Diplomarbeit

Children and altitude

A summary of the physiological background and resulting consequences for children that are exposed to moderate and high altitude, with special remarks on alpine sports and aviation

eingereicht von

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Eidesstattliche Erklärung

Ich erkläre ehrenwörtlich, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst habe, andere als die angegebenen Quellen nicht verwendet habe und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Graz, am 21.11.2017 *Barbara Röhrer eh*

Preamble

Mountain sports and mountain tourism have boomed in the past few years, in turn making air travel become more and more popular for a broad mass of people in our society. Activities that were earlier only done by few alpinists are now becoming more and more modern, and remote alpine areas that were earlier only accessible for some tough adventurers are now often becoming easily reached by everyone. All types of people are now taking part in several kinds of outdoor activities like hiking, climbing, skiing or just traveling to high altitudes – and are often taking their children with them.

This composition will focus on the differences between children and adults when exposed to altitude and will illustrate other factors that should be considered when taking children to the mountains. This gained knowledge and summarized considerations should provide a basis for a safe and pleasant stay in higher altitudes for parents and their children.

Acknowledgment

I would really like to thank my family and all my friends who have supported me throughout my studies- and embellished my free time.

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Lastly, I would like to thank my supervisor, Priv.Doz. Dr. Klaus Pfurtscheller from the Medical University of Graz who first stimulated my interest for this exciting topic through his presentation at an elective course about alpine medicine.
He was always a very kind and friendly mentor. I really enjoyed talking to him about my research and I am more than glad that he enabled me to write this thesis about children and high altitude!

Thank you all!

Zusammenfassung

Einleitung:

Sowohl Hochgebirgsregionen als auch Flugreisen verzeichnen einen großen Zuwachs, der alle Altersgruppen betrifft. Da klinische Studien- wie meist in der Medizin- größtenteils aus dem Erwachsenenbereich kommen, soll diese Arbeit nun den etwas jüngeren BergsportlerInnen und Reisenden gewidemet werden und daraus folgend hauptsächlich pädiatrische höhenmedizinische Fragen behandeln.

Methoden:

Zu diesem Zweck wurden zuerst wichtige Kenntnisse über die dahinterstehende Physik und Physiologie erhoben, welche in der Einleitung kurz zusammengefasst werden sollen.
Danach erfolgte eine strukturierte Literaturrecherche der Datenbank Pubmed, des relevanten Inventars der Universitätsbibliothek Tromsø und privater Literatur des Betreuers, PD Dr. Pfurtscheller.
Diese Recherche bezog sich größtenteils auf Fragen zu physiologischen Veränderungen, höhenassoziierten Erkrankungen, einem möglichen erhöhten Risiko für Sudden infant death syndrom (SIDS), Fliegen und zu Bergsport mit Kindern.

Ergebnisse:

Dabei ergaben sich interessanten Ergebnissen über kinderspezifische Besonderheiten bei Akuter Höhenkrankheit (AMS), Höhenlungenödem (HAPE), Höhenhirnödem (HACE), das wahrscheinlich gesteigerte Risiko für SIDS mit zunehmender Höhe, andere wichtige Faktoren wie akute Infektionen der Luftwege, Kälte, Sonne und Dehydration, auf die geachtet werden muss und schlussendlich auch Empfehlungen über die (berg-)sportliche Belastbarkeit des Kindes, für welches Alter, welche Aktivität als angemessen angesehen wird und Vorteile von Bergsport für den kindlichen Entwicklungsprozess.

Konklusion:

Allgemein gesagt, stellen Höhenexposition, Bergsport und Flugreisen keine relevante Gefahr für gesunde Kinder dar. Jedoch muss man auf bestimmte Grundlagen und auch Erkrankungen achten, bei welchen besondere Vorsicht geboten ist.
Außerdem ist es wichtig, die Eltern im Vorfeld über mögliche frühe Symptome von höhen-assoziierten Erkrankungen aufzuklären- eventuell mithilfe des Children Lake Louise

Scores (Kapitel 3.2.1.3.1) - und sie natürlich auch über Möglichkeiten der Prävention solcher Symptome zu informieren, damit es gar nicht erst so weit kommt.
Des Weiteren, ist auf spezielle Gefahren in der Höhe, wie die Möglichkeit der Dehydration, die intensivere Sonneneinstrahlung und Kälte hinzuweisen.
In Bezug auf die sportliche Intensität des jeweiligen Bergsports ist zu sagen, dass Kinder generell sehr gute Voraussetzungen für längere Ausdaueraktivitäten aufweisen, wohingegen kurze, anaerobe Belastungen und großer, kurzzeitiger Kraftaufwand vermieden werden sollten. Außerdem ist natürlich zu bedenken, dass technisch schwierigere Aktivitäten, sowie auch jene, bei welchen ein größeres Verantwortungsbewusstsein notwendig ist, erst mit einem höheren Alter empfohlen werden können (z.B. Sichern beim Klettern im Vorstieg).

Abstract

Objective:

As already stated in the preamble, there is a steady increase in both mountain sports and aircraft traveling throughout the world and throughout different age groups. Since most clinical studies are done on adults, this thesis is supposed to focus on younger “alpinists” and travelers and will be dedicated to questions that arise from pediatric alpine medicine.

Methods:

For this reason, important knowledge about the relevant physical and physiological backgrounds was acquired in a first step, which will be summarized to a brief explanation in the introduction.

Afterwards, a structured literature research was done on the database PubMed, the university library in Tromsø, Norway, and some private literature provided by the supervisor, PD Dr. Pfurtscheller.

In this research, questions about physiological changes, altitude related illnesses, Sudden infant death syndrome (SIDS), aircraft traveling and mountain sports in childhood were emphasized.

Results:

As a result, some interesting results were obtained about special features in children concerning Acute mountain sickness (AMS), High altitude pulmonary edema (HAPE) and High altitude cerebral edema (HACE). Furthermore, it could be seen that there is probably an increased risk of SIDS with increasing altitude and that there are some other important factors, such as acute respiratory illness, cold, sun and dehydration that should be kept in mind. Finally, information about different kinds of mountain sports’ effect on children, their advantages regarding children’s development, possible dangers, the recommended age for starting with different types of sports and similar issues were analyzed.

Conclusion:

As long as a certain amount of precaution is given, there is no crucial reason that would dissuade parents to go to the mountains or travel in an airplane with their healthy children. However, special precautions should be taken when the child is sick.

Furthermore, the parents should be well informed about early signs of altitude related illnesses in their children, possibly using the Children's Lake Louise Score (chapter 3.2.1.3.1), and other factors like increased solar radiation. When it comes to the intensity of the activity, it can be said that children generally have a good endurance capacity, since their body provides best conditions for longer aerobic activities, and that this capacity can be trained from early ages on. Nevertheless, parents must be careful when it comes to anaerobic, high- intensity training or technically demanding sports which are not recommended at very young ages. Furthermore, only older children should partake in more responsible activities such as belaying each other in lead climbing.

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Abbreviations

SIDS	Sudden infant death syndrome
PiO_2	Inspiratory oxygen pressure
PaO_2	Arterial oxygen pressure
SaO_2	Arterial oxygen saturation
Patm	Barometric/atmospheric pressure
MS	Mountain sickness
HAPE	High altitude pulmonary edema
HACE	High altitude cerebral edema
CMS	Chronic mountain sickness
CSHAPH	Chronic symptomatic high altitude pulmonary hypertension
VC	Vital capacity
RV	Residual volume
FEV1	Forced expiratory volume in 1s
AMS	Acute mountain sickness
HVR	Hypoxic ventilatory response
BBB	Blood-brain barrier
CBF	Cerebral blood flow
CBV	Cerebral blood volume
iNOS	Inducible nitric oxide synthase
Pcap	Capillary pressure
VEGF	Vascular endothelial growth factor
EPO	Erythropoetin (a hormone that stimulates erythrocytes production)
NIRS	Near-infrared spectroscopy
IFI	In-flight injury

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1 Introduction

1.1 The importance of the topic

As already stated, the first thing that should be mentioned is that both mountain tourism and sports as well as civilian flights are steadily growing fields which are becoming more and more "trendy" among broader masses of people with different backgrounds, fitness states and- which this thesis wants to focus on- ages.

