Applied Exercise Physiology: a serendipitous personal journey toward a place that didn't exist when the journey started

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ABSTRACT

Applied exercise physiology is a rich profession in much of the developed world in the early 21st century. However, in the early 1970's there was no such profession, just the scientific discipline of exercise physiology. Linked to the 1975 publication of the first edition of ACSM's Guidelines for Graded Exercise Testing and Exercise Prescription, the authors career has been linked to a serendipitous series of events that have seen the development of the profession of applied exercise physiology. Taken as a whole, these parallel stories inform us of the importance of serendipity within the process of scientific discovery.

Keywords: Science; Exercise Physiology; Clinical Exercise Physiology.

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When I was a graduate student, in the early 1970's, the American College of Sports Medicine, at the time a young professional society headed toward international recognition, defined an exercise physiologist as a "doctoral level research scientist", one who studies the fundamental laws of physiology during a particular slice of life, muscular exercise. We had no idea that exercise would ever be understood well enough that it could be used as a professional tool by physicians, health care workers and coaches. We certainly had no idea that exercise physiologists would ever be anything more than laboratory bound academics, collecting interesting, if not particularly, useful information. Although we had more than adequate evidence that exercise was related to good health (Morris et al. 1966, Paffenbarger et al. 1970), the idea that "Exercise is Medicine" (Sallis 2009) was over the knowledge horizon, fully 40 years into the future. We were beginning to characterize athletes, and could predict why some athletes were particularly good, and others (like myself) not quite so good (Saltin & Astrand 1967). Although we were just coming to the point of understanding how different permutations of exercise training (Pollock 1973) effected physiological capacity, represented by the VO_2max (Shephard et al. 1968) we had no clear idea that exercise training could be quantitated well enough to predict training responses, not only in normal people, but in top level athletes and in patients with chronic diseases as well. We had the beginnings of an idea that the response to exercise was not as linear as early studies of the heart rate response would suggest (Hollmann 1985). Wasserman and McIlroy (1964) had coined the term "anaerobic threshold" as early as 1964.We had an idea, from the venerable Dallas bedrest study (Saltin et al. 1968), how exercise might contribute to the treatment of patients after myocardial infarction, and how it might serve as a countermeasure for the physical deterioration induced by spaceflight. As such, it was an important follow-up to the "arm-chair" method of treating patients recovering from acute myocardial infarction, pioneered by Levine and Lown (1952). Exercise research, and the exercise physiologists who performed it, were part of a noble academic discipline, a discipline that was beginning to understand the parameters of the response to both acute and chronic exercise. However, the idea that what we were finding in our research laboratories could ever be applied by professionals, to do something useful for mankind, was not yet imagined. The OMG moment, where we could see the larger value of our data had not arrived (Figure 01).

As an aside, it is important to know that in the 18th century, an Englishman named Horace Walpole had written a children's book "The Princes of Serendip". These were stories of three "buddies" who traveled the world, having adventures that always seemed to turn out well. In the stories, they solved the problems of their adventures, by "accident and sagacity", what we today call serendiptity. In essence this means that they stumbled onto things they didn't expect, were just smart enough to see the solution, and often got more than they were looking for as a result. Serendipity has played a large role in science and technology, from the apple falling on Newton's head, to the discovery of plastic, to the discovery of penicillin, to the development of cardiac catheterization, even to the development of Viagra. Serendipity, this experience of getting more than you were expecting, , is going to play a large role in my personal journey that parallels the rise of a profession called applied exercise physiology.

Figure 01. Typical posture when serendipity is acting

Source: The Author.

Caption: The OMG moment, when you suddenly see the logic in some data or an idea, when just enough "sagacity" creeps into your brain to make the "accident" into a brilliant moment. If you are patient, serendipity often gives you this moment, but you have to let the moment come to you.

