was consumed at 800 ml/h. There was no NaCl in this drink, and the osmolarity was 260 mOsm. Rate of water absorption was not reported. Addition of 20 mM NaCl to this drink would presumably increase the rate of water absorption and probably also the rate of carbohydrate absorption. A reduction in the carbohydrate content would probably accelerate water uptake at the expense of reducing carbohydrate uptake slightly.

- Use of a highly branched glucose polymer with a high molecular weight can reduce the solute concentration and accelerate emptying of the stomach. A drink containing 10% of this polymer had a total solute concentration of 150 mOsm and emptied from the stomach more rapidly than a drink containing 10% of the usual maltodextrins with a concentration of 270 mOsm (Takii et al., 2005). Effects on absorption/oxidation of carbohydrate were not reported.

- Research on the composition of sports drinks will presumably continue for several years yet. In the meantime we would opt for a drink containing ~20 mM NaCl and ~10% carbohydrate in the form of the usual maltodextrins (6.5%) and fructose (3.5%). It would also be worth trialing a drink containing 11% of the glucose polymer of Takii et al. (2005) along with 4% fructose and 20 mM NaCl.

In conclusion, we emphasize that our recommendations apply to use of a drink in endurance competitions, not in training for such competitions. The optimal composition of a drink for training will depend on various factors, including whether it is consumed before, during or after training, what kind of training session is undertaken, and in what training phase the session occurs. On occasions the best drink may contain protein, amino acids, carbohydrate, or only water. Sometimes no drink might be the best strategy.

References

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Theories and Fallacies of muscle cramps

Muscle cramps - even more pervasive mis-marketing, but a complex issue
The industry that has sprung up around the muscle cramp issue has spread far and wide. It includes Gatorade, who advocates the use of their drinks to replace the loss of salt which is, according to their research, responsible for the cramp in the first place! But more than this, there are dozens of products that claim to prevent cramp - next time you are in a pharmacy, take a look at the range - everything from gels, to creams, to pills, to effervescent tablets.

The two broad theories for muscle cramps
All these products work off the same premise - they put back the electrolytes that exercise will take out. And it's the loss of those serum electrolytes, the theory goes, that are responsible for the cramps during exercise. This theory, over 100 years old, is one broad category of theories for muscle cramps.

The second theory is that muscle cramps are caused by a 'malfunction' in the control of the muscle by the nerves - an abnormality of neuromuscular control which is caused by fatigue.

Defining cramp
Firstly, cramp has been defined as a "spasmodic, painful, involuntary contraction of the skeletal muscle that occurs during or immediately after exercise". Note that this definition applies to exercise-related cramps only, and therefore, it excludes a whole host of other possible cramps. We must point out that if you do suffer from very regular cramping, there are some conditions that can cause this - endocrinologic, neurologic, and vascular disorders, treatment with certain drugs, and occupational factors. Then of course, some cramps are what the experts call "idiopathic", which means they have no cause (but actually means we don't know what causes them, but it sounds better to say "idiopathic"!). If you are a regular cramper, it's probably worth seeing a doctor and just having an exam to determine whether any of these broad factors might be responsible.

But returning to muscle cramps, the lifetime prevalence of cramping is reported to be as high as 50%, which is remarkably high. Some people are also quite clearly more susceptible, and you can actually predict with a fair degree of accuracy who will cramp
during a marathon based on their history and their racing strategies (more on this later).

The history of cramping - the electrolyte depletion theory
The earliest reports of muscle cramps come from 100 years ago, when labourers in hot and humid conditions of the mines and shipyards suffered from cramps. Even that far back, the sweat could be analysed, and it was noticed that the builders had a high chloride level in their sweat (chloride, incidentally, is one half of the salt in your sweat). The conclusion that was made was that the labourers were sweating out valuable electrolytes, causing their muscles (and nerves) to malfunction. The heat and humidity were key factors that caused this situation. It must be pointed out that no one prospectively measured the sweat of the labourers who DID NOT CRAMP. Later, the builders of the Hoover Dam famously recovered from cramp when they were made to drink salty milk, entrenching the theory that salt loss was the cause of cramp.

