ALL THE KING'S HORSES AND ALL THE KING'S MEN – PERHAPS EXERCISE PHYSIOLOGISTS CAN PUT SA SPORT TOGETHER AGAIN

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ABOUT THE AUTHOR

Elmarie Terblanche was born in 1964 in Cape Town and completed her high school education in Johannesburg before returning to Stellenbosch in 1983 as a first-year student in Physical Education. In 1991 she was appointed lecturer in the Division of Medical Physiology at the Faculty of Health Sciences, Stellenbosch University. In 1996 she received her PhD in Medical Physiology. In 2004 she was appointed associate professor in the Department of Sport Science and she was promoted to professor in 2008. Since 2006 she has been the chairperson of the Department of Sport Science and in 2007 she was elected president of the South African Association for Human Movement Sciences. She is an accredited sport scientist of the British Association of Sport and Exercise Sciences. She has an interest in research of a practical nature and she addresses questions that are of relevance to athletes at all levels. Her work on bioelectrical impedance analysis is considered to be of exceptionally high quality with international relevance.

All the king's horses and all the king's men – perhaps exercise physiologists can put SA sport together again

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ALL THE KING'S HORSES AND ALL THE KING'S MEN – PERHAPS EXERCISE PHYSIOLOGISTS CAN PUT SA SPORT TOGETHER AGAIN

I am usually quite confused as to what to call myself when someone asks me about my specialty. Sometimes I call myself an *exercise physiologist*, sometimes a *sport physiologist*. On occasion I call myself a *sport scientist*. Why all the confusion? What is in a name, anyway?

The reason for my uncertainty is my own background. My university education started in the Department of Physical Education, and from the first day I set my sights on one day doing research and perhaps a little bit of teaching on the side. (Today I teach and do a little bit of research on the side.) Then I moved to the Department of Medical Physiology at the Faculty of Health Sciences, Tygerberg, where I completed most of my postgraduate studies. There I was regarded as a physiologist with an interest in sport and exercise. It is actually only since 2004, when I returned to the Department of Sport Science, that I have focused solely on exercise and sport physiology. Although the criss-crossing between the various disciplines may cause confusion in some individuals, I am not unhappy being confused because to really understand human performance you need to 'cross some wires' and look at your subject from all angles. Because of that, no one job title fits me terribly well. However, the majority of my research concerns exercise and physiology and therefore I feel at ease with the title *exercise physiologist*.

Exercise physiology is defined as the study of the function of the human body during various acute and chronic exercise conditions as well as the identification of physiological mechanisms underlying physical activity. Exercise represents one of the highest levels of stress to which the body can be exposed. The development of modern exercise physiology can be traced back to physical education, which was a strong academic field in South Africa when it was still part of the school curriculum. Exercise physiology grew out of physical education teachers who identified more with the scientific approach to athletics than teaching physical activities.

Part of the job description of an exercise physiologist is the analysis, improvement and maintenance of health and fitness, assisting in the recovery of an individual from injury, disease or exercise to a state of wellness and the professional guidance and counselling of athletes. In the latter case, basic exercise physiology is applied to the special demands of sport. Concepts derived from exercise physiology are used to optimise the training of athletes and enhance their performance. For example, physiologists have studied for years the responses of human beings at high altitudes. From this, the practice of high-altitude training was derived and today elite athletes use this strategy to augment their competition performance at sea level.

Some would argue that the job of an exercise physiologist is to help an obese person achieve a healthy weight or a cardiac patient regain a healthy lifestyle and that we should leave elite athletes for the sport scientists. It is my contention that exercise physiologists, who study in depth both the basic and applied principles of exercise and training and its integration with all physiological systems, are in a superior position to understand the complete athlete. How can I say this?

A sport scientist, in my opinion, is a generalist. He or she is someone who has a working knowledge of all aspects of human movement and exercise sciences, for instance biomechanics, motor control, anthropometry, sport psychology, fitness, nutrition, exercise physiology and so forth. These are the types of student that we train in South Africa. It is not without reason that we train our students as 'generalists' because, as is the case in nature, 'generalists' have a much greater chance of survival than 'specialists'. However, the important question is whether we really can afford to have so many generalists in the field. If the aim is to develop athletes to achieve optimal performance levels, the answer is a definite no. Elite athletes don't do general training, they don't follow a general diet, they don't have general needs. If an athlete has a psychological issue, he or she seeks the advice of a sport psychologist, not a sport scientist. We need specialists to work with elite athletes. Therefore, if we want to make sport science count in South Africa so that our athletes can benefit from our knowledge and expertise, we need to focus our academic programmes on very specific areas of specialisation in the sport sciences. We need sport biomechanists, sport nutritionists, sport psychologists … and lots of exercise physiologists!

Sport scientists, in general, have another problem in that everyone has an opinion on sport and they don't hesitate to let everyone know about it! More seriously, though, is that we have to contend with the encroachment upon our specialisation by other health care professions who for some reason consider themselves experts in our field. Personal trainers are not exercise physiologists. Neither are sport medicine professionals. In South Africa, exercise physiology is not recognised as a profession for which you are registered with the Medical Council. And herein lies the problem. Anyone can call him- or herself an exercise physiologist. However, having done a module or two in exercise physiology during your undergraduate studies does not make you an exercise physiologist. Thus including conditioning coaches, physiotherapists, biokineticists and medical doctors in the support team of elite athletes and national teams does not mean you have the full complement of sport science and medicine expertise. In South Africa, the potential of exercise physiologists, and sport scientists in general, in the development of our athletes has hardly been tapped. This is one of the primary reasons why we haven't been consistently successful in the international sport arena and specifically at the Olympic Games.