In the spring of 1970, with my B.S, degree in zoology nearly complete, with the knowledge that I almost certainly was *not* going to become the great 1500m runner that I had envisioned, and with the knowledge that I was probably *not* going to win selection to medical school, I was at a challenging point in my life; what to do when the first two major ambitions of my adult life are clearly *not* going to be realized. I was visiting the University of Texas at Austin, to attend the *Texas Relays*, a very good track meet. One morning, while walking around the university campus, with no particular agenda in mind, a particularly attractive young lady crossed in front of me and went into the student union building. I suddenly realized that that if I was to fully appreciate the University of Texas, that I should see the student union building. Alas, I never saw the attractive young lady again. But I did, serendipitiously, see an exhibit presented by the Department of Physical Education, including a section on the research of Dr Jack Daniels. Jack is a well-known athletics coach, who has been on the cover of *Runners World*, as the "Worlds' Greatest Track Coach". Jack is also a Ph.D., who did his own doctoral work on adaptation to altitude in advance of the 1968 Olympiad in Mexico City (Daniels and Oldridge 1970). To say that this the exhibit, highlighting his work, appealed to me is the greatest of understatements. Within weeks I was not only accepted to graduate school, but had moved to Austin, Texas to pursue my Ph.D. I think that Jack was a bit taken aback when I walked into his lab the first day of the academic year and introduced myself as his new Ph.D. student. We had only minimal preliminary correspondence and had actually never met face to face. However, serendipity is a powerful force. We got along well. His relaxed and witty style was a good foil to my 'bull in the china closet' energy. Six years later (Figure 02) we knew more about how laboratory measured physiological parameters, and some elements of training, matched with competitive performance (Foster et al. 1977, Foster et al. 1978, Daniels et al. 1977, Daniels et al. 1978).

Figure 02. Lab Work 1974

Source: The Author.

Caption: Lab work in the mid 1970's. Data collection was with Douglas bags, and gas analysis was with the Lloyd-Galenkamp and the Tissot spirometer. Each 'bag' cost 5-7 minutes of analysis after the test was over, so data collection was much more tedious than today. The good news is that the slow methods made you 'feel' the data.

However, despite the enjoyment of graduate school, of becoming one of those 'doctoral level research scientists' that ACSM talked about, we still weren't doing anything particularly useful. Jack was an ever more successful athletics coach, but coaching is more about insight and understanding individual athletes that it is about the systematic application of a scientific body of knowledge. Again, serendipity comes into the story. In 1975, a year before I finished my Ph.D., I had to take a bus ride (poor student) acrossTexas (big place) to visit my family. Just before I left, Jack received from his own doctoral mentor a copy of the first edition of *ACSM's Guidelines for Graded Exercise Testing and Prescription (*Pescatello et al. 2014*).* It wasn't about distance running, so it was low on Jack's reading priorities list, so he tossed it to me, telling me to read it on the bus ride. Jack's professor was Dr Bruno Balke. Bruno was one of the German scientists who came to the U.S. after WW II to help with the human factors related to the emerging aerospace program He was also important in founding on of the first clinical exercise programs in the U.S., at the University of Wisconsin-Madison. The group that wrote the first *Guidelines,* including John Falkner, Fran Nagel, Larry Golding, Bill Haskell, Mike Pollock, Henry Miller, Sam Fox, Ed Howley and Neil Oldridge all had close professional connections with Bruno, indeed some were either faculty or students with Bruno at the University of Wisconsin. They gathered at Bruno's retirement home outside Aspen, Colorado to write the document. The *Guidelines* was a revelation. It showed how the 'body of knowledge' that we had been putting into dusty library shelves could be applied to help people use exercise to prevent heart disease, and applied to help patients who already had heart disease recover more effectively. In the moment of its' publication, the *Guidelines* gave birth to the profession of clinical exercise physiology. For me, personally, it was as if I had been given the roadmap to much of my subsequent career. Serendipity, an accident (Bruno Balke sends the first edition of the *Guidelines,* to my professor, just on the day when I had to take a long boring trip and needed something to read) meets sagacity (a student, who always intended to be a physician and who knew just enough to see the possibilities of the *Guidelines*). The *Guidelines* must have appealed to a lot of other people as well. It's now in it's 9th edition, 42 years after first publication. It is the reference document for the clinical exercise physiology community.

When I graduated the next year, I had nothing to do. University jobs were in short supply that year, 1976. Serendipity came to the rescue yet again. Professor Bill Evans, then a masters student in the laboratory of Professor David Costill, at Ball State University, wrote an NIH grant to study exercise training in juvenile diabetics. Normally M.S. students don't write NIH grants. But, Bill Evans was no ordinary student. As a student, he couldn't receive the grant, but Costill could. Soon, Costill had need for a post-doc in his laboratory, to help with the work proposed in the grant. I had worked briefly with Costill during my Ph.D. work. So, I became a post-doc at Ball State University. It was a revelation, a chance to apply some of the skills that I had developed with athletes into working with real people, who needed my help. As an added bonus, in addition to being a very good scholar, Dave Costill is an extraordinary communicator, both on the lectern in in written format. I received an education in scientific communication that was far beyond the scientific polishing that a post-doc normally expects. Serendipity means you get different (e.g. more) than you expect. I got much more than I ever expected from the serendipity of a graduate student (Bill Evans) writing a grant at exactly the same time as I was finished with my Ph.D., and unemployed.

