Sport Science

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SUMMARY

SPORT SCIENCE IS A VALUABLE PROFESSION THAT IS OFTEN MISUNDERSTOOD. THIS UNIQUE DISCIPLINE CAN EXERT A GREAT IMPACT ON PERFORMANCE DURING SPORTING EVENTS. THIS ROUNDTABLE IS DESIGNED TO CLARIFY SEVERAL KEY CONCEPTS CENTRAL TO UNDERSTANDING WHAT SPORT SCIENCE IS AND HOW TO BECOME A SPORT SCIENTIST.

INTRODUCTION

Sport should be considered one of the more important aspects of daily life. This may be supported by the fact that there are magazines, television stations, Web sites, and newspaper sections that are dedicated to sport. Additionally, the Olympic Games, Super Bowl, and Soccer World Cup are some of the most watched sporting events throughout the world. There is a great potential for science to positively impact performance during sporting events. The discipline of sport science would thus appear to be essential to the optimization of sports performance. In this capacity, sport science would involve a tight interaction between the sport scientists and the direction of the development and implementation of the training interventions the athlete undergoes in an attempt to optimize sports performance at all levels (1).

Although it appears that sport science is a valuable profession, there is a large amount of misunderstanding about what sport science entails. Most university programs targeting sport or exercise science in the United States focus on exercise behavior in areas central to the public health domain (6). Additionally, in the research domain, many universities do not perform research in a direct attempt to improve athletic performance. Conversely, they use sport as a perturbation in which physiological, biomechanical, or psychological responses to exercise are studied. Although sport science is embraced throughout the world as an important discipline, within the United States, it appears to be an area on the decline (1).

To better understand sport science, the present roundtable has assembled sport scientists from around the world. The roundtable is designed to clarify several key concepts central to understanding what sport science is and its role in the development of athletes and how one best prepares to become a sport scientist.

QUESTION 1: WHAT IS SPORT SCIENCE?

Bishop: Sport science is a multidisciplinary field (i.e., exercise physiology, biomechanics, motor control and motor development, sport psychology, sports nutrition, and so on) concerned with the understanding and enhancement of sports performance. Sport science can be thought of as using the scientific process to guide the practice of sport with the ultimate aim of improving sports performance (2). It is about using the best available evidence at the right time, in the right environment, and for the right individual to improve their performance. To achieve at least some of these goals, it is necessary to use the findings of well-designed research studies and to translate them into everyday practice (3).

Hoffman: Sport science can be defined as the study of maximizing competitive athletic performance. This field of study is rooted in physiology, biochemistry, biomechanics, nutrition, and endocrinology. However, it specifically examines how these systems interact to maximize athletic performance and how manipulation of different training paradigms can accomplish these goals. In addition, specific areas of research also examine issues that are important not only to maximize athletic performance but also to maintain performance during periods of high-intensity training. Such areas of study may include examination of markers used to predict fatigue or overtraining syndrome; examination of methods to enhance recovery from exercise, such as sport supplementation, massage, and so on; and methods used to predict athletic performance and enhance team selection. In addition, there is a component to sport science that involves a hands-on approach in working with athletes. For instance, many exercise scientists perform research on recreationally trained populations and want to infer their results on what would happen to the competitive athlete. If we accept the fact that competitive athletes are different than recreationally trained athletes, then this clearly becomes a violation of the principle of specificity (1).

Kawamori: Sport science is a discipline of science that is related to the improvement of sports performance and may range from applied sport science to basic sport science. Research that is directly relevant to athletes (and coaches) and immediately applicable could be defined as applied sport science, whereas research that is not immediately relevant or applicable could be defined as basic sport science.

Newton: The word science is derived from the Latin word "scientia," meaning knowledge. Therefore, sport science is knowledge specifically relating to sport. This knowledge has to be obtained through scientific inquiry rather than supposition, theory, accepted practice, or opinion. This knowledge and the process of gathering and applying it are very broad in nature because of the numerous sports that we pursue, the strategy and skills practice that we perform, the physical and psychological training that is used to prepare for competition, and all aspects of the actual competition. Sport science encompasses many disciplines, such as physiology, genetics, endocrinology, biomechanics, motor control, psychology, nutrition, and the list goes on.

Sands: Quite simply, sport science is the study of sport. Applying science to sport is much like applying science to anything. Observations are made, questions are prepared, tentative explanations are offered (theories), the theories are made testable by hypotheses, and scientists usually test hypotheses to provide a framework for a series of experiments that characterize something of interest. Sport science is primarily an applied science, as opposed to basic science. As an applied science, sport science is a combination of research, development, application, and innovation.

Stone: Sport science deals with sport performance enhancement (including creating better equipment) through the use of scientific methods.

QUESTION 2: WHAT ARE THE DIFFERENCES BETWEEN SPORT SCIENCE AND EXERCISE SCIENCE?

Bishop: This is a good question as exercise and sport are often used interchangeably. For me, the following definitions are useful:

1. Physical activity is any activity that increases energy expenditure.
2. Exercise is any planned structured physical activity with a clear goal (i.e., better health or improved performance).
3. Sport is a specialized subcomponent of exercise where the goal is to improve sporting performance.

Following this scheme, sport science can be seen as a specialized component of exercise science. However, to avoid confusion, I think that it is useful to consider sport science as concerned with improving sports performance, whereas exercise science is concerned with the use of exercise to maintain or improve health. There will inevitably be some overlap as, for example, many physiological changes in response to exercise will also occur in response to sports training. The difference, however, lies in the ultimate goal of the intervention.

Hoffman: Sport science looks at exercise as a way to maximize athletic performance, whereas exercise science uses a more global approach in examining how exercise can benefit the entire population. The exercise scientist may direct their research agenda to examining the health benefits associated with various types of training programs, nutritional supplements, and lifestyles with the goals of improving quality of life issues. The sport scientist examines specific questions that arises on the field of competition by both coaches and athletes and uses research to find the most appropriate response.

Kawamori: Sport science should ultimately contribute to sports performance enhancement of athletes, regardless of whether such contribution is immediate or direct. On the other hand, the purpose of exercise science is to investigate the short-term responses and long-term adaptations to exercise and is mainly concerned with phenomenon other than sports performance, such as health-related issues and underlying physiological mechanisms (6). There could be some overlaps between sport science and exercise science, and the distinction between them may not be always obvious. However, what ultimately differentiates them should be whether the end results of research are related to sports performance enhancement (sport science) or something else (exercise science).