After every Olympic Games, we discuss the dismal performances of our athletes and suddenly everyone has an opinion on the reasons for our lack of medals. This is followed by a number of high-level meetings, workshops and symposia to which the South African sport scientists are sometimes, but not always, invited and then complicated plans are tabled to get things right ~~this time.~~ Usually the outcomes of these meetings are to fire a few coaches, managers and administrators (especially those who are successful), to restructure the national governing bodies in sport and to set up elaborate plans to outline the way ahead. The problem is that we go through this exercise every four years. It's been 17 years since South Africa's readmission to international sport and we are still discussing the same issues.

Of course there are a multitude of reasons why our athletes don't bring home the medals … or at least the number of medals that the politicians and administrators decide would be appropriate. It is by no means an easy problem to solve and there is definitely not a 'one-fits-all' solution. However, the failure of politicians, sport federations, administrators, athletes and coaches to recognise the potential of sport scientists and the role they can and should play in South African sport is a tragedy. It is easier for a personal trainer with no or at best questionable credentials to become the head conditioning coach of a national sports team than for an exercise physiologist with a PhD and NRF rating to become involved in South African sport. Alas, it is time that exercise physiologists take charge.

I will use some examples from my research to illustrate the role that I think exercise physiologists should play to promote the growth and application of sport science in South Africa. My research is mainly at the applied end of the research pathway, building on existing concepts and ideas where there is often a sound fundamental knowledge base.

EXERCISE PHYSIOLOGISTS SHOULD VENTURE OUTSIDE THE ORDINARY

> *If you are tired of life, emotionally depressed, or depleted of energy, ALTERNATE. That is to say, for a moment, do the opposite of what you were doing. You will see the results for yourself.*
>
> Jacques Pezé

Just do it … backwards

A few years ago I saw a brief story on television of an athlete running backwards in the streets of Manhattan. The athlete was adamant that training in this manner enhanced his performance as a marathon runner. In addition, he said, it provided a little variation in his training programme. I was immediately intrigued and wanted to find out more about this alternative exercise mode because I recognised its application in many different sports. It turned out that the Chinese had been practicing backward walking and running for thousands of years and are considered the pioneers of this mode of exercise. Today, backward walking and running is an official sport in many countries.

The first official backward running (BW) race was held in 1987 by the New York Health and Racquet Club when runners competed over a 1-mile distance. Since then retro running has gained popularity all over the United States, but most notably in Europe. The first world championship was held in 2006 in Switzerland and the second in Italy in 2008. Athletes compete over distances from 100 m to a marathon. The African continent has yet to discover retro running, with the only two backward running events ever held in Africa taking place in Stellenbosch in 2004 and 2005. Participants in both meetings were mainly sport science students and on both occasions our students set new world records in a number of events. In fact, Stellenbosch held the men's record in the 4 x 100-m relay until last year when a new record was set at the world championships. Apparently plans are underway to organise the first Olympic retro running marathon during the London Olympics in 2012.

In the mid-1980s, researchers became intrigued by anecdotal evidence suggesting that backward walking and running provided unique training and rehabilitative benefits. The first official publication on backward running appeared in 1981 and was written by an American, Dr Robert K Stevenson. Since then, much of the research has focused on the biomechanics of backward locomotion as well as the comparison of the energy cost of backward and forward exercise. Backward exercise has been suggested for the rehabilitation of overuse running injuries and knee joint pathology as backward locomotion increases the strength and power of the quadriceps muscles while reducing the compressive forces at the patellofemoral joint. It also prevents overstretching of the anterior cruciate ligament during quadriceps action and decreases force absorption by the knee.

We contributed to this body of knowledge by determining the transition speed between backward (BW) walking and running.[1] The transition speed is defined as the speed at which a person spontaneously elects to start to run rather than to walk. This transition speed is often referred to as the spontaneous transition speed. The assumption is that gait transition during human locomotion takes place at speeds that minimise metabolic energy consumption and therefore some authors refer to this as the metabolic transition speed. The transition speed is theoretically determined by biomechanical aspects, such as articular limitations and lever advantages, amplitude of movement, limb length, stride length and stride frequency. Other factors, such as previous experience, purpose of locomotion, sensory feedback and perception of exercise exertion, also influence the transition speed. The spontaneous and metabolic transition speeds are therefore not necessarily at the same absolute work intensity.

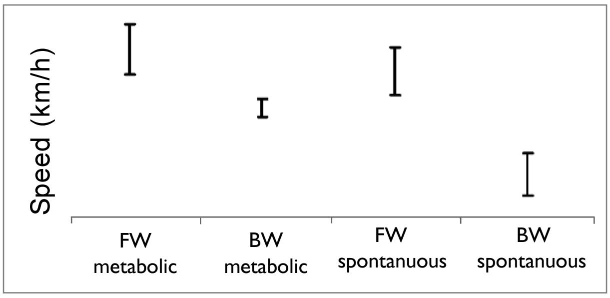


Figure 1: *A comparison of the metabolic and spontaneous transition speeds during backward and forward locomotion*

We were the first group to establish that the metabolic transition between backward walking and running takes place between 6.4 and 6.7 km/h (see Fig. 1). This speed interval is higher than the apparent spontaneous transition speed for backward exercise (6.5 km/h) but lower than the metabolic transition speed for forward locomotion (7.2–7.9 km/h). Our results further suggested that gait transition during backward locomotion does not take place in order to minimise metabolic energy consumption. A possible reason is that peripheral mechanoreceptors detect the discomfort due to inefficient muscle function and this then initiates gait transition. These results have important implications for the design and application of rehabilitation and exercise programmes that include backward walking/running training.

