Scand J Med Sci Sports 2015: 25: 7–15
doi: 10.1111/sms.12594

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

Review

Along paths converging to Bengt Saltin's early contributions in exercise physiology

P. Schantz

Research Unit for Movement, Health and Environment, The Åstrand Laboratory, The Swedish School of Sports and Health Sciences, GIH, Stockholm, Sweden
Corresponding author: Peter Schantz, Research Unit for Movement, Health and Environment, The Åstrand Laboratory, The Swedish School of Sports and Health Sciences, GIH, Box 5626, SE-114 86 Stockholm, Sweden. Tel: +46812053818, E-mail: peter.schantz@gih.se

Accepted for publication 28 September 2015

A fascinating chain of events led in 1941 to the formation of the Department of Physiology at the Royal Gymnastic Central Institute (GCI) in Stockholm, Sweden. Erik Hohwü Christensen, from the scientifically advanced Lindhard School in Copenhagen became its first professor. A central research question for him concerned determining the limiting factors for maximal physical performance in man. This was the academic setting where the sports interested medical student Bengt Saltin was introduced to exercise physiology. In the summer of 1959, he became involved in a study on intermittent vs continuous running. A doctoral project, with Per-Olof Åstrand as his tutor, resulted in 1964 as the thesis "Aerobic work capacity and circulation at exercise in man. With special reference to the effect of prolonged exercise and/or heat exposure". In the decade that followed, Saltin continued along that path. However, he also added a vital research line involving pioneering studies on skeletal muscles in the exercising man, a series of novel studies on the physiological demands in various sports, and studies of the effects of physical training within the general population.

Life paths are usually influenced by a great number of external and internal factors. They are often framed by historical facts that we are unaware of or do not reflect much upon. For example, ideas are formulated and spread before institutions are created. Institutions are normally prerequisites for professional positions, and the individuals having them are bearers and developers of cultures that, combined with, e.g., written material, scientific instrumentations and techniques, create study environments of various kinds. Founding ideas, institutions and positions are examples of framing elements, and the outflow from them becomes formative factors within their contexts.

This article illuminates external factors, from individual to societal levels, as well as present and past ones, that framed and formed Bengt Saltin's path into an exercise physiology research culture at the Department of Physiology of the Royal Gymnastic Central Institute (GCI) in Stockholm, Sweden, beginning in 1959. Thereafter, it describes this setting which formed Saltin as an exercise physiologist, and later how he himself formed the department through more important independent and novel steps up to 1973, i.e., during his first period as a researcher in Sweden. During that period he created, e.g., pioneering research lines in muscle physiology and took initiatives with clear pedagogical value. No doubt, from initially being formed by external factors, Bengt Saltin, his research and team soon became a strong formative element for others. And so it continued.

Framing factors

What then were the more important ingredients in the flow of historical events that led to the research setting that Saltin entered into in the summer of 1959?

In the history of mankind, there are three periods in which bodily exercise stands out more markedly as a cultural expression of human life: antiquity, the Renaissance and the period from the late 18th century and onwards. The ideas leading to the latter period can be traced back to two books by Jean-Jacques Rousseau, published in 1762. In the first book, "Of the Social Contract, or Principles of Political Right", he delineated a new social structure with a political role for the citizens. A closely related subject, educa-

tion, was the focus of his next book, "Emile, or On Education". There, among other things, he argued for the role of bodily exercise. These ideas were spread via such ideological agents as Johann B. Basedow and Johann C. F. GutsMuths and reached Copenhagen where Franz Nachtegall formed a private educational institution for them. That setting became a strong formative element for a literature student from Sweden who returned to his native country and became the fencing master at the University of Lund in 1804. His name was Per Henrik Ling, and with him the ideas of gymnastics got a strong bearer in Sweden (Westerblad, 1909).

The next event with a strong historical impact was when Russia, in 1808, invaded the eastern half of Sweden, what is now known as Finland, and conquered it in 1809. This had the effect that the Karolinska Institute (KI) was formed in 1810 for the training of field surgeons. KI later developed into a full medical school, which Saltin entered in 1956. Another need for the nation after the loss of Finland was to strengthen its soldiers. One pathway for that was sought through the formation of GCI in 1813. Per Henrik Ling became its organizer and ideological father. His gymnastic system included four subdisciplines: military, medical, pedagogical, and aesthetic gymnastics, and one of his basic ideas was that human movements should be based on the laws of the human organism (Ling, 1840). In those days, this was a novel idea. Thereby, studies in anatomy and physiology became central within the field of studies of gymnastics at GCI (Westerblad, 1909).