Newton: These 2 sciences are closely aligned and share considerable knowledge and practice. I believe in the purist sense that sport science applies to the competitive environment where the ultimate goal of the activity is performance. Exercise science encompasses more the pursuit of health and physical structure and function.

Sands: Sport science studies athlete's preparedness to understand and thereby predict and enhance performance. Exercise science studies exercise in the context of biology to discover principles and laws regarding human response to activity. Sport scientists operate under a different covenant with athletes than exercise scientists do with research subjects. A sport scientist has a covenant more like that of a physician treating a patient than an academic-oriented researcher studying an exercise phenomenon. The orientation of the sport scientist is to help an athlete and/or team, with little concern of generalization to a population. The sport scientist is usually more concerned with internal validity than external validity. For example, a sport scientist does a study involving 20 athletes on a particular team with some kind of intervention that is designed to improve preparedness. The study is a pretest-posttest design (no control group). The results show that 15 of the athletes get better, 3 of the athletes stay about the same, and 2 of the athletes get worse. Typical statistical analysis would very likely indicate statistically significant results with laudable confidence intervals showing that the intervention was effective. In exercise science, this would likely be the end of the story, or a control group would be added to enhance the overall design. Assuming that the control group behaves like a control group, the exercise scientist considers the experiment successful. However, the sport scientist knows the athletes in this study, they are all elite athletes, some of them are very best in the world, making the assignment of a control group impossible by definition–there is no equivalent group of athletes of similar ability to the experimental group. Finally, the sport scientist and the coach know that the 2 athletes who got worse are the 2 best athletes who have the greatest shot at winning a medal. Thus, to the exercise scientist, the experiment was a success, and to the sport scientist and the coach, the experiment was a failure.

The sport scientist tends to use more time-series analyses and single-subject research designs, whereas the exercise scientist tends to use pretest-posttest designs with control groups and placebo control designs. Athletes are not served well by single "snapshot" experiments as much as careful monitoring over months and years. Training is looked at as a long-term process. The exercise scientist tends to see exercise responses in shorter time frames involving usually weeks and thereby keeping his/her subjects only long enough to do pertinent pretests and posttests. Athletes are a relatively captive group while the typical academic research subject is more likely to be lost because of attrition, change of semesters, and/or loss of interest. The sport scientist can lose athletes from a study also, but these losses are usually because of injury, retirement, competition demands, and so forth.

Participation of typical research subjects in an exercise science study usually involves the subject's consent/assent and possibly his/her parent's or guardian's permission. The sport scientist must obtain permission from the athlete and parents or guardians but most importantly from the athlete's coach. Coaches are often involved in sport science at various levels, some extensively and some almost not at all, but no research takes place on athletes without a coach's permission. In addition to facing reticent coaches, the sport scientist also faces problems of human subjects' research approval. It is nearly impossible to prevent an athlete from wondering whether the information gained from investigations might be used for selection purposes. Moreover, can an athlete really withdraw participation from a research project if the coach has decided that the team will participate? There are a number of interesting issues surrounding coercion that rapidly become apparent when doing research on an intact team of athletes.

Stone: Exercise science is a study of physiological mechanisms (and typically health issues) using exercise and training as an intervention. Typical exercise science involves quasi-isolated studies of exercise behavior, largely in a public health domain. Rather than study sport, exercise scientists use sport as a vehicle to attempt to clarify and study physiological, biomechanical, and psychological aspects of exercise. Thus, the exercise scientists' goal is not betterment of the sport and the performance of athletes involved in the sport but to understand how physiology (or psychology) is altered by exercise and training.

In contrast, sport science deals with the enhancement of sport through the use of scientific methods and principles and includes components of physiology, biomechanics, psychology, and aspects of sport medicine. It is paramount in the development of sport scientists that they have an excellent background in both basic and applied sciences. A sport scientist must first be a good scientist having a basic knowledge of physiology and have an understanding of the underlying physical mechanisms and how they can be altered by exercise and training. However, the goal of the sport scientist is not only to understand the physiological alterations (and mechanisms) accompanying exercise and training but also to understand the accompanying performance alterations and how these alterations can be used to better sport performance. In this endeavor, the sport scientist interacts directly with coaches and athletes over an extended period (often for many years) with the goal of improving sport performance. In this context, sport scientists can be divided (loosely because there is overlap) into service providers versus researchers. Service providers would be concerned primarily with the regular (often day-to-day) monitoring of athletes progress, and the researcher would be primarily involved in hypothesis generating or hypothesis testing paradigms designed to further performance.

QUESTION 3: WHAT TYPES OF ACADEMIC TRAINING ARE NECESSARY TO BECOME A SPORT SCIENTIST?

Bishop: I have to admit some bias because all of my education has been conducted in Australia. Nonetheless, I think that the scheme presented in Figure 1 works well (note that it is based on the Australian system but also includes some personal ideas and modifications). Although a PhD is increasingly becoming a prerequisite to work as a sport scientist, I believe that in many cases, a "masters in sport science" may be sufficient. Regardless, I firmly believe that a sport scientist needs to have some knowledge of research so as to be able to better interpret published research and to collaborate on applied research studies. As detailed in Figure 1, I believe that it is an advantage if the sport scientist also has some practical experience of coaching athletes or working with athletes/coaches.

Hoffman: A sport scientist is an individual who can perform independent research. Thus, a doctorate degree in applied physiology, biomechanics, or other sport science discipline would be appropriate. However, I would find it difficult to believe that someone who does not have a background as a competitive athlete or a coach would be able to succeed in this field. The competitive athletic or coaching background provides a measure of credibility when working with this population group. It also provides a tremendous background in developing pertinent questions to form the basis of a research program.