During my year in Muncie, I also met Dr Mike Pollock. Mike was visiting in Costill's laboratory one week, as they were both in the leadership of ACSM (Dave was the President and Mike a vice President, destined to be President two years later when I worked for him). Mike was also the guy who did the bulk of the well-controlled training studies that formed the nucleus (Pollock 1973) for the *Guidelines*. He was also in the process of moving to Sinai Samaritan Medical Center in Milwaukee, to start the first Phase II (in hospital) cardiac rehabilitation program in the USA. As it happened, he needed a young scholar to run his research laboratory and to help with the clinical program. So, serendipitously, I found my first real job.

When I moved to Sinai Samaritan, a teaching hospital for the University of Wisconsin, a couple of interesting things happened. First, we quickly found out that cardiac rehabilitation was different than we had expected it to be. Yes, the patients became fitter (Foster et al. 1984). But, we also found that providing "an extra pair of eyes and ears for the physicians", what Mike called surveillance, was very, very important (Sennett et al. 1987, Dolatowski et al. 1983, Dion et al. 1982, Silvidi et al. 1982). At the time, we were actually afraid that problems in the rehabilitation clinic, would make the physicians worry about sending their patients to us. After all, we were the "jocks' and there was a good bit of suspicion that we really didn't understand sick people very well. It quickly emerged, however, that sending 40% of patients to their physicians for unscheduled office visits served to improve the medical management of these patients. Against expectations, the doctors loved what we did. Serendipity, my old friend, had again given us something different, and better, than expected, simply because we were "just clever enough to see something more important than we expected".

During this period of time, I was also working in the nuclear cardiology laboratory, essentially taking movies of the heart during exercise stress tests (Figure 03). We were bothered that some of the young and healthy controls that we were recruiting to provide a reference standard weren't responding as we expected. The big word for this is cognitative dissonance. One day, one of the cardiologists looked into the laboratory just as we were testing a rugby player. He joked about "what would happen to that gorilla if you just put him on the bike and said go?" Coming back to my office afterwards, I noted that I had received a reprint from Dr James Barnard, at UCLA, about something called 'sudden strenuous exercise' (Barnard et al.1973) Within the context of the joke made by the cardiologist, Barnard's paper was very interesting. It led us into a series of studies that helped up to understand how the heart, both healthy and diseased, worked during different types of exercise (Anholm et al.1982, Dymond et al. 1984, Foster et al. 1981, Foster et al. 1982a, Foster et al. 1983, Foster 1998), including during interval and resistance training in patients with heart failure (Meyer et al.1998, Karlsdottir et al. 2002). Thus, a joke and a reprint arriving on the same day (accident) and just a little sagacity, led us on an interesting journey that lead to ways of augmenting exercise stress testing, which improve the ability of physicians to evaluate their patients.

Figure 03. Nuclear Cardiology Laboratory 1992

Source: The Author.

Caption: Working in the Nuclear Cardiology laboratory in the 1980's. Here we used radioisotopes to let us take movies of the heart during exercise. It led to an enhanced ability to perform diagnostic tests in patients with heart disease, and opened doors to understanding how the heart responded during unusual periods of exercise (starting, stopping) and in people ranging from athlete to very sick patients. Often, conversations or simple questions in the midst of routine data collection suggested the next question that needed to be asked in the research program.

During the same period in Milwaukee, by pure chance (serendipity), someone put us together with the U.S. speed skating team. I'm from Texas (not much winter sport), Mike Pollock (1973) was from California (not much winter sport), but we each had done work with high level competitive athletes. Suddenly we were paired with a group of elite winter sport athletes. We didn't know much, and there wasn't much literature about speed skating. But, we are exercise physiologists. Wind us up and we measure VO_2max, which really isn't very interesting in speed skaters (Maksud et al. 1982, Foster et al. 1982b, Foster et al. 1989, Foster et al. 1993c, Foster et al. 1999). Fortunately, serendipity acted again. Studies being done in Sweden (Sjodin et al. 1982, Svedenhag & Sjodin 1985) and Germany (Hollmann 1985, Olbrecht et al. 1985, Stegmann et al. 1981), as well as at the U.S. Olympic Training center, were showing how some of the laboratory measurements that exercise physiologists make could be applied to be useful to coaches in their guidance of athletes. This led us to the realization that for laboratory tests to be applied they had to not only correlate with performance, but also track changes with training, and be ameniable to goal setting. The need to travel with the team, where heavy laboratory cycles were hard to move, led us into developing the time trial model (Foster et al. 1993b, Foster et al. 1997), which has come to be recognized as a superior method of evaluating athletes.