Ling Gymnastics soon began to spread widely and GCI became a Mecca for students from different parts of the world. One of them was Knud Anton Knudsen from Denmark. He graduated from GCI in 1891, returned to Denmark and became a strong factor in the decision to establish in 1909 the theory and practice of gymnastics as a subject at university level in Copenhagen (Trangbæk, 2009). The physician Johannes Lindhard acquired the position of teacher in the theory of gymnastics and soon he initiated critically oriented studies on some of the claims of Ling Gymnastics (e.g., Lindhard, 1926). Johannes Lindhard and August Krogh, whereof which the latter was awarded the Nobel Prize in Physiology or Medicine in 1920, developed a strong scientific environment for studies on humans in exercise, and one of Lindhard's doctoral students was Erik Hohwü Christensen (Schantz, 1988, 2009; Åstrand, 1991).

The "1910 Commission" at GCI in Stockholm suggested that a chair in physiology should be established (Schantz, 2009). However, it took 28 years before the government and the parliament took that decision. The idea of the chair came from Johan Erik Johansson, who was professor of physiology at the Karolinska Institute, and was a member of the Board of GCI. He himself had been a pioneering researcher in exercise physiology during the 19th century (Liljestrand, 1954). Another interesting detail is that the positive scientific development achieved by Lindhard and Krogh in Copenhagen with regard to movement physiology became a good example that was referred to by GCI when they argued in the 1930s for the chair (Schantz, 2009).

It was Lindhard's student, Erik Hohwü Christensen, who got the chair, and in 1941 he traveled to Stockholm to start his new work. This was his first visit to GCI, and when he came, soldiers were using the localities where he was supposed to establish a laboratory. This added to a rather immediate thought to return to Copenhagen. However, as German Nazi troops had invaded Denmark, he decided to stay in Stockholm.

For GCI, this led to an historical turning point. The first sound steps of scientific research, in line with the ideas of Ling that movements should be based on the laws of the human organism, were now taken. The initial study was performed at the original localities for GCI in downtown Stockholm, at what today is called Sergel's Square. It dealt with the relationship between metabolic rate, body temperature, and heart rate in various physical exercises (Berggren & Hohwü Christensen, 1950). Christensen soon became involved in modifying the plans for a new building for the Department of Physiology, which led to the building of a subatmospheric pressure chamber and a treadmill, the latter of which was produced in Denmark. In 1944, GCI moved to its new localities (Fig. 1). The same year, a student who would become of great importance for the development of exercise physiology entered GCI for his studies in gymnastics. His name was Per-Olof Åstrand. In 1946, he started as an assistant research fellow at the Department of Physiology. Based on his thesis work (Åstrand, 1952), the methodology for measuring maximal oxygen uptake in man was developed. This became an important methodological and principal milestone in that so much of exercise physiological phenomena are described and understood in relation to that measure.

The importance of this contribution should also be regarded in relation to a major research theme that had emerged in the Lindhard School in Copenhagen: What are the limiting factors for maximal physical performance in man? (Schantz, 2009). Christensen brought that theme with him to GCI in Stockholm.

Christensen's chair was in the Physiology of Bodily Exercises and Hygiene. But he had much wider ambitions than the primary aims of his position, i.e., teaching exercise physiology for the physical education teacher students and establishing exercise physiology research. Soon after the Second World War

Fig. 1. The setting at the Royal Gymnastic Central Institute, to which Bengt Saltin came in 1959. The Department of Physiology was located in the building behind the flagpole. Photo: Axel Eliassons Konstförlag AB, Stockholm.

ended in Europe, but was still ongoing in the Pacific Ocean Region, Christensen traveled on a study tour to USA with the chief of the Swedish Air Force. In line with this, an Aviation Medicine Unit was later formed at the Department. Furthermore, an Industrial Physiology Unit and a Methods Time Measurement Unit were established. During the 1950s, applied sports physiology was also developed, initially primarily involving cross-country skiing and distance running (Hohwü Christensen, 1961). Thus, there was a broad spectrum of study opportunities available when Saltin visited the department for the first time in 1959.