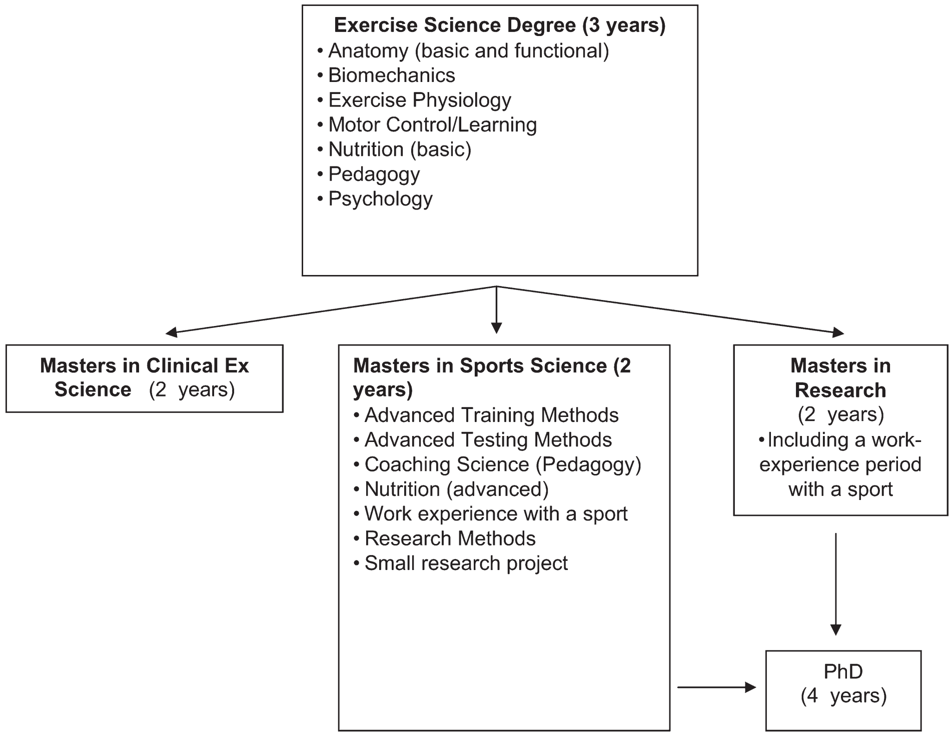

Figure 1. Hierarchy of study for sport science.

Kawamori: A sport scientist needs to be able to deliver sport science services to athletes (e.g., strength and conditioning programming, physiological/fitness testing, motion analysis, psychological counseling, and nutrition advice), conduct sport science research to answer various research questions, and critically evaluate the validity of both scientific and coaching information coming from research journals, coaching magazines, Web sites, media, and others using scientific knowledge and principles. To acquire these skills and expertise, I believe a master's degree by research in the field of sport science is necessary, and a PhD would be preferable. In addition to such "academic" training, a sport scientist also needs some practical experience of actually coaching athletes so that he/she understands the reality of coaching and better relates his/her research to the actual training and competition situations.

Newton: At a minimum, an undergraduate degree in sport science is necessary for the sport scientist to have the basic required skills and knowledge to apply this effectively with athletes. However, depending on the level of competition and sophistication of the program required, a masters or PhD may be required. Certainly, at the professional and Olympic levels, a master's degree is required just to be able to interact effectively with other sport scientists and medical staff. The undergraduate degree is a very generalist qualification covering all the major disciplines. However, greater specialization is required through graduate school to really be effective as a sport scientist.

Sands: Although academic training is extremely important, I believe that direct sport experience as a high-level athlete and coach are also very important. Most of the barriers to doing effective sport science lie not with poor academic training but rather from a poor understanding of the crucial needs of the sport. The sport scientist has to work closely with coaches and athletes and should intrude as little as possible on training time for investigations. Questions for investigation come from multiple sources in sport: the coach, the athlete, administrators, scientists, and previous research. Rarely will coaches and athletes at high levels permit investigations that have little chance of improving the preparedness of the athletes serving as subjects.

The sport scientist should be broadly trained. Although academic preparation tends to compartmentalize knowledge, these compartments have fractionalized sport science such that nutritionists do not talk to biomechanists, who rarely talk to physiologists, who talk even less to psychologists with the isolation of knowledge, resulting in an inability of scientists to provide a coherent message to athletes and coaches. Each group has their own conferences, their own publications, and their own language. Seldom do athletes have preparedness problems that can be simply aligned with only 1 or 2 academic disciplines. Sadly, most scientists are prisoners of their paradigm and do not see that the athlete's problem may not lie in their area of expertise, but the scientists only know their area, so every problem they encounter is distorted by an enthusiasm to apply what they know whether it fits or not. If all you have is a hammer, then every problem tends to look like a nail.

Stone: Much of the academic training would be similar (e.g., basic science, applied sciences such as exercise physiology and so on); however, the sport scientist should receive training in how these apply to sport performance (e.g., sport physiology) and how basic science and an understanding of underlying physiological mechanisms can be applied (and manipulated) in a sport setting (i.e., sport conditioning). Furthermore, the potential sport scientist should be regularly exposed to both monitoring and research programs dealing directly with athletes. The importance of performance improvement, rapid data return, and coach-scientists interaction skills should become part of the academic training. Furthermore, potential sport scientists should have a good working knowledge of coaching skills, methods, and techniques because this will enhance communication between the scientists and the coaching staff. Thus, the academic training should encompass basic science, applied science, and practical aspects. One point that is not completely settled (in any one's mind) is the level of training (e.g., master's degree versus PhD). In my opinion, if research is the goal of the sport scientists, a PhD is necessary and if service is the goal, then a master's degree can suffice. This does not mean that having a master's degree only precludes research, but certainly, the training involved in (good) doctoral work, especially with a sport science emphasis, better prepares the sport scientists for research.

QUESTION 4: DOES SPORT SCIENCE INFLUENCE TRAINING OR COMPETITIVE PRACTICES?

Bishop: I think there is no doubt that sport science does influence training and competitive practices. The difficulty is in quantifying this influence, and I believe that a study examining the influence of sport science on sport practices would be very valuable. Some specific examples of sport science influencing practice include the invention of the Klap Skates; the sports drink and supplementation industry, and the increasing use of heart rates, lactate thresholds; and percentages of aerobic power ($\dot{V}O_2max$) to design training programs. Having said this, there is also no doubt that the influence of sport science on training and competitive practices could be improved by better communication of sport science research to coaches and by better designed research studies (1). It is also important to keep in mind that, like any science, it takes time for the results of sport science research to influence practice. For example, it has been estimated that it may take as long as 1 or 2 decades for original medical research to be translated into routine medical practice (4). Thus, when evaluating the influence of sport science on practice, we need to be patient.

