THE USE OF ALTITUDE TRAINING IN SPORTS – FROM ANTIQUITY TO PRESENT DAY

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Review paper

Abstract
This article briefly summarises a selection of what we consider the key stages in the history of making use of higher altitudes (2 000 m a.s.l) to increase performance in sport. Altitude training and stays are currently considered one of the main ways to legally increase performance limits, primarily for endurance sports. From the ancient Olympics up until the end of the nineteenth century, higher altitudes were not utilised to increase performance. In the first half of the twentieth century it was addressed for mountain climbers, as part of mountain expeditions thousand-metre peaks. The first systematic findings on the use of altitude for increasing sporting performance came from a study connected to preparations for the Olympics in Mexico City (1968, 2 200 m a.s.l. In the 70s and 80s, the methodology of altitude training was elaborated upon, but only in a small number of countries. The 1990s were characterised by a spread of altitude training camps to many countries around the world. In this period, stays at artificially induced altitude (hypoxic tents, chambers, rooms) also began to be used increasingly. The start of the new millennium was characterised by permanent relocation of (primarily) endurance athletes to altitudes.

Keywords: *hypoxia, sport, training, Olympic Games, history.*

Introduction

The use of hypoxia is currently considered one of the main options for increasing performance limits, particularly for endurance sports. Hypoxia (anoxic) is the reduction of the partial pressure of oxygen in the blood that occurs, for example, when staying at increased altitudes or in a barochamber (Wilber, 2004). In 1648, Pascal demonstrated that the barometric pressure is lower in the mountains compared to sea level (Ward et al., 1995). Then in 1777, Lavoiser described oxygen and other gases that are part of the air (Wilber, 2004). In 1878, French scientist Bert (1878) demonstrated the effect of lower partial pressure lowering the performance of non-adapted individuals. These discoveries in sports training only found application decades later: before the onset of adaptive changes, during and after training at altitudes of 2 000 m a.s.l. the cardiac response during medium intensity exercise can be 20 to 30% higher than near sea level in non-adapted individuals. The level of maximum oxygen consumption (VO_{2max}) for non-adapted individuals at an altitude of 1 200 m a.s.l. is reduced by roughly 5 to 10%, from 1 600 m a.s.l. there is a drop of 9 to 11% for each 1 000 m a.s.l. (Robergs and Roberts, 1997). At an altitude of 2 000 m a.s.l. the body adapts after approximately 15 to 20 days. Currently, experts agree that living and training at altitude has positive effects, primarily improving biochemical and certain physiological indicators (Korčok & Pupiš, 2006; Pupiš, 2014). Aside from new trends in the efficiency of sports training management, it is one of the few legal ways to increase performance limits. Previously, altitude training was recommended exclusively for endurance sports. In the current literature we find agreement on the positives of using altitude (1 800 to 2 200 m a.s.l.) for sports where the races last longer than 90 sec. For collective sports, where technical and tactical factors play a central role, stays at altitude have very little significance and are thus not overly used in practice. Despite the amount of information published, not all issues concerning altitude training have been resolved. There is a consensus in assessing the significance of preparation under lower partial air pressure in the following areas: preparation for competitions to be held at altitude and increasing conditioning for subsequent stays near sea level. In terms of the focus of training, the second variant can fulfil the intentions of condition training or of preparation for races at low altitudes (Suchý et. al, 2009). A major stimulus for specially preparing for stays in high mountains (up to 4 000 m a.s.l.) was World War I, in particular fighting in the mountainous part of the Isonzo Front, where special mountain troops and artillery units were deployed. The history of adaptation by mountain climbers to higher altitudes has been dealt with relatively broadly (Welshman, 1998).The use of oxygen when climbing in the Himalayas was pioneered by the British expedition up Mount Everest in 1922, and with its help mountain climbers George Mallory and Howard Somervell reached a height of 8 225 m (Herzog, 1989). We do not deal with this issue in this article, because this generally concerns acclimatising to altitude, which is not used to increase the performance limits of athletes. The development of the use of higher altitudes essentially copies the venues of the Olympic Games and the global political situation, particularly its bipolarity – i.e. competition between "East" and "West" and the subsequent collapse of the Eastern bloc. Higher altitudes (1 800 to 2 300 m a.s.l.) were first used on a wider scale in sport during preparations for the Olympics in Mexico City (1968).

Given that the games were to take place at an altitude of 2 240 m a.s.l., some athletes trained at a similar altitude in order to acclimatise to the altitude of the Olympics. Subsequently the inclusion of intensive training in the mountains became increasingly frequent. In the 1980s, artificially induced altitude began to be used (hypoxic chambers, tents and masks). Currently we can observe a trend of primarily top endurance athletes moving to higher altitudes permanently. Over the last roughly fifty years, thousands of studies have been published on the issue of higher altitudes. The motive for this text is the fact that we found only a minimum of historical looks back at the development of this issue in the academic literature.

Aim and methods

The aim of the presented study is to summarise selected periods that in our opinion had a marked influence on the use of altitude in sports training. It is a theoretical work; information was collected from the available literature. Data were processed in the form of a comparison of the results of a study of the literature, analysis thereof and subsequent interpretation.

Findings and discussion

Due to the fact that up until the emergence of the modern Olympic Games, the most advanced sports training system was formulated in theory and practice by trainers active in the period of the Roman and even more so Greek antiquity, we open our work by considering what role altitude could have played in the training of ancient athletes. We also look to Greek antiquity due to the fact that in the ancient Greek city-states, as today, the training cycle was planned out so that the athlete would give their optimum performance at the competition that was the culmination of the annual season, meaning attendance at one of the Panhellenic Games.