Another framing perspective deals with the question of which forms of movement culture were legitimate to study at GCI. It should be known that Ling gymnastics was the only form of bodily exercises at GCI during the 19th century (Lundvall & Schantz, 2013) and that it was non-competitive and aimed at public health. However, from the 1880s, there was an ongoing battle between Ling Gymnastics and the idea of competitive sports. It lasted about seven decades, ending with the power era of Lings Gymnastics quickly fading away during the 1950s. That was also the case within GCI, and it resulted in sports becoming the new predominant movement culture at GCI from the 1960s and onwards (Lundvall & Schantz, 2013). From a research perspective, sports thereby also became a highly legitimate study object.

Another necessary ingredient for understanding the institutional setting at the Department of Physiology when Saltin entered it was the idea of rationalization. It had been spreading in society at large for a longer period of time and affected both the view on industrial work and on training for sports (Svensson, 2013). It is my hypothesis that is was the ideas of rationalization of heavy manual work in industry that molded Christensen's interest in the physiology of continuous and intermittent work, which was the field via which Saltin was introduced into research. Later, the knowledge acquired from that research was transferred to a sport context of rational training and was then termed "interval training".

Much of the stage was now set, but the developmental drama that Saltin was embedded in did also include important formative elements during his childhood and youth. Let us therefore turn to that period now.

Formative episodes from childhood to early adulthood

Bengt Saltin was born on June 3, 1935, at Ålsten in Bromma, a suburb of Stockholm, Sweden. He was the son of Margareta, born Johansson, and Bengt

Hellstenius. However, he never met his biological father. Instead, Sven Saltin, whom his mother later married, became his stepfather. He and Margareta were both teachers, and that created a natural educational setting for Bengt in their home. It was, as he stated, "a reading home".

During his early childhood he contracted asthma, for which reason the family moved to more rural areas, first to Rönninge and later to Nykvarn, both located south of Stockholm. Possibly, this was important in forming Saltin's attachment to nature, which was a lifelong, strong part of his identity. He loved forests, and he loved flowers.

When in grammar school in Södertälje, an outdoor running competition was attended by the local pharmacist. He made use of the order in which the runners reached the goal for the recruitment of new members into the local orienteering club. Saltin thereby became the primary target for recruitment, and in that way he became an orienteer. In that social setting, a number of individuals were professionally connected to forestry. And, interestingly, Saltin soon decided to take a year off from school and work in the forest. He then decided to become a forestry officer. However, when he learned that such studies demanded full grades from grammar school, he reentered school.

When Bengt Saltin told me about his life it was important for me to find out more about his early contact with different movement cultures. He summarized it all as follows:

> So I had a very active connection to sports during my youth, with orienteering as a basis, and with ice hockey as more of a hobby, but since I played ice hockey as if I was left-handed, there was always use for me, and so I played in rather advanced circumstances. But the most important thing that ice hockey did for me was that it led to me being asked to help at a bandy match there in January. It was the year of the matriculation examination.
>
> And so, in bandy one doesn't wear any protection for the legs, and so on, and then I fell so badly that I completely blew out one knee cap, the right one, and it led to that at the turn of January and February, and 6 weeks ahead, I had my whole leg like this, could not go to school, and sat at home and prepared for the matriculation exams.
>
> And most of the teachers raised an eyebrow when they saw the results of the exams. I had really studied hard, which was a source of some happiness, so I got reasonable grades,... But then, the dramatic situation developed with a mother who dictates and I listen, and where I had prepared myself to become a forestry officer, but she just said: "You may not become that. You shall become a physician!"

Thus, we can conclude that he had been socialized into sports and that he got a severe knee injury in bandy that led to good grades in school. And without them, his mother's choice of profession for her son might not have been realistic at all. In any case, he followed his mother's choice for him and commenced medical studies at KI in Stockholm in 1956. An initiative to start an orienteering club for students, which was based at the Royal College for Forestry in Stockholm, could perhaps be regarded as a small compensation for his taking the medical pathway.