Hoffman: It can, but unfortunately, in the United States, there are very few individuals who are actually performing sport science. Although competitive sport in North America is a multibillion industry that includes both professional and collegiate sports, these organizations do not hire sport scientists to work closely with their athletes or coaching staffs. In the past decade, most professional and collegiate teams have begun hiring strength and conditioning professionals. However, outside of Major League Baseball, no other major sport organization (National Collegiate Athletics Association, National Football League, National Basketball Association, or National Hockey League) has set minimal hiring criteria/standards for these individuals, and the idea of hiring or bringing in a sport scientist consultant has been approached by only a handful of programs. This is unfortunate considering the potential resource of faculty at many major university athletic programs.

If we examine the U.S. performance in international competition, we generally do quite well in medal counts. However, this may be more of a function of our population numbers versus our sport science programs. A biochemist from Great Britain, who is a good friend, made it a point to highlight this for me after the recent Olympic Games. The United States with a population of 305 million people won 110 medals at the 2008 Beijing Summer Olympic Games. This is an average of 1 medal for every 2.77 million Americans. In contrast, the 47 medals won by British athletes from a country of 61 million people results in an average of 1 medal for every 1.3 million Britons. My friend tends to believe that this is because of the superior sport science that Great Britain has. Although this brings a few laughs, in reality, it does bring up a cause for debate. How much sport science exists in this country and could it have an effect? If we take a look at other countries that make an effort in sport science, for instance, Croatia, they won 5 medals in a country of 4.4 million individuals. They average 1 medal for every 880,000 Croatians. Not bad! Now, did sport science make a difference? I would believe that it contributed to this. The ability to maximize talent is dependent upon a strong sport science effort. Talent alone will not be enough, as President Calvin Coolidge once said, "nothing is more common than unsuccessful men with talent," it is the ability to study, examine, and research that will maximize athletic performance.

Kawamori: Yes, it should, by either validating the effectiveness of existing/traditional practices or inventing better training or competitive practices. If not, it is not sport science.

Newton: We are in trouble if science does not inform our practices; otherwise, we are operating on dogma rather than on established reality. There is a vast amount of scientific knowledge in the sport sciences built over centuries as far in the past as the ancient Greeks and earlier. The strength and conditioning specialist and coach would be foolish not to draw on this science. The level to which sport science influences training and competitive practices does vary across different sports and competitive levels, but it is difficult to think of a single scenario where sport science has no role to play. Even in some of the very traditional sports, such as tae kwon do and wushu, coaches are accepting sport science as beneficial and modern techniques are being added to the old ways of preparing their athletes. For the modern elite athlete, sport science is ubiquitous to their daily lives impacting on training, travel, nutrition, and competition. Sports such as swimming and cycling are pushing the limits of sport science knowledge, and recent success by the English cycling is testament to the effectiveness of an integrated sport science program.

Sands: Yes, but the influence is a long road. Like most of science, it takes some time for scientific findings to make it to application. Most coaches do not read scientific journals and lack the scientific training to interpret the methods and presentation of scientific studies. Whenever someone enters a new world of knowledge, they often require a host who can translate that world into a language that the newcomer can understand. Sport science, like all professions, has some good translators and those who are not so good. Moreover, given the rapidly changing world of all science, it is very difficult to keep up even in a narrow area of study. There is a tendency for coaches to believe scientists simply because of their title. This belief places pressure on scientists to stay current and able to sift through the myriad of studies and cull only those that are relevant, evaluate each one's quality, and thus provide the best advice possible. Interpreting scientific studies is a slippery problem based largely on the example problem described above under question number 2. Studies performed on physical education students, the elderly, untrained subjects, different sports, and different genders may be promising but will have to be replicated with the athletes for whom the results are intended.

To influence training and competitive practice, the scientist must adapt information to meet the needs of the coach and athlete. No scientific information, regardless of the quality of the science, makes it to an athlete without first being funneled (and filtered) through a coach. Coaches are not particularly interested in "the science," how it was obtained, which cool software or hardware did the measurement, or whether the science is "interesting." Coaches want solutions to their problems. Science influences training and competition when it provides these solutions.

Stone: Not as much as it should; however, this may deal with several factors, such as the coaches' mistrust of the motives of scientists. In many cases in which the sport scientists work directly with sports for relatively long periods (and trust is developed), coaches will begin to make alterations in the training process–one major endeavor that can help accomplish this goal is to begin a monitoring/research program, which regularly gives feedback to the coaches. Ideally, this will develop into a sports performance enhancement team (coaches, sport scientists, and sport medicine personnel) that will (driven by the coach) assess the athletes on a regular basis and create/plan the long-term training process. This is happening around the world (although the United States lags behind) with excellent results in most cases (e.g., Australian Institute of Sport, English Institute of Sport, and so on).

QUESTION 5: GENERALLY HOW DOES A SPORT SCIENTIST BRIDGE THE GAP BETWEEN SCIENCE AND SPORTS?

Bishop: I believe that the sport scientist and coach need to collaborate on a number of levels to bridge the gap. A draft model is presented in Figure 2. In this model, the coach or trainer communicates what they believe to be the most important problems to solve. The sport scientists then work with the coach and attempts to provide a "solution" to the problem (via research studies and/or deductive reasoning). Once a solution has been found, the coach/trainer then attempts to implement the "solution" and communicates any deficiencies in the "solution" back to the sport scientist so that further "solutions" can be modified to better answer the problem. Another important aspect of "bridging the gap" is that the sport scientist (possibly with the coach) also communicates the research results in more applied easier to read coaching magazines or journals. In practice, the roles described below are unlikely to be as clearly delineated. For example, the coach or trainer may have a major role in the execution of the research study, or the sport scientist may trial new practical ideas in a sports setting with athletes.

Hoffman: I believe that there are 2 ways; the first is to perform sport specific research that is clearly applicable to the coach and/or athlete. The second is to interpret research in a manner that is understandable and applicable to the coach and/or athlete.

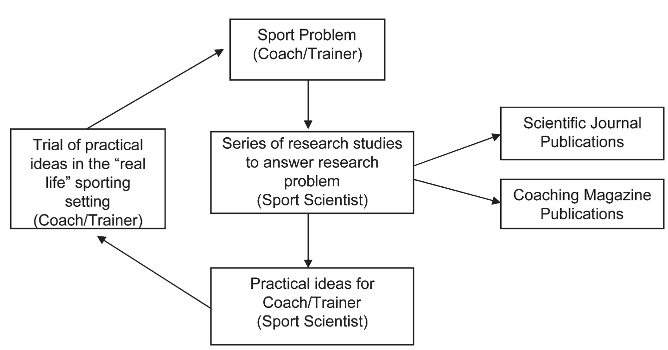

Figure 2. Model for bridging the gap between sport scientists and coaches.