Likewise, we today have adopted from the ancient Greeks (though not entirely consciously) the concept of national representation, including the celebration and rewarding of Olympic champions by the fellow citizens and political representatives of the country in whose colours the athlete was victorious. The peak performances at the Panhellenic Games were meant to serve as a model so that all free Greeks would practise sport in their spare time, which is a concept on which there is great emphasis in many countries today.

The contemporary contribution of top-level sports towards the health and military readiness of a country's population also mirror that of the ancient Greek city-states. The significance of top performances and training for them for reasons of military readiness is no longer as publicised, but the interest of the military in elite sport is more than evident from the support that it provides to selected sports.

Antiquity

Training, as it is characterised in the present, is associated with the emergence of modern sport in the nineteenthcentury. The development complex of sport competitions and the associated training system in ancient Greece, however, in many ways surpassed the preparation of athletes for international competitions at the start of the twentieth century, including the Olympics. The overture of training for the ancient Olympics and other Panhellenic Games was already taking place in the palaces of the Minoan civilisation (named after the legendary King Minos), the home of which was on Crete at the beginning of the second millennium before Christ. Wall reliefs of boxers were created here in the sixteen century BCE. Another sport typical for Minoan culture was acrobatic bull-leaping. Like the pictures of boxers, at the archaeological site HagiaTriada we can find wall paintings and sculptures depicting men in acrobatic positions over a bull. The interpretation of these depictions is not clear-cut, but the most likely explanation would seem to be that an acrobat is leaping over the bull's back by quickly grabbing its horns at the moment it is charging.

It is evident that thorough training was required to manage this discipline, focused on the most important components without which no contemporary top athlete can make do – development of motor skills, skills training and mental preparation (Decker, 2012). A look at a map of the mountainous island of Crete could, in the context of the topic we are analysing, tempt one to believe that altitude did play a role in the fitness training of Minoan athletes.

Given however that the majority of economic, political, cultural and religious life took place in palaces of an urban type, and the best known palace at Knossos, one of the ancient wonders of the world built around 1900 BCE, and other palaces Malia and Phaistos, were built not far from the sea, we cannot cling to this hypothesis. It is likely that some of the population of Crete did live at higher altitudes, which is attested to by the findings of the famed Kamares wares in the village of Kamares in the Ida mountain range with peaks of over 2000 m a.s.l., but unfortunately it is not possible to determine from the archaeological findings whether or not people from the mountains numbered among the Minoan athletes. Crete was struck by natural disasters around 1700 and then in the first half of the 15th century BCE, which ushered in the end of the Minoan civilisation.

A hierarchical system of sports events, games and competitions (including artistic ones), called Agon, was created by the citizens of ancient Greek city-states (Polis). Agon: in ancient Greek it originally meant a gathering of people who decided on the most important matters. Homer used this term for a gathering of heroes at which improvised competitions took place. In the post-Homeric period it was increasingly used to indicate athletic competitions and festivals (Decker, 2012).

In ancient Greece we can observe competitions that show all the signs of contemporary competitive sport: regional and Panhellenic competitions, sport disciplines with defined rules, a system of athletic training focused on improving performance and giving the best performance at top competitions and last but not least spectator interest in athletic competitions and the celebration of sports heroes. The Greeks resonated with a dual identity, i.e. they identified with their native municipality (state) and at the same time with the culture and cult of all of Greece and its ethical values. The Greeks loved science, art, sport and celebrations of all kinds. The embodiment of panhellenic identity were the Panhellenic Games, which were a highly well attended festival of top sport as well as an event of deep religious significance. These were the Olympic Games dedicated to the god Zeus, which took place at Olympia in the state of Elis in western Peloponnese. They started as regional games in the nine century BCE. The date given for the first Panhellenic Olympic Games is 776 BCE, the date of the first recorded Olympic champion for a race of one stadium-length (stade). After the Olympics, the second most important were the Pythian Games at Delphi, which, as with the Olympics, took place once every 4 years. From the start of the 6th century BCE they took place as part of the celebration of Apollo and were named after the legendary priestess and oracle Pythia.

Rounding out the four Panhellenic Games were the Isthmian (in Corinth) and Nemean (in Nemea) Games, which took place every two years, the origins of which also stretch back to the sixth century BCE. Aside from the Panhellenic Games, there were also a whole range of local sporting holidays in Graeco-Roman antiquity. The sporting programme of the various Panhellenic and local games was not identical, but we can state that the sporting Agon unfolded within the following sporting disciplines: combat sports – wrestling (palé), boxing (pygme), and pankration. These man-on-man fights without any weight categories or time limits were highly popular with the public and fans were willing to travel over long distances to see matches involving their heroes.

