Scientific Approach for Optimising Performance, Health and Safety in High-Altitude Observatories

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The ESO coordinated study "Optimising Performance, Health and Safety in High-Altitude Observatories" is based on a psychological approach using a questionnaire for data collection and assessment of high-altitude effects. During 2007 and 2008, data from 28 staff and visitors involved in APEX and ALMA were collected and analysed and the first results of the study are summarised. While there is a lot of information about biomedical changes at high altitude, relatively few studies have focussed on psychological changes, for example with respect to performance of mental tasks, safety consciousness and emotions. Both, biomedical and psychological changes are relevant factors in occupational safety and health. The results of the questionnaire on safety, health and performance issues demonstrate that the working conditions at high altitude are less detrimental than expected.

Environmental influences at high altitude

High-altitude environments are exposed to increased radiation, low humidity, thunderstorms, wind chills, and temperature variation. These environmental influences need to be considered when studying human behaviour at high altitude. Sakamoto et al. (2003) studied the cosmic radiation exposure for workers at the Chajnantor site. Cosmic rays are enhanced to a level that even the effects on very-large-scale integration electronic instruments, such as correlators, may not be negligible. The measured annual gamma ray dose rate (including ~ 0.45 mSv per year contribution of terrestrial gamma rays) was 3.14 mSv at Pampa La Bola, 1.70 mSv at San Pedro de Atacama, and 0.99 mSv at Santiago, respectively. As for the neutron component, altitude dependence is more severe: the measured neutron dose rates were 0.80 mSv at Pampa La Bola, and 0.25 mSv per year at San Pedro de Atacama, whereas it was 0.01 mSv per year at Santiago. After correction for the effects of solar activity and indoor shielding, Sakamoto et al. (2003) estimate the occupational exposure of an 8–6 shift employee to be 2.0 mSv per year, which exceeds that of a typical worker engaged in nuclear fuel cycle processing. Nevertheless the measured data is within the thresholds for health effects recommended by Euratom (Vogt, 2002).

In addition to the effects of radiation, workers at high altitude are also confronted with a variety of weather effects. Thunderstorms, lightning and lightning electromagnetic pulses occur during the entire year, but especially during winter time. Thunderstorms over the Chajnantor Plateau are usually strong with lightning frequency of 1.6 flashes per minute. Measurements between April 1995 and June 2003 demonstrated that the temperature is usually in the range between –20˚C and +20˚C at the Chajnantor site. At the APEX station in Sequitor and the ALMA Operations Support Facility (OSF) site, the ambient air pressure is 750 mbar ± 100 mbar, which corresponds to an air density of 0.96 kg/m^3 and a temperature range between –10˚C and +30˚C is expected. Hence, humans and materials must cope with the environmental high-altitude constraints, for example with a temperature shock from indoors to outdoors, and vice versa, of up to 30˚C.

The ALMA and APEX high sites are exposed to an environment of 0 to 30 per cent relative humidity and the annual precipitation on the site is in the range of 100 to 300 mm. Most of this falls as snow but thunderstorms with rain (and without) do occur. Heavy rain and hail may occur. From around 2 000 m up to about 3 000 m altitude, the expected relative humidity is 5 to 30 per cent with maximum rainfall of 20 mm/h. No hail precipitation is expected. Whereas the expected wind speed has a maximum of 65 m/s at the very high-altitude site, the wind speed at the Array Operations Site (AOS) and Sequitor will not exceed 40 m/s. The wind chill strongly affects people working at Chajnantor.

The above-mentioned data demonstrate that the environmental conditions are a continuous challenge for all humans working at very high altitudes. In particular the outdoor ALMA construction work requires strict rules and regulations as well as sustainable processes to allow people to adequately cope with the environmental demands. Several information campaigns have emphasised the danger of too rapid ascent to the high sites and the importance of the acclimatisation and adaptation of human behaviour to the environmental conditions. The recommended break times at the ALMA OSF as well as the mandatory safety instructions for staff members, for example, are effective occupational safety and health (OSH) enablers. Measures to improve work conditions, organisation, human behaviour, safety, and health awareness must be developed under strong medical supervision for all staff working at the high-altitude site.

Rationale of the study: behavioural and organisational issues

The environmental conditions mentioned above have an impact on technical equipment but also on the human physiology, well-being and behaviour. In addition to the directly related high-altitude disease symptoms, there are a number of minor symptoms when working at high altitude (West, 2003), for example:
(1) loss of appetite;
(2) loss of body weight (mainly related to 1);
(3) bright flashing arcs of light in the peripheral vision when blinking, possibly due to dehydration of the eye caused by stretching of the retina;
(4) fingernails separating from the skin further down the nail than usual and the tops of the nails becoming very white;
(5) constipation.