It has also been established that backward walking and running produce increased metabolic cost and cardiopulmonary demand compared with forward locomotion at the same constant speed. Runners typically perceive equal efforts during backward running at speeds of about 80% of those of forward running. The differences in energy cost have been attributed to (a) increased stride frequency and decreased stride length during backward walking compared to forward walking 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. It has therefore been suggested that individuals could follow a backward walking/running training programme during rehabilitation and still exercise at an intensity that is sufficient to maintain cardiovascular fitness levels. However, the cardiovascular and metabolic effects of a progressive backward locomotion training programme have not been quantified and this was therefore the focus of our next research project.

In a study involving young sedentary women, we showed that a six-week backward walking/running training programme caused significantly greater improvements in the aerobic fitness and movement economy than a forward walking/running training programme.[2] Participants in the backward intervention group also lost 3% in body fat while the forward walking/running training group only lost 1% in body fat. These results suggest that the increased physiological demands on the human body with backward locomotion are a benefit for the elite athlete interested in alternative training method modalities as well as for the recreational athlete or individual interested in burning more calories in a shorter period of time.

Table 1: *The changes in body composition and aerobic fitness of women after a backward and forward training programme*

	BW training (n = 13)		FW training (n = 13)	
	Before	After	Before	After
Age	21 ± 0.8		20 ± 1.6	
Weight (kg)	61 ± 7.9	61 ± 6.8	60 ± 10.8	60 ± 11.4
∑ Skinfolds (mm)	112 ± 27.4	90 ± 18.9 *	110 ± 47.6	106 ± 45.5
Body fat %	26 ± 4.0	23 ± 3.5 *	24 ± 6.7	23 ± 6.3
VO_{2max} (ml/kg/min)	38 ± 6.6	40 ± 5.6 *	38 ± 6.6	38 ± 6.0

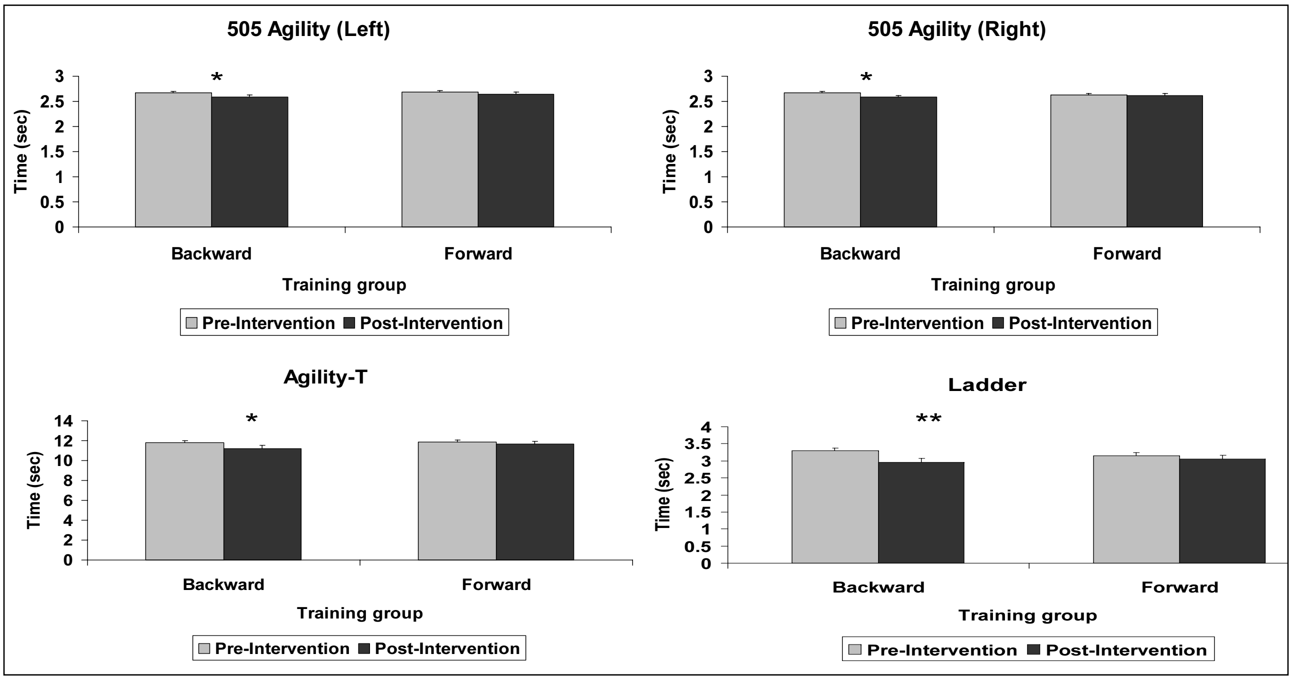
* P = 0.01

Our next aim was to investigate the sport-specific advantages of backward training, specifically the speed, agility and power of netball players. From a training perspective, it has been proposed that BW locomotion has a variety of benefits, including the facilitation of balance and coordination, promotion of a more erect posture during performance, development of a stronger foundation (i.e. improved muscle balance) upon which to improve performance and facilitation of neuro-muscular function. It is specifically the latter that is very important. If it is the objective to train players to be more skilful at faster speeds and with greater precision, the neuro-muscular system must be regularly challenged with different recruitment patterns and different stimuli. We proposed that novel BW training activities incorporated into conventional training programmes would significantly facilitate the improvement of sport performance.

To this end, a group of trained netball players was subjected to an intervention programme in which netball-specific training drills were performed in a backward direction. Their responses were compared to those of a group who performed similar drills in the forward direction (FW). The backward training group significantly improved both agility and quickness while the forward training group either showed no change or a decrease in performance.