Boxing and the pankration were among the toughest disciplines in history. Boxing was done without gloves, and open hand strikes and kicks to the legs of the opponent were permitted. The Spartans did not participate in boxing competitions because in boxing, a boxer whose injuries prevented him from continuing gives up and the Spartans' code of honour (with a shield or without a shield) prohibited this. They did not have a problem with wrestling, because it ended at the moment one of the wrestlers' back touched the ground. Pankration was an even more brutal sport – a combination of boxing and wrestling. Pankration perfectly fulfilled the concept of total warfare. It is likely that the only things that were prohibited were biting and poking the eyes, nose and ears. Unlike in boxing, the majority of matches were likely decided on the ground, but while in wrestling weight was the deciding factor and in boxing the length of one's arms, in pankration it was strength, quick reactions and the ability to endure pain.[16]Endurance was not the deciding factor in these martial sports, though it did have an influence on the result, but primary were genetic physical conditions, in particular: height and weight, strength, resistance to pain, etc. Another group of antique sports present at the games were equestrian sports, i.e. horseracing and chariot racing. Here the jockeys and charioteers naturally spent years of training to learn their discipline, but the fact that they needed a hippodrome to practise indicates that they did not train at altitude. The existence of hippodromes is attested to, aside from the sites of the Panhellenic Games, in Athens, Thebes, Sparta, Alexandria, and on the island of Delos. In the context of the issues we are examining – potential use of altitude training – we must of course focus on running disciplines and the pentathlon. We shall leave aside the not yet entirely satisfactory answer to the question of whether the "stade" run was truly the first discipline at the antique Olympics or how they started and go over the facts that are known.

The central running disciplines were the stade and the Diaulos – a double-stadium race, at Olympia nearly 400 m. The distance of the race depended on the length of the track at the stadium, which varied based on where the games were taking place, e.g. Olympia 192 m, Delphi 177 m, Nemea 181 m. The length of the double-stadium run cannot be determined down to the centimetre because it was a straight track, with the runners turning 180°, which required dexterity and sophisticated tactics because we can assume collisions and pushing took place at the turnaround point. In today's terminology we can term these disciplines sprints, though 400 metres is a medium track. The third running event of Greek antiquity can be called long-distance in today's terminology – Dolichos, the name of which is derived from the Greek word for long. The length of the track ranged from five to twenty-four stadium lengths.

At Olympia it was 20 stades, which corresponds to nearly 4 kilometres. Long-distance events were naturally run by runners with different training and somatotypes than sprinters. The last running discipline of the Olympic Games was, starting in 520 BCE, the Hoplite race (racers ran in a helmet with greaves and a shield), in Olympia for two stades and in Nemea for four. The most versatile discipline at the antique games was the pentathlon:
1) Discus throw:this was a sporting event even mentioned in the Iliad. Copper discs weighing around 5 kg were thrown; there is no consensus on whether they were thrown rotating the whole body.
2) Long jump: a jump with two weights (the jumper held one in each hand) made of various materials (stone, lead, bronze), but for each competition the jumpers used the same type. The Greeks believed that the use of such equipment helped achieve a clean landing. The time to take the jump was defined by music played on a flute.

3) The javelin throw was, like other disciplines of antique sport, closely tied to military training. The javelin included a leather thong into which the athlete inserted two fingers, which they could not forget about when letting go of the javelin. Javelin-throwers had a special fenced-off sector at the games so that their throws could not threaten the spectators.
4) Running was likely done at a length of one stade.
5) The last event was wrestling. Specialists in wrestling (i.e. large, strong and heavy athletes) generally did not win in the overall pentathlon results. The ideal pentathlete was similar to the ideal decathlete of today. At the same time, however, wrestling was the culmination of the whole competition, thus the remaining athletes likely faced off in a KO system. It is likely that either the best of the previous 3 disciplines moved on to the wrestling stage or that the competitors who placed the worst in the previous 3 events were dropped.

We examined the events of antique sport in somewhat more detail because it is not possible to analyse training in antiquity with regard for whether it could have taken place at altitude without knowledge of the disciplines for which the competitors were preparing. Training during the golden age of Greek antiquity, i.e. in the fifth and fourth century BCE up until the Roman era, had all the characteristics of modern training, as evidenced by preserved studies by Greek authors dealing with the issue of training. In the fifth century BCE, one of the best known authors was Ikkos of Taranto, an Olympic champion in the pentathlon, as were Herodikos of Selymbria and Theon of Alexandria. The best known training theoreticians during the Roman era included Philostratos, who came from a well-known family of sophists.

Physicians also took an interest in the training process from the perspective of nutrition and hygiene, including one of the greatest antique physicians Galen of Pergamon. Antique sports training theory in no way lagged behind athlete preparation concepts in the twenty-first century, in large part because it was based on a comprehensive system, with the individual components of training forming a coherent whole, the realisation of which was focused on optimising performance, particularly at the Panhellenic Games – e.g. before the Olympic Games athletes attended a month-long training camp. Here we will attempt to mention the main features of training in the ancient world:

- Selection of athletes according to somatotype for the various martial sports, the sprint or long-distance running, or the pentathlon.
- Training of youth categories focused on even development of general physical and motor skills and skills tied to a specific type of sport. The age of athletes was taken into account, along with load level during training and the time spent regenerating.
- Special nutrition and hygiene. Wrestler Milo of Croton, the ancient world's most famous sports hero, who in the sixth century BCE won 6 times at Olympia, 7 times in Delphi, 10 times in Corinth and 9 times in Nemea, which indicates that he was at his sporting peak for over a quarter century, ate around 10 kg of meat a day and drank 9 litres of wine (this could have been water mixed with wine) (Decker, 2012), which seems, judging by his sporting successes, to have been an adequate diet for large doses of strength training (in terms of both volume and intensity). In contrast a vegetarian diet was recommended for runners.
- Alternating between strength or speed training and training of skills and rest.
- Knowledge and utilisation of psychological motivation, the means of which trainers adopted.
- Use of the experiences of successful athletes from both preparation and competition.
- Development of tactical skills: e.g. for runners depending on the nature of the track, specific opponents, etc.
- Medical care for athletes: due to frequent injuries, primarily in the fighting sports, sport traumatology was of very high quality.