High-altitude workplaces are defined as workplaces at a level of 3 000 m and above. A recently published article in the Scientific American, entitled "Into Thin Air: Mountain Climbing Kills Brain Cells" (Fields, 2008) caused uncertainty among astronomers about OSH at high-altitude observatories. The article described a study of a small sample of eight Aconcagua climbers who all suffered from a reduction of brain cortex ('cortical atrophy') detected in brain scans. Mountain climbing is physically very strenuous and requires much more oxygen compared to the typical work of most astronomers and technical staff at high-altitude sites. However the ESO internal medical statistics demonstrate that there are several cases of minor high-altitude sickness per week and preventive OSH measures should be in place at all high-altitude observatory sites. Although mountain climbing, as mentioned above, is in a different category, the negative influence of high altitude should by no means be underestimated and it is always present at ESO's APEX and ALMA sites at 5 050 m on the Altiplano de Chajnantor.

Workers whose itineraries take them above an altitude of about 2 400 m must be aware of the risk of altitude illness and potentially impaired mental performance. While the individual response to high altitude can vary, all people are at risk of altitude illness above about 3 000 m. The current internal ESO statistics of those working at the ESO ALMA and APEX high sites and the ALMA OSF do not suggest that certain demographics like age, sex or physical condition correlate with the susceptibility to altitude sickness. Wu et al. (2007) found some contra-indications for going to high-altitude sites based on a sample of 14 050 workers with an average age of 29.5 ± 7.4 years. But finally, there is no clear indication who will suffer from high-altitude illness. Wu et al. (2007) suggest that neither taking a rather permissive stance nor setting rigid rules of contra-indication are appropriate to decide who should ascend or not. On the one hand, one may put some persons at undue risk, but, on the other hand, one may exclude too many people from ascending. Obviously, poor physical condition (chronic obstructive pulmonary disease with notable arterial desaturation, cardiac infarction, heart failure, obesity with sleep apnea, or severe hypertension) at sea level will worsen at high altitude.

Conditions at the very high-altitude sites affect nearly all biological processes, particularly rhythms, including sleep. Due to the reduced adjustment of the body at high altitude, the person concerned has to work against bodily demands. Finally, the low oxygen (hypoxic) stress of altitude can impair work efficiency, performance and best practice, mainly due to maladaptive behaviour, distorted consciousness, impaired biomedical functioning and reduced sleep quality.

West (2004) attributes all medical effects of high altitude to the low partial pressure of oxygen in the inspired air, and so the most effective way of improving human performance is to add supplementary oxygen. Recent technical advances allow this to be done very efficiently by oxygen enrichment of room air or outdoors through use of small movable oxygen bottles with pulsatile nasal oxygen supply. However, an interface risk assessment must be performed, too. In case of indoor oxygen supplement, other OSH risks, such as an increased risk of fire, must be considered (West, 1997). Today's movable respiration systems for people working outdoors, or inside the ALMA antennas, are very comfortable, practicable and usable even in narrow spaces. Nevertheless, the system might hinder people from safely performing their work if it is not properly secured or if the environment is not properly designed for these processes. Hence, additional protective measures have been implemented at the site and to the technical equipment. There is, for example, the special operator seat in the ALMA antenna transporter which allows the driver to use the oxygen bottles during operation. However, a general use of oxygen might slow down the acclimatisation process of people at very high-altitude sites.

While there is a lot of knowledge about biomedical changes at high altitude and under low oxygen conditions, changes in behaviour, cognition, and emotion have rarely been systematically investigated. The study presented here, which was introduced in the earlier article by Böcker & Vogt (2007), bridges this gap using an elaborate questionnaire. Moreover, issues of work and organisation beyond the individual visitor and worker, such as planning of work and team performance, are addressed. Previous studies were often conducted on mountaineers with only a few persons taking part, and are thus not representative of the situation at an observatory. Therefore, people working or visiting the ALMA and APEX high-altitude observatory sites have been invited to fill in the questionnaire. The project aims to provide more systematic information on potential high-altitude induced hazards at the individual and work process level in order to better protect staff from negative effects and accidents, and to prevent damage to expensive scientific instruments. Changes in ability at the individual level have an impact on actual work behaviour at the process level as, for example, driving a car or planning of work. Finally, the project also considers potential performance losses such as performed capacity or meeting client demands, as well as problems in decision making during commissioning or operation of complex astronomical systems. These can be relevant for organisational performance, which is explicitly considered in the scope of this project.