Agility training loses its effectiveness when the athlete learns to anticipate the next move. Therefore, when coaches always use the same agility drills and these drills do not require the athlete to respond to directional orders, neural adaptation takes place and no further improvement in agility is noted. This is probably what happened to the FW training group. The players were all experienced and trained and they were used to the traditional netball agility drills. However, the BW training group was challenged with a different movement pattern in which little coordination existed between the central nervous system (CNS) signal and proprioceptive feedback. Different muscles were involved with the BW exercises and the CNS had to relearn which muscle fibres to stimulate, how many motor units to activate and how frequently to stimulate the motor units. It would therefore seem that the novelty of the BW agility exercises sufficiently stressed the neuro-muscular system, which led to improvements in agility and quickness.

Figure 2: *The effect of backward and forward training on the agility and quickness of netball players*



EXERCISE PHYSIOLOGISTS SHOULD DISTINGUISH BETWEEN GIMMICKS AND WORTHWHILE TECHNOLOGY

Innovation plays a major role in every aspect of our daily lives and in sport it is no different. Perhaps the best recent example is the Speedo LZR Racer swimsuit, which caused so much uproar last year. In this case it seems that Speedo, together with NASA, has perfected the technology by creating the Formula One of swimsuits. No less than 55 world records were broken by swimmers in the LZR Racer suit; those swimmers without a Speedo endorsement must have felt lonely on the starter's block.

Every now and then a new product appears on the market, but very few are actually developed in conjunction with credible sport science experts. The people behind the marketing campaigns of these products often get so carried away that their claims of what these products can do to improve athletic performance border on ludicrousness. The problem is that they get away with this as most athletes would do anything to gain the edge over their opponents. This is not to say that there is no space for new and innovative products that can legally enhance the performance of athletes. However, exercise physiologists should play a central role in determining whether or not there is scientific merit in these sometimes 'too-good-to-be-true' claims.

The case of compression socks

When Paula Ratcliff, the current world record holder in the marathon, started running with compression socks, it wasn't long before claims were made that these socks improve athletes' maximal exercise capacity, power production and endurance performance. People argued that if a world-class athlete runs in these socks, they must surely enhance performance as these socks are definitely not a fashion item. As is the case with most new 'aids' that appear on the market, not much sport-specific research was done on these socks to justify their widespread use by athletes. Existing research also reported equivocal results, with some showing enhanced athletic performance and others reporting no effect.

Compression garments were first applied in the clinical setting, specifically treating various circulatory conditions in patients. They have been successfully used to treat venous insufficiencies and calf muscle pump dysfunction and to prevent blood pooling, oedema and deep-vein thrombosis. Most compression garments provide graduated pressures across specific body parts, which typically decrease from the distal to the proximal portions of isolated limbs. Theoretically, this pressure gradient should improve venous blood flow and venous return, resulting in an increased preloading of the heart and stronger ventricular contractions. The resultant increase in stroke volume and cardiac output may result in enhanced oxygen delivery to the muscles and therefore improved endurance performance. However, there is little evidence in the literature of the ergogenic benefits of compression garments.

We had 20 fit men perform a maximal exercise test with and without graded compression socks and found no significant difference in maximal exercise capacity (VO_{2max}) or maximal treadmill speed between the two trials. Our results were therefore in agreement with previous literature that compression socks have no significant performance benefits. However, these studies were limited to relatively short distances and we argued that the true benefits of the compression socks may only manifest during longer runs when the calf muscle pump start to fatigue. We then had seven long-distance runners complete a 2-hour protocol in the laboratory on two occasions, with and without compression socks. The treadmill protocol simulated up- and downhills for 90 minutes, followed by a 30-min downhill run at a 10% gradient. Again, there were no significant differences in the physiological and performance responses of the runners between the two trials.

The interesting finding was that when the runners were followed up for three days after each run to study the recovery phase there was significantly lower creatine kinase concentrations and less swelling in the calf muscles after they had run with the compression socks (see Fig. 3). (This really is the stuff that telemarketers of 'Wait-there-is-more' fame dream of.) Our results indicated that there was less muscle damage and therefore less inflammation in the muscles when wearing the compression socks. This is an important finding and we are of the opinion that this is the ultimate benefit of the compression socks: The socks provide physical support to the muscles, in this case the calf muscle, which reduces the muscle oscillations and friction during exercise. This then causes less muscle damage and therefore the athlete experiences less soreness and pain.

