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# PULSE OXIMETRY DURING SEVERE PHYSICAL EXERCISE AT HIGH ALTITUDE*

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## Abstract

**Introduction:** During sojourns at high altitude pulse oximetry is widely used to facilitate the diagnosis of high altitude illness at an early state and to assess the individual acclimatization status. With regard to the second topic there is good evidence that measurements during physical exercise have a higher significance compared to measurements at rest. However, physical exercise, especially moving hands may influence the measurements. This raises the question whether body movement compromises the use of pulse oximetry during physical exercise.

**Objective**: To investigate the amount of incorrect measurements during severe physical exercise with extreme manual activity at high altitude.

**Methods:** The used device (PalmSat 2500®; Nonin) records the measured values for $SpO_2$ and pulse every 4 seconds. To minimize interference with the ice axes we placed the flex finger sensor not on the index but on the forth finger. The hands were covered with gloves. The study was performed during an extreme ice-climb to the summit of Les Courtes (3856 m; NE-gully: 800 m; 50°) in two experienced ice-climbers (both 32 yrs., 72 /74 kg, non-smoking man). The recorded data were transferred to Excel and evaluated. The PalmSat 2500 assigns the figure "500" to each incorrect (missing or suspect) measurement. This ensures a value every 4 seconds. We calculated the ratio of these "500"-values compared to the total number for the extreme situation during the ice-climb as well as for the whole tour.

**Results:** During the whole tour and during the ice-climb we recorded 2252 data points for $SpO_2$. In total we had 24.8% (1333/5368) of incorrect measurements and 34.5 (778/2252) for the ice climb. If we exclude the ice-climb the rate of incorrect measurement is 17.8 (555/3116) and if we further exclude the 6 min for preparation immediately before the ice-climb the rate of incorrect measurements is 16.8 (510/3028).

**Conclusions:** Even under these extreme conditions pulse oximetry provides meaningful results. For practical use 2/3 of usable results is sufficient. In situations where considerable hand-movements are unavoidable the use of ear-sensors might reduce the rate of incorrect measurements.

***Key words:*** *acute mountain sickness, pulse oximetry, oxygen saturation, moving artifact*

## Introduction

During sojourns at high altitude oxygen saturation measured by pulse oximetry ($SpO_2$) is widely used to facilitate the diagnosis of high altitude illness at an early state and to assess the individual acclimatization status [1]. With regard to the second topic there is good evidence that measurements during physical exercise have a higher significance compared to measurements at rest [2-5]. But physical exercise, especially moving hands / fingers may influence the measurements [6]. This raises the question whether body movements compromise the use of pulse oximetry during physical exercise. Therefore, we tested a modern pulse oximeter device under the extreme conditions of a steep ice-gully-climb that requires severe manual work with ice-axes.

The aim of this study was to investigate the amount of incorrect $SpO_2$- measurements during this severe physical exercise at high altitude.

## Methods

### *Procedures*

The study was performed during an extreme ice-climb to the summit of Les Courtes (3856 m; area of Mont Blanc) in two experienced ice-climbers (both 32 yrs., 72 /74 kg, non-smoking man). The whole ascend can be divided in several parts:

1. The drive by car to the bottom of the cable car (1210 m) and the administrative work there (7:32–8:30); 2. The ascend by cable car to 2620 m (8:30–9:04); 3. The fast ascend by ski touring to 3100 m (9:04–9:29); 4. The descent by ski to the glacier d'Argentiere 2650 m (9:29–9:38 a.m.); 5. The ascent by ski touring to the bottom of the gully 3050 m (9:38–10:24); 6. The preparation for the ice climb 3050 m (10:24–10:30); 7. The ice-climb of the NE-gully of Les Courtes (800 m; 50°) 3856 m (10:30 –13:00) (Fig. 1)

* Results were presented during the 6th EUROPEAN HYPOXIA SYMPOSIUM – Hypoxia, High Altitude Physiology And Sports In Science And Practice, Zakopane, Dolina Chochołowska, 12-15 September, 2013.