Considering that point, some numbers are given here in the beginning in order to show the dimensions: It is estimated that every year there are about 10 million hikers and skiers going to moderate altitudes in Austria and 40 million to the alps in general. (1) There are estimated to be hundreds of millions of mountain tourists are estimated worldwide. (2) These numbers lead consequently to different types of medical problems, or- more positively- to different types of medical questions that occur in the alpine areas. However, there is no independent specialization for altitude medicine because it consists of so many different fields of medicine. (3) Hence, there is no extra specialization for pediatric mountain or altitude medicine either and research is mostly done by doctors and scientists that are personally interested in that topic and often keen on mountain sports on themselves. With that in mind, it is even more impressive that there are quite a few staging posts for altitude related research in the world.

Three of them are positioned in Austria: (4)

Table 1- Research stations in Austria (4)

Alpinmedizinnische Forschungsstation Dachstein	2700m	Dachstein
Medizinische Station Rudolfshütte	2315m	Hohe Tauern
Alpines Leistungszentrum Obertauern	1740m	Niedere Tauern

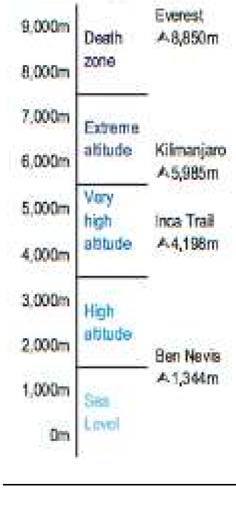
Here we can see that there is in fact an interest in altitude research. Nevertheless, studies are- like most of studies generally- mainly done on adults. This leads to the question about whether or not the results can be marked valid for children as well, and what kinds of crucial differences in physiology that must be considered.

To come back to the previous point, it is a fact that many of those mentioned mountain tourists also want to bring their children. That does not necessarily mean that all have ambitious sport plans with them, but it raises a series of questions (5) that doctors often don't know how to answer professionally. Physicians are asked by concerned parents questions such as if it is possible to bring their babies to the mountains, which altitude has zero risk for them to sleep on, if there are any special health risks they should consider, and from what age it is seen harmless for babies to fly with an airplane?
Unfortunately, the answers given to some of these questions, opinions and results of research are not that clear or diverging.
Therefore, the goal of the thesis is to give an overview of the important backgrounds as well as to find and compare convenient results with precise literature research so that the relevant information is more structured. Furthermore, it should allow for questions like those mentioned above, which could be answered more accurately in the future.

1.2 Some definitions in the beginning

In the following text, it will often be referred to "moderate" and "high" altitude. But where do the two divide? What is the limit saying whether it is "high" or not? Concerning this question it has been stated that high altitude is defined as an elevation above 2500m (8000ft) over sea level which leads to about 140 million people that are permanently residing at high altitude. (6)
However, other sources graduate those levels differently. Therefore, it should be kept in mind always to check first what the author considers to be "high altitude".
The following classification is from a book from Medex (7) and shows an alternative way of testing the height limits. Furthermore, some well-known hallmark points are shown.

Table 2 - Definition of "High Altitude"(7)



The following map was added to serve as a concrete graphic representation of areas in the world where high mountain areas can be found:

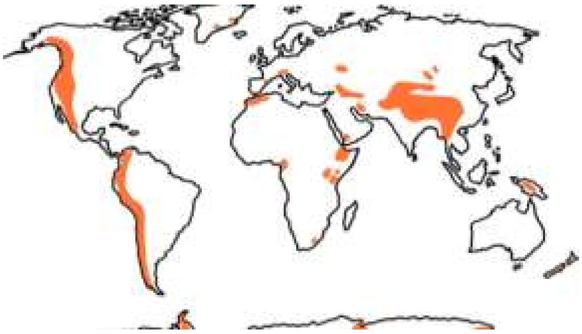


Figure 1- Regions of high altitude in the world (7)

1.3 Physical background

1.3.1 Barometric pressure

Even if it is generally known that the barometric pressure decreases with altitude, the underlying reasons for that fact are often remaining a bit unclear. Therefore, the following explanation was added:

Basically, it is because the air above us has a certain weight, which leads - through the simple fact that there is more air above us on lower sea levels – to higher barometric pressure. One would now maybe suppose that the pressure is decreasing linearly. That would be the case if the atmosphere would be incompressible- almost like a liquid- but since it is air, the air at lower altitude is compressed and barometric pressure decreases more rapidly with height near the surface of the earth. This decrease would now be exponential. However, there is an important factor influencing it: the temperature. It also decreases with height (about 1° per 150m) and makes the pressure fall even faster than it would be expected to according to the exponential law. (8)

This can be illustrated by the ideal gas law:

PV = nRT

P……. pressure

V…… volume

n……. number of gram molecules of the gas

R…… gas constant (8,314 kPa · Liter · mol-1 · K-1) (9)

T…… absolute temperature

Another law that is important for the topic is Dalton’s Law:

Px = PFx

Px…... partial pressure
P……..total pressure
Fx……fractional concentration of gas x

This law states that each gas in a mixture behaves as if it was alone, with a pressure only according to its own concentration and independent from the other gases in that mixture. (8)
Regarding altitude medicine, oxygen is the gas of most interest. When the constant 21% that is found in the atmosphere is inserted into the formula above and combined with the decreasing total pressure in increasing altitude, a decrease in the partial pressure of the oxygen can be seen- with its specific implications, especially the resulting hypoxia.

But even if that hypoxia is probably the most discussed point, there are also other distinctive characteristics of high altitude environment, such as: (6)

- Increased solar radiation:
- Greater diurnal temperature fluctuation
- Aridity
- Low biomass
- Limitations on energy production

1.3.2 Increased solar radiation

Ultraviolet light penetration increases approximately 4% per 300 m (984 ft) gain in altitude, which increases the risk of sun burn, skin cancer and snowblindness (ultraviolet keratits). Furthermore, the reflection of sunlight on snow and glaciers can cause intense radiation. (10)

1.3.3 Temperature

According to the book Wilderness Medicine (10), the temperature decreases on average of 6,5° per 1000 m, which is slightly different to the 1° per 150 m from John West's chapter in High Altitude- An Exploration of Human Adaption (8) used above, but we are only talking about guiding values which can be influenced by different factors.
In any case, the cold can cause medical problems such as cold injuries and hypothermia. Similarly, heat can cause- often unrecognized- problems, which is primarily heat exhaustion. Temperatures of 40- 42° C have been observed in tents on both Mt. Everest and Mt. McKinley because of the sunlight reflection on the glaciers, especially in the absence of wind. (10)

1.3.4 Aridity

Above the snow line the so-called "high-altitude desert" can be found. Water can only be obtained by melting snow or ice. Furthermore, humans lose more water both through the lungs from respiration and through the skin, which can easily result in dehydration.

It seems obvious that all those points mentioned above impact human beings exposed to altitude, both the young and the old. What is now important is to see how their bodies react and adapt to these peculiar conditions, which will be discussed in the following chapter.

1.4 Physiological Response

1.4.1 Hypoxia

The decreased barometric pressure – according to the physical laws discussed above- leads to a decrease of the inspiratory oxygen pressure (piO_2). This affects again the arterial oxygen pressure (PaO_2) and the arterial oxygen saturation (SaO_2) which are both decreasing.
That reduction can be seen as a hypoxia which can affect the body both chronically or acutely. (11)

The following table gives an overview about the dimension of that hypoxia (11):

Table 3 - Characteristics of the barometric pressure (Patm), the inspiratoric oxygen pressure (PiO2) and the arterial oxygen pressure (PaO2) in relation to an increase in altitude in adults (11)

Meter	P atm torr	PiO2 mmHg	PaO2 mmHg	SaO2 %
0	760	149	94	97
1500	630	122	66	92
2500	564	108	60	89
3000	523	100	53	85
5000	405	75	40	?

1.4.2 The reaction of the organism to that hypoxia

Generally, it can be divided between individuals that are "hypoxia tolerant" and "hypoxia-sensitive" (12) which includes both genetic and functional changes in the organism. These changes range from adaptions on a molecular, sub-cellular level to changes concerning the organism as a whole. (13)

According to Hochachka (14) there are at least the following responses to hypoxia occurring: Regulation of hypoxic ventilatory response (HVR) by carotid body chemoreceptors, oxygen sensors at pulmonary vasculature that regulate the hypoxic vasoconstrictor response and the ventilation-perfusion matching, oxygen sensors in other tissues involved in the activation of the vascular endothelial growth factor and thus the angiogenesis especially in the heart and probably in the brain, and oxygen sensors in the kidney and liver involved in an enhanced erythropoietin expression. Also, the metabolic efficiency is higher in species that are genetically adapted to hypoxia (13).