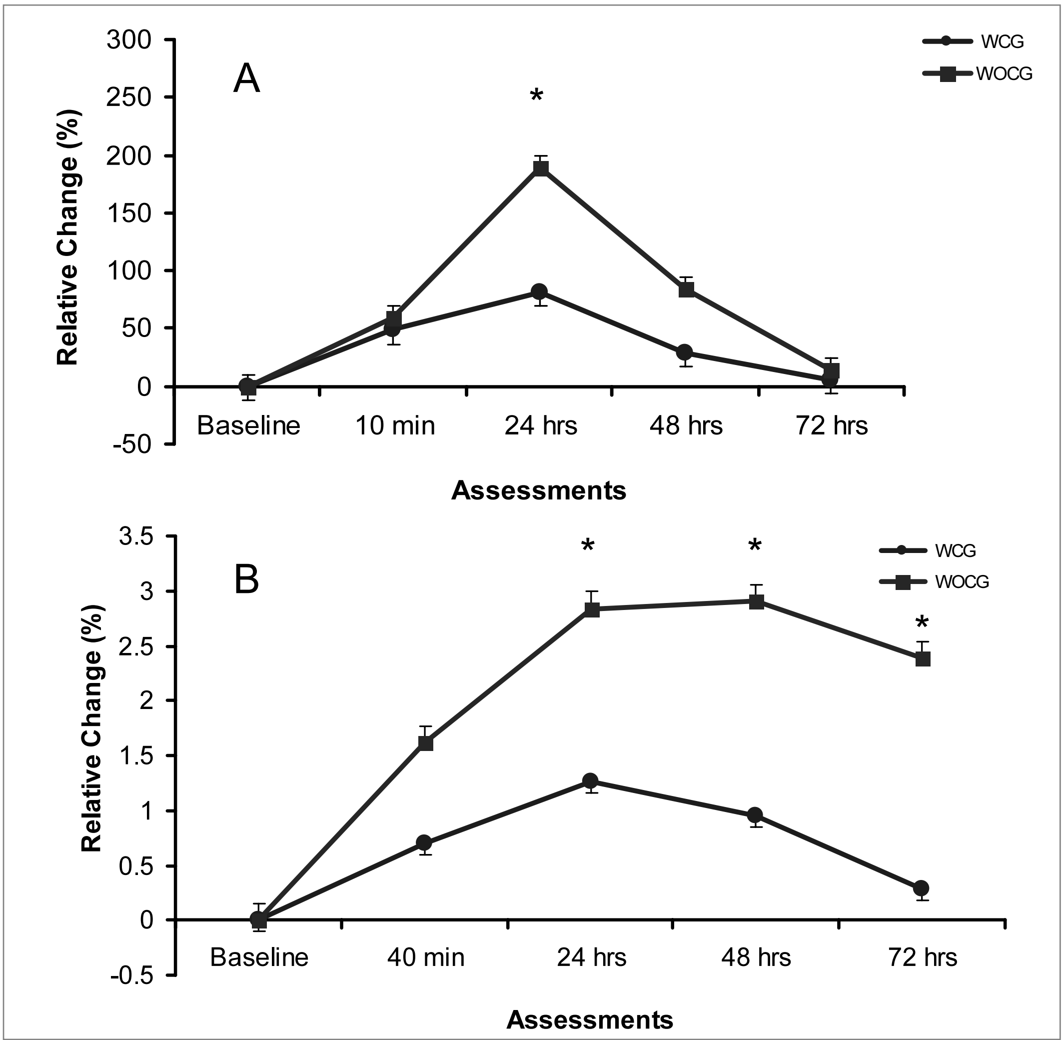


***Figure 3:** The relative changes (%) in (A) creatine kinase concentration and (B) calf muscle circumferences after running with (WCG) and without (WOCG) compression socks (* P < 0.05)*

The implications of these findings are that athletes who recover faster and more effectively will be able to resume training sooner after a race and therefore accumulate more training hours. This will not only enhance their performance but also enable them to participate in more races during the competition season. For elite athletes, this obviously means greater potential income in terms of race earnings and endorsements.

EXERCISE PHYSIOLOGISTS SHOULD ESTABLISH BEST PRACTICES

Best practice asserts that there is a technique, method or process that is more effective at delivering a particular outcome than any other technique, method or process. With proper processes, checks and testing, a desired outcome can be delivered with fewer problems and unforeseen complications. Best practices can also be defined as the most efficient (least amount of effort) and effective (best results) way of accomplishing a task or achieving a goal. Sometimes best practices are established through experience; however, the true validity and reliability of procedures and protocols in sport science can only be established through exhaustive scientific research. Although a lot of research is being done on the effectiveness of various recovery strategies in sport, the best practices of some of these strategies have not yet been determined.

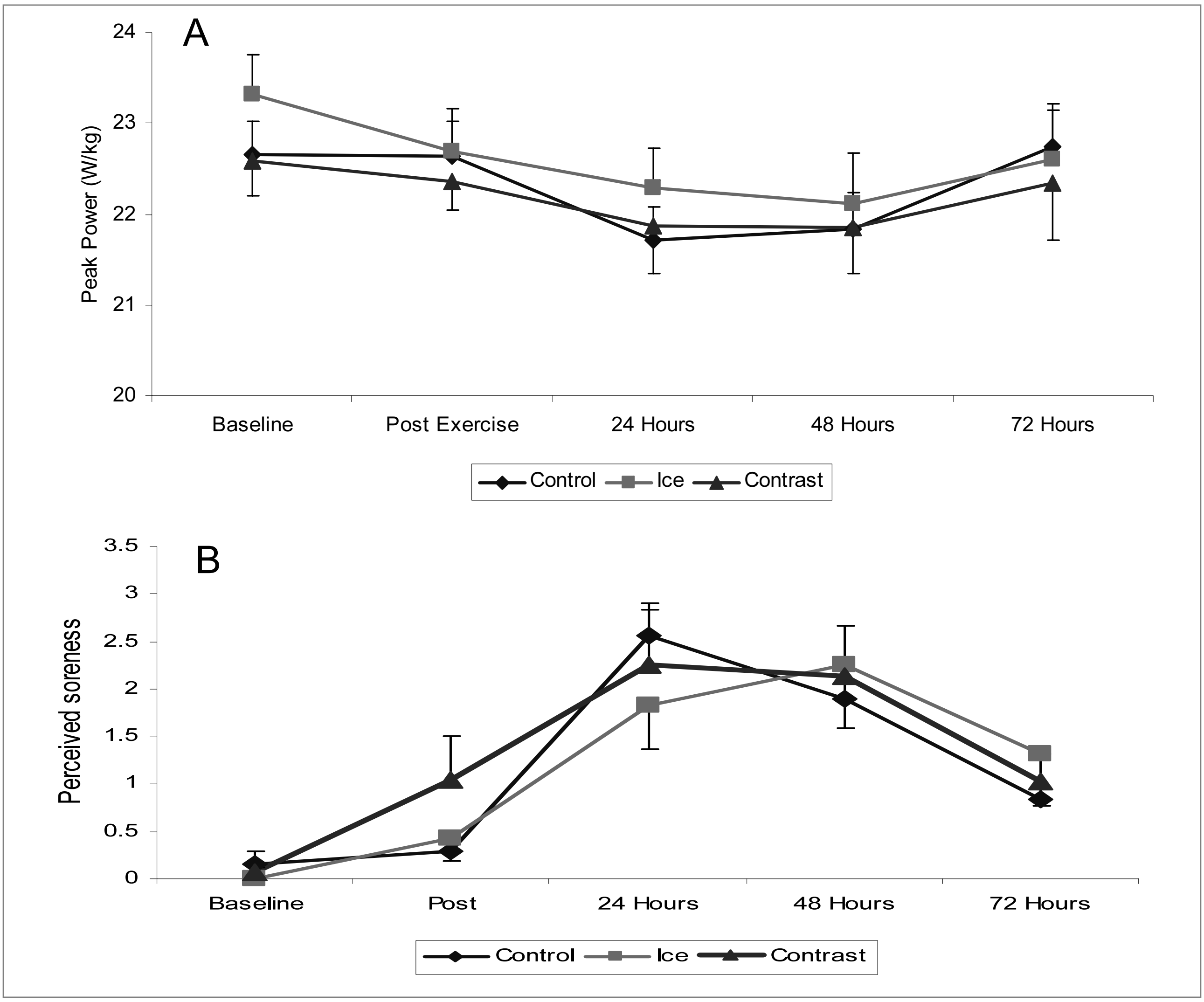
How cool are you?

