

THE INFLUENCE OF RESPIRATORY PROTECTIVE
DEVICES ON WEARERS AT SUB-MAXIMUM DOSED WORK STRESS

Dr. Gerhard Blume
Personliche Schutzausrüstung
Gaisbergstrasse 11
6900 Heidelberg, West Germany

Mr. Ernst Furst
Hauptstelle für das
Grubenrettungswesen
8126 Hohenpeissenberg
Unterbau 71 1/8
Munich, West Germany

Note: Drawings and pictures referred to in the text were not available for printing

INTRODUCTION

The use of respiratory protection devices is a noticeable, additional physical stress to the wearer. This is noticeable especially during physical work. This additional stress is primarily the result of the following breathing apparatus factors:

- Weight of the breathing apparatus (with compressed breathing apparatus, for example up to 25% of the body weight).
- Additional breathing labor to overcome the breathing resistance of respiratory protective device (up to 15 mbar with full facepieces and combination chemical/aerosol filter cartridges).
- Dynamic deadspace of the facepiece (with full facepieces, for example increase of the carbon dioxide content in the inhalation air up to double the threshold limit value).

The additional stress is so great that in mining it has always been customary to give medical examinations to the wearers of respiratory protective devices before they could use these. This is to see if physically they could stand up to the expected stress.

The German Mutual Accidents Insurance Organization has worked out the principals for work-medical preventive examinations G 26 "Wearers of Respiratory Protective Devices for Work and Rescue". During the preparation it became evident that there exist only a few reports which are comprehensive and backed up by statistics that give information about the stress of the different respiratory protective devices on the wearers. Studies involving larger numbers of participants are especially rare. Due to the very large individual differences, however, tests with single persons are of limited value only.

For this reason the work group "Respiratory Protection" of work circle 1 "Work Physiology" of the committee WORK MEDICINE has introduced and carried out a comprehensive research project on the stress resulting from the wearing of respiratory protective devices, especially for older workers too. The financial means were supplied by the main Association of the Professional Mutual Accidents Insurance Organizations in Bonn.

RESEARCH START AND EXAMINATION SCOPE

Selection of Participants

In order to get a representative collection of positively motivated wearers of respiratory protective equipment of average health, the test persons were chosen from participants of respiratory protective equipment protective courses. These courses are conducted continually at the Chief Mine Rescue Station of the Mining Mutual Accidents Insurance Organization in Hohenpeissenberg, Bavaria. In order to measure the effect of age, the test persons were divided into seven groups:

Group 1:	18 - 25 years
Group 2:	26 - 30 years
Group 3:	31 - 35 years
Group 4:	36 - 40 years
Group 5:	41 - 45 years
Group 6:	46 - 50 years
Group 7:	51 years and older

In order to obtain statistically sound results, there were at least 30 persons in each age group during each of two studies projects. Participation was voluntary.

Work Stress

For obvious reasons it is hardly possible to conduct work-physiological tests of the necessary scope on wearers of respiratory protective devices at their work place or during real life rescue operations.

As a substitute, dosed work stress was measured on a tread-mill type ergometer at the Chief Mine Rescue Station in Hohenpeissenberg.

The speed of the treadmill was set at 2.25 kilometers per hour and the incline angle at approximately 11 percent, so that a test person weighing 75 kilograms was subjected to a stress of approximately 90 Watts.

Metholodogy

As indicated on Table 1, the research project was carried out in two parts.

Part I of the study investigated the influence of the weight of the respiratory protective equipment on the wearer. Here one of the most common models of compressed air breathing apparatus (DA 58/1600) was used. The weight of this apparatus without facepiece is 16 kilograms. Here each test person had to make two test runs.

- Test run 1: With facepiece without compressed air breathing apparatus, and
- Test run 2: With facepiece with compressed air breathing apparatus.

The test set-up is illustrated in schematic drawings 1 and 2.

Part II of the study investigated the influence of breathing resistance and facepiece deadspace on the wearers of respiratory protective equipment. Gas masks were used consisting of a full facepiece with a combination chemical/aerosol filter cartridge, protection grade 3c (B/St), (in future: B2-P3, according to German Standard DIN 3181, Part I). Here each person had to make three test runs..

- Test run 1: Without facepiece
- Test run 2: With facepiece without filter cartridge, and
- Test run 3: With facepiece with filter cartridge.

The test set-up is described in schematic drawings 3 and 4

During all test runs the measurement dimensions of stress on lungs, heart, and circulatory system as indicated in Table 2 were used.

HOHENPEISSENBERG STUDY: Part I and II, Table II
Measurement dimensions

A. Stress on lungs

- Breathing minute volume (AMV; gas gauge)
- Breathing frequency (AF, Thermistor conduction)
- Breathing volume (AV, mathematical).

B. Stress on Heart-Circulatory system

Due to absence of facepieces, there were no measurements of breathing volume and breathing minute volume during test run 1, of Part II of the study.

During test runs 2 and 3 of