But what is it that makes an individual hypoxia tolerant or hypoxia sensitive?

In the following image, Huicho (13) gives a summary about the relationship between physiological response to hypoxia and time. He therefore identified several factors that influence this process. These factors are:

- Genetic background
- Modifying factors like lifestyle, the environment, chronic (respiratory) diseases
- The idea that there are possible long-term effects of external factors like poverty, malnutrition and environmental agents, which influence the response to hypoxia in the fetal and early postnatal vulnerable periods of life, called "programming" by Huicho

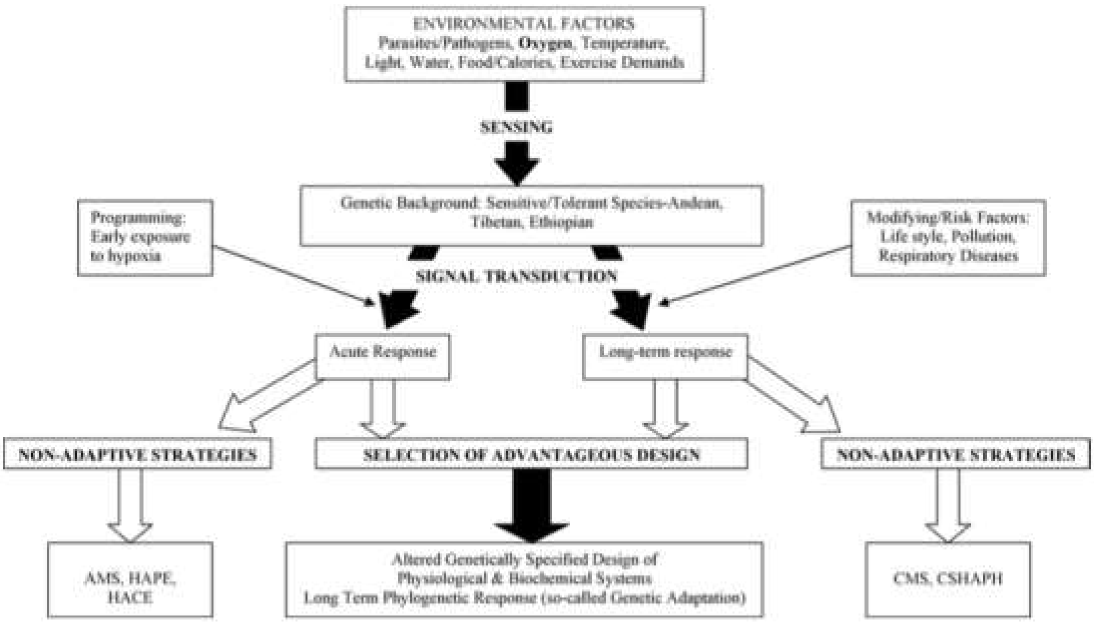


Figure 2 - Relationship between time of exposure to hypoxia and physiological responses
MS: acute mountain sickness; HAPE: high altitude pulmonary edema; HACE: high altitude cerebral edema; CMS: chronic mountain sickness; CSHAPH: chronic symptomatic high altitude pulmonary hypertension (13)

Additionally, the figure differentiates between acute and long-term response to hypoxia. The acute response takes place within hours or days and is also known as “acclimation”, whereas the long-term response can last over a life time. However, all components of the cascade of responses can change through evolutionary time (genetic adaptation). (13)

It is interesting that the patterns of adaption of Tibetan, Andean and Ethiopian populations significantly differ from one another. Andean people, for example, show erythrocytosis, hypoxemia and often pulmonary hypertension (15), while in Ethiopian natives, their found hemoglobin concentrations and arterial oxygen saturation levels were comparable to populations living at sea level despite the ambient hypoxia. (16). It would be beyond the scope of the text to go into more details here, however, it is important to state that there were different adaption mechanisms found.

1.4.2.1 Clinical outcome

But what does all that really mean concerning the clinical outcome? Which visible and measurable clinical parameters are changed? Which organ systems are mostly affected and how?

The following table will give an overview about those questions:

Table 4 - Physiological reactions of different organ systems (11)
VC: vital capacity; RV: residual volume, FEV1: forced expiratory volume in 1s

Respiratory System	**Cardiovascular System**	**Central Nervous System**
Arterial pO2 and SaO2 ↓	Heart Rate ↑	Cerebral blood flow ↑
Ventilation per minute ↑	Cardiac output ↑	Intracranial pressure ↑
pCO_2 ↓	Pulmonary artery pressure ↑	
O_2 consumption/ Co2 production ↓	Pulmonary vascular resistance ↑	
Lung volumes (VC, RV) ↑	Capillary leak ↑	
FEV1 (Peak Flow) ↓	Erythropoetin/Erythorcytes↑	
Nightly arousals ↑		
Periodic breathing ↑		

It can be seen that there are many different reactions taking place, most notably in the respiratory and cardiovascular system.
By implication, the following question now arises: What happens if those reactions are somehow insufficient, incomplete or deficient? In order to answer these pressing questions, full attention will be given to the results later in chapter 3.2 about altitude related syndromes and illness.

1.4.3 Distinctive features in children

1.4.3.1 Situations where children are exposed to hypoxia

Firstly, the scenarios we are speaking about should be identified i.e. the settings where children are temporarily exposed to hypoxia. The fact that this happens not only on holidays in the mountains should be illustrated by the following list (17):

- Residence at high altitude (18)
- Airline travel (19)
- Seating devices (20)
- Slings (21)
- Children with common respiratory conditions like bronchiolitis or asthma (17)

Special attention should be given to the last point, because children with acute airway obstructions from acute infections and a higher reactivity of the airways are therefore even more prone to hypoxia in all other situations where it is likely to experience a hypoxia anyway. (11)

1.4.3.2 Physiological response

In the chapter above the physiological response to altitude in adults was discussed. The question now is how similar these patterns of response are to those found in children.
Concerning this matter, there is an interesting study from Yaron et. al (22), which will be described here briefly.
In that study, they exposed 24 children (13 girls and 11 boys) at the ages between 3 to 36 months to acute altitude. A basement measurement was done at 1610 m and another measurement after a 24-h exposure to 3109 m, checking the following parameters:

- Pulse
- Respiratory rate
- End- tidal CO_2
- Arterial oxygen saturation (by pulse oximetry)
- Cerebral tissue oxygenation (by near- infrared spectroscopy)
- Middle cerebral artery resistive index (by transcranial Doppler)
- Lateral ventricle volumes (by cranial ultrasound)
- Clinical evaluation for the presence of acute mountain sickness (by Children's Lake Louise Score (explained in chapter 2.5.1.3.1))

What they found out was that the children showed an increase in respiratory rate, accompanied by a decrease of end-tidal CO_2, a reduction in arterial oxygen saturation and a decreased cerebral tissue oxygenation (with lower saturations in younger children). For an increased intracranial pressure, there was no evidence found.
Also worth mentioning is that 7 probands developed symptoms of AMS (acute mountain sickness), but there was no relationship noted between the presence of AMS and the physiologic measurements.

To conclude, it can be said that the altitude exposure resulted in:

- Tachypnea
- Relative hypoxia
- Hypocapnia
- Reduction in cerebral tissue oxygenation

Those changes are similar to the patterns seen in adults with equivalent altitude exposure. (22)

2 Material and Methods

2.1 Searching for Data

This thesis is based on a systematic research of different relevant literature. This literature was mainly found on the database PubMed (https://www.ncbi.nlm.nih.gov/pubmed) from typing in keywords like “children”, “altitude” and similar terms connected to the topic. Furthermore, journals from specific societies such as ÖGAHM (Österreichische Gesellschaft für Alpin- und Höhenmedizin), ARGE Alpinmedizin, Österreichischer Alpenverein, Wiener Medizinische Wochenschrift etc. were used, as well as books from the university library at the Arctic University of Norway in Tromsø and privately collected literature from the supervisor, PD Dr. Pfurtscheller.