Kawamori: There are several ways to bridge the gap between science and sports. The most direct way is for applied sport scientists to provide sport science services to athletes and coaches in the field or on the court on a day-to-day basis. In fact, many national/state sport institutes as well as professional sport teams all over the world now use or contract applied sport scientists to benefit from the advancement of sport science. Even a better way would be a team approach where applied sport scientists working closely with athletes and coaches collaborate with academic sport scientists (e.g., university professors) whose main job is to do research rather than providing sport science services. Such collaboration would facilitate the rapid spread of the latest sport science information from the laboratory to the field and also allow academic sport scientists to gather relevant research questions from the field (2,3). The downside of this approach is that only elite level athletes could benefit from it. If sport science is to influence a larger population of athletes and coaches at all levels, more indirect ways to bridge the gap between science and sports would be useful and necessary. One example is coach education in sport science. Sport scientists can help coaches improve their sport science knowledge through seminars, coaching accreditation process, and degree programs in sport science so that coaches can effectively interpret and apply the latest research information to their own work with athletes. In addition, sport scientists can also disseminate sport science information to coaches and athletes through various media (book, magazine, television, and Internet). Moreover, professional organizations such as National Strength and Conditioning Association (NSCA) can bring sport scientists together and issue position stands and make them available to the public (2).

Newton: It is certainly valuable for the sport scientist to also be a "salesperson" for their work by publishing and presenting at professional as well as scientific conferences and seminars. Sport scientists based in universities need to be very effective at relaying their latest knowledge to graduate and undergraduate students as well as colleagues because this "pyramid selling" strategy can have very high impact out in the profession. At sports academies and institutes, the conduit between coach and scientist is shorter and so even greater exchange hopefully occurs.

However, a certain component of research has to be applied immediately to be of relevance. There is certainly a role for more basic research if we are to answer the really big questions, but coaches and other sports professionals have more pressing concerns.

I believe that the transfer of knowledge is improving because the number of journals, magazines, and Web sites dedicated to communication with athletes and coaches increases and the skills of their journalists in scouring the sport science research literature and packaging it for coaches and athletes improve. Position stands from professional organizations, such as NSCA, can be very helpful in this regard. Such published documents are generally very well read and represent the opinions of several experts in the field.

Scientific journals should continue to support and promote the publication of literature reviews. For research reports, a section at the end of the articles called "Practical Applications" is useful for 2 purposes. First, coaches and athletes can receive practical advice, and second, this helps the scientists to think more about the practical implications of their research.

Sports organizations could place greater emphasis on advisory boards and ensure that there is adequate representation on these boards by sport scientists.

Sands: The basic assumption that there is a "gap" between science and sport emphasizes a fundamental disconnect that reaches beyond the relatively straightforward worlds of science and sport. Science literacy in America is relatively poor. The attitudes of many academics still proceed from an assumption that human abilities are a "zero-sum game," that if you are smart you cannot be athletic and vice versa. The dumb-jock stereotype serves no one and too often causes one group to ignore that which could help them and the other group from directly serving the community. The "gap" exists largely because of reluctance on both sides to communicate. Sport scientists need to learn to modify their language and develop better teaching methods to bring science to sport without intimidation and unnecessary complexity. Sport scientists need to frame their presentations and writing in forms that help solve coaching problems. Coaches and athletes should understand that science proceeds slowly, and like athletics require a great deal of planning, correct choices, changes in behavior, patience through learning, and ultimately a system of evaluation and feedback. Science proceeds slowly and incrementally. Usually, only the synthesis of many studies helps coaches and athletes acquire enough quality information to change their approaches to training intelligently.

Too often, sport scientists have overpromised and under delivered, too often connected to a profit motive. I once asked an open question on a biomechanics listserv for anyone to tell me what biomechanics has done to actually improve an athlete's performance that was not first shown by a coach or athlete. I got one response, Klap Skates. Interestingly, there may be more contributions from biomechanics, but they are mostly related to equipment. In physiology, I would argue that there have been more "paradigm shifts" (carbohydrate loading, nutrition timing, altitude training, intervals, and so on), but these are still relatively rare and are often tried first by smart coaches only later to be verified and validated in the laboratory. The list of promulgated ideas that later turned out to be less of a silver bullet than first thought is long: lactate testing, plyometrics, isokinetics, bee pollen, maximum $\dot{V}O_2$, muscle fiber typing, electromyostimulation, an aerobic base, altitude tents, calorie blockers, structured water, and many others.

Stone: I believe the following are reasonable in bridging gaps:

- Hard work, this includes making a real effort to communicate with the coaches.
- Providing educational opportunities–these would include both formal and informal meetings with the coaching staff (and with athletes), holding regular symposia, clinics, and the like, providing an insight as to what sport science is and can do in terms of helping sport to progress.
- However, the best method is actual work with the coaches and athletes, providing evidence that sport science can produce meaningful useful data, rapid return, that the scientists is not trying to take over and that a team approach is superior. This means gaining the trust of the coach (including the strength coaches).

QUESTION 6: WHAT ARE SOME OF THE RESEARCH DIFFICULTIES THAT A SPORT SCIENTIST MIGHT EXPERIENCE?

Bishop: Many of the research difficulties faced by a sport scientist are the same as for any other scientist. It is difficult to obtain the financial support to conduct research, and it is often difficult to conduct research on the population of interest (i.e., elite athletes in the case of the sport scientist). An added difficulty, in my opinion, is that coaches and athletes demand immediate results. Unfortunately, research rarely works like this, and it is more likely that revolutionary ideas will come from a series of well–thought-out experiments conducted over years, than from a single study. Other research difficulties include the complications associated with long-term training studies (i.e., more than 2–3 months and more representative of the actual training of athletes), issues of concurrent training, and the problematic definition of "performance" in some sports (e.g., team sports).