Training equipment naturally corresponded to the technology of the period. In order to develop their strength, it was recommended that heavy athletes carry heavy loads, bend metal plates, and tame bulls; that long-distance runners develop their speed and improve their fitness by running with horses and hares, etc. Compared to today's athletes, these ancient ones had other trump cards that were meant to help them to victory, the popularity of which grew especially during the Roman period: prophecy, dream reading and magic. Due to the fact that the use of mysticism was completely absent from the education of the authors of this article, we dare not judge the effectiveness of these means, but a certain parallel can be found with today's psychological preparation, which has in recent years been used almost to excess, in elite sport especially.

The practical and theoretical training of trainers was also of excellent quality, because they completed what was essentially higher education, being trained at gymnasia, which were the highest type of educational institution in ancient Greece, with science and art also developed there. For many trainers, sports training became a profession, but we have only sparse information about their income – for example, an inscription from Miletus from 199 BCE states 30 drachmae a month. In the same period in Anatolian Teos a top trainer earned 500 drachmae a year. The drachma was the daily or bi-daily salary of a qualified tradesperson in classical Athens, from which his family could also live well. The price of a slave ranged from 150 to 250 drachmae. In the context of our topic let us pose the question of what role altitude played in preparing athletes in antiquity. There were no training camps at an altitude of around 2000 metres above sea level, or at least we find no mention of such in the works of ancient authors.

The Panhellenic Games took place at lower altitudes and thus altitude acclimatisation was not necessary. Despite this, altitude could have played a role in the performance of ancient athletes, particularly for runners and pentathletes. At 80% mountains and hills, Greece is among the most mountainous countries of Europe, and the peaks of some mountain ranges exceed 2000 m a.s.l. The centres of most Greek city-states were in the lowlands, and it was also here that people trained at the gymnasia and stadiums, which is also true of Sparta. But altitude could have played a certain role in the training of Spartans, because the military training of boys and men lasted from 7 to 30 years of age and included frequent long marches, during which the Spartans likely did not avoid the mountains that enclose the plains of Laconia. Alpine training was likely of considerable importance for long-distance runners.

For many of them, overcoming long routes, including through mountains, was their daily bread. Between the eighth and sixth century BCE, a number of city-states arose on the Peloponnese that were quite isolated, because ancient Greece had practically no infrastructure of roads and paths. Even so, the inhabitants of these states had to communicate together for political, trade, military, cultural and personal reasons. The intermediaries for such communication were special runners who brought news, correspondence and small packages. We do not know much of their equipment and armaments, but they almost certainly would have had to have been as light as possible. They could not have got by without a travel bag and likely also some sort of weapon to protect them from wild animals (Buzek andOndřejová, 1989). Not all of them took their profession to the racetrack at the stadium, but due to their demanding and lonely occupation they had all the physical and mental prerequisites for long-distance running.

We can thus imagine that they achieved their physical fitness and mental resilience by traversing the mountain ranges that formed the natural boundaries between individual states. What remains unanswered is the question of whether contemporary endurance athletes who live and train at high altitudes would be able to keep up with them. We have only a little information on their abilities: for example the Argive runner Ageus, who won the long-distance race at the Olympic Games in 328 BCE, set out on the day of his victory to report his success to his home town of Argos, located approximately 100 km as the crow flies from Olympia (Jokl, 1968).

First half of the twentieth century: the first systematic evidence

Experts in the biomedical sciences first registered physiological and anatomic differences in the inhabitants of the mountainous regions of the Peruvian Andes. This was later confirmed in permanent inhabitants of the Himalayas and high mountains in the United States. A significantly lower incidence of myocardial infarction was found in populations living permanently at high altitudes (Buzek, Ondřejová, 1989).After World War II, the first studies began to be conducted that proved that "healthy inhabitants" of these areas show specific findings – a certain degree of pulmonary hypertension, as well as hypertrophy of the right ventricle. Pugh (1954, 1967) published selected physiological and purely practical findings from climbing Mount Everest. These findings, and they were not alone, filtered through into the opinions of experts on the performance of athletes who were born at higher altitudes. In connection with these findings, fatigue labs began to expand their focus beyond standard physiological and biochemical tests to include the influence of altitude on the performance of athletes (Beamish, Ritchie, 2005). Officially speaking, the influence of altitude on performance seems to have been first discussed at the congress for the Central American Games, held under the auspices of the IOC in Paris in 1924.

These games took place in Mexico City in 1926 and again in 1955 (Wrynn, 2006). Long-term or even lifelong residence at high altitudes is not the sole prerequisite for higher performance, particularly in endurance disciplines. Leaving aside individual dispositions, for instance genetics and training methodology, there is a whole range of conditions, political (in particular state support for sport), economic and social. Only the aggregate and cohesion of these prerequisites leads to the birth of champions. Where most of these attributes are absent, so too are sporting successes. This is evidenced in part by comparing the success of, for instance, Ethiopian, Kenyan. These representatives and trainers, in particular, managed to take advantage of this "lifelong" preparation in a long-term mountainous environment to achieve a whole range of successes on the athletic track, though from the perspective of Olympic results, it is not a permanent domination. A key role in the development of athletics throughout the whole African continent was demonstrated by the phenomenal success achieved by AbebeBikila, the winner of the marathon at the 1960 with a new world record time of 2:15:16.2 having run the entire race barefoot. In the 1964 Olympics in Tokyo, Bikila became the first marathon runner in history to defend his gold medal, and improved his world record by three seconds. In the years 1960-1966 he participated in a total of thirteen marathons, of which he won twelve.