And perhaps rather surprisingly, that was it - based on those anecdotal observations, the theory which you probably hold true today, was born. That is, cramp is caused by a loss of sodium, chloride, and later calcium and magnesium were added to the mix. Heat and high humidity were implicated as "accessories", and the term "Heat-Cramps" was even conceived. According to this theory, cramps happen because athletes exercise in the heat, lose electrolytes in their sweat, and the depletion combined with high body temperatures cause muscle cramp.

The problems with the serum electrolyte depletion theory
First of all, there is a key conceptual problem here, and that is that when you sweat, you don't actually reduce electrolyte concentration. That is, there are certainly electrolytes in the sweat, but the concentration of these electrolytes is so low, that sweating is likely to make you HYPERTONIC, not hypotonic. We looked at this in our posts on fluid - when you sweat, you lose more water than electrolytes, because the sweat is HYPOTONIC. Therefore, sweating cannot lead to a fall in electrolyte concentration.

What transpired was that Gatorade (and the rest of the 'industry', it must be said) developed the theory of "salty sweaters", which is the term they gave to people who they said have abnormally high salt levels in their sweat. Small problem - no one actually knows what a salty sweater is. How much salt does there need to be in the sweat before you are placed in this group? No one knows. The truth is, even the saltiest sweaters around still have hypotonic sweat, and so the more they sweat, the more they will cause
their electrolyte levels to rise, not to decrease. This is a very obvious problem that is overlooked by the electrolyte replacement advocates.

**The cramping paradox - why specific muscles?**
The second problem is something we asked you in yesterday's post. We asked whether the depletion of serum electrolytes would be expected to cause cramps in specific muscles, or all over? Hopefully it is evident that if a cramp was caused by a loss of serum electrolytes, there is no reason for the cramp to be limited to one muscle only. Rather, you would cramp everywhere. In fact, in people who have lost a great deal of salt and have become hyponatremic (not during exercise, but clinically), we know that they cramp in ALL their muscles. But somewhat surprisingly, exercise-associated muscle cramps **ONLY happen in the muscles that have been used** extensively for exercise.
The Effect of Backward Locomotion Training on the Body Composition and Cardiorespiratory Fitness of Young Women

Abstract

This study investigated the effect of a backward training program on the physical and fitness condition of young women. Twenty-six healthy female university students (aged 18 – 23 years) took part in three different baseline tests: body composition, a submaximal treadmill test, and a 20-m shuttle run test. Subjects were divided into a training group (n = 13) and a control group (n = 13). The training group completed a six-week backward run/walk training program. The control group was restricted to their daily activities similar to the four weeks prior to the onset of the baseline tests. The training group showed a significant (p = 0.01) decrease in O2 consumption during both submaximal forward and backward exercise on the treadmill (32% decrease during backward and 30% decrease during forward exercise). A significant (p = 0.01) decrease in percentage body fat (2.4%), a 19.7% decrease in the sum of skinfolds (p = 0.001) and significantly (p = 0.013) improved predicted VO2max values from the forward 20-m shuttle run test (5.2%) were also found in the case of the training group. The findings suggest that backward walk/run training improves cardiorespiratory fitness for both forward and backward exercise and causes significant changes in body composition in young women.

Key words
Retro exercise · anthropometry · VO2max · muscle strength

Introduction

In many sports, particularly team sports such as hockey, netball, basketball, soccer, rugby, and most racquet sports, players must be able to move forward, backward, and laterally with speed and agility. A successful training program for these athletes will therefore include drills and movements in many different directions.

Various movement patterns, specifically backward walking and running, have not only been suggested for use in sports conditioning programs, but also for the rehabilitation of overuse running injuries and knee joint pathology [12]. The rationale for the latter is that backward locomotion increases the strength and power of the quadriceps muscles [14,19,23], while reducing the compressive forces at the patellofemoral joint [13], prevent overstretching of the anterior cruciate ligament (ACL) during quadriceps action [19] and decrease force absorption [14].

To date, research has focused mainly on the biomechanics of backward walking and running [7,9,14], as well as the comparison of the energy cost of backward and forward movement [5,8,12,25]. It has been established that backward walking and running require increased metabolic cost and cardiopulmonary demand compared with forward walking and running at the same constant speed [12], as well as at the same speed, but dif-
ficient treadmill elevations [5]. The differences in metabolic costs have been attributed to (a) increased stride frequency and decreased stride length during backward walking compared to forward walking [12] and (b) the concentric actions of the quadriceps muscle group during backward walking, which has been shown to have a higher energy cost than eccentric muscular work [1].