Hoffman: I believe that one of the most difficult problems is the accessibility to a competitive athletic population. As I mentioned earlier, there are very few athletic programs in this country (either amateur or professional) that use the services of a sport scientist. Most collegiate programs generally have an imaginary barrier that separates athletics from academics. It becomes a challenge to cross that barrier, and most of the time, the reason that it exists is not very clear. I believe that the sport scientist at the collegiate level should make the effort to educate the athletic administration, coaching staffs and strength and conditioning personnel about the benefits that collaboration would bring. It is at this point that the sport scientist needs to provide some level of credibility to those individuals. Collaborating for the sake of "it would be interesting" would not invite a tremendous amount of cooperation. The coaches and athletic administrators need to be convinced of the benefits they would achieve by working collaboratively with sport scientists.

Another area of problem is research funding. Federal funding agencies are generally not interested in providing funds for research involving sport science. Because the academic lives of many faculty are tied to their funding history, this area of research may not be conducive for attracting government research dollars. Most sport scientists are then forced to fund themselves with industry dollars. This is very competitive and often is quite limited. Thus, developing a laboratory with funding for graduate assistants can be quite challenging.

Kawamori: The biggest difficulty a sport scientist may face is a lack of employment and funding resources. As a result of a worldwide shift of research focus toward exercise science (e.g., physical activity, obesity, related lifestyle, and medical issues), the number of sport science jobs in higher education has declined, although universities continue to recruit staffs with expertise and skills in the area of exercise science. Similarly, it is now very difficult for a sport scientist to receive enough amount of research grant to pay the direct costs of sport science research, unless they concurrently conduct research in other areas such as exercise science where research funding is abundant (6).

Even if a sport scientist could secure a job and research grant, he/she still has to face other research difficulties. For example, it is usually difficult to recruit elite or high-performance athletes as subjects for sport science research because those athletes and coaches tend to be afraid that their participation in sport science research may hinder their performance in training and competition. It is a sport scientist's job to select appropriate research design and to convince athletes and coaches that their participation in research does not interfere with athletes' performance and in fact contributes to their performance enhancement. This process could be easier if coaches possess basic sport science knowledge and are open to sport science research.

Once a sport scientist successfully recruits elite or high-performance athletes as research subjects, he/she faces another problem of small sample size. Because elite or high-performance athletes are rare, it is difficult for a sport scientist to recruit large enough number of subjects to detect statistically significant differences and/or relationships based on p values derived from a null-hypothesis test. Moreover, when monitoring individual athletes, a sport scientist cannot apply traditional null-hypothesis testing methods. To overcome these problems, a sport scientist could report practical significance of effects (instead of statistical significance) based on magnitude-based inferences (1). Unfortunately, such a statistical approach is not widely accepted at this stage, and publishing sport science research in academic journals or obtaining ethics approval could be difficult (journal editorial office, reviewers, and ethics committee tend to ask for large sample size and reporting p values).

Newton: Number 1 is of course funding for their research. Sport science never receives anywhere near the money directed to exercise science let alone medical research. Here, I believe that equipment companies, sporting organizations, and government could be much more innovative in how they support such applied sport science research projects. Clearly, equipment manufacturers are making considerable income on the back of the population's passion for sport, and the safety and performance of our athletes could be improved markedly by well funded and directed research through industry partnerships.

Sands: Sport science investigations do not fit well into the research framework of higher education. Sport science investigations usually require long-term data collection that exceeds the duration of quarters and semesters. These investigations often involve practical issues that may not rise to the level of an academic paper suitable for a peer-reviewed journal, so the busy scientist/professor may elect to steer away from sport science simply because of the pressures of publish or perish. In fact, higher education has largely shifted from publish or perish to "grant or perish," and there is very little funding available for sport science research.

Training and competition problems often arise suddenly and require quick interventions from the sport scientist. To apply the interventions intelligently, he/she needs to conduct testing on athletes rapidly–too rapidly for most university human subject committees to evaluate a research proposal and respond. I vividly remember wanting to measure standing height, based on some Japanese papers, as an indicator of training load (spinal compression) in track and field athletes. The proposal was 6 months in the review process. By the time it was approved, the athletes were gone on summer break. Although I strongly believe in research oversight, is 6 months really necessary to approve the measurement of standing height?

Stone: There are several difficulties.

- One is a mistrust, by the coaches, of the scientists that stems from 2 major areas:

1. In the past, scientists have used sport as a vehicle for their own research agenda, while the welfare of the sport (athletes and coach) and improved performance were not the priority. Data were returned slowly or not at all.
2. In some cases, it is possible that the coach may be intimidated by "science" and "scientists" and feel that they may lose their influence as a coach.

- Communication with coaches can be difficult at times because scientific language and coaching languages are not always compatible. Additionally, not all coaches (probably few in the United Sates) have a good understanding of science or scientific methods.
- Some types of research are not possible (or at least very difficult), for example, it is very difficult to carry out comparative studies of different types of training because this type of study implies that one training program will be inferior to the other, no coach wants this to happen. Also, nutritional supplement studies may be difficult because many coaches and athletes, as well as national governing bodies (NGBs) are concerned with product contamination (and rightly so). Thus, much of the research must be carried out in the monitoring program and becomes more descriptive in nature.
- As the monitoring/research programs can be long-term (years), this in itself can present obstacles (i.e., defining performance, separating combination training effects, and so on).
- Finding methods of statistically describing the very small changes in performance that is meaningful (a major problem), a major factor separating exercise and sport science.
- Finding better methods of rapid data return to the coach and athletes, the primary factor separating exercise and sport science.
- Finding funding for sport-related service and research projects (it is much easier to fund health-related projects), another major factor separating exercise and sport science.
- There is also an ethical dilemma that sport scientists face that exercise scientists usually do not face. Suppose that a real breakthrough in training or supplementation is found that gives your team (perhaps an Olympic team) a real advantage in competition, how long should you wait before presenting or publishing the results (4 years or never?).

QUESTION 7: HOW IMPORTANT IS IT FOR COACHES TO HAVE SOME BASIC SPORT SCIENCE TRAINING?

Bishop: In my response to question 3, I suggested that it is important for the sport scientist to have some practical experience in a sporting setting. I believe that the same applies for coaches, and it is important that they have some basic knowledge of sport science. Coaches need to understand the basic scientific principles that form the foundation of training, and they need to understand the research process (the need for the sequential accumulation of knowledge, the importance of reliability and validity, and so on). Thus, I believe that better communication is possible if the sport scientist has some basic coaching training and the coach has some basic sport science training.