In their quest for excellence, athletes have to cope with tough training programmes and perform well in competitions on a regular basis. Athletes also sometimes compete in extreme weather conditions (i.e. very cold or very hot and humid) or at high altitude, which will further stress the importance of optimal recovery. It is for these reasons that post-exercise recovery has become an integral part of an athlete's training regime.

Most athletes employ a variety of recovery strategies without knowing whether what they are doing is actually beneficial. Some of the most popular post-exercise recovery strategies include active and passive recovery, water immersion, sport massage, stretching, prophylactic therapies (ultrasound, transcutaneous and micro-current electrical nerve stimulation) and compression garments. None of these recovery strategies except active and passive recovery has been scientifically investigated to such an extent that sport scientists can confidently recommend one above the other. Published results are inconsistent and sometimes contradictory and only very few studies have been done on well-trained athletes. It is well known that results from untrained individuals cannot be extrapolated to athletes who compete at a high level. It is also not known whether these recovery strategies are actually better than active recovery.

Two of the most popular recovery modalities in recent years have been cryotherapy (ice bath) and contrast therapy (the alternation between hot and cold immersions). It is purported that cryotherapy constricts capillaries and reduces capillary permeability and blood flow, thereby attenuating swelling, the inflammatory response and the resultant pain following strenuous exercise. Contrast therapy is the alternation between hot and cold water immersion to create an alternating mechanical force through active vasoconstriction and vasodilation. This vaso-pumping action is suggested to be similar to the alternating muscular contraction and relaxation during low-intensity exercise. It is suggested that contrast therapy would enhance recovery through stimulating blood flow to the muscles, increasing the removal of metabolites and reducing inflammation and oedema.

Figure 4: *A comparison of the post-exercise recovery in (A) peak power output and (B) perceived soreness in individuals after ice and contrast bath therapy*



Despite its widespread use, the efficacy of these recovery modalities in enhancing between-training and between-competition recovery has not been well established. Furthermore, the myriad of protocols used, in other words alternating between hot and cold, the variation in the duration of immersion, the variation in body position (sitting, standing and lying down) and the timing of the post-exercise recovery session, is evidence of the fact that no one really knows what the best practices are. Some of our research therefore focuses on establishing appropriate treatment guidelines.

In one of these studies, we compared ice bath to contrast bath treatments following a bout of eccentric running exercise. After completion of the running protocol, participants were subjected to one of the treatment protocols for 12 minutes each. Follow-up measurements were done for 72 hours post-exercise. Figure 4 shows that there were no differences in the treatment effects between these two recovery modalities with regard to sensation of pain and the recovery of peak power output. More importantly, recovery for the two treatment groups was not significantly better than for those in the passive rest (control) group. We had to conclude that neither ice nor contrast therapy is an effective strategy to treat muscle soreness and reverse muscle damage after strenuous exercise.

Subsequently we repeated these experiments whereby we manipulated the time of treatment, either directly after exercise or one hour after exercise, and the duration of treatment was varied between five minutes and 15 minutes. None of our results pointed to an optimal protocol that produces the required effects and therefore my conclusion is that ice bath and contrast bath therapy are not effective strategies to treat post-exercise muscle soreness. Whether these recovery modalities would be effective in treating muscle fatigue due to training and competition and whether they would enable athletes to tolerate greater training loads are still questions for further research. The possibility that these recovery strategies primarily have psychological and minimal direct physiological effects should also be considered. The jury is still out on this one.

EXERCISE PHYSIOLOGISTS SHOULD CHALLENGE TRADITIONAL BELIEFS

In exercise physiology there are a few classic concepts that have shaped much of our understanding of the limiting factors of exercise performance. Examples of these include the idea that an oxygen limitation develops during maximal exercise, causing skeletal muscle hypoxia to terminate exercise, and the anaerobic threshold theory that suggests that there is a critical workload where skeletal muscles start to produce lactate due to anaerobiosis. Many of these hypotheses have been challenged and alternative physiological models have been proposed to enhance our understanding of the multitude of factors and mechanisms that cause skeletal muscle fatigue. Another area of contention is the respiratory system and whether the lungs are truly 'over-built' for exercise, as most physiology textbooks would suggest. Lately, attention has shifted to the role of the respiratory muscles and the possible ergogenic benefits of respiratory muscle (RM) training.