Figure 04. Pacing Research 2006

Source: The Author.

Caption: Laboratory work related to understanding the problems of pacing during heavy exercise. In this example from ~2002, we are using bags filled with low O2 gas, to mimic abrupt altitude exposure, which gives a sense of how humans use both anticipation and feedback to make decisions relative to the momentary effort to expend. However, the serendipitious moment that led to this work was a simple argument over how anaerobic energy expenditure is "managed" and the arrival of a grant proposal from the IOC on the very next day.

The time trial model led us into cooperation with Professor Jos de Koning from Amsterdam. Jos really does know something about speed skating (Gemser et al. 1999). Together, we developed the concept of pacing that recognized that muscle and brain interacting together could explain fatigue (de Koning et al. 2005, de Koning et al. 2011, Foster et al. 1993a, Foster et al. 1994, Foster et al. 2004, Foster et al. 2009a, Johnson et al. 2009, Joseph et al. 2008, St Clair Gibson et al. 2006, St Clair Gibson & Foster 2007, St Clair Gibson et al. 2013). This has even led to studies of pacing with patients, in that we recognized that humans (regardless of how athletic) live their lives by accomplishing tasks, and pacing their effort so that the task wasn't unduly stressful (Foster et al. 1997, van der Zwaard et al. 2015). Interestingly, the breakthrough in the pacing research came the day after Jos de Koning and I had had a very big argument about how anaerobic energy was used in the control of effort during time trials. The very next day we went to his office and, serendipitiously, there was a request for proposals for studies at the 2002 Winter Olympics in Salt Lake City. We both admitted that we would probably apply for the grant, and realized that we had a very strong research question (from the day before), and that together we couldn't be denied. Thus, the serendipity of an argument on a certain day, and a proposal arriving the very next day led us to interesting findings (Figure 04). Some of that work, serendipitiously triggered, has led us back from applied sport physiology back to clinical exercise physiology.

One of the routine tasks for clinical exercise physiologists is to give advice to patients and healthy people about how to exercise, usually based on the results of a graded exercise testing. Based on the fundamental organizing principles articulated in the *Guidelines*, the usual practice was to give the patient a target heart rate, which would put them into a zone where exercise would be effective but not likely to provoke side effects. The process works reasonably well, although until the development of the radiotelemetric heart rate monitor by Polar in the early 1980's the accuracy of the patient monitoring their own heart rate was suspect. This was always on the back of my mind, our friend cognitative dissonance again. One day, a patient said to me "forget the target heart rate, I want to know if I need to walk or to jog, and if so how fast. I also want to know if I can play tennis". After mumbling a few platitudes, I realized that he had asked me a fundamental question, the answer to which would greatly improve the process of exercise prescription. Sometimes serendipity is in the words of your patients. About this same time I, serendipitiously, tested a pair of twin brothers. Because they were twins, their maximal and target heart rates were very similar. However, one was quite fit, while the other was rather sedentary. I noticed that the path of their heart rate during both a standard exercise test in the laboratory, and to increasing speeds in the clinic was rather different. This suggested the idea that I could "translate' the exercise test, based on the path of the heart rate response and come up with a speed of ambulation during training that would give me the heart rate at which I wanted the patient to train (Foster et al. 1986). It even worked for game activities (Foster et al. 1991). Later, we found that we could use Talk Test responses, which aren't compromised by many of the heart rate altering medications used by patients, to accomplish the same "translation" of exercise test responses to exercise prescription, in healthy people (Foster et al. 2008, Foster et al. 2009b), in cardiac patients (Cannon et al. 2004, Lyon et al. 2014) and in athletic individuals (Jeans et al. 2011, Woltmann et al. 2015, Rodriguez-Marroyo & Foster 2013). What would have happened if my patient had not asked a fundamentally interesting question, just immediately before I had a couple of twins in the laboratory? Serendipity, if you let it do its' job, is always your friend.