2.2 Collecting Data

This data was collected and- after deciding whether it was relevant for the setting or not- ordered in groups according to the specific chapters. Some references are fitting into more than one subgroup.
The following table illustrates the number of references used for the different topics:

Table 5- Collection of data

Introduction/ General Material	7
Physics	4
Physiology	12
Growth	5
Cognition	7
Altitude related illnesses	32
SIDS	9
Aviation	7
Mountain sports	4
Others	3

2.3 Management of Data

To keep an overview of the collected data and to make it easily accessed when needed, the program Endnote (endnote.com) was used. Also, the different thematic groups mentioned above simplified the process.

3 Results

3.1 Parameters influenced by altitude exposition in children

3.1.1 Growth

Studies have shown that there is generally a growth retardation among chronic hypoxia. (11) There was found an adverse effect on height in 0-3-year-old children in Tibet, which is claimed to be independent of the socioeconomic status of the children.(23)
Another study from Turkey claimed that “starting at ages 0-10 years, height, weight and BMI values of children and adolescents of both genders living at an altitude of 2000 meters were noticeably lower than those reported for their counterparts living in areas of lower altitude in Turkey” (24) Also, in another part of the world- the Andes- similar results were found: “Associations between SpO_2 or altitude and total limb and zeugopod length z scores exist among Andean children. However, the relationships are relatively weak, and while the relationship between anthropometry and altitude may be partly mediated by SpO_2, other factors that covary with altitude (e.g., socioeconomic status, health) are likely to influence anthropometry.”(25)
To conclude, I would say that- even if there was another study from Saudi-Arabia , saying that thinness is more common among children in the lowlands (26), but that could also be influenced by many other factors than the hypoxia in the higher altitude group- we can assume that there is a limitation of growth in children living at high altitude.

3.1.2 Cognition

Concerning this topic, it is difficult to give a clear answer. Generally spoken, a cognitive impairment in children under chronic or intermittent exposure to high altitude cannot be excluded. (11)
However, there are some contradictory results being found: Hill et al. (27) found for example that “the impact on cognition appears to be subtle and related only to the speed of more complex cognitive operations, rather than to their accuracy”, while Richardson et al. (28) states that “Neuropsychological testing revealed no deficits in the high altitude group, despite significantly reduced blood oxygen saturation”. Rimoldi et al. (29) in turn claim that “Acute short-term exposure to an altitude at which major tourist destinations are located induces marked executive and memory deficits in healthy children. These deficits

are equally marked or more severe in children permanently living at high altitude and are expected to impair their learning abilities."

In another study on Bolivian children from Virues- Ortega et al. (30) a "comprehensive neuropsychological assessment was administered, including tests of executive functions, attention, memory and psychomotor performance. Participants living at extreme altitude showed lower levels of performance in all executive tests, whereas all other domains remained unaffected by altitude of residence."

As a result to studies such as this, West et al. (31) postulate in a quite new study from 2016 that- because it is quite impractical to bring all school children to lower altitude by bus - special oxygen conditioning should be installed in schools because the learning process is impaired. Bass et al. (17) wrote an "Review of Evidence" and concluded there that "adverse impacts on development, academic achievement, and behavior have been clearly documented in many well- designed controlled pediatric studies (…)".

After consideration of all those studies, I would conclude that an impairment is at least quite likely and that this knowledge should be taken into account.

3.2 Altitude related illnesses in children

Generally speaking, there are quite similar altitude related illnesses in children compared to those detected in adults. Acute mountain sickness (AMS), High altitude pulmonary edema (HAPE) and- in children very seldom- High altitude cerebral edema (HACE) can be found. Additionally, there is the subacute infantile mountain sickness (SIMS), which only occurs in infants. (11)

There are different factors influencing the incidence and severity of altitude related illnesses (10), such as:

- Attained altitude (especially the sleeping altitude)
- Length of altitude exposure
- Level of exertion (32)
- (inherent) physiologic susceptibly (33)

3.2.1 Acute mountain sickness (AMS)

3.2.1.1 Incidence

Although AMS and the related symptoms have been known for a long time now, public attention is only growing in the last years because of the increasing number of victims related to the increasing number of visitors in high altitude regions. (10)

To get an idea of the approximate number of children being affected, there is a clearly arranged table by Pfurtscheller (11), which was adapted and results from some newer studies were added:

Table 6 - Incidence of AMS in children

Location	Number of Children	Age	AMS	Reference
Tibet, 4550m	464	0 - 15 years	34 %	Wu, 1994 (34)
Colorado, 2835m	558	9 - 14 years	28 %	Honigmann, 1993 (35)
Colorado, 3488m	23	3 - 36 months	22 %	Yaron, 1998 (36)
Colorado, 3109m	37	3 - 36 months	19 %	Yaron, 2002 (37)
Chile, 3500m	16	6 - 48 months 13 - 18 years	100 % 50 %	Moraga, 2002 (38)
Chile, 3500m	16	3 - 5 years	92 %	Moraga, 2008 (39)
Himalaya, 4380m	36	3 – 15 years	47,2 % (25% in those who ascended in 2 or more nights, 75% in those who only spent one night on the way)	Pradhan, 2009(40)
Taiwan, 3952m	96	11 – 12 years	59 %	Chan, 2016 (41)

Admittedly, when observing these results, one must bear in mind that the group of studies is quite heterogeneous with different age groups, altitudes, ascending times etc. Nevertheless, I think they give a sense of the (high) incidence of AMS.

3.2.1.2 Pathophysiology of AMS

But what is AMS exactly? Where does it come from?

Following this question, there is an illustrative chart in Auerbach's book Wilderness Medicine (10) which helps a lot to understand the pathophysiology of AMS:

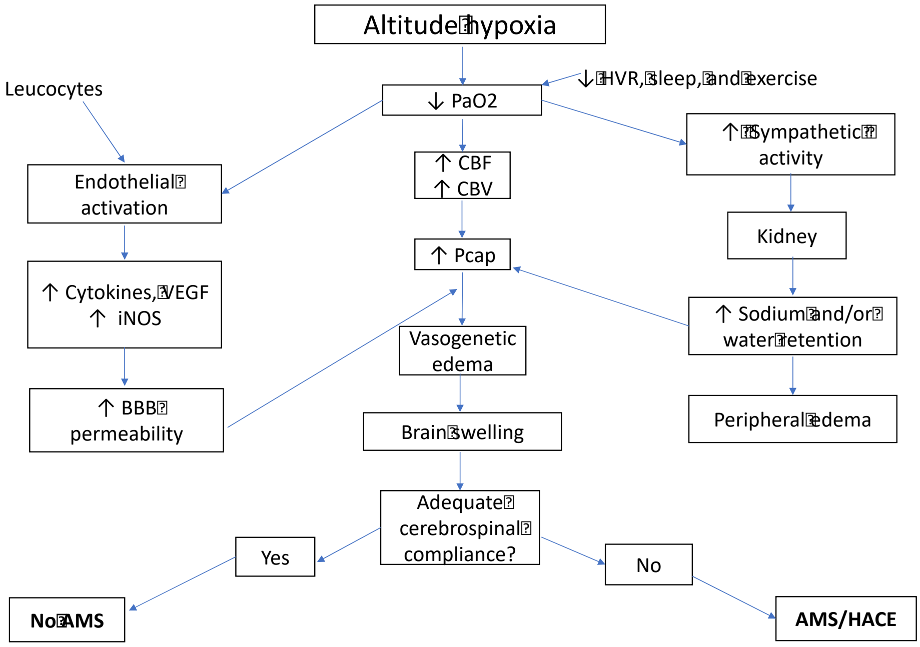


Figure 3- Pathophysiology of AMS (10)

HVR= Hypoxic ventilatory response

BBB= Blood-brain barrier

CBF= Cerebral blood flow

CBV= Cerebral blood volume

iNOS= Inducible nitric oxide synthase

Pcap= Capillary pressure

VEGF= Vascular endothelial growth factor

This pathophysiology seems to be very complex and not yet totally understood (if that could be one day the case at all). There is a great number of different pathways and factors that enhance the development of AMS- and all are somehow connected to each other.

But now there is an explanation about the figure above:

In the basic chapters about physics and the physiological response to those physical conditions, the key role of hypoxia when speaking about high altitude was already emphasized. The hypoxia that leads to a decreased arterial oxygen pressure (PaO_2). This is where everything starts.