It has been suggested that athletes could follow a backward walking/run training program during rehabilitation, and still exercise at an intensity that is sufficient to maintain cardiovascular fitness levels [12,21]. Myatt et al. [21] and Clarkson et al. [8] reported that both men and women can exercise at the recommended training intensities of 50–85% of \( \text{V}O_2 \text{peak} \) or 65–90% of maximal heart rate to develop and maintain cardiorespiratory fitness. However, the cardiovascular and metabolic effects of a progressive backward locomotion training program have not yet been described or quantified.

The aims of this study were to determine whether a backward walk-and-run training program (a) will improve the body composition and (b) will result in increased aerobic fitness in young, healthy women.

Methodology

Subjects
Healthy, habitually active women, who did not participate in any organized or competitive sport, volunteered to participate in the study. Following a detailed explanation of the tests involved and the training program, all subjects (n = 26) gave their written, informed consent. None of the subjects experienced any activity-limiting lower extremity dysfunction that may have influenced their responses to the physical tests or training program. Subjects were divided into a training group (n = 13) and a control group (n = 13) and all subjects were tested before and after the 6-week intervention (training program). The experimental protocol was approved by the Ethics Committee of the Faculty of Health Sciences, University of Stellenbosch.

Testing procedures
All tests were conducted indoors on four separate days, but within one week. Tests included an anthropometric assessment and isokinetic test (first visit), a submaximal treadmill test (second visit), and a 20-m progressive shuttle run test (third and fourth visit).

Anthropometric assessment
Height (to the nearest cm) and weight (to the nearest 0.1 kg) were recorded with subjects dressed in exercise clothes and without shoes. Skinfold measurements (to the nearest mm) were obtained from seven sites (biceps, triceps, subscapular, suprailiac, front thigh, mid calf, abdominal) on the right side of the body by the same investigator using a Harpenden skinfold caliper. The investigator was blinded to the individual subject’s group assignment for both baseline and follow-up tests. Percent body fat was calculated using the Durnin-Womersley equation [11]. Standing height and weight was used to calculate BMI (weight, kg)/(height, m²).

Isokinetic test
Knee flexor and extensor strength was measured on the Biodex System 3 isokinetic dynamometer (Biodex Corporation, Shirley, NY). Drouin et al. [10] have shown that the Biodex System 3 is both reliable (trial-to-trial reliability: \( r = 0.99 \); day-to-day reliability: \( r = 0.99 \)) and valid (\( r = 0.99 \)). Before the measurement session, the subjects received instruction in the performance of maximal isokinetic efforts and were given 3 practice efforts.

The dynamometer placement was adjusted for each leg so that the axis of rotation of the knee joint was aligned with the axis of rotation of the dynamometer rod. The torso, hip, and thigh of the subject were restrained with straps for stabilization and to prevent any other movement that could affect the measurement. Torque measures were corrected for the effects of gravity on the lower leg and the dynamometer’s resistance pad. The torque output on the dynamometer was checked with a calibration weight on a regular basis throughout the study. Subjects performed five repetitions at an angular speed of 60°/s with a 10-second rest period after each effort. Subjects were verbally encouraged throughout the test to ensure maximal performance. The highest torque reading of the five attempts for both knee extension and flexion was recorded.

Submaximal test
The submaximal walk and run test was performed on a treadmill. The interval protocol consisted of a 2-min forward walk at a treadmill speed of 4 km·h⁻¹, a 2-min rest interval, and a 2-min forward run at a treadmill speed of 7 km·h⁻¹. This was followed by a 10-min rest before walking and running backwards using the same protocol. During the exercise test, expired gases were collected and analyzed continuously using the Cortex Metalyzer 3B cardiopulmonary system (Cortex Biophysik, Leipzig, Germany). Before each testing session, the gas analyzers were calibrated against a precision analyzed gas mixture (\( \text{CO}_2: 3.5\% \); \( O_2: 17.8\% \)). The volume transducer was calibrated with a 3-L syringe.