When studying physiology at KI, he had Ulf von Euler, who later became a Nobel laureate, as his teacher. One day von Euler asked him if he could think of becoming a student instructor. This was then often used as a position to follow up and further evaluate potential research students. Saltin accepted the offer. Later he spoke of his interest in sports, and von Euler then contacted Christensen at GCI, which he thought would be a more appropriate person for his further development.

Being formed by a research culture

"It is my birthplace", Saltin said to me, referring to the Department of Physiology at GCI, and his life as exercise physiologist. There he met professor Hohwü Christensen, was welcomed to GCI, and participated in one of a series of studies initiated by him. The theme was to understand more about the nature of intermittent vs continuous work. Saltin became one of the two subjects in the study, which was undertaken during the summer of 1959. He also assisted in the analyses of the samples. He described the daily routines as follows: the days began with the exercise test measurements, which were followed by analyses of the gas samples using the Haldane technique, and then the blood lactate samples. At 15:00 hours, Christensen came out from his office to the coffee room, knocked his pipe on the table and then expected to be able to partake of the findings from the morning measurements. The overall results indicated that oxygen was stored in the muscles during the rest periods in between the intermittent exercises (Hohwü Christensen et al., 1960).

As early as 1959, and partly in parallel with the completion of some basic medical courses, Saltin started to work on his thesis, and from 1961 the research studies were full time. It had been suggested that some findings from Edward F. Adolph's extensive studies entitled "Physiology of man in the desert" (Adolph and associates, 1947) should be followed up

by studying the effects of thermal vs exercise dehydration. However, the thesis came to deal with many more issues, e.g., methodological studies and central dimensions involving the interplay between the ingredients in Fick's principle (oxygen uptake, stroke volume, heart rate, and arteriovenous oxygen difference) with increasing exercise intensities.

Saltin was tutored by Per-Olof Åstrand (Fig. 2), who was head of the department when Christensen was on leave during 1961–1964 for work as an expert with the International Labour Organization in India, as well as to work in Copenhagen as professor and vice chancellor at the Danish Higher Institute for Bodily Exercises. The thesis, defended in 1964, included nine different studies and is titled "Aerobic Work Capacity and Circulation at Exercise in Man. With Special Reference to the Effect of Prolonged Exercise and/or Heat Exposure" (Saltin, 1964). It displays a wealth of studies and results, an ability to grasp wide and diverse fields, as well as a capacity for intricate analytical reasoning.

In the last paragraph of the summary of the thesis, Saltin states: "Reduced aerobic work capacity may be excluded as an essential explanation for the gradual decrease in physical work capacity during dehydration. The results may be interpreted to indicate that the explanation should be sought at the cellular level". Perhaps this way of ending his thesis could be interpreted as a delineation of the pathway that he was soon to develop, i.e., understanding physical exercise in man in relation to muscle metabolism and cell composition.

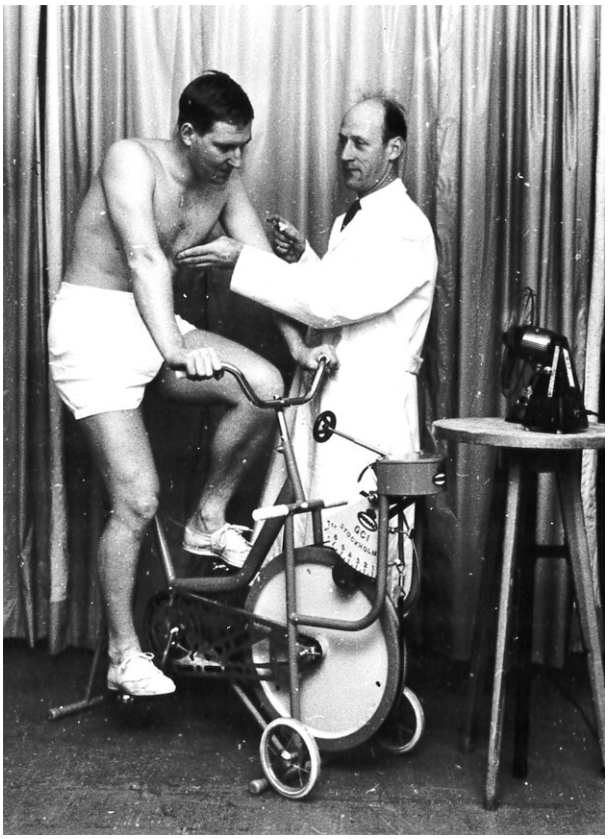

Fig. 2. The tutor, Per-Olof Åstrand, and the doctoral student, Bengt Saltin, sitting on the Monark ergometer cycle, an invention by Wilhelm von Döbeln, who worked at the department. Photo: Lars Falck.