Preparations for the Mexico City Olympic Games 1968: systematic use of altitude

Detailed deliberations on an analysis of the influence of higher altitudes on athletic performance and the issues with training at such altitudes began in connection with the preparations for the 1968 Summer Olympics in Mexico City, which took place at an altitude of around 2 200 m a.s.l. The USOC organised a conference on this issue in March of 1966, where the consensuses laid out in the introduction to this article about the principles of using higher altitudes to improve performance limits were mentioned, but opinions

on the utilisation of altitude were by no means unanimous at that time. Just five years before the Mexico Olympics, the International Olympic Committee (IOC) had stated that the altitude of Mexico City (2 240 m a.s.l.) would not have an impact on the performance of athletes. This statement was a reaction to the statements of Bikila, who had won the Olympic marathon in Rome and Tokyo and was asked whether we would win in Mexico as well, to which he responded that he would because it is the same height as Addis Ababa, where he was born and trains (Kasperowski, 2009). Preparations for the Mexico Olympics specifically required acclimatisation to altitude, meaning long-term stays in the mountains.

The USSR built a sports centre in Tsaghkadzor and near Alma Ata (both centres are located at altitudes between 1 900 and 2 300 m a.s.l.) leading up to the Games, France started to make use of Fort Romeau (1 900 m a.s.l.) and the US Colorado Springs (2 200 m a.s.l.), where the USOC has its headquarters today. Numerous studies published during the Olympics(Buskirk, 1967) as well as practical and casuistic experiences of athletes produced a range of innovative findings on how to prepare for competitions at higher altitudes. Wrynn (2006)states that experts, unlike the (evidently politically motivated statements of the) IOC, already expected before the Mexico Olympics that the altitude would rather suit sprinters and jumpers, while a negative effect was expected for endurance disciplines. These expectations were confirmed. Eight new world records were achieved in Mexico for speed events (100 m, 200 m, 400 m, 4x100 m, 400 m hurdles, triple jump, long jump).

In contrast, no world record was broken in endurance events. The winners of the 5 km and 10 km races ran approximately 6% slower than the world record of the time. Australian Ron Clark was a holder of 17 world records, of which two were still in place when the Mexico Olympics took place: the 5 km (7 May 1966) and the 10 km (14 July 1965) (Sýkora, 1970).This legendary runner placed fifth in the final 10 km run and collapsed at the finish line (www.bbc.co.uk, 2016).His unexpected failure and collapse were likely caused by the high altitude. Although he did undergo camps in the Alps before the games, he could not keep up with the runners from Africa. A detailed comparison of the times and world records achieved is presented in Table 1.

The altitude of Mexico City led to poorer performances in long-distance races, but the positives of altitude training were confirmed, because success was achieved at the Mexico Olympics by middle- and long-distance runners from Kenya and Ethiopia who were born and lived permanently at altitude. Other than a few brilliant exceptions (AbebeBikila), athletes from these countries had attended only a minimum of top athletics competitions before these Olympics. Kenyans alone acquired 39% of the medals for medium- and long-distance races. Based on the results of Africans and (inter alia) an analysis of the preparation of Ron Clark, it is ideal for success in endurance disciplines to be born and/or live long-term and train at high altitudes. An example is the area of the Great Rift Valley in Kenya and Ethiopia, from which all the medium- and long-distance runners successful at the Olympics from these countries come. Experts then focused their research on the results of Africans from the Great Rift Valley and discovered that their excellent results do not stem solely from the genetic disposition of having been born and lived at altitude, but also from their somatotype. Larsen (2003) states that Kenyans have 5% longer legs and 12% lighter muscles than Scandinavians, who are among the tallest nations. The success of Kenyans is also significantly helped by the great popularity of running there and the economic motivation due to the low standard of living (GNI per capita in Kenya: 100 USD/month, Great Rift Valley: approx. 250 USD/month) (http://data.worldbank.org/country/kenya, 2016).

Also contributing positively to their top performances are the specific ergonomics of running (running barefoot from a young age on the front of the foot) and the traditional "Kenyan diet" consisting primarily of the consumption of "ugali" (a dish made of maize flour, salt and water) and "Chai"(Black tea with cream and high amount of sugar) –i.e. the diet of the majority of African long-distance runners is based primarily on complex carbohydrates.

Table 1. Difference between world record and time achieved at 1968 Olympics in selected men's track and field events (www.olympic.cz)

Event	*Winning time at 1968 Olympics*	*World record before 1968 Olympics*	*Difference between '68 Olympics time & world record*
100 m	*9.9*	*9.9*	*0 %*
200 m	*19.8*	*19.9*	*+ 0.5 %*
400 m	*43.8*	*43.8*	*0 %*
800 m	*1:44.2*	*1:44.3*	*0 %*
1 500 m	*3:34.9*	*3:31.1*	*- 1.8 %*
3 000 m hurdles	*8:51.9*	*8:24.4*	*- 5.2 %*
5 000 m	*14:05.0*	*13:16.1*	*- 5.8 %*
10 000 m	*29:27.4*	*27:39.0*	*-6.1 %*

The seventies and eighties: dominance of athletes from East Germany, USA, Kenya and Ethiopia, refining the methodology for incorporating altitude into the annual training cycle (ATC)

Detailed analyses of the preparation for and success at the Mexico Olympics confirmed the positive effects both for athletes living permanently at altitude and for those who were born in lowlands but who at least partially trained at altitude. These findings then sparked further extensive studies on the impact of training and staying at higher altitudes on performance at both higher and lower altitudes. Following up on these and other results, the methodology for making use of higher altitudes to increase fitness for competing both at sea level and at altitude was naturally elaborated upon and refined.