Hoffman: It is critical that coaches have a basic understanding of physiological adaptations to training, nutrition, and biomechanics. Unfortunately, we may be one of the few countries in the world that allows anyone to coach. We do not have a minimal competency level that is required for coaches at any level, except for strength and conditioning coaches. Many countries require coaches to have at least 2 years of classroom instruction, with a focus on applied physiology, to sit for a certification examination. This is often supported and enforced by government agencies. This ensures that coaches have successfully passed a minimal level of competency.

Our primary method of training coaches in the United States today is through graduate assistantships. However, there is no planned course of study, and a future coach can study in a profession with little to no relation with sport science. Unfortunately, we are left in a situation where the athletes who need the best coaching (e.g., high-school athletes) are left with the "math teacher" who played maybe 2 years of college football. At this level, coaches work with young athletes with varying levels of maturity. The understanding of maturational differences among preadolescents, adolescents, and adults is important in developing training programs and setting realistic training goals.

It is not only important for coaches to have a basic understanding of sport science but also sports administrators, such as general managers and player personnel directors, who need to have a solid background in sport science. On the professional level, athletes are often signed based on what they have done, not what they will do. Understanding of expected performance declines or performance maintenance based on fitness evaluation would potentially make contractual decisions more scientific and not to chance.

Kawamori: If sport science is to influence training and competitive practices, it is necessary that coaches have some basic sport science training because they are the end users of sport science research in most instances. With basic sport science knowledge, coaches can make more objective judgments in their coaching process rather than solely relying on their personal experiences as coaches and/or former athletes. Moreover, basic sport science knowledge will help coaches understand and apply the latest sport science information and will also facilitate the communication between coaches and sport scientists by allowing them to speak the same language.

Newton: Regardless of level, I believe that it is essential. Even coaching the under 10 basketball team, the coach needs to have sufficient knowledge of sport science to ensure the safety of his/her athletes. At the elite level, if the coach cannot read, understand, and integrate the latest knowledge, it is unlikely that they will be competitive.

Sands: Obviously, I believe that science knowledge is important for everyone, including coaches. Let me offer a brief quotation:

"Even in periods of great aversion to it, science does march on. And like it or not, the affairs of man can only be managed by people who have the skills and concepts of a quantitatively trained mind and the competence for scientific, critical thinking. People who don't know how to work things out, who are not quantitatively and scientifically literate are at the absolute mercy of people who are."—Louis W. Cabot

Stone: It is very important. Good communication is paramount for any successful program, and furthermore, communication is a 2-way street. In our opinion and experiences, most of the time, the primary failing in communication is on the coaches' part (at least in the United States). Many coaches do not have the educational background necessary for good communication (or understanding) of sport science. Thus, the worth of good sport science/sport interface cannot always be appreciated. We have not as often found the reverse to be true. Most sport scientists learn coaching language and the like and many, if not most, sport scientists come from a coaching background.

We have found that in most cases, coaches from Europe have a much better background in sport science than those from the United States (in this context, it should be noted that of the coaches at the United States Olympic Committee (USOC) and employed by NGBs, more than 50% are foreigners). Indeed, many of the coaches we have encountered in Europe are good sport scientists.

Indeed, a background in the sciences provides both better communication and a better understanding of science and the outcomes of monitoring and research projects. Thus, the coach will have a better understanding of how the results of these programs can be better used to design or alter the training process.

QUESTION 8: IDEALLY, WHAT WOULD BE THE ROLE OF THE SPORT SCIENTIST IN A MULTIDIMENSIONAL PERFORMANCE ENHANCEMENT TEAM?

Bishop: To answer this question, I think that it is important to define 2 types of sport scientist: an applied sport scientist and a sport science researcher. In this scheme (Figure 3), the role of the applied sport scientist would be to implement a training program based on sound sport science principles and to identify the most crucial gaps in the current knowledge (which would then be communicated to the sport science researcher). The role of the sport science researcher would be to conduct research projects (in collaboration with the sport scientists and coach), communicate the latest research findings to the performance enhancement team, and act as a point of reference when the annual (or multiannual) training plan is being developed. In all cases, it is important that there is good communication with the coaching and medical staffs.

Hoffman: I am not familiar with the term "multidimensional performance enhancement team," unless it is synonymous with the "sports medicine team." Regardless, I see the role of the sport scientist as primarily that of research and advising on athlete performance and development. Depending on the program, the sport scientist could also be involved with team athlete selection.

Kawamori: A multidimensional performance enhancement team usually comprises experts, such as physiologists, biomechanists, nutritionists, psychologists, strength and conditioning coaches, athletic trainers, physical therapists, and medical doctors. The role of the sport scientist is to contribute to the team's goal of enhancing

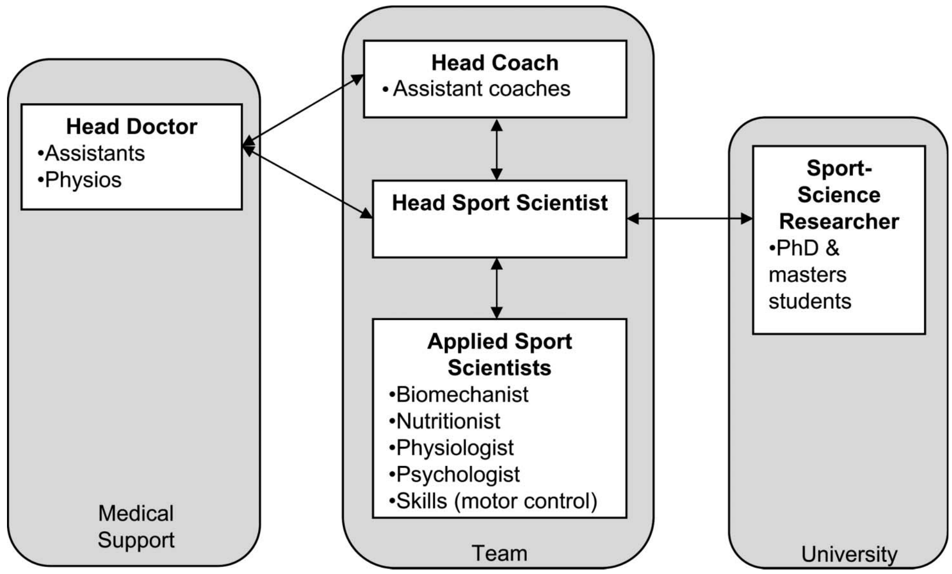

Figure 3. Hypothetical multidisciplinary sports performance enhancement team.

athletes' or teams' performance using skills and knowledge in his/her area of expertise. It is important that team members work closely together because the team's effort tends to have a synergetic effect, and each member working independently will not result in the maximal effect of the team's support activity.