Becoming a formative agent as a researcher

By then, the biopsy needle as a tool for studying human muscle tissue had been used for some years in Stockholm (Bergström, 1962), and the physicians Jonas Bergström and Erik Hultman at St. Erik's Hospital pioneered some years later in describing a supercompensation mechanism governing muscle glycogen synthesis following exercise-induced glycogen depletion. The findings were published in Nature (Bergström & Hultman, 1966). The potential for new forms of studies was obvious, and Saltin initiated a collaboration with Bergström and Hultman, in which they repeated a study regimen created by Christensen and Ove Hansen in Copenhagen in the 1930s. They had then showed that, depending on the type of food intake prior to exercise (carbohydrates vs fat and protein), the time to fatigue could be altered (Hohwü Christensen & Hansen, 1939). In the repeated study in the 1960s, it was shown that the fatigue was related to muscle glycogen depletion, and that it was possible to alter the pre-exercise levels of stored muscle glycogen by varying the dietary intake (Bergström et al., 1967).

Saltin soon started the path to develop a histochemistry laboratory at GCI, and simultaneously he initiated a collaboration with Bertil Diamant, at the Department of Pharmacology at KI, who had a fluorimeter with which one could measure metabolites and enzyme activities. This was used by Saltin's first doctoral student, Jan Karlsson, who in his first study described the lactate levels in muscle at rest and after maximal exercise (Diamant et al., 1968). Another early achievement was the organization of the high class symposium "Muscle Metabolism During Exercise" at KI in Stockholm, which presented the broader status for this new dynamic field up to 1970, and resulted in elaborated proceedings (Pernow & Saltin 1971). Important for the methodological and study efforts during these years were also the visits by several foreign researchers, whereof which Saltin particularly pointed out the contributions by Philip Gollnick, who was trained in biochemistry, and David Costill, both from the USA. One example of a study during that period was a cross-sectional analysis of muscle specimens from various types of athletes. It was concluded that higher levels of the oxidative enzyme succinate dehydrogenase was found in endurance athletes, and that a predominance of slow twitch fibers was noted in the same

Fig. 3. Measurement of the oxygen uptake of the track and field athlete Anders Gärderud in October 1965 in Mexico City. The cyclist is Bengt Saltin, and standing on the bicycle is a Mexican assistant. This study of the applied exercise physiology at high altitude was published as Saltin (1966). It is an example of several applied sports physiology oriented reports that Saltin took initiative to, that, however, only exist in Swedish. Photo: Lars Falck.

category of athletes (Gollnick et al., 1972). Another example is that when the depletion of glycogen in different fiber types was followed in the 30-km Lidingö running race, it was concluded that "histochemical staining of the muscle for glycogen revealed a marked depletion in the slow twitch fibers. Only a small glycogen depletion occurred in the fast twitch fibers. This suggests a primary reliance upon slow twitch fibers during prolonged running" (Costill et al., 1973). An important methodological development initiated by Saltin in the beginning of 1973 was the technique permitting biochemical analyses of pooled single human skeletal muscle fibers of various types (Essén & Henriksson, 1974; Essén et al., 1975). The muscle research line was, however, only a part of the subject matters that Saltin focused on during these years. Besides that he continued with issues from his thesis, and was involved in training studies, whereof which the Dallas Bed Rest Study (Saltin et al., 1968) is the most well-known. Of interest is also a later extensively used questionnaire, which he was involved in developing in order to assess physical activity patterns of athletes (Saltin & Grimby, 1968).