The first to systematically use this type of training were trainers from what was then the German Democratic Republic (East Germany), who were the first to present the model of "21 days of training at 2 000 m a.s.l. and then 21 days after returning to lowlands shining at the World Championship/Olympics", validated primarily for swimming and rowing, as these were the events in which they achieved top international results. The trainers (allegedly at first the swimmers and rowers, but then also of medium- and long-distance runners) and methodologists in East Germany were convinced that altitude training played a significant role in the success of their charges.

However, this was without the backing of scientifically validated research. These assertions come to us through hearsay, as neither we nor other authors have been able to track down primary sources published in the former East Germany on this issue. For example as part of previous studies we held controlled structured interviews with trainers and athletes who were active in the 1990s and this information made the rounds within this community (Suchý et al., 2009).

The fact that training at high altitudes played a fundamental role in the preparation of African and East German endurance athletes in the seventies is confirmed by the word of Lasse Virén, a Finnish athlete who ruled the five and ten kilometre tracks at the 1972 and 1976 Olympics: "The media was always interested in why I managed to win the Olympics four times and I have no problem answering*… The important thing is that I trained at high altitudes a lot, and that helped me succeed "*In the case of the Munich Olympics, Virén spent a number of weeks at altitude in Kenya, while before the Montreal Games he was in Colombia and again in Kenya, also training at Fort Romeau and Colorado Springs (www.racingpast.ca, 2016).

Sutton et al. (1983) published one of the first sets of results of lab tests in a hypobaric chamber, which helped expand the knowledge of the influence of altitude on physical activity. Studies with artificially induced altitude were also conducted in Czechoslovakia before the Moscow Olympics – for example for canoe racers wearing oxygen masks (Suchý et al., 2009).

The nineties and the beginning of the new millennium: hypoxic tents and chambers, expansion of the use of altitude to many countries

For elite endurance athletes in particular, the number of training days under the ATC spent at high altitudes has increased over the last three decades of the twentieth century. For this reason, the facilities of training centres located at altitudes of around 2 000 m a.s.l. have also improved. In the beginning, ordinary ski resorts were used for training camps at high altitudes, offering no special services or sports facilities. These days, extensive, well-equipped sports complexes have been built in many places around the world (see Table 2) and can compare to centres built at low altitudes. Detailed knowledge of training at altitude for the variant of preparing for competition at altitude became significant once again leading up to the Winter Olympics in Salt Lake City (2002). The issue of altitude was addressed in particular detail for these Olympics for cross-country skiing, the Nordic combined and biathlon, as these events were to take place at Soldier Hollow, where the track is located at an altitude of 1 670 to 1 793 m a.s.l.

The use of altitude was also important during preparations for the Turin Olympics (2006), where some events also took place in the mountains (see Table 3).

Table 2. High-altitude sports centres

Site	Country	m	Site	Country	m
Addis Ababa	Ethiopia	2	La Paz	Bolivia	3 100
Belmeken	Bulgaria	2	Mexico	Mexico	2 200
Bogota	Colombia	2	Nairobi	Kenya	1 840
Boulder	USA	2	Pontresin	Switzerla	1 900
Tsaghkadzor	Armenia	1	Karakol	Kyrgyzsta	1 800
Colorado	USA	2	PyatraArs	Romania	1 950
Flagstaff	USA	2	Quito	Ecuador	2 218
Font Romeau	France	1	Sestriere	Italy	2 035
Ircan	Morocco	1	Silvretta	Austria	1 800
Issyk–Kull	Kyrgyzsta	1	St. Moritz	Switzerla	1 820
Kaprun	Austria	1	Tamga	Kyrgyzsta	1 700
Kesenoy–Am	Russia	2	Toluca	Mexico	2 700
Keystone	USA	2	Zetersfel	Austria	1 950
Kunming	China	1			

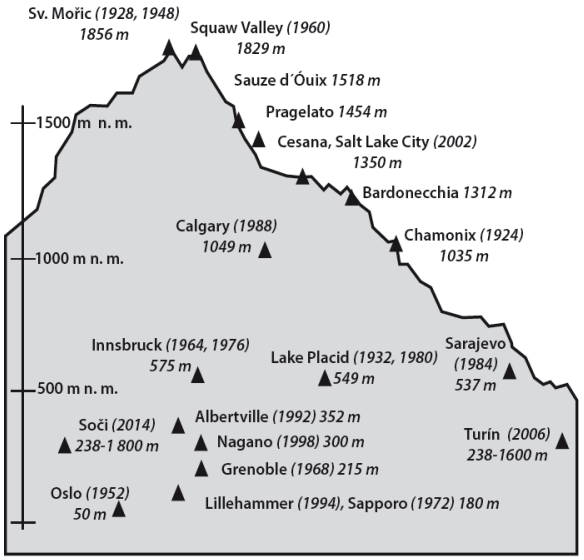

Figure 1: Altitude of Winter Olympic Games

A typical example of the spread in application of altitude training beyond the original pioneers (i.e. certain European countries, the USSR and USA) is Canada. After the lack of success of Canadian athletes at the 1988 Olympics in Seoul and based on the success of countries that had included altitude training and succeeded, they decided to incorporate training camps at altitude into the training process as well. In the first phase, they trained based on information acquired from East Germany, but this strategy led to overtraining.