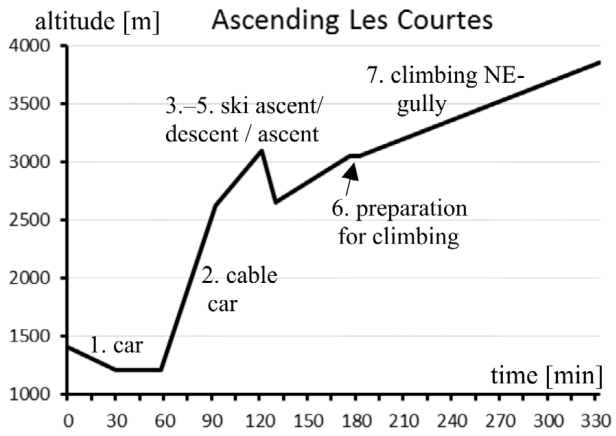


Fig. 1. *Altitude profile of ascending Les Courtes (3856 m)*

The used pulse oximeter device (PalmSat 2500®; Nonin) records the measured values for $SpO_2$ and pulse every 4 seconds and its memory has a capacity of 72 hours. The measurement started at 7:32 a.m. and ended at 1 p.m. on the summit. We used the adult FlexSensor® that is soft and flat and can be worn under gloves. The hands were covered with gloves the whole time except part 1. We placed the FlexSensor not on the index but on the forth finger because the index finger is required for proper security work (rope work, security points, …). The recorded data were transferred to Excel for evaluation. The PalmSat 2500 assigns the figure "500" to each incorrect (missing or suspect) measurement. This ensures a value every 4 seconds. We calculated the ratio of these "500"-values compared to the total number of data points for the extreme situation during the ice-climb (part 7.) as well as for the whole tour (part 1.-7.).

## Results

During the ice-climb of the gully we recorded 2252 and in total 5368 data points for $SpO_2$. In total (part 1-7) we had 24.8% (1333/5368) (Fig. 2) of incorrect measurements (inc-mes) and 34.5% (778/2252) (Fig. 3) for the ice climb (part 7). If we exclude the ice-climb (part 7) the rate of inc-mes for part 1-6 was 17.8% (555/3116). If we further exclude the 6 min for preparation (part 6: eating and drinking, putting on crampons etc.) immediately before the ice-climb that had the highest rate of inc-mes, 55.6% (81/145) we got a rate of 16.8% (510/3028). This reflects a standard alpine activity (Fig. 4). Even during the car drive and the administrative work (part 1), the rate of inc-mes is 5.5% (72/1312).

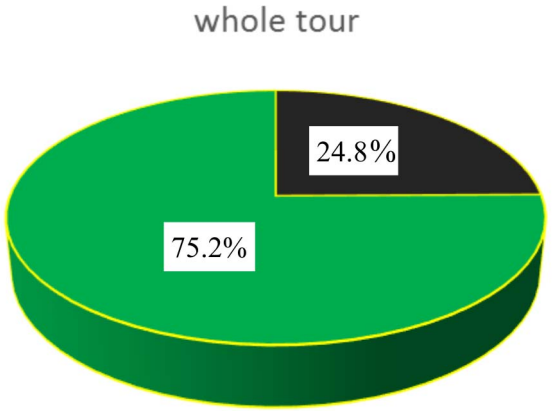


Fig. 2. *During the whole tour, the rate of incorrect measurements was 24.8 %*

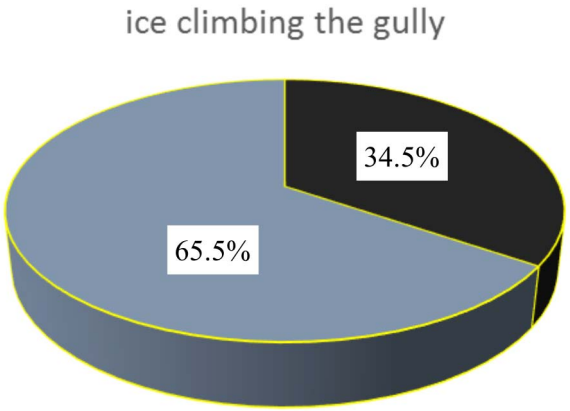


Fig. 3. *During the ice climb of the gully, the rate of incorrect measurements was 34.5%*

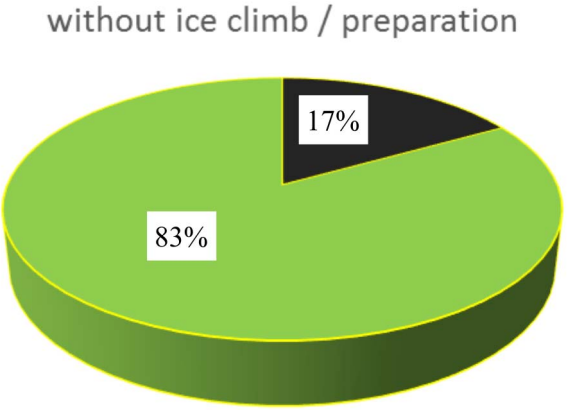


Fig. 4. *Incorrect measurements during a standard alpine activity (whole ascent without the ice climb and without the 6 min of preparation for it)*

## Discussion

Even under these extreme conditions, pulse oximetry provides meaningful results. The value of 17% (Fig. 4) can serve as direction for the rate of incorrect measurements of pulse oximetry during outdoor measurements and physical exercise. If we subtract the base line inc-mes during the car drive (5.5%) from the ice climb (34.5%) we can calculate that this severe physical exercise with extreme manual activity induces inc-mes of 29%.