Method

To systematically develop adequate recommendations, a questionnaire has been developed in English and Spanish to obtain the subjective impressions of visitors and employees (subsequently visitors/workers) when staying at high altitude. It was made available to all visitors/workers at the ALMA and APEX sites and returned by 28.

The first part of the questionnaire obtains work-related biographical data. The participants are asked how often they spend time at high altitude and how they prepare for the missions. They may also describe any unusual event at altitude workplaces and if they felt any limitations with respect to their work which may have been due to altitude (e.g. "Have you experienced limitations in planning and coordination"?). This is the introductory question concerning potential hazard areas, which are further elaborated in the second section of part one of the questionnaire. Here, 17 physical and psychological complaints are listed and the participants report to what extent they experienced complaints on a scale from 1 = extremely to 5 = not at all (e.g. emotions such as anger, irritability).

In the third section of the first part of the questionnaire the participants are asked to rate the change of abilities, work behaviour, and work performance at high altitude. The scale ranges from 1 = strongly impaired, through 3 = not changed, to 5 = strongly improved at altitude (example ability item: "Perceptual speed: ability to perceive and compare information quickly and accurately"; example work behaviour item: "Driving a car"; example performance item: "Performed capacity"). This final section of part one of the questionnaire was designed to draw conclusions on potentially impaired performance at high altitude.

The second part of the questionnaire refers to OSH programmes and their perceived benefit. In the first section of part two of the questionnaire the participant is asked to list all safety-related information he used and any other support (e.g. "Briefing by Supervisor") used to become knowledgeable and fit for high-altitude workplaces. The participants are also asked to estimate the amount of time spent with each document/support as well as how beneficial they have been concerning work at high altitude. In the second section of part two of the questionnaire, the document/support with the highest perceived benefit is described and rated by the participant.

The third part contains a "Performance and Well-being Diary" consisting of three tables. The participant rates the average workload per day, before, during and after his mission, in the first table and how it was managed in the second table. The third table describes the well-being, before, during, and after the mission. Of the questionnaires returned so far, this final part was not well filled in. It will be covered in one of the following reports.

Study participants

28 questionnaires were returned. 86 per cent of the respondents were men. The largest age group was between 41 and 45 years old (32 per cent), however, all age groups, from less than 25 to older than 51, were represented in the sample. The majority of the participants were working as technicians or engineers (61 per cent). Roughly half of them were visitors at high altitude; the other half consisted of regular workers.

Results

Generally, the study participants did not report major problems at high altitude; the level of limitations, complaints, and difficulties was rather low, mostly not significantly different compared to normal altitude. The differences between visitors and workers show that – at this low-problem level – workers reported slightly more limitations, slightly more complaints, and slightly more difficulties; however, only very few differences were statistically significant. Figure 1 shows, for example, the average limitations of tasks at high altitude reported by visitors/workers.

The visitors reported only slight to no limitations of planning, team work, manual and other tasks (e.g. computer programming). The workers tended to report slightly more limitations heading towards 3 (moderately limited), but not statistically different from 4 (slightly limited). However, in most cases a significant difference to the rating 5 ("not at all limited") was found, indicating that there are limitations under high-altitude conditions, although they are only moderate in the case of the worst-affected task (other tasks such as programming). Team work can have a social activation function, in that it reduces the fatigue and attention problems that might be induced by high-altitude conditions and travel jet lag. Workers tended to report more limitations than visitors; however, no group difference was statistically significant.

The experience of physical and psychological complaints at altitude workplaces ranged on average from slight to non-existent. Concentration problems, fatigue, reduction of usual activities, and shortness of breath were the only complaints from workers with means below 4 and – in case of shortness of breath – also for visitors. Fatigue and shortness of breath are the two symptoms, in which the deviation from rating 5 (not at all) to 4 (slightly) is statistically significant and not a mere variation by chance in both groups.
For visitors, the experienced slight concentration problems and dizziness/vertigo are significantly different from rating 5 (= not at all). For workers, the reduction of normal activities is significantly different from 5. Most other complaints that have been reported by mountaineers were not experienced at all by the ESO site workers and visitors (e.g. isolation, nausea and vomiting). There was a slight tendency that visitors report fewer complaints than workers, however, no group difference reached statistical significance.