Table 3. Altitude of venues at Turin Olympics (based on Dovalil et al., 2006)

Event	*Altitude*
Cross-country skiing, Nordic	*1 524 m a.s.l.*
Biathlon	*1 618 m a.s.l.*
Curling	*376 m a.s.l.*
Figure skating	*Turin (~ 200 m a.s.l.)*
Ice hockey	*Turin (~ 200 m a.s.l.)*
Giant slalom, slalom	*2 035 m a.s.l.*
Speed-skating, short track	*Turin (~ 200 m a.s.l.)*
Luge, skeleton, bobsleigh	*1 569 m a.s.l.*
Downhill, combined slalom (men	*1 738 a 2 035 m a.s.l.*
Freestyle skiing	*1 524 m a.s.l.*
Ski jumping	*1 535 m a.s.l.*
Halfpipe, parallel giant slalom, snowboard cross	*1 312 m a.s.l.*

These negative experiences led to the creation of their own "Canadian" model, under which the following three key themes for training at altitudes of around 2 200 m a.s.l. are distinguished (Suchý, 2012):

a) improving general fitness (length of altitude stay: 10 to 14 days)
b) improving special prerequisites (length of altitude stay: 14 to 21 days)
c) final preparation for top-level competitions (length of altitude stay: 17 to 21 days).

Leading up to the Olympics in Vancouver and Sochi, which took place near sea level, most athletes nominated for endurance sports prepared according to the following model: three weeks of training camp at an altitude of 2 200 m a.s.l. and a week near sea level in the following months: July, August, October and November; preparatory races at the start of January. An altitude stay three to six weeks before the Olympics; Olympic start 21 to 28 days after returning to sea level. This model is today generally accepted as suitable for athletes born and permanently living at low altitudes.

A shift in the use of altitude has also occurred for the sprint and short track (where races take less than 90 seconds), where further legal ways to boost performance are constantly being sought out. A similar design has started to be used for these sports, but with a combination of 10 days at altitude and 20 days at sea level; before the Olympics 10 days at altitude followed by an Olympic start three weeks after returning to low altitudes. As part of altitude training and stays, many athletes have begun to make regular use of the "yo-yo" effect (i.e. acceleration of haematopoiesis): five to seven times during a three-week training camp at an altitude of 2 200 m a.s.l. they undergo low-intensity training of up to two hours at an altitude of 2 800 m a.s.l.

Likewise, when training at sea level they incorporate a training at 2 200 m a.s.l. every three or four days. For technical and organisational reasons, they sometimes use artificially induced altitude, but natural altitude is more suitable. This approach (using natural altitude) was first presented by Daniels and Oldridge (1970), who demonstrated an increase in haemoglobin levels of 6% under this model. Their results were confirmed by others (Klausen et al., 1991).

Use of artificially induced higher altitudes

In order to reduce the negative impact of staying in the mountains (technical, organisational, climactic, financial, family factors, etc.), in the 1990s hypoxic tents and rooms began to be used increasingly. A pioneer Professor Rusko, who published officially scientific information, built a nitrogen house in Finland at the start of the 90s (Rusko, 1996). Wilber (2004) and other authors and personal testimonies indicate that oxygen tents and homes were already in use at the start of the 80s by experts and trainers in the former East Germany. Systems for commercial use began being mass-produced by the US company Hypoxico (www.hypoxico.com, 2016). Levine and Stray-Gundersen (1997) subsequently also presented a study in which they stated the benefits of sleeping in an artificially induced hypoxic environment and training at sea level to increase performance.

At the turn of the millennium, the use of tents was relatively popular, though their use is highly demanding in terms of methodology. The primary risk is overtraining, with other negative aspects being: slower recuperation, which the body has a harder time identifying, and lack of quality sleep (the noise of the generator and dry air). Intermittent hypoxic training (IHT) began to be used, and not just in top-level sport, with artificially induced altitude being applied during exercise at sea level at regular intervals (Pupiš & Korčok , 2007). Based on interviews with athletes, who understandably wish to remain anonymous, we believe that for some athletes the declaration that they use an artificially induced hypoxic environment is intended to cover up limit red blood cell values induced in an illegal manner. Certain sports federations (in cooperation with WADA) reacted to these facts with their traditional delay at the end of the first decade of the new millennium by gradually introducing "biological passports", the standardisation of which is, however, complicated with unclear guidelines - an example is the dispute between cyclist Roman Kreuziger with UCI and WADA.

Present day – permanent relocation of endurance athletes to high altitudes

The authors are of the opinion that there was a significant increase in the number of altitude training camps used in preparing for the 2000 Olympics in Sydney and 2004 games in Athens. This trend is illustrated by Table 4, using the example of Japanese swimmers, whose national coach was willing to publish his estimate. After the Olympics in Athens we observe a trend of permanent relocation of many endurance athletes to higher altitudes (Suchý et al, 2009). The question with this is how long after residence at altitude the athlete's body acclimatises to competitions near sea level.

There is a consensus that athletes have to be at sea level at least 10 days, optimally starting at major competitions around the 15th day. A condition for acclimatising well to sea level is having at least two high-intensity training sessions there.