During the daily work the user does not recognize the "500" values, they are not displayed by the device. The pulse oximeter notifies a weak signal by changing the pulse synchronic green flash light to yellow or red. In these cases, the measurement situation should be optimized like stop moving, replacing the sensor

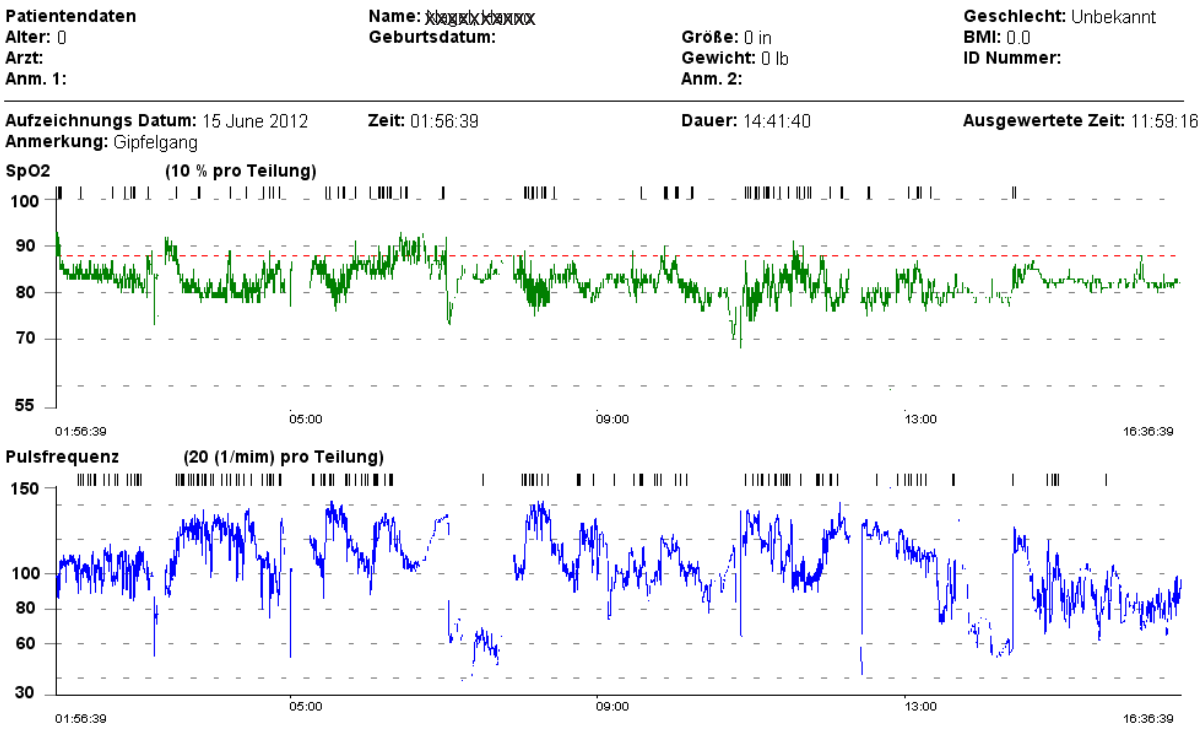


Fig. 5. *Climbing Artesonrajo (6025) by its steep SW-face. $SpO_2$ and pulse are illustrated with the Nonin evaluation software nVision. Incorrect measurements ("500-values") are not displayed and are expressed by gaps. These gaps do not disturb the visual impression.*

in a proper position, warming the fingers, etc. Even if the measurements have to be displayed with the Nonin evaluation software (nVision®) these inc-mes-values are negligible, because they do not influence the visual impression (Fig. 5).

In scientific research, these inc-mes-values are more problematic. If statistical parameters have to be calculated, they must be removed. This might cause a systematical error but it is small compared to including them in the calculation of means or standard deviations. For diagrams, we recommend not to remove but to replace them by the adjacent values. Otherwise, the timeline of the diagram would be shortened significantly. In situations where considerable hand-movements are unavoidable the use of ear-sensors might reduce the rate of incorrect measurements.

In conclusion, even under the extreme condition of climbing a steep ice gully (part 7) pulse oximetry with the FlexSensor put on the forth finger provides 2/3 of useable $SpO_2$-values. For practical use, this is sufficient.

## Declaration of interest

The authors report no conflicts of interest.

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