The last big effect of serendipity also occurred during this same period of time. Thanks to the work on quantitating exercise that Mike Pollock (1973) had done, on our work with both patients and speed skaters, and some very interesting work on training quantification by Professor Erik Banister in Canada (Fitz-Clarke et al. 1991, Morton et al. 1990), we were interested in a simple way of combining the intensity and duration of training. If you can measure the "input" from a training stimulus, you have some hope of measuring the "output" from participation in a training program, which means that patients and/or athletes can achieve predictable results. One day, after a ride on the bike in the exercise center, I was sitting in the shower room, and spontaneously said "wow, that was hard". In one of those "lightbulb moments" that one occasionally has, I realized that I had just used the Perceived Exertion scale developed in Sweden by Professor Borg in a new and different way. I also realized that my own children would come home from sports practice and say something to the effect "that was really hard, the coach almost killed us". In other words, people will use simple verbal expressions to convey how a whole workout felt (e.g. intensity x duration). A few laboratory studies later (Day et al. 2004, Foster et al. 1995, Foster et al. 1996, Foster et al. 2001a, Foster et al. 2001b, Sweet et al. 2004) we realized that we had developed a very simple tool for quantitating training. Because it is very simple, indeed almost "idiot proof", it has been wel- accepted world-wide. At the same time, just as I was moving to the University of Wisconsin-La Crosse (the physicians at Sinai Samaritan were going into private practice, non-physicians not invited), my new colleague, Dr John Porcari, was looking for thesis projects for new graduate students, and happened on the interesting concept of the Talk Test. I realized that the Talk Test was potentially a surrogate of the ventilatory threshold, which might make it very interesting to develop. As it turns out, the Talk Test is very interesting indeed (Dehart et al. 2000), and we now know that it is an effective tool for prescribing exercise in people ranging from cardiac patients (Cannon et al. 2004, Lyon et al. 2014) to athletes (Woltmann et al. 2015, Rodriguez-Marroyo & Foster 2013). That this occurs at just the time when exercise testing, one of the anchors for the *Guidelines*, is being done less and less, and that exercise prescription based on "threshold concepts" is becoming more widely recognized (Mezzani et al. 2012) was really serendipitious.

So, in the early 1970's, we knew a fair amount about exercise, but we had no clear idea that the academic discipline of exercise physiology could ever be structured into an applied science. The recognition of the potential for applying this knowledge created the definition of both clinical exercise physiologist and sports physiologist. For myself, a serendipitious series of events has led me to be part of the emergence of applied exercise physiology. Applied physiology did not exist when I started. However, it's emergence has opened doors for me for almost all of my professional career. The people who wrote the *Guidelines* are certainly the ones who deserve the credit for seeing the synthesis in clinical application of more fundamental knowledge. A variety of workers, mostly during the early 1980's also showed us the way to apply sports physiology to help coaches guide their athletes.

I don't think that I'm unique. I know for sure that I'm not any smarter than average. If I have as skill it's being able to think broadly, to always ask myself the context of what I'm seeing, to adopt the mindset inherent in the structure of the *Guidelines*. But, I have been very lucky, because senendipity has always been very good to me. Much of what has happened during this journey is not the result of designed experiments. Serendipity led us to ask the questions that turned out to be much more important. I have no quarrel with experimental design, it's fundamental to good science. But, serendipity often shows us that the first design for a study isn't the right design. It's led to changes om the experiment; hundreds of times. It has suggested the next experiment that needs to be done, if only I've listened to its' persistent voice. It's the tool that Mother Nature uses to say "don't look there, stupid; look here".

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Fisiologia do Exercício Aplicada: descobertas de uma viagem pessoal rumo a um lugar que não existia quando a jornada começou

RESUMO

A fisiologia do exercício aplicada é uma profissão rica em grande parte do mundo, desenvolvido no início do século XXI. No entanto, no início dos anos 1970 não havia tal profissão, apenas a disciplina científica fisiologia do exercício. Ligado à publicação de 1975 da primeira edição das diretrizes do ACSM para os testes do exercício e a prescrição do exercício, a carreira do autor foi ligada a uma série de descobertas afortunadas dos eventos que viram o desenvolvimento da profissão da fisiologia do exercício aplicada. Tomadas como um todo, essas histórias paralelas nos informam da importância das descobertas afortunadas no processo científico.

Palavras-Chave: Ciência; Fisiologia do Exercício; Fisiologia do Exercício Clínico.

Submission: 13/09/2016
Acceptance: 28/11/2016