Altitude: Acute Effects

Sport is a global game and athletes, teams and therefore the spectators who follow have to travel to areas with differing environmental conditions. These conditions can affect both health and performance so preparation is key to ensure personal bests can be achieved and records broken.

In 1968 Mexico City opened its doors to the Olympics games. Situated approximately 2,240m above sea-level much debate was had about how performance was going to be affected and how best to prepare athletes. In a time of Olympic amateurism, weeks of acclimatisation training would place financial strain on participants. The 1,500m, 5,000m and 10,000m were all slower in pace and African athletes from Ethiopia to Kenya who trained at altitude in their home country claimed the top spots. These games saw sports science and research into the effects of altitude rise and post-games the US Olympic Committee moved their training base to 1,840m above sea-level in Colorado Springs.

Figure ?: A collapsed track athlete supplied with oxygen at the Estadio Olimpico in Mexico City. (image found here: Altitude had major impact on performances at Mexico City Olympic Games - Global Sport Matters)

The debate rumbles on and in 2007 FIFA gave a ruling to ban international matches at stadiums situated more than 2,750m above sea-level. The Hernando Siles stadium in La Paz, Bolivia is one of the highest stadiums in the world at 3,600m. Often leaving visitors exhausted and requiring oxygen, regular protests stated the home side had an unfair advantage. The double World Cup-winning side Argentina didn't record a victory at Hernando Siles from 1973 to 2005! However, FIFA lifted the ban a year later after a campaign featured the Bolivian President and a 47-year-old Maradona playing at the stadium for over an hour. However, FIFA did impose acclimatisation rules of 1 week up to 3,000m and 15 days for matches over 3,000m putting pressure on scheduling.

Image ?: The Hernando Siles football stadium standing at 3,600m in La Paz, Bolivia.

The concerns at the Mexico City Olympics and by FIFA were based on health concerns for the performers. So, what happens to the human body at altitude and how does it affect health and performance?

As altitude increases barometric pressure decreases and although the composition of the atmospheric air remains the same with 20.93% of oxygen, the partial pressure of oxygen (pO_2) also decreases (pO_2 = 0.2093 x barometric pressure, see table ?).

Gases diffuse down the pressure gradient from an area of high to an area of low pressure, and the greater the pressure gradient the greater the rate of diffusion. The greater the difference in areas of pressure from the atmospheric air in the alveoli (high) to the oxygen deficient blood in the pulmonary capillaries (low) the better.

Location	**Altitude** (m)	**Barometric pressure** (mmHg)	**PO_2** (mmHg)	**Resting pressure gradient**
London	Sea-level	760	159	119
Hernando Siles Stadium, La Paz, Bolivia	3,600	499	105	65

Table ?: The altitude, barometric pressure and partial pressure of oxygen in London compared to the Hernando Siles football stadium in Bolivia.

At rest the pO_2 of deoxygenated blood arriving at the alveoli is around 40 mmHg. At sea level there is a diffusion gradient of 119 from the alveolar air to the capillary blood, this decreases by 45% with an ascent to 3,600m meaning the rate of diffusion into the capillary blood is significantly reduced. The presentation of a lower volume of oxygen to the passing haemoglobin poses little problem at rest however, as we start to exercise the effect becomes dramatic.

During exercise the reduction in pressure gradient reduces arterial haemoglobin saturation with oxygen and results in poor oxygen transportation to the skeletal muscles tissues for aerobic energy production. This has a significant effect on aerobic performers, indeed at the Mexico Olympics there were no new records set in events lasting for more than 2.5 minutes. Indeed, researchers have found a 2-4% reduction in running performance at altitudes above 1000m. Significant reductions in oxygen transportation to the skeletal muscles result in any form of physical activity being difficult to sustain at very high altitudes such as the Himalayan peaks.

The reduction in oxygen supply to the skeletal muscles results in a decreased production of ATP by the skeletal muscle cell mitochondria. This translates to a reduced capacity for aerobic work. Acute exposure to 4,300m reduces sea-level aerobic capacity by approximately 32%, and reaching the heights of Mount Everest although myocardial function is stable and cardiac contractile function is maintained, the aerobic capacity is reduced by 70% and similar to that of a sedentary 80-year old male at sea-level.

Normal circulating oxygen saturation in the capillary blood is 97-100%. Below 95% would be cause for concern and below 92% would require gas assessment and potentially oxygen therapy. At 5,486m (close to the peak of Mount Kilimanjaro, Tanzania) oxy-haemoglobin saturation is maintained at a dangerous 73%. Under these conditions acclimatisation is key and the access to, and availability of hyperoxic breathing gases (additional oxygen) is essential.