As seen in the figure, the decrease in PaO_2 is also influenced by sleep, exercise and HVR. HVR is the hypoxic ventilatory response. There are persons which have a low HVR while others have a higher one. It has been observed that those with the low HVR have a higher risk for AMS than those with a higher ventilatory drive. (42-44)

There are more pathways that finally lead to brain swelling via a vasogenetic edema, which is thought – in case of inadequate compliance – to cause AMS and HACE (High altitude cerebral edema) (see chapter 3.2.2). (10)

One of the mechanisms is the increased sympathetic activity, which reduces renal blood flow, glomerular filtration rate, and urine output, and suppresses renin. (10, 45) Even if the exact mechanisms are not known, the renal water balance is supposed to play an important role in the development of AMS. It seems that there is a switch from net loss or no change to net gain of water as persons start to suffer from AMS. A point that strengthens that hypothesis is, that diuretics are often effective in the treatment of AMS, so the importance of fluid shifts and fluid retentions seems to be likely. (10, 46, 47)

The middle pathway shows that the reduced arterial pressure leads to an increase in both cerebral blood flow and cerebral blood volume which results in an increased capillary pressure consequently – and afterwards we are again at the vasogenetic edema.

However, Hackett (48) and Krasney (49) thought the factors named above are not complete and suggested the role of a decreased blood brain barrier (BBB) in the pathophysiology of AMS. As factors that could be altering the BBB they suggested vascular endothelial growth factor (VEGF), inflammatory cytokines, products of lipid peroxidation, endothelium- derived products, such as nitric oxide, and direct neural and humoral factors which are known to affect the BBB. (10) And as seen in the figure, the increase of the permeability of the BBB also maintains the genesis of a vasogenetic edema with all its resulting consequences.

This explanation might be only a small extract of the complex formation of AMS. Nevertheless, I thought it could give some basic understanding when reading through the following- more clinical and manifest – chapters about children and AMS.

3.2.1.3 Symptoms

Generally speaking, symptoms of AMS in children are very unspecific and therefore hard to detect. It is especially hard to differentiate them from other symptoms that are also likely to occur in the respective same situation. These symptoms could result from general stress

because of the traveling, dietological issues, intoxications or just a simple infection. Symptoms can already occur from 4 to 12 hours after ascent.
In elderly children (over 8) the symptoms of AMS are more similar to those occurring in adults- and therefore easier to detect. Headaches, nausea, emesis, loss of appetite, sleeping problems or unspecified deafness are typical manifestations. (11)

3.2.1.3.1 The Children Lake Louise Scale (CLLS)

Since it can be hard to interpret and recognize AMS symptoms in young children, the Children Lake Louise Scale has been invented.(36)
This score consists of two parts, the fussiness score (Table 7) and the pediatric symptom score (Table 8) which can be added together in the end:

The Fussiness Score (FS) intents to measure the intensity and the amount of (unexplained) fussiness. At this score it is possible to give from 0 (no fussiness) to 6 (constant fussiness when awake) points concerning the amount of fussiness, as well as from 0 (no fussiness) to 6 (hard crying and extreme fussiness) points concerning the intensity of fussiness.
The Pediatric Symptoms Score (PSS) assesses the eating, sleeping and playing behavior of the child compared to normal comportment and gives points from 0 to 3 for every sector.

The diagnose of AMS in preverbal children can now be set like that (11):

- Result in the Pediatric Symptoms Score (PSS) which is ≥ 3
- Result in the Fussiness Score which is (FS) which is ≥ 4
- Result in total score (PSS + FS) ≥ 7

Table 7- CLLS (Fussiness Score) (36), (50)

<table>
<tr><td colspan="7">Amount of unexplained fussiness</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td colspan="2">No fussiness</td><td colspan="3">Intermittent fussiness</td><td colspan="2">Constant fussiness when awake</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">Intensity of fussiness</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td colspan="2">No fussiness</td><td colspan="3">Moderate fussiness</td><td colspan="2">Hard crying and extreme fussiness</td></tr>
</table>

Table 8 - CLLS (Pediatric Symptoms Score) (36),(50)

Eating	Normal	0
	Slightly less than normal	1
	Much less than normal	2
	Vomiting or not eating	3
Playing	Normal	0
	Playing slightly less	1
	Playing much less than normal	2
	Not playing	3
Sleeping	Normal	0
	Slightly less or more than normal	1
	Much less or more than normal	2
	Not able to sleep	3

3.2.1.4 Prevention of AMS

But of course, it is even better to prevent the development of AMS.

Therefor the following points are recommended (11):

- Slow ascent
    - Max. 300m / day over 2500m
    - Recovery day every 1000m

- Altitude for sleeping
    - Under 2 years: ≤ 2000m
    - From 2 to 10 years: ≤ 3000m

3.2.1.5 Drug prophylaxis

This way of dealing with altitude should normally be avoided and it is better to choose a slower ascent as a prophylaxis instead. That would have the same effect but without the risks related to the drugs. In some rare cases, however, a pharmacologic prophylaxis can be wise. This can be the case when for some reason a rapid ascent is unavoidable, and children with known previous susceptibility to AMS may benefit from prophylaxis as well.

The prophylaxis would be done with acetazolamide, which can have side effects like paresthesia, skin rashes and possibly dehydration. (33)

3.2.1.6 Treatment of AMS

Unfortunately, it was not possible to find any studies on the medical AMS treatment on children and generally not a lot of literature. There was an article by Kriemler et al. (51) where they described the successful treatment of severe AMS in a prepubertal girl with dexamethason.

Beside the dexamethason treatment for severe AMS it is- because of the lack of proper studies- assumed that the actions that are useful in adults with AMS are also good for children. This would also include a therapy with oxygen and analgesics such as ibuprofen and paracetamol (no ASS in children) against the altitude induced headache as well as offering oxygen. (11, 33)

However, probably the most important treatment is to descend to lower regions as early as possible.

3.2.2 High altitude cerebral edema (HACE)

HACE seems to be a consequence of AMS- or AMS a pre-stage of HACE (11), which also seems plausible when looking at the genesis of AMS explained above (Fig 3) with brain swelling etc. It is supposed that there is an impaired reaction to the hypoxia. This decreased hypoxic ventilatory response (HVR) causes an increase in the relative CO_2 partial pressure which leads to an increase in the cerebral blood flow. Fluid retention and an increase in the capillary permeability also occur at the same time so that, as a result, a HACE can occur. (52)

Descend to lower altitude, oxygen, dexamethasone and the use of a hypobaric chamber are suggested therapeutic procedures.(11, 33)

However, there is not a lot of literature at all about HACE in children, which lets us assume that it is a rare event.

3.2.3 High altitude pulmonary edema (HAPE)

3.2.3.1 Incidence

A study by Wu et al. (34) carried out in Tibet stated a prevalence of 1,5% at 4450m, which would be similar to the prevalence found in adults.

However, another newer study from Allemann et al. (53) assessed 118 healthy non-acclimated children and adolescents (mean ± SD; age: 11 ± 2 yr) on a rapid ascend to 3450m, where none of them developed HAPE. This was the case even if the measured "pulmonary artery pressure was more than twofold higher at high than at low altitude (35 ± 11 vs. 16 ± 3 mmHg; $P < 0.0001$), and there existed a wide variability of pulmonary artery pressure at high altitude with an estimated upper 95% limit of 52 mmHg." Therefore, it can be assumed that HAPE seems to be a rare event in children as well.

Durmovics et al. (54) propose that inflammatory processes may predispose children to develop HAPE. Their research was done on children with preexisting inflammations, such as viral respiratory infections.

They "speculate that the release of inflammatory mediators associated with these illnesses may be tolerated at sea level but may predispose children to increased capillary permeability when superimposed on hypoxia and, possibly, cold and exercise."

3.2.3.2 Pathophysiology

But what is it now that leads to HAPE? The basic mechanisms that lead to this phenomenon are (55):

- Exaggerated hypoxic pulmonary vasoconstriction and pulmonary hypertension
- Increased capillary pressure and pulmonary capillary hypertension
- High permeability type of edema- 'stress failure' of the pulmonary capillaries
- Reduced fluid clearance from the alveolar space

Therefor some explanation: It has been seen that in contrast to "normal" systemic blood vessels, the pulmonary vessels constrict under hypoxic conditions (systemic blood vessels would dilate). However, this constriction is not homogenous, which could reflect the- inhomogeneous- distribution of smooth muscle cells in the artery walls. (56) An increased capillary pressure and pulmonary capillary hypertension are occurring caused by (at least) two mechanisms: One is the local over perfusion of some areas because, as stated above, the vasoconstriction is not homogenous. (57) The other one applies to the pulmonary veins where also a hypoxic vasoconstriction takes place. This increases the resistance downstream in the region of fluid filtration. (58)

A study by West et al. (59) showed in rabbit lungs that a rapid exposure of the pulmonary micro circular system to high pressures soon causes hydraulic stress that “exceeds the load bearing limits of the membrane collagen network and results in ruptures of the basement membrane and thus the alveolar-capillary barrier”. (60) They called this phenomenon “stress failure”.