The outflow of Saltin's efforts during this period is enormous and can, for the main part, easily be traced in electronic literature resources. However, there is another impressive line of popular science work which has been published only in Swedish and therefore deserves to be briefly illuminated here. In 1965, Saltin got involved in issues concerning exercise at high altitudes, which had become relevant from an applied sport perspective in relation to the Olympic Games in Mexico City in 1968. A pedagogically oriented sports physiology report about the findings was published in 1966 (Saltin, 1966) (Figure 3). It was written in Swedish with the aim of communicating with interested

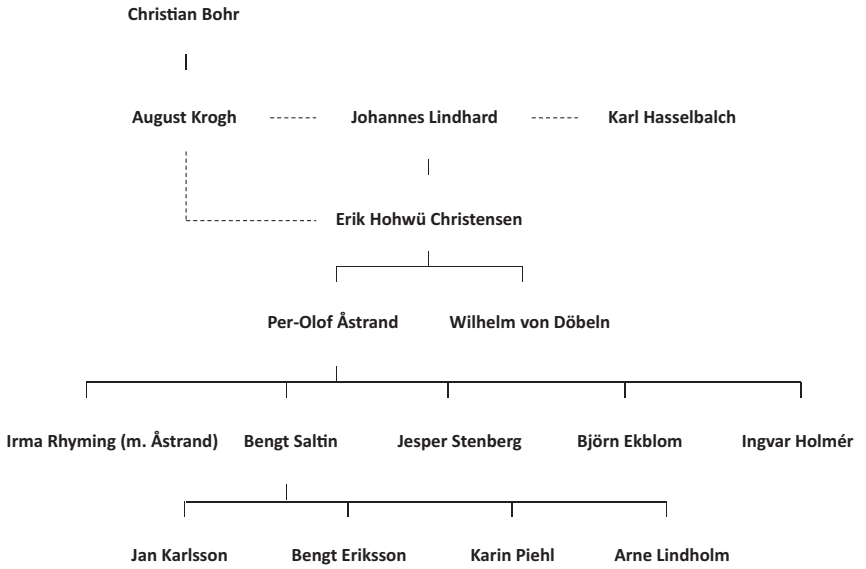

Fig. 4. The tutorial tree from Erik Hohwü Christensen at GCI with his, Per-Olof Åstrand's, and Bengt Saltin's doctoral students during his first Stockholm period. These theses were presented in the following order: Åstrand (1952), von Döbeln (1956), Åstrand (1960), Saltin (1964), Stenberg (1966), Ekblom (1969), Karlsson (1971), Eriksson (1972), Piehl (1974), Lindholm (1974) and Holmér (1974). For information on other of Saltin's early Swedish research students, see the text. Connected with Erik Hohwü Christensen and upward is his tutor Johannes Lindhard. Hatched lines between individuals indicate strong scientific influences within the Lindhard School. This tree is developed from Schantz (2009).

sportsmen and -women, as well as their trainers, and it became the start of a series of such reports which deepened our understanding of the specific physical demands in different types of sports. Saltin co-authored reports on, e.g., motocross, downhill skiing, speed skating, running and orienteering. Also exercise training studies on ordinary humans (e.g., Hartley et al., 1969) were presented in accessible and easily understandable manners (Saltin, 1969). In the same spirit, he wrote and acted as editor for articles on physical training, health, and disease (Saltin, 1970). These accomplishments were very important, in a Swedish context, for the interest in the field of exercise physiology.

This endeavor was well in line with the existence of a strong disseminating culture at the GCI Department of Physiology (Hohwü Christensen, 1961) and led to a large number of texts and studies that only exist in Swedish. Christensen and Åstrand had, e.g., written their own separate books about exercise physiology for the general population. What Saltin pioneered in, in this respect, was the clearly sports-oriented writings.

The crown jewel of the pedagogical spirit at the department was Åstrand's writings in the Textbook of Work Physiology: Physiological Bases for Exercise (Åstrand & Rodahl, 1970). It framed exercise physiology in a holistic fashion that never had been seen before, and it was deeply appreciated by Saltin as a contribution to the field.

One day in 1972, Christensen asked Saltin if they could take a walk in the forest Lill-Jansskogen in the vicinity of GCI after lunch. And so they did. Christensen then suggested that Saltin should apply for the chair in the theory of gymnastics that was originally held by Johannes Lindhard in Copenhagen. Saltin considered the advice seriously, and decided to follow it. A year later this was done.