Newton: All members of the enhancement team should be sport scientists in their own right. Each has to be able to review the literature, glean what is useful to them in their role, and develop as a professional. If there are specific sport scientists in the team, there has to be concerted effort to perceive their role as of equal importance. Similarly, the sport scientist must understand that they do not have all the answers. Coach, athlete, and scientist have to communicate openly and frequently in a collaborative environment.

Sands: Frankly, this is one of the few ways in which sport science works, when those from multiple disciplines work as a team to solve preparedness problems. The role of sport scientists in preparedness enhancement teams is to provide counseling to the entire team about the best way to handle a problem based on their experience and background. Interestingly, this idea is counter to modern graduate training. Graduate students are taught to be "independent" scientists and thus are often ill prepared to work in a team environment. Graduate education may need to alter this mentality to produce graduates who are able to work alone and within a team to solve a problem presented by an athlete, coach, or team.

Stone: In my opinion, the training process should be developed by a performance enhancement team, which ideally would contain sport scientists (nutrition, physiology, biomechanics, and psychology), sport medicine personnel, and the coaching staff (including the strength staff). If for no other reason, many heads are usually better than one. In this context, the coach should drive the team, making sure that regular meeting occurs (this is not always the case in the beginning). If one investigates carefully the successful approaches to sport training currently being used around the world, the team approach is at the top of the list.

QUESTION 9: IN YOUR OPINION WHAT IS THE FUTURE OF SPORT SCIENCE?

Bishop: In my opinion, there are some good signs with Australian sporting clubs increasingly investing in sport science support. However, this can only continue if sport scientists can continue to demonstrate that their input makes a difference to the performance of the athlete or team. To do this, I think that sport scientists need to focus their efforts on areas where they can make the most difference. For example, with respect to team sports, I believe that sport scientists need to place less emphasis on training and devote more time to injury prevention, recovery from training and matches, and how to better rotate players. In addition, I believe that sport scientists need to be more "courageous" and seek novel ways to improve performance (based on scientific principles), rather than the often-seen practice of verifying if current practices are indeed effective.

Hoffman: Presently, there are few individuals in the United States who perform sport science as a primary job description. Even our Olympic training centers do not provide athletes with the scientific support necessary to maximize their potential. Too often, athletes are forced to search for the "gurus" and do not have the resources necessary within the confines of their respective sports governing bodies to consult with. To enhance sport science, one of the first things that we have to acknowledge is that we are lacking. Although there are many outstanding exercise scientists and applied physiologists who work on the fringes of sport science, without having the day-to-day interaction with athletic performance, their impact is not exploited. To enhance sport science, I believe that we have to begin developing collaborative programs within university settings with full cooperation from coaching, training, and administrative personnel. In addition, for academic programs that wish to emphasize sport science, a curriculum based on athletic performance development should be incorporated that is different than the basic exercise science curriculums that are presently in place.

I also believe that the future will involve certification and licensure programs for coaches that will involve reliance upon academic departments of sport science to help prepare students for careers in coaching. Presently, several states are exploring the licensure of personal trainers. It would not be unfathomable to imagine that if these laws are passed that they would eventually include coaching.

Kawamori: I am afraid that the future of sport science in higher education will be questionable because of the factors I discussed in question 6. Most of academic sport scientists at universities will have to conduct non–sport science research (probably in the area of exercise science related to physical activity and medical issues) to survive as academic scholars by publishing research articles in high-impact journals and receiving external research grants. Only after they secure their jobs and research funding, could they use extra money and time to conduct sport science research. Of course, I hope that this will not be the case and that sport science in higher education would once again become a research focus at universities.

On the other hand, I could see future growth prospects for sport science in applied/practical settings. Many countries now use applied sport scientists at national sport institutes in the quest for sporting success at major international competitions such as the Olympic Games, and I believe that this trend will continue. Similarly, more and more professional sport teams (e.g., soccer, football, and rugby) now use or contract applied sport scientists to better prepare their athletes for long competitive seasons. Because most sport science needs of professional teams are in the area of fitness, great opportunity exists for sport scientists working in the fields of strength and conditioning, physiology, and nutrition.

Newton: The era of being able to compete at the elite level based on genetics and talent is finished. Sport science pervades all aspects of elite sport from talent identification to equipment revolutions. Countries that do not invest heavily in sport science expertise and infrastructure will be relegated in the Olympic standings, professional competition, and international rivalry. Many countries including Australia were surprised at how much previously noncompetitive countries faired in the 2008 Olympics, and analysis reveals that the turnaround was a result of large and consistent investment in sport science. If professional teams and national sports wish to compete in the modern era, they will have to follow suit, and this can only mean higher esteem, more opportunity, greater career prospects, and ultimately the rapid advancement of sport science as a profession and a discipline.

Sands: Given the constraints outlined above, my view of the future of sport science is not as bright as I would like. Although many programs prepare students and scientists in their area of expertise (i.e., major), they are generally not prepared for the fast-moving world of modern sport, broadly trained in multiple disciplines so that they can be a problem solver in areas near their own or somewhat tangential, familiar with single-subject research designs, trained in time-series analysis, and taught how to analyze a sport problem with the eye of a coach, and the ability to coach it to a high level. Modern sport scientists should be able to handle the total athlete with perhaps greater expertise in 1 or 2 areas.

Stone: Until recently, sport science was on the downturn in the United States (this is not necessarily true worldwide), for commentary on this, see Ref. (1). However, recent developments at East Tennessee State University (ETSU), (with help from the USOC) may alter this course. At ETSU, a reemphasis on sport science is being made at both the undergraduate and graduate levels. A cooperative program (the Sport Performance Enhancement Consortium) has been developed with the ETSU Intercollegiate Athletic Department. This program provides a monitoring system for the coaches and athletes, and in many cases, a true sport performance team has been developed. Additionally, this year, a Center of Excellence for Sport Science and Coach Education (CESSCE) has been created. The CESSCE is unique in academics and provides support for the academic programs as well as provides educational, research, and service opportunities for students, coaches, and athletes. Hopefully, this type of approach to sport science within an academic setting will provide a model for other institutions in the future.

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