The last point, which is only intended to be mentioned briefly here, is that the clearance of fluid filtered into the alveoli seems to be impaired, which could may also be involved in the pathophysiology of HAPE. (61) For more detailed information about that mechanisms (including explanations about the involved Na channels, Na+ K+ ATPases etc.) see “High altitude pulmonary edema-clinical features, pathophysiology, prevention and treatment” from Swapnil J. Paralikar (55).

3.2.4 Subacute Infantile Mountain Sickness (SIMS)

In his article “Infants under influence of altitude – an overview” (11) Pfurtscheller also brought up the entity of SIMS, the subacute infantile mountain sickness, which should be mentioned here.

Affected are only infants within their first months of life and after a longer stay at high altitude. An incidence of 0,96% between 3050 and 5188m was mentioned.

Possible symptoms are the following:

- Dyspnea
- Cyanosis
- Coughing
- Sweating
- Feeding problems
- Edemas
- Oliguria
- Hepatomegaly

→ These accord with right heart failure, caused through pulmonary hypertension.

Therefore, the mortality rate of 15 % of the hospitalized children is quite high. (11, 34, 62)

3.3 Sudden infant death syndrome (SIDS)

3.3.1 Introduction

This chapter will be dedicated to Sudden infant death syndrome. First, a short overview about this entity will be given and afterwards it will be tried to find out if there is evidence for a connection between altitude and the risk of SIDS.

3.3.2 Definition

In Nelson Textbook of Pediatrics (63) – and many other sources – SIDS is defined as "the sudden death of an infant that is unexpected by history and unexplained by a thorough postmortem examination, which includes a complete autopsy, investigation of the scene of death, and review of the medical history."

This autopsy is indispensable to differentiate between SIDS and other causes of unexpected death, like for example infections or some previously unknown congenital anomalies which could have led to death. Furthermore, it is very important to check whether there was a child abuse involved, leading to lethal trauma. However, the autopsy cannot reliably distinguish between SIDS and intentional suffocation. Therefore, a scene investigation and medical history is useful to find out about that possibility.

3.3.3 Incidence

SIDS is the most common cause of post- neonatal infant mortality and reason for 40 – 50% of infant deaths between 1 month and 1 year of age. Furthermore, it is the 3rd leading cause of infant mortality generally. (63)

But luckily the incidence was constantly decreasing over the last decades, which is mostly because of the recommendation that children should not sleep in prone- position. That reduces the risk of SIDS extensively.

This data is from the US, but it is assumed that it accounts as well for western European countries.

3.3.4 Risk factors

Until now there is no accepted pathological mechanism about the etiology of SIDS. Lately, mutations in a growing number of genes have been found post mortem in SIDS cases, notably genes encoding ion channels.(64)
However, there are also several other risk factors that can increase the likelihood of death by SIDS. The most important ones should be mentioned here, which were taken from Illustrated Textbook of Paediatrics by Lissauer/Clayden (65):

The environment:

- Infant sleeps in prone position
- Infant is overheated from high room temperature and too many cloths and covers, particularly when ill

The infant:

- Age 1 -6 months, peak at 12 weeks
- Low birthweight and preterm
- Sex (60% boys)
- Multiple births

The parents:

- Poor or overcrowded housing
- Parental smoking after baby's birth
- Single unsupported mother

→ and high altitude?

3.3.5 The possible influence of high altitude exposure to the risk for SIDS

Unfortunately, there have not been a lot of studies done on that question, and those being done show partially different results. For that reason, I would like to summarize and compare them in a chronological order to make the topic at least a bit clearer to interpret.

One of the basic thoughts in that discussion seems to be a link between hypoxia and SIDS (66) since hypoxemia has been detected in children with SIDS.

An older study from McCullough et al., 1977 (67) found a 73% higher mortality rate in preterm infants at altitude >2740m compared to that rate in the lowland. This difference was only attributable for respiratory deaths and non-existing for other non-respiratory deaths. As a possible reason for those findings, they named a smaller birth-weight in infants at high altitude and that the hypoxia therefore influences the intra-uterine growth as well as lung development, which in turn increases the risk of suffering from hypoxaemia and respiratory mortality.
Another older study from Barkin et al., 1981 (68) did not find any link between SIDS and the altitude of 2200m, while Getts et al., 1982 (69) found an increase of incidence with increasing altitude.

Years later in 1998 Kohldorfer et al. (70) did a retrospective study in Tyrol, Austria, on 99 cases of infants with SIDS and 136 randomly selected control cases. Data was collected with a standardized questionnaire investigating the following factors: pregnancy, delivery, child care practice, and socio-demographic characteristics including altitude of residence. As a result, they found that "the risk of SIDS increased gradually with increasing altitude of residence. This relation remained independently significant when the analysis was adjusted for gestational age, birth weight, prenatal care, mother's age at delivery, educational level of parents, and cigarette smoking during pregnancy. The prone sleeping position emerged as an obligatory cofactor in this association." Therefore, they concluded that altitude of residence is a significant risk predictor for SIDS. However, they did not demonstrate a clear reason for that finding (that was not the aim of the study), but named that this association could possibly appear because of the reduced oxygen saturation levels, but also because of respiratory disturbances or lower temperatures in high altitude regions.

Neary et al., 2013 (64) did research on a mouse model and thereafter suggested "a potentially more widespread role for cardiac arrhythmia in SIDS without needing to invoke inheritance of abnormal ion channel genes." They "propose a model for SIDS pathogenesis whereby postnatal hypoxia leads to delayed maturation of the cardiac conduction system and an increased risk of cardiac arrhythmia." This model of explanation would fit into the suggested connection of SIDS and high altitude. They even added “environmental hypoxia”- which concerns our field of interest- to their model.

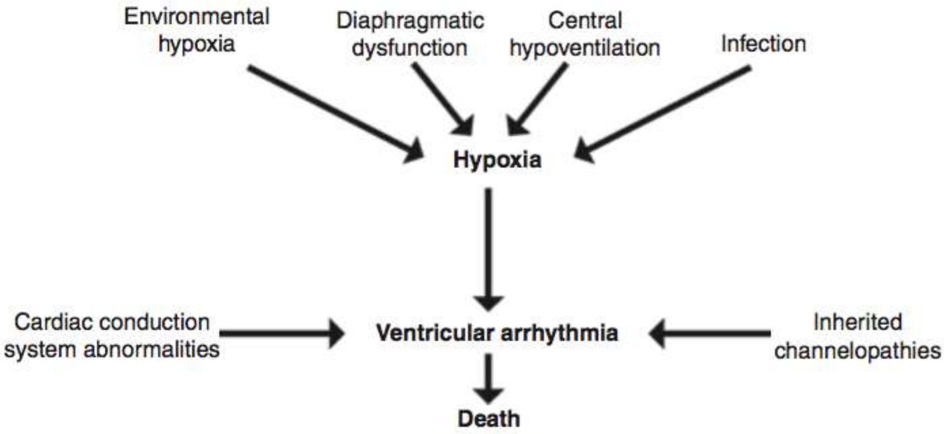


Figure 4 - Suggested model for the pathogeneses of SIDS by Neary et al. (63)

The newest good study that could be found about a possible association between SIDS incidence and infant residential altitude was done in 2012 by Katz et al. (71) in Colorado. It was a retrospective cohort study and included 393216 infants born between 2007 und 2012. As a result, they found out that “residence at high altitude was significantly associated with an increased adjusted risk for SIDS.”

In consideration of all the studies mentioned above, I would conclude that we can now assume that there is in fact an association between SIDS and high altitude.