The cardiorespiratory variables measured included oxygen uptake (\( \text{VO}_2, \text{ml·kg}^{-1}·\text{min}^{-1} \)), carbon dioxide production (\( \text{VCO}_2, \text{L·min}^{-1} \)), and minute ventilation (\( \text{VE}, \text{L·min}^{-1} \)). Heart rate was measured by telemetry (Polar Heart Rate Monitor, Kempele, Finland) and automatically interfaced with the other physiological variables via the metalyzer software. Five capillary blood samples were obtained by means of a finger prick and blood lactate concentration was measured using the Accusport Lactate Analyzer (Boehringer Mannheim, Germany) (validity = 0.96 and reliability = 0.99) [4]. Samples were taken at rest and immediately after each of the four exercise intervals.

20-m progressive shuttle run test
Subjects performed two 20-m shuttle run tests (one forward and one backward), on a flat, hard surface on separate days. Subjects were required to run repeatedly between two beacons, 20 meters apart. A portable cassette player with an audiocassette set the pace for running between the beacons. Each subject was allowed to voluntarily cease the test at fatigue or was stopped by the observer/researcher when she failed to reach the beacon before or at the “bleep” on two occasions. The level and shuttle that was completed was noted as the score achieved. Predicted \( \text{VO}_2 \text{max} \) values were calculated from the forward run scores using the following formula: \( \text{VO}_2 \text{max}, \text{ml·kg}^{-1}·\text{min}^{-1} = 31.025 + 3.238 \text{ (speed, m·s}^{-1}\text{) \times } 0.065 \).
km · h⁻¹) – 3.248 (age, yr) + 0.1536 (age × speed) [18]. The validity and test-retest reliability of the 20-m shuttle run test for adults were reported as 0.90 and 0.95, respectively [18].

Training program
The training group followed a backward training program for six weeks, consisting of three sessions per week for a total of 18 sessions. The duration of the sessions was progressively increased over the period of six weeks. The first three sessions were 15 minutes long, with the primary aim to familiarize the participants with the mode of training and to ensure that everyone will cope with backward walking. The next week started with 25 minutes per session and the duration of the sessions was increased by 5 minutes per week, ending with 45 minutes in the last week. In total, 40% of the exercise time consisted of backward walking, while the majority (60%) of the training program consisted of backward running exercises. The exercise sessions took place at the athletics track, except for one session during the first week that took place indoors due to adverse weather conditions.

All training sessions took place in the afternoon at 17:00. There were always two supervisors present to take heart rate measurements at the start and end of the session, to assist in counting the number of laps completed around the track, to control the duration of the session with a stopwatch and to monitor the session in general. The training group started off together, but each individual was allowed to walk at her own pace. Participants were asked to try and increase the number of laps they could complete around the athletics track. The track was divided into four sections and completed laps were for example recorded as six and a half laps or five and a quarter laps. The participants were regularly informed of the time elapsed during the session. Subjects in the control group were asked to avoid any major changes in their diet and/or exercise regimen while participating in the study.

Statistical analysis
Descriptive statistics were calculated as the means and standard deviations (mean ± SD). Data were analyzed using a 2 × 2 ANOVA (group vs. pre/post measurement) for repeated measures. Differences detected by the ANOVAs were located with Scheffe post hoc tests. Statistical significance was accepted at the p < 0.05 level.

Results
Table 1 shows the physical characteristics of the trained and untrained groups, both before and after the 6-week intervention.

There were no statistically significant differences in age, height, weight, sum of skinfolds, % body fat, and BMI between the trained and untrained groups before the start of the intervention. The trained group showed statistically significant decreases in skinfold thickness (19.6%; p = 0.001) and % body fat (2.4%; p = 0.01) after participation in the 6-week backward training program. There were no statistically significant changes in the physical characteristics of the untrained groups.

The predicted VO₂max-values calculated from the results of the 20-m forward shuttle run test are presented in Table 1. The trained group showed a statistically significant increase of 5.2% (p = 0.01) in maximal oxygen uptake following the 6-week backward training program. This improvement in maximal aerobic capacity followed after the trained group completed significantly more shuttles during both the forward (57 ± SD 19.5 shuttles vs. 63 ± SD 17.7 shuttles; p = 0.03) and backward (15 ± SD 6.1 shuttles vs. 19 ± SD 6.1 shuttle; p = 0.002) 20-m shuttle run tests after the training program (Fig. 1).