Work behaviour reported by workers and visitors was not significantly changed (average of 3 = not changed). This is not surprising because the underlying abilities were, if at all, only slightly impaired and humans can compensate for ability losses by increasing effort. This might lead to the conclusion that, for example, the influence of critical incidents (accidents, armed robbery or similar) on the compensation ability might be negatively affected for staff working at very high altitude. Vogt et al. (2004, 2007) reported up to 30 per cent loss of planning ability after critical incidents, if these critical incidents were not treated properly. It has been demonstrated that Critical Incident Stress Management (CISM) is a useful intervention tool. Untreated staff were straining harder and needed significantly longer recovery periods compared to their normal performance.

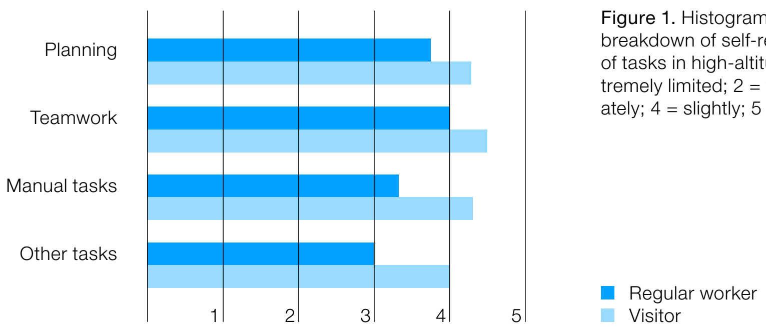

Figure 1. Histogram showing the breakdown of self-reported limitations of tasks in high-altitude work (1 = extremely limited; 2 = very; 3 = moderately; 4 = slightly; 5 = not at all limited).

Study conclusions

From the perspective of visitors/workers at high altitude, the results of this study document fewer problems than expected. The visitors/workers neither reported major psychosomatic complaints nor impairment of abilities, work behaviour or work performance. However, the data indicated some areas worthy of further study that bear potential improvement for OSH programmes, such as concentration/awareness problems, fatigue/under-arousal and reduced capacity. Although not statistically significant from the study so far, workers generally report slightly more problems at high altitude than visitors. However, cultural differences, for example, optimism of local workers *versus* critical view of visiting scientists, probably also play a role.

With respect to the preparations for high-altitude work and the benefits of OSH programmes, one result of this pilot study is that some participants did not report any preparation in matters of safety for their work at high altitude. The remaining visitors and workers, who reported on their preparations, mostly used more than one method. Some visitors have done more than expected. Additional information which exceeds that contained in the ALMA High Altitude Visitors Information packet and the site safety instruction by the site safety officer, was sometimes mentioned in the questionnaire returns. This diligence implies that high-altitude safety and health issues are seriously considered also by visitors – an indication that most of them were concerned about visiting a high-altitude site and, therefore, were interested in getting useful background information.

Although only a minority of participants did not report about preparations for ascent to high altitude, serious incidents may be more likely to happen to individual high-altitude visitors/workers with reduced safety consciousness. Thus, we need to find out how to convince everybody to adequately prepare for the work at very high altitude. This finding is in line with other studies, for example, with air traffic controllers, who in two thirds of cases concerning critical incidents had attended a stress management programme and in one third had not (Vogt et al., 2004; 2007). The latter third demonstrated a reduced performance for a longer period after an incident. The organisational culture and the safety attitude of supervisors play an important role in the decision of employees to use OSH programmes or not. With improved attractiveness and marketing of the materials/programmes on the one hand, and organisational culture and safety leadership on the other, we have the necessary tools to win over everyone to an appropriate preparation for and use of OSH materials/programmes.

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Report on the ESO and Radionet Workshop on

Gas and Stars in Galaxies – A Multi-Wavelength 3D Perspective

held at ESO Garching, Germany, 10–13 June 2008

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An overview of the ESO/Radionet workshop devoted to 3D optical/near-infrared and sub-mm/radio observations of gas and stars in galaxies is presented. There will be no published proceedings but presentations are available at *http://www.eso.org/sci/meetings/gal3D2008/program.html*.

The main aim of this ESO/Radionet workshop was to bring together the optical/near-IR and sub-mm/radio communities working on three-dimensional (3D) extragalactic data. The meeting was attended by more than 150 scientists. This article, due to space limitations, provides a, necessarily biased, overview of the meeting. We decided not to publish proceedings, but the presentations are available from the workshop homepage at *http://www.eso.org/sci/meetings/gal3D2008/program.html*. The names of speakers relevant to a topic are included here so that