3.4 Other factors to consider

3.4.1 The cold

The risks coming along with cold exposure in the mountains are big in children. This is especially because they have a large surface area to volume ratio (33). Other risk factors contain excessive energy expenditure or low energy production (when the child is carried and maybe sleeping as well) or wrong clothing. This should be taken into particular consideration in preverbal children that cannot tell that they feel cold. Adequate insulation of the head and extremities and a windproof outer layer are indispensable to avoid misery, hypothermia and frostbites and always keep in mind that the carried child needs more layers than the adult who is carrying it. (72)

3.4.2 The sun

Also, this danger should be kept in mind since ultra- violet radiation can have huge harmful effects on children. Therefore, it is essential to use sunblock creams, hats and long sleeved clothing. Moreover, one must keep in mind that sunburns can also occur on cloudy days and especially in snow that reflects the radiation. Googles are also required in order to prevent snow blindness. (72)

3.4.3 Fluid balance

Another important point that should be mentioned here is that parents must take care of an appropriate and sufficient fluid intake of their children. Everyone needs lots of fluids at high altitude, especially while doing sports there, and since children often do not think of their thirst on their own, it is the parents' responsibility to ensure they drink enough to meet the increase in requirement. (72)

3.5 Aviation

3.5.1 Introduction

With increasing numbers of people traveling on aircrafts, there is also an increase in the number of children and infants travelling with those. Nevertheless, there has not been much published literature about that topic, and that what can be found are mostly case reports and observational studies, but no studies in the form of trials about specific actions. (66)

I will anyhow try to give an overview about that topic, so that it is easier to know afterwards what to answer to concerned parents about the safety of aircraft travel.

3.5.2 Environmental changes in aircrafts

As a first step, it should be clarified what kind of changes the children are exposed to in the planes. Samules (66) gives the following list about environmental changes that arise from altitude in aircrafts:

- Humidity ↓
- Irritation

- Temperature ↓
- Atmospheric pressure and partial pressure of oxygen ↓

Furthermore, there can be additional effects occurring from

- Motion
- Vibration
- Noise
- Lack of space
- Fatigue (“jet lag”)

It can be seen, that there are several issues arising. The one with the most severe consequences is of course the fall in oxygen partial pressure, but it should be pointed out that there are also lots of other (co-)factors impacting on the child in the plane.

3.5.3 Decrease in O_2 pressure and oxygen saturation

It seems obvious that the pressure at the flying altitude of airplanes (9150 - 13000m) would be too low for humans- children and adults. Therefore, aircraft cabins are environmentally modified to atmospheric pressures of 1530 – 2440m above sea level. (66)
Cottrell (73) did a study in 1988 and found out that the median altitude exposure for all flights was 1894m (6214ft), with cabin altitudes varying from sea level to 2717m.
In either case, it can be seen that this “artificial” altitude is still high and therefore having its certain consequences on the travelers.

Lee et al.(19) measured oxygen saturation and heart rate in 80 healthy children (between 6 months and 14 years) before boarding a commercial aircraft and also after 3 hours and after 7 hours on the flight. They found that oxygen saturation declines significantly during the flight and there was no “acclimation” of oxygenation as the length of the trip increased. However, there were no clinically notable ill effects being discovered in those healthy children. Lee at al., however, advise that one should take care with people with preexisting illnesses on which the sudden decline in oxygen saturation could have a more severe impact. In this context, they spoke about preexisting anemia or cardiopulmonary disease.

3.5.4 Conditions that require special attention

There are also other diseases, where special attention is needed in order to enable a safe flight for the children.

Pfurtscheller (11) mentions the following:

- Respiratory infections in children < 1 year of age
- Air in body cavities (e.g. otitis media, pneumothorax)
- Chronical pulmonary disease (e.g. former premature infants, cystic fibrosis, obstructive sleep apnea)
- (Congenital) heart disease (e.g. cardiomyopathy, ventricular septal defect, persisting ductus arteriosus, pulmonary hypertension, arrhythmia)
- Thoracic problems (e.g. restrictive lung diseases, muscle disease)
- Sickle cell disease

It can be seen that most of those diseases already show some kind of impairment of oxygen saturation, wherefore a further decrease could lead to severe problems. In the other conditions, such as air in body cavities and respiratory infections, the pressure can lead to problems and the failure to equilibrate that pressure. In healthy children, simple maneuvers such as swallowing drinking liquids, and Valsalvas during ascent and descent can help to avoid problems with pressure equilibration. (66)

3.5.5 Emergency transport or interfacility transport of sick children

When thinking about air traveling with children, one also has to include the air transport which is due to sanitary needs such as emergency helicopter transports or transport of sick neonates to specialized units. In addition to the already existing problems, the effects from air travel have an impact on the child's health. For example, gravitational forces during take-off and landing can lead to pooling of blood, in the lower extremities on take-off if the head is placed towards the front of the aircraft. This may be harmful in shock, as can the pooling of blood in the head when experiencing elevated intracranial pressure. (66)
These were only some examples that were regarded as representative of the importance of the topic and there is a lot more to read about it. Anyhow, those things must also be kept in mind and special monitoring is required.

Stroud at al. (74) for example suggest a cerebral oxygenation monitoring using NIRS (near- infrared spectroscopy) technology during pediatric helicopter transport because they suspect changes in cerebral oxygenation with acute changes in altitude, especially in those pediatric patients that need respiratory support. But also here, it is the start of a complete new topic which would go beyond the scope of this thesis about “Children and high altitude”. I just wanted to give an impression about the broadness of the topic and show with this short example that there is a lot more to consider than one would probably initially assume.

3.5.6 Other thoughts about traveling with children

In the Norwegian Guidebook “Barn I bagasjen- Alt du trenger å vite for å reise med småfolk” (75) there are a lot of useful tips for parents traveling with children, also in relation to aircraft travel. It was recommended that parents prepare their (older) children for the trip by talking to them about planes and airports, reading in children books fitting to the topic and explaining everything that is going to happen before and while it takes place. Furthermore, it is recommended to bring enough food, napkins and other things that are always useful for an everyday with children, and warm cloths since air conditioning can be very cold.

Alves et al. (76) did a study in 2016 about in-flight injuries (IFI) in children where they stated that pediatric in- flight injuries are “relatively infrequent” but not negligible. They found out that “Unrestrained lap children are prone to IFIs, particularly during meal service or turbulence, but not only then. Children occupying aisle seats are vulnerable to injury from fallen objects, aisle traffic, and burns from mishandled hot items. The possible protection from using in-flight child restraints might extend beyond takeoff and landing operations or during turbulence.”

Finally, of course other travel related risk factors such as infections, poor hygiene etc. should be taken into account and prevented with vaccinations and other corresponding preventive arrangements. (77)

3.6 *Mountain sports*

3.6.1 Positive health and developmental effects

The importance of sport for people of all ages is nowadays trivial. Especially in children there are lots of positive effects when they are doing some kind of sports or movements from a young age on. These effects range from increased quality of life through development of good sensory-motoric abilities to an improvement in psychosocial development, development of creativity, prevention of different kind of diseases and of course physical development in areas like balance, speed, flexibility of the body, muscular strength and endurance. (78)

In the Norwegian book “Fysisk aktivisering av barn og unge” (78) there is even a whole chapter about “Friluftsliv”, basically translated into outdoor-life where the authors point out a great number of advantages that occur when children are playing and hiking outdoors from a young age on. Even if they say it is the most Norwegian thing to go on a “Søndagstur” with backpack, thermos and lunch pack, I think this kind of weekend activity is also quite popular in Austria. The advantages mentioned range from happier children and better social solidarity and team spirit over better awareness of nature and environment, skills in biology and ecology to more creative development, inspired by building things out of snow, sand, rocks and other natural materials while on a trip in the mountains.

3.6.2 Limits and guiding values

So now there is an agreement on the positive effect or even importance of (mountain) sports amongst children. But how much effort can they stand? What kind of tours are doable for the youngest and where does one have to be careful? Are there certain age limits for different sports? Questions like that come into the mind of many parents and might make them worried.

In his article “Kinderarbeit” Christoph Höbenreich (79) gives explanations about the endurance capacity and physical limits of children during mountain sports, which should be summarized here briefly.

As a main message, he said that it is never too early for adequate training of endurance capacity, while one should be careful concerning short, intense, anaerobe activities. He states that in earlier days the cardiovascular system of children has often been underrated,

while now they found out that school children have especially favorable physical conditions for long time performances (>30 min). He explains that these favorable conditions come from a bigger quotient between body size/body weight compared to adults which leads to a lower expenditure of energy to conduct movements. This makes children virtually predestined to endurance sports, such as mountain hiking.
He furthermore rebuts the concern about causing some damage on the cardiovascular system through premature or overly long training, because he explains that in healthy children the skeletal musculature would always exhaust first before the heart muscle- and therefore the activity would have to be stopped anyway.