On average, the untrained group completed one more shuttle in the forward shuttle run during the follow-up measurements (55 ± SD 13.5 shuttles vs. 56 ± SD 18.5 shuttles), but could not improve on their performance in the backward shuttle run test (12 ± SD 15.1 shuttles vs. 12 ± SD 13.7 shuttles). There was also no significant change in predicted VO₂max-values following the 6-week period (Table 1).

Table 1 Mean values (± SD) for physical measures of the trained and untrained groups before and after the 6-week training program

<table>
<thead>
<tr>
<th>Measures</th>
<th>Trained group (n = 13)</th>
<th>Untrained group (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>21 ± 0.8</td>
<td>20 ± 1.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166 ± 4.9</td>
<td>168 ± 6.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61 ± 7.9</td>
<td>61 ± 6.8</td>
</tr>
<tr>
<td>BMI</td>
<td>22 ± 1.9</td>
<td>22 ± 1.6</td>
</tr>
<tr>
<td>∑ Skinfolds (mm)</td>
<td>112 ± 27.4</td>
<td>110 ± 47.6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>26 ± 4.0</td>
<td>23 ± 3.5</td>
</tr>
<tr>
<td>VO₂max (ml·kg⁻¹·min⁻¹)</td>
<td>38 ± 6.6</td>
<td>38 ± 4.6</td>
</tr>
</tbody>
</table>

# Predicted VO₂max, derived from 20-m shuttle test. * Significant change (p < 0.01)

Fig. 1 Number of shuttles (means ± SD) completed during the forward (⁎ p = 0.03) and backward (# p = 0.002) shuttle run tests before and after the 6-week training program.

Table 2: Mean values (± SD) for the forward/backward exercise submaximal measures of the trained and untrained groups before and after the 6-week training program

<table>
<thead>
<tr>
<th>Measures</th>
<th>Trained group (n = 13)</th>
<th>Untrained group (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td><strong>4 km·h⁻¹</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂ (m·kg⁻¹·min⁻¹)</td>
<td>15 ± 5.0</td>
<td>10 ± 1.3 *</td>
</tr>
<tr>
<td>HR (b·min⁻¹)</td>
<td>109 ± 14.3</td>
<td>103 ± 12.1</td>
</tr>
<tr>
<td>VE (L·min⁻¹)</td>
<td>16 ± 4.3</td>
<td>17 ± 3.2</td>
</tr>
<tr>
<td>La (mM·L⁻¹)</td>
<td>2.8 ± 1.2</td>
<td>2.6 ± 1.0</td>
</tr>
</tbody>
</table>

| **7 km·h⁻¹** | | | | |
| VO₂ (m·kg⁻¹·min⁻¹) | 33 ± 9.2 | 23 ± 2.0 * | 29 ± 9.6 | 26 ± 6.6 |
| HR (b·min⁻¹) | 145 ± 13.6 | 143 ± 12.1 | 144 ± 10.8 | 145 ± 11.8 |
| VE (L·min⁻¹) | 34 ± 8.5 | 35 ± 6.4 | 33 ± 11.9 | 33 ± 10.6 |
| La (mM·L⁻¹) | 3.5 ± 1.7 | 2.9 ± 1.0 | 3.1 ± 0.9 | 3.4 ± 0.9 |

**Backward exercise**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td><strong>4 km·h⁻¹</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂ (m·kg⁻¹·min⁻¹)</td>
<td>22 ± 6.2</td>
<td>15 ± 2.4 *</td>
<td>19 ± 9.1</td>
<td>14 ± 2.1</td>
</tr>
<tr>
<td>HR (b·min⁻¹)</td>
<td>131 ± 19.5</td>
<td>121 ± 13.8 *</td>
<td>124 ± 13.9</td>
<td>127 ± 16.2</td>
</tr>
<tr>
<td>VE (L·min⁻¹)</td>
<td>24 ± 6.1</td>
<td>23 ± 4.5</td>
<td>23 ± 8.2</td>
<td>22 ± 8.3</td>
</tr>
<tr>
<td>La (mM·L⁻¹)</td>
<td>3.2 ± 1.3</td>
<td>2.7 ± 0.7</td>
<td>3.1 ± 1.1</td>
<td>3.1 ± 0.6</td>
</tr>
</tbody>
</table>