Respiratory muscle (RM) function and training

The traditional perspective is that the pulmonary system has a large reserve capacity that is more than capable to meet the demands of very heavy physical exercise in healthy individuals. It is also postulated that the only exception to the latter is the exercise-induced arterial hypoxemia that is observed in some highly trained individuals at maximal exercise. However, several studies have demonstrated that RMs can fatigue during prolonged exercise when the intensity of exercise exceeds 80% of VO_{2max} and this phenomenon is not limited to untrained individuals.

The oxygen cost of breathing at rest is only about 2% of total body oxygen consumption. During exercise, this can rise from 3 to 5% during moderate exercise to 10% during strenuous exercise. In highly trained individuals, the latter may rise to 15–16% of VO_{2max}. The implication of this higher oxygen cost of breathing is that the respiratory muscles require a higher proportion of the cardiac output with an increase in exercise intensity, thus leaving a smaller percentage of cardiac output available to the active limb locomotor muscles. It has further been suggested that RM fatigue causes a sympathetically mediated vasoconstriction of the lower limbs, thus reducing blood flow to the active muscles. There is also the possibility that reflex mechanisms of sympathoexcitation are triggered by metaboreceptors in the diaphragm as the muscles begin to accumulate metabolic end products during strenuous exercise. All these factors may significantly contribute to the onset of skeletal muscle fatigue and subsequently have negative effects on performance.

Research on respiratory muscle function and the effects of respiratory muscle training is limited to endurance sport. Over the past two years, we have collected respiratory muscle function data of numerous team sport athletes and have also assessed the degree of respiratory muscle fatigue after exercise. The data show that respiratory muscle fatigue is not only limited to endurance sport but is also experienced by highly trained individuals in most team sport. If the exercise intensity is greater than 80% of VO_{2max}, respiratory muscles fatigue significantly, even during intermittent sport. It has been shown that competitive team sport is most often played at these high intensities; therefore, one could expect that respiratory muscle fatigue may be detrimental to performance during activities such as field hockey, soccer, rugby and netball.

We also embarked on a respiratory muscle-training study, using highly competitive field hockey players to determine whether a six-week RM-training intervention would improve the RM function of hockey players, reverse the significant levels of RM fatigue during exercise and perhaps have positive effects on their overall performance. This was not only the first RM-training study involving a team sport but it was also the first training study not limited to the laboratory. We argued that the semi-crouched position of hockey players during games may increase their susceptibility to develop respiratory muscle fatigue, as the thorax and lungs have limited room for expansion during breathing and their body position may increase the use of the accessory respiratory muscles, which are less fatigue resistant than the diaphragm.

We found significant improvements of between 5 and 13% in respiratory muscle function after the intervention as well as a significant (8%) improvement in aerobic fitness levels of the hockey players. This was therefore the first study to show that team sport athletes may also benefit from respiratory muscle training and that RM fatigue is not limited to endurance sport. Training of the respiratory muscles is a safe, inexpensive and legal ergogenic aid that can be easily incorporated in the training programmes of athletes.

EXERCISE PHYSIOLOGISTS SHOULD BROADEN THE APPLICATION OF EXISTING TECHNOLOGIES

It is a fact that South Africa does not have the financial resources to spend millions of rands on the development of elite athletes. It is also likely that most sport scientists will never have access to sufficient funding in order to perform world-class research on a consistent basis. South Africa therefore needs exercise physiologists with sound theoretical and practical knowledge to engage in research and innovation that seek affordable solutions to complex problems.

Bioelectrical impedance analysis (BIA)

There are certain parameters in sport science and related health professions that are routinely measured and that form an integral part of monitoring an individual's health status and progress during rehabilitation and training. Examples of these are the measurement of maximal exercise capacity – VO_{2max} – and skeletal muscle mass.

VO_{2max} is an indicator of cardiorespiratory fitness and the functional capacity of the cardiovascular system. While elite endurance athletes usually have very high levels of VO_{2max}, low levels of VO_{2max} is associated with numerous clinical conditions, for instance cardiovascular, respiratory and neuro-muscular disease as well as health risk factors such as obesity and hypertension.

The accurate measurement of skeletal muscle mass has numerous applications in both the clinical and sport science setting. For instance, the severity of protein energy malnutrition, catabolic stress, anorexia, sarcopenia and the effects of immobilisation can be reliably indicated by skeletal muscle mass. In rehabilitation and sport, the monitoring of skeletal muscle mass is an indicator of training progress.

Very sophisticated techniques and equipment are available to measure these variables; however, access to these methods is limited to those who can afford the expensive equipment and have qualified staff to perform and evaluate the measurements. Furthermore, most of these methods are time consuming and can only be carried out under continuous medical supervision, thus making them unsuitable for studying large cohorts and performing routine measurements.