Mountain activities like climbing or generally more difficult tours that require technical skills, sense of responsibility or the ability to concentrate for a longer time are of course more recommended for older children while easy walks and playing in safe terrain can be done from very young age on.
The following list (79) gives an overview about what is recommended at which age and therefore it could be useful when advising parents.

Pre-school age (3-5):

- Half-day hikes
- Max. ca. 4 hours on diversified, interesting paths in safe terrain
- Many breaks to relax, play and discover nature
- Playful training of coordination and “surefootedness”
- Belaying when danger of falling

Early school age (6-9):

- Full-day hikes
- Steeper paths and terrain without paths at all
- Interest in activities with a group of children at the same age
- Ability to concentrate is improving for coordinately more challenging activities like climbing
- Ability for longer endurance can be obtained

Late school- age (10 - 13)

- Longer mountain tours
- Longer ability to concentrate enables tours till 8h of walking time and over 1000-meter altitude difference
- More- day hikes and glacier tours possible
- Growing awareness of possible dangers
- Understanding of preventive security procedures
- Start of a playful alpine education

Adolescents (14- 17)

- Climbing and alpine tours
- Rock, firn and ice
- Via ferratas and trekking
- Tops and levels of difficulty get interesting as a challenge that wants to be mastered
- High motivation when comparing with other adolescents or conflicting with adults

Adult age (from 18)

- Whole spectrum of alpine sports and full physical resilience

3.6.3 The route

Generally, it should be said that mountain tours with children must always be planned according to the needs and abilities of the youngest- and not according to the parents' wishes. (79) For that purpose, there is also the famous saying that "children are not hiking with their parents, but parents are accompanying their children". Especially for the younger ones it is more important that the tour is at an exciting path and terrain than that a prestigious top is reached. The most important component is the way where many things can be discovered. A waterfall, a lake, a river, a climbing block or a cabin can for example be a perfect place to play. Round trips and routes with many different stages like those mentioned above are generally preferable to boring logging roads or to taking the same way back again. It can also make the tour more interesting for children when several different pieces of sports equipment are used, like for example a sledge, skis or a bike sometimes. And of course, the classical story telling can make even a boring piece of way easily doable.

3.6.4 The speed

A rule of the thumb is that the speed of the hike should be chosen in the way that the child is still able to speak in whole sentences. Otherwise children often tend to start too fast and tire out too soon.

3.6.5 The backpack

Another aspect of hiking is having a backpack on the trip. Here it is important that the children are not carrying too heavy burdens, which is often the case when compared to the correlating backpack weight to adults' body weight. (80) It is, however, recommended that the rucksack should only scale 10 % of the child's body weight and it is also important that it fits ergonomically well, so that the child's musculoskeletal system is not harmed. (79)

3.6.6 Climbing

Sport climbing has kind of a special role among mountain sports with children because it involves bigger responsibility and risk. Medically seen, there is no contraindication for healthy children to perform climbing, since the muscles will always get tired before the cardiopulmonary system is overburdened. (81) It is important, however, that climbing harness and helmet are well fitted for children. Since climbing is kind of a natural "instinct" for children, there is no special need for technical training and this is mostly considered as boring anyway.

There is a lot of discussion about the appropriate age when children can belay each other on their own. Referring to this, Küpper (81) gives the following advices: Top-rope belaying indoors or in a climbing garden from the age of 6 if the climbing partner has approximately the same weight or a stand belay has been installed. Self- responsible belaying of someone climbing on lead, however, is only recommended from an age level of about 12, depending of course on the development level of the child, and always with stand. He adds that it is also convenient if a child of about 10 years belays another same-weight child that is climbing lead, when an adult is assisting from behind.

3.7 The fetus as an “alpinist”

First I wanted to write this last chapter about mountaineering and high altitude activity druing pregnancy. In my research, however, I found an interesting article that regards the foetus as an “alpinist” and decided to rather give an overview about that then raising the other - far too big and mostly gynaecological - topic here. I thought this is also a nice way to encourage own thoughts about physiological altitude adaption once again before finishing up with reading this thesis.

In his article “Der Fetus als “Alpinist” – Gedanken eines Neonatolgen” (literally translated into: the fetus as an alpinist- thoughts of a neonatologist) Schubinger (82) makes an interesting comparison between the foetal handling of low oxygen and that from “born people” in high altitude and thereby detects some similarities but also differences in the management of hypoxemia.

He first explains that people have a lower oxygen saturation at higher altitude and that this is comparable to the cardiovascular situation in the foetus due to the special prenatal situation when is its whole circulatory system is filled with mixed (oxygen-rich and oxygen- poor) blood. (for further explanation see physiology books)
In order to deal with that constant hypoxemia, the body has several strategies which are used in neonatology, altitude medicine or only in the foetus and which will be summarized briefly.

The strategy of O_2 affinity:
The foetal haemoglobin is very special because it has a higher O_2 affinity than the adult haemoglobin which leads to a left-shift of the oxygen dissociation curve and for this reason to a higher oxygen saturation even if the oxygen partial pressure is low. Adults do not have that type of haemoglobin anymore and, for this reason, they have to use other strategies to create a left-shift of the curve. Therefore, they hyperventilate and thereby increase the pH which also results in a left-shift of the oxygen dissociation curve.

The strategy of the O_2 carriers:
At this point, people in the mountains and foetuses use the same technique: they increase the number of O_2 carriers to facilitate better O_2 transport through the body. This can be

seen in the high levels of red blood cells, the high number of reticulocytes and the elevated levels of EPO.

The strategy of cardiac output:
Adults can increase their oxygen turnover by increasing their cardiac output. This strategy is not suitable for the foetus, since its heart rate is already physiologically at the upper possible limit.

The strategy of energy saving:
Hereby foetuses use once again the same techniques as children and adults. They save energy with selectively less blood flow in certain organ systems while other more important ones- such as brain and lungs- are privileged.

I hope that comparison on the one hand raised some thoughts and stimulated the idea that often things are logical and somehow similar or linked to each other, and on the other hand brought- now almost at the end of this thesis- physiology back to mind, which is the basis of everything.

4 Discussion

This is probably the most important point after reading a text like mine. So, what did we read? What do we remember? What did we learn from it? Is there something we could directly use in our every-day praxis?

One of the key points is that it is generally considered safe to go to the mountains or travel in airplanes with children as long as they are healthy. Special attention, however, should be given to children that suffer from illnesses. This can be especially important when these illnesses are already somehow impairing the oxygen saturation anyway or when there is free air in body cavities.

The SIDS risk seems to be slightly increased in higher altitudes, but I would not see that as a reason that is so crucial to recommend parents to move to lower areas. Nevertheless, it is very important to inform the parents about other possibilities to reduce the risk of SIDS like avoiding prone position, overheating of the sleeping room etc., but that is important in any altitude level.

Another important point is, that parents should be well informed about early signs of altitude related illnesses in their children and arrangements to avoid them. Furthermore, it should be clarified that they must take special care about the increased solar radiation, the cold and the possibility of dehydrating easily in arid high mountain areas.

Concerning mountain sports, I can summarize that these are a very good way for children- and adults- to improve their health, creativity, social sense and much more. Even if this may sound a bit impertinent, I personally do believe that doing mountain sports and being out in nature with children kind of makes them “better” people, or at least encourages a development to good, responsible members of our society.

Activities in the mountains often provide a variable terrain with many possibilities to play and discover new things. It should be kept in mind that those things are more interesting for smaller children than reaching a prestigious top. Generally, children’s needs should always be regarded as the highest priority when choosing a route or planning a trip.

Concerning performance, it can be summarized that there is no danger of harming the cardiovascular system with overly long endurance activities since the skeletal muscles would always get tired first and lead to an abruption of the activity. Children generally have good conditions for endurance sports- and these can be trained from early age on- but one must be careful with short anaerobic stresses and strains and strength training where an older start is favorable. Also, technically demanding sports and those that demand a higher sense of responsibility, like for example belaying each other in lead climbing, are recommended from a later age level on – even though it depends of course also on the developmental level of the child.

So, to finalize this thesis, I want to encourage everyone to go out and go up with your children and use the great opportunity nature and mountains provide us to support a positive development in many different fields!

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