| **7 km·h⁻¹** | | | | |
| VO₂ (m·kg⁻¹·min⁻¹) | 40 ± 13.4 | 27 ± 2.5 * | 37 ± 14.5 | 30 ± 6.6 |
| HR (b·min⁻¹) | 165 ± 14.3 | 163 ± 12.7 | 163 ± 13.0 | 166 ± 11.7 |
| VE (L·min⁻¹) | 48 ± 10.3 | 50 ± 13.3 | 48 ± 19.6 | 53 ± 19.9 |
| La (mM·L⁻¹) | 5.3 ± 1.9 | 4.5 ± 1.7 * | 4.6 ± 1.1 | 4.9 ± 1.0 |

* Significant change (p = 0.01)

The cardiorespiratory and metabolic responses of the women during the submaximal treadmill tests are summarized in Table 2. There was a statistically significant (p = 0.01) decrease in oxygen consumption in the trained group for both forward and backward exercise at a walking speed of 4 km·h⁻¹ and a running speed of 7 km·h⁻¹. Although there were decreases in heart rate and blood [La] in all four exercise conditions in the trained group, this decrease was only significant (p = 0.01) for backward walking at 4 km·h⁻¹ (HR: 131 ± SD 19.5 vs. 121 ± SD 13.7) and backward running at 7 km·h⁻¹ ([La]: 5.3 ± SD 1.8 vs. 4.5 ± SD 1.8). There were no statistically significant changes in the exercise responses of the untrained group for either forward or backward exercise.

Table 3 shows that the backward training program had little or no effect on the isokinetic strength of the quadriceps and hamstring muscles. The trained group showed statistically significant (p = 0.04) improvements in the peak torque for both the left and right hamstring muscles, but no significant change in the peak torque of the quadriceps muscles. Although the trained group showed increases in the total work done by both the left and right hamstrings, the change was only significant (p = 0.006) for the left leg (409 ± SD 76.4 J vs. 443 ± SD 88.0 J). Furthermore, the untrained group also showed significant improvements in total work done by both the left and right hamstring muscles (p = 0.006). There were no significant changes in any of the concentric strength measurements for the quadriceps muscles in either of the groups.

**Discussion**

Forward locomotion (walking and running) is probably one of the most common modes of aerobic conditioning and numerous studies have shown the benefits of different kinds of forward walk/run training programs [16,20]. Backward locomotion is a training technique often used in team sports to increase coordination and endurance [22], however, the effect of a backward walk/run training program on the aerobic fitness of healthy individuals has not been quantified before. The results of this study provide, for the first time, evidence that backward locomotion can improve cardiorespiratory fitness and possibly lead to positive body composition changes in young women.

In order to develop and maintain cardiorespiratory fitness, it is recommended that both men and women exercise at intensities that correspond to 65–90% of maximal heart rate or 50–85% of VO₂peak [22]. Although it was not possible to monitor exercise intensity during the backward training sessions, the program was designed along the same principles as for any forward training program. Both the intensity and duration of the individual ses-
sions were increased steadily over the six weeks and in the last week the women exercised for 45 min per session.

The most important, and novel, finding of this study was that the women following the 6-week training program significantly improved their aerobic fitness. This was evident in both the submaximal treadmill tests and the endurance test (20-m shuttle run). The results of the submaximal treadmill tests indicate that the trained women improved their economy of motion during backward walking at 4 km·h⁻¹ and running at 7 km·h⁻¹. It is known that backward exercise requires a higher metabolic demand than forward exercise at the same speed, primarily due to the novelty of the task and mainly concentric muscle contractions during backward walking and running. However, Childs et al. [6] demonstrated that the metabolic cost of backward exercise decreases within 12 exercise sessions, due to the fact that individuals become more accustomed to this novel task.

The subjects in this study trained for a total of 18 sessions and one could therefore argue that the improvement in the submaximal backward exercise is attributed to familiarization of the task. However, the trained group also showed a significant decreased economic cost during forward exercise at 4 and 7 km·h⁻¹. Furthermore, although not statistically significant, there was a tendency for a reduced accumulation of blood lactate during both backward and forward exercise, while it was unchanged in the control group. From these results it can be concluded that the trained subjects became more economical, not only because they were more familiar with backward exercise, but also because they were fitter.