A number of thesis projects were initiated during Saltin's first period in Stockholm. The subjects were all focused on muscle and metabolism. Figure 4 indicates the authors of those thesis projects that were

Fig. 5. Bengt Saltin with his research team at the Second International Symposium on the Biochemistry of Exercise, in Magglingen, Switzerland, 1973. The theme was: Metabolic Adaptation to Prolonged Physical Exercise. For proceedings, see Howald & Poortmans (1975). Standing from the left: David Costill, Albert W. Taylor, Bertil Sjödin, Jan Karlsson, Arne Lindholm, Bengt Saltin, Anders Lundin, Jan Henriksson, Alf Thorstensson and Philip Gollnick. Sitting from the left: Eva Jansson, Birgitta Essén, Erik Hohwü Christensen, Karin Piehl and Bodil Hultén. Photo: unknown photographer.

completed before or the year after Saltin left for Copenhagen. As stated before, Jan Karlsson was Saltin's first doctoral student and completed his thesis in 1971 (Karlsson, 1971). When Saltin left for Copenhagen, Jan Karlsson led and developed the muscle physiology section at GCI. The next person tutored by Saltin was Bengt Eriksson (Eriksson, 1972). Two other early doctoral students completed their thesis works in 1974, i.e., a year after Saltin had left for Copenhagen (Lindholm, 1974; Piehl, 1974). Eva Jansson and Birgitta Essén were also research students of Saltin, but were in an early phase of their projects, and relocated to the clinical physiology department at the Karolinska hospital in Stockholm, where they were tutored by Lennart Kaijser (Essén, 1978; Jansson, 1980). Saltin was instrumental in assisting in establishing a biochemistry laboratory for them there, and participated in their research work for about two years when he commuted back and forth between Stockholm and Copenhagen. Finally, Jan Henriksson had started his studies in Stockholm, but followed Saltin to Copenhagen and completed his thesis work there (Henriksson, 1977).

In conclusion, although Bengt Saltin had entered into a department with a primary focus on circulation and respiration (Schantz, 2009), he left a department that also had a vital research line devoted to muscle physiology and biochemistry. That renewal was due to the endeavors of Saltin and his team (Fig. 5), and there is no doubt that during the period at GCI he made significant contributions by revealing a number of laws that govern man in motion. In this way, he certainly had acted in conformity with the ideas originally fostered by the founder of GCI, Per Henrik Ling, and without whom a research setting such as the one at GCI might not have existed in Stockholm. In such a case, it is likely that the life path of Bengt Saltin would have been another one.

Perspectives

The present text adds in three ways to previous texts on the importance of the Lindhard School for the development of exercise physiology in Stockholm, Sweden (Åstrand, 1988, 1991; Schantz, 1988, 2009; Svensson, 2013). It describes: (a) the greater historical background to the development of these research cultures; (b) the path into this research culture by Bengt Saltin; and (c) characteristics of his early contributions to exercise physiology.

Key words: Royal Gymnastic Central Institute, biopsy needle, muscle physiology, sports, Per Henrik Ling, Johan Erik Johansson, Johannes Lindhard, Erik Hohwü Christensen, Per-Olof Åstrand.

Acknowledgements

Aside from the printed sources, this text is based on information from one interview that Per-Olof Åstrand and Paul Högberg made with Erik Hohwü Christensen in 1987, and a number of interviews, or in some cases merely control questions to independent sources, that I have undertaken with or posed to: Bengt Saltin, Erik Hohwü Christensen, Per-Olof Åstrand, Björn Ekblom, Karin Piehl-Aulin, Eva Jansson, Birgitta Essén-Gustavsson, Jan Henriksson and Bengt Eriksson. I am grateful for their generosity in sharing memories with me. I am also grateful for comments on the manuscript from Ann-Sofi Colling-Saltin, Birgitta Essén-Gustavsson, Björn Ekblom, Gunnar Grimby, Rune Hedman and the two anonymous reviewers. Finally, I thank Isaac Austin for his language check, and Karin Jäppinen as well as Eva Jansson for assistance with photos.

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