Another current trend is to undergo at least two high-intensity training sessions at sea level during a seven-day micro-cycle at altitude. With regard for technical and organisational complications, these training sessions tend to be realised not only at low altitude, but in many cases using supplemental oxygen. For permanent residence at altitude, oxygen saturation is also used to speed up regeneration processes.

Table 4. Use of altitude training camps among swimmers–Summer Olympic attendees (Suchý et al., 2009)

Olympics	Medallists	Finalists	Total
Sydney (2000)	1/3	5/14	9/21 (45%)
Athens (2004)	5/7	9/14	14/20 (70%)
Note: data do not include relay races			

Conclusion

The history of the gradual increase in inclusion of altitude stays and training to improve athletic performance is naturally much broader and goes beyond the bounds and scope of this text. Given this, we have presented only selected key historical periods, which in our opinion had a more marked influence on the formation of altitude training methodology for athletes. In antiquity, i.e. in relation to the topic of our work in the prehistoric period of athletic training in the mountains, we cannot speak of residence at altitude as a deliberate component of athletic training.

We do however believe that in the case of long-distance runners who delivered messages and as part of their work had to overcome mountain ridges that do meet the parameters of residence at higher altitudes, then this professional training could have contributed quite significantly to the quality of their performances at stadiums.

Teams of professionals training athletes only began to systematically take up athletic training at altitude in connection with the Mexico Olympics. Leading up to these Olympics they began seeking the answer not only to the question of how the altitude of the site would affect the athletic performances in various events, but also how training at altitudes of around 2 000 m a.s.l. could stimulate overall athletic performance.

We consider the following facts to be the main limitations of the study: experts from the former East Germany pursued the issue at hand systematically and in depth (as we state in the footnote), but information on their procedure in written form is unfortunately essentially untraceable as it was never officially published. Acquiring access to primary information from the archives of the former East Germany is highly complicated. The reason for the secrecy around this information was that athletic success was used as one of the main pillars of propaganda in East Germany and other Soviet satellites of the time.

For this reason, some information presented in the article may have a limited value, as many experts today take the same approach to publication as the methodologists and trainers in the former East Germany. However we have long observed this limitation not only in the field of altitude training methodology, but for all information concerning performance limits.

It can be seen in the relevant literary sources that if the results of important studies are published at all, then it is with a delay of as much as one or two Olympic cycles. These statements are not only based on the results of literary research, but are also confirmed by the trainers questioned by Suchý and Dovalil (2009). Perhaps these are also the reasons that the current trend of relocation of (predominantly endurance) athletes to altitudes around 2 000 m a.s.l. has not yet been methodologically captured in publicly available sources.

In Table 1 it would be interesting to compare not only the world records valid at the time, but for example the ten best times achieved in 1968. We unfortunately did not manage to track down these data. Another option would be comparing the best marathon times, but here the resulting time is fundamentally influenced by the track profile, thus we did not provide this comparison in the text. Artificially induced hypoxia (primarily oxygen tents) were highly popular at the turn of the millennium. The doubts as to their use presented herein are, for obvious reasons, not supported by publications.

Currently, artificially induced altitude is used to a limited extent; in contrast, the use of artificially induced sea level at training camps and permanent residence at altitude is on the rise. The presented text focused on information on performance limits and adult athletes. Pollard et al. (2001)published a consensus statement on children and altitude; subsequently pilot studies were realised in this area (Suchý, Opočenský, 2015). The use of high altitudes to improve performance limits has been applied in the past fifty years in elite sport with high frequency primarily for endurance sports.

The use of altitude started leading up to the 1968 Olympics (Mexico City), then the methodology was gradually refined and the number of training days spent at altitude increased. Further milestones for broadening knowledge after the Mexico Olympics were later Olympics held at high altitudes (Turin and Salt Lake City). Currently, evidently due to the tightening of anti-doping rules, many endurance athletes are relocating permanently to higher altitudes.

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KORIŠTENJE VISINSKOG TRENINGA U SPORTU – OD ANTIKE DA DANAŠNJIH DANA

Sažetak
Ovaj članak ukratko sažima odabir onoga što smatramo ključnim fazama u povijesti korištenja viših nadmorskih visina (2 000 m a.s.l) kako bismo povećali učinkovitost u sportu. Trening na višoj nadmorskoj visini i prebivališta trenutačno se smatraju jednim od glavnih načina za pravno prihvatljivo povećanje granica izvedbe, prvenstveno sportske izdržljivosti. Od antičkih olimpijskih igara do kraja devetnaestog stoljeća, više visine nisu korištene za povećanje performansi. U prvoj polovici dvadesetog stoljeća upućivalo se na planinare, kao dio planinskih ekspedicija, tisuća metara visokih vrhova. Prvi sustavni nalazi o korištenju nadmorske visine za povećanje sportskih performansi dolazili su iz studije vezane za pripremu za Olimpijske igre u Mexico Cityju (1968, 2200 m nm). U 70-im i 80-im godinama izrađivana je metodologija rada na višoj nadmorskoj visini, ali samo u malom broju zemalja, a devedesete godine prošlog stoljeća obilježile su širenje nadmorske tablice u mnoge zemlje diljem svijeta, a u tom je razdoblju i dalje bilo je sve više korištenja umjetno inducirane nadmorske visine (hipoksični šatori, komore, sobe). Početak novog tisućljeća obilježio je trajno preseljavanje (prvenstveno) sportaša u treningu izdržljivosti na veće visine.

Ključne riječi: *hipoksija, sport, trening, Olimpijske igre, povijest.*

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