It may be speculated that the improvement in forward locomotion in response to a backward training program is due to the high metabolic cost and cardiopulmonary demand of backward locomotion. Our data suggest that the changes can possibly be attributed to changes in muscle metabolism, as suggested by the blood lactate values during the submaximal walk/run test, rather than changes in central factors, i.e. cardiac output. Previous studies [5,12] have shown that backward walking, compared with forward walking, resulted in greater respiratory and metabolic responses than cardiovascular responses. These findings therefore also support a possible peripheral, rather than a central adaptation to backward running training.

The trained group was also able to improve their maximal endurance capacity (Table 1 and Fig.1). Again, these improvements were not limited to backward exercise. The trained group also improved their aerobic capacity for forward running. They showed a statistically significant increase in the number of shuttles completed during the forward shuttle run test, which resulted in a significantly higher predicted VO₂max-value (38.4 ± 6.6 ml·kg⁻¹·min⁻¹ vs. 40.4 ± 5.6 ml·kg⁻¹·min⁻¹). Given that backward walking requires 38–119% more energy consumption than forward walking at the same speed [21], and that the subjects improved their walking and running economy for both forward and backward exercise, this improvement in aerobic capacity may be expected.

The improvement in aerobic fitness in the trained group was further accompanied by a decrease in skinfold thickness and percentage body fat, while there were no significant changes in these measurements in the control group. As already indicated, backward exercise is metabolically a far more demanding activity than forward exercise and it is therefore not inconceivable that our backward training program led to substantial energy expenditure. Hawley [15] stated that low intensity exercise strongly stimulates lipolysis from peripheral adipocytes, while the rate of fat oxidation is highest during moderate activities. It has also been reported that exercise training decreases body fat and maintains or increases body fat-free mass, while dieting is more effective in reducing body weight [3,24]. We therefore speculate that our backward training program was probably of sufficient intensity to promote fat loss, while maintaining fat-free body mass.

Although the subjects' diets were not monitored, they were requested not to change their eating patterns during the study. The majority of the subjects reside and have their meals in student residences on campus, which suggests that it is unlikely that their diets changed over the 6-week study period and that
it was the same for the trained and control groups. However, since the participants’ diets were not monitored during the study, it remains speculative that their eating patterns did not change. This is therefore an important limitation of the study.

If the subjects’ eating patterns have in fact not changed during the course of the study, it is encouraging that the trained group showed significant changes in body composition within a relatively short time period. This would suggest that the backward training program was of sufficient duration and intensity to induce these changes. It remains to be seen whether backward training causes more, or less, fat loss in women compared to forward training.

Although it has been suggested that backward running training increases quadriceps power and strength [19,23], similar effects were not found in this study. Mackie and Dean [19] trained their subjects for three months on a treadmill and showed that the power of the subjects’ legs increased significantly, while the strength of the knee flexors and extensors decreased in most subjects. Threlkeld et al. [23] found that backward running (as part of a forward running program over 8 weeks) increased the peak concentric isokinetic torque of the quadriceps at angular velocities of 75° and 120°/s, but not at 180° or 210°/s. The mechanism for the improvement in quadriceps strength is probably related to the isometric and concentric nature of the muscle actions during backward running [11], as well as the fact that the leg muscles are active for a longer sustained period during backward locomotion compared to forward locomotion [11,17].

In a similar study to ours, using a 6-week backward running training program, Anderson et al. [2] also found no significant improvements in either quadriceps or hamstrings muscle strength (concentric and eccentric). It is therefore possible that a 6-week training program is marginally too short, or that the running program must be conducted over variable terrain and not only on a flat surface (as in the case of Anderson’s study and this study). Other reasons why we could not show conclusively whether backward running training improves muscle strength, or not, are the small sample size and large standard deviations of our results.

The importance of maintaining a healthy lifestyle is continuously emphasized by health authorities and those involved in the fitness industry. However, it is also a reality that many competitive and recreational runners will suffer debilitating injuries, particularly affecting the knee joints, as a direct consequence of their running. The results of this study confirm previous suggestions that backward exercise may be used to maintain or improve an individual’s aerobic fitness level who are unable to engage in forward exercise [13,14,23]. However, backward locomotion is not limited only to rehabilitation programs, but may also be a useful supplement to traditional forward running training programs.

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References

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