In the early eighties, a technique known as bioelectrical impedance analysis (BIA) has gained recognition as an affordable, non-invasive, easy-to-operate and fast alternative to assess body composition. Initially, the BIA models employed a so-called whole-body approach in which the body is modelled as one single cylinder and electrodes are placed at the wrist and ankle of one side of the body. When an electrical current is passed through the body, the body slows or stops the current. The current that is applied varies between 200 and 800 μA at a frequency of 50 kHz. Such currents are small enough that they will not be detected by the body. The extent to which the current is slowed depends on the amount *and* type of tissue through which it passes. For example, adipose tissue does not conduct the current well (i.e. only a small amount of a certain current passes through it), since it contains only about 20% of water. In contrast, skeletal muscles have high water content (~75%). Therefore a relatively large proportion of an applied current will pass through muscles. The extent to which a medium slows or stops an applied current is measured by electrical impedance. Hence, adipose tissue is said to have high impedance whereas muscle tissue has low impedance. Based on these differential effects of various tissues on the applied electrical current, in other words their bio-electrical impedances, BIA is used to determine fat mass (FM), fat free mass (FFM) and total body water (TBW). In the past decade, newer bioelectrical impedance devices were developed that can operate over a broad range of frequencies and together with more sophisticated modelling techniques, the applications of BIA was extended beyond the measurement of body composition. We contributed to this body of knowledge by developing mathematical models by which VO_{2max} [3,5] and skeletal muscle mass[4] can be estimated through BIA.

The majority of non-exercise models do not take the genetic variability in VO_{2max} into account and therefore the predictive value of these models is limited. A more accurate model would thus be obtained when physiological factors that are known to affect VO_{2max} are taken into account. These include blood volume, which accounts for up to 80% of the variance in VO_{2max}, and skeletal muscle mass, which has been shown to be highly correlated with VO_{2max} (r = 0.92). Thus, it was hypothesised that the inclusion of both these factors in future prediction equations would increase the predictive value of non-exercise models to determine VO_{2max}. In previous studies it was shown that the impedance index (height^2/impedance), obtained through BIA, is a valid predictor for both blood volume and skeletal muscle mass. We therefore evaluated the impedance index as a potential predictor of VO_{2max}, using both whole-body and segmental multi-frequency BIA modelling techniques.

Our study revealed strong associations between resistance indices and VO_{2max} in a heterogeneous cohort of men and women diverse in age, body composition and fitness levels, with the intracellular resistance index yielding the strongest correlation with VO_{2max} (r = 0.89). We also found a trend for the relationship between VO_{2max} and resistance indices to improve with increasing frequency. First-order correlations were lowest at 0 kHz (r = 0.76) and highest at infinity (r = 0.84). Despite its theoretical advantage, the segmental approach did not improve the predictive value of the resistance index and therefore the use of whole-body BIA seems sufficient when testing healthy individuals. The advantage of the segmental approach may therefore only be noticeable in populations with specific body builds or in situations when the fluid distribution between body segments is altered. Overall our model was an improvement of existing non-exercise models to predict VO_{2max}. In practice this means that the measurement of cardiorespiratory fitness, through the inexpensive and easy-to-use BIA technique, is within the reach of many practitioners.

Our work on the applications of BIA was further extended to the estimation of upper- and lower-limb muscle volume using multiple bioimpedance measurements as well as frequencies higher than 50 kHz. These muscle volume estimates from BIA were compared to measurements determined by MRI. Our results indicated that leg muscle volume determined by this new BIA model was underestimated by a mean of less than 0.5% at 500 kHz (%SEE = 3.6%) and that this model was superior to the conventional whole-body and segmental models based on simple linear regression analysis. Arm muscle volume was overestimated by 1.5% (%SEE = 10.8%) at 500 kHz by the new BIA model, but this model was not an improvement on conventional segmental BIA models. The main advantage of the new BIA model is that no sample-specific regression algorithm is needed to estimate muscle volume and this model is therefore suitable for a wide range of populations.

Merging science and sport

Exercise physiologists have been among the best thinkers on the factors that influence athletic performance and mechanisms through which it can be optimised. Yet, I am not pretending that exercise physiologists have all the answers. Neither am I saying that if South African athletes wear compression socks and run backwards will they win medals at the Olympic Games. However, I think it is time to put some serious science behind South African sport, with an integrated plan whereby sport scientists are intimately involved in the day-to-day preparation of the athletes. More importantly, we should then be patient and let athletes develop and reach peak performance and not look for quick fixes every four years after the Olympic Games.

There are a number of sport scientists in South Africa, and in particular very well-educated exercise physiologists, who are doing excellent work. They publish in highly rated international scientific journals and they present their work at international conferences. Perhaps, like me, they also have had more interest in their work from people outside of our country's borders than from within. In one way or the other we will have to make the administrators, the coaches and the athletes sit up and listen.

There are excellent examples of where this has actually happened and the results have made South Africans proud. There are the successes of our national rugby team at the 1995 and 2007 World Cups. In both instances, the coach surrounded himself with the best scientific expertise he could find and a well-worked-out long-term plan was followed in the greatest detail. The national cricket team, who recently outperformed the Australians in both one-day and test cricket, also built their team over an extensive period of time, and inputs from scientists on proper training and recovery strategies were taken seriously. The current coach of the Springbok Sevens Rugby Team work closely with sport scientists and since then this team has enjoyed huge success. In the Department of Sport Science there are a number of experts in sport for persons with disabilities. These are individuals who not only have experience in working with these athletes; they actually have PhDs in this subject. It is therefore no coincidence that a significant number of Paralymic athletes trained at Stellenbosch prior to the Beijing Olympic Games and that most of these athletes contributed to the impressive medal tally of the Paralympic Team.

It is clear that a marriage between science and sport is possible, even in South Africa. What we need is properly trained scientists who get the opportunity to specialise in a particular sport or a specific aspect of sport science. Then we need coaches and athletes who can put their trust in scientists and work together to optimise the performance of the athletes. Above all, we need sport administrators who will recognise that they are neither a coach nor a sport scientist but that they are in dire need of both to develop sport in our country.

> *When there's an ache, you want to be like aspirin, not vitamins. Aspirin solves a very particular problem someone has, whereas vitamins are a general "nice to have" market.*
>
> (Reed Hastings, Netflix founder).

In my view, exercise physiologists are the aspirin of South African sport.

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