Acute effects of altitude on the body systems

Respiratory function:

- At high altitude the immediate response is hyperventilation. Chemoreceptors located in the aortic arch quickly sense the lower arterial pO_2 at altitudes around 2,000m and trigger the inspiratory centre to increase respiratory rate. This attempt to load oxygen into the blood stream is the first defence of the body to the lower pO_2 in the atmospheric air at altitude.

Cardiovascular function:

- Acute altitude exposure increases resting blood pressure, heart rate and cardiac output – up to 50% compared to sea-level values. Stroke volume remains largely unchanged due to the capacity of the cardiac muscle and maintenance of contractile force. The increase in cardiac output largely makes up for the lower levels of oxyhaemoglobin saturation.

Hydration status:

- High altitude atmospheric air is cool and dry leading to significant body water evaporation, increased total sweat loss, moderate dehydration, and mouth/throat dryness.

Sensory function:

- As altitude increases and arterial oxygen saturation decreases there are also decreases in sensory functions, such as a 5% decrease in light sensitivity at 1,524m, a 30% decrease in visual perception at 3,048m, and a 15% decrease in cognition at 4,572m.

(McArdle et al., (2023) Exercise Physiology: Nutrition, Energy and Human Performance. Wolters Kluwer, UK)

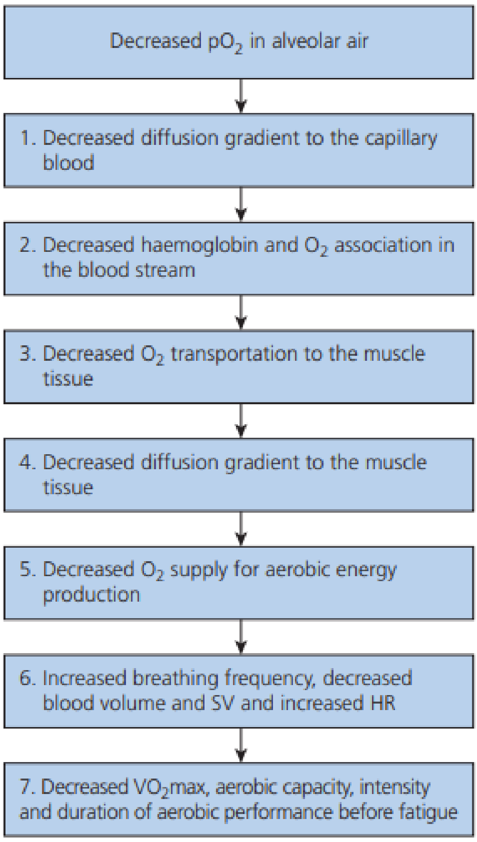

Figure ?: Overview of the acute effects of altitude exposure on the respiratory and cardiovascular systems. (I drew this flowchart for the OCR textbook. Not sure if it can be used or recreated?)

The potential threats of altitude

Acute mountain sickness

Acute mountain sickness (AMS) is a condition affecting those who ascend to altitudes of around 2,500m and above.

Symptoms usually present within 4-12 hours and include a severe headache, dizziness, fatigue, nausea, vomiting, general weakness, decreased urine output, and poor sleep. The susceptibility to AMS is unique to the individual however, a fast rate of ascent especially without any altitude pre-exposure symptoms are common. Unfortunate for mountaineers, climbers and adventure tourists AMS is exacerbated by physical activity in the first few hours and performance is significantly decreased. Cognitive function declines and decision-making becomes difficult with increasing ascent.

Prevention
Although symptoms tend to dissipate within a week and can be removed with a return to low altitude, moderate intensities of exercise become unbearable with AMS, so prevention is key. The best way is with acclimatisation: several nights around 2,500m, before a staged ascent to high altitude, adding an extra night for each additional 750m.
AMS reduces thirst and appetite, and performers tend to severely reduce their energy intake. However, maintaining carbohydrate intake and hydration reduces the severity of AMS and impact on performance, and increases the tolerance to further increases in altitude.

How common is it?
At an academic conference held in the Rocky Mountains in Colorado, USA (3,000m) 42% of epidemiologists (professionals who study the incidence, distribution and control of disease) suffered with AMS! 59% suffered headaches and shortness of breath and 45% found it difficult to sleep. Researchers have conducted extensive research on how common AMS is and at what altitudes performers experience symptoms, see table? for two research examples.

Location	**Participants**	**% of participants with AMS symptoms**			**References to find out more**
		2,700-2,900m	**3,600-3,800m**	**4,500-4,800m**	
Swiss Alps	Recreational climbers	9%	34%	53%	Maggiorini et al., (1990). Prevalence of acute mountain sickness in the Swiss Alps. *British Medical Journal*, 301:853–5
Kilimanjaro, Tanzania	Mountaineers	9%	44%	58%	Karinen et al., (2008). Prevalence of acute mountain sickness among Finnish trekkers on Mount Kilimanjaro, Tanzania: an observational study. *High Altitude Medicine and Biology*, 8:301–6

Table ?: The percentage of participants who suffered acute mountain sickness at varying altitudes.

Further conditions include;

- *High-altitude pulmonary oedema* – a potentially life-threatening accumulation of fluid in the lungs above 3,000m. Headaches become incapacitating, heart and respiratory rate become rapid, a blueish skin colour and cough with pink frothy sputum are symptoms. Immediate descent to lower altitudes can allow for complete recovery within several days.

- *High-altitude cerebral oedema* – a potentially fatal increase in the intercranial pressure as an increased cerebral fluid volume distorts brain structures and increases sympathetic nervous activity. Affecting approximately 1% of climbers with existing AMS immediate decent to lower altitudes for diagnosis could be life-saving.

Further reading can be found in a review by Luks, Swenson and Bartsch (2017) at Acute high-altitude sickness - PubMed (nih.gov).

Include images such as;

Figure ?: Climbers ascending Mount Kilimanjaro, Tanzania (from image search – I can't verify it is Kilimanjaro!: 5 Most Important Tips To Follow For Climbing Mount Kilimanjaro | Seeking Alpha)

Figure ?: The tough effects of acute mountain sickness (from image search: Acute Mountain Sickness – Active Sherpa Trekking)

Figure ?: Points to Remember for adventurers attempting to climb Kilimanjaro. (I found this image here: Mount Kilimanjaro Deaths 2023 - Climbing Kilimanjaro (climbing-kilimanjaro.com)).

Did you know?

There is around 40% success rate for adventure tourists attempting to summit Uhuru Peak, Mount Kilimanjaro in Tanzania standing at 5,985m above sea-level. However, that doesn't stop professional athletes who compete in some of the world's toughest races. The International Skyrunning Federation represent the governing body of skyrunning – mountain running at altitudes above 2,000m on extremely technical terrain.

In 2022, competitors started out with a seven-day ascent and acclimatisation on Kilimanjaro to get to the start line at 4,895m above sea-level. From here races started in three stages;

- **Stage 1**: 3.5km with 1,000m **vertical** climb to the summit of Uhuru Peak at 5,895m
- **Stage 2**: For those continuing… the world's highest **marathon**, 42.2km - including the 1,000m vertical climb to 5,895m and a further 3,700m of downhill descent
- **Stage 3**: For those continuing… the world's highest **ultramarathon**, a further 11.4km to the finish line covering a total of 53.6km and a total descent of 4,800m

Rob Edmond, Co-Founder and Co-Director of the World's Highest Marathon, stated, *"Be under no illusion that this will be easy, even for the most experienced runners. Running up to 5,895m in a Vertical Kilometre and then adding an Ultra Marathon will definitely see the field thin out and see who's got what it takes to be a world record holder. Completing the course is the aim and regardless of winning, it will be simply incredible for all that finish."*

	Stage 1: Vertical	**Stage 2: Marathon**	**Stage 3: Ultramarathon**
Male 1st place	Roberto Delorenzi (SUI), 1hr 17min	Roberto Delorenzi (SUI), 7hr 35min	Roberto Delorenzi (SUI), 8h 52min
Female 1st place	Mussa Mwakyuse (TAN), 1hr 52min	Sandi Menchi Abahan (PHI), 9hr 00min	Sandi Menchi Abahan (PHI), 11hr 3min (sole finisher)

Table ?: Winners and their times for the three stages of the World Skyrunning Series on Mount Kilimanjaro in May, 2022 (see: World's highest marathon records set - The International Skyrunning Federation).

Key terms
Altitude: the height or elevation of an area above sea level
Barometric pressure: the pressure exerted by the earth's atmosphere at any given point
Partial pressure: the pressure exerted by an individual gas held in a mixture of gases
Hypoxia: insufficient O_2 at the tissues due to low O_2 pressure in atmospheric air
Arterial hypoxia: insufficient O_2 at the tissue cells caused by low arterial O_2 pressure

Exam Board Links:
OCR
1.1.d: Environmental effects on body systems: effect of altitude on the cardiovascular and respiratory systems
Edexcel
2.2.12: Preparation for performance at altitude

Dr Sarah Powell is a lecturer at Lancaster Medical School, for the BSc (Hons.) in Sports and Exercise Science, and author of a range of A-level PE textbooks and resources.

Acclimatisation to Altitude

As performance at altitude increases the

Long-term effects of altitude on the body systems

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(McArdle et al., (2023) Exercise Physiology: Nutrition, Energy and Human Performance. Wolters Kluwer, UK)

Exam Board Links:
OCR: Environmental effects on body systems: Acclimatisation, including the importance of timing arrival at altitude (above 2400m)
AQA: Altitude training
Edexcel: Preparation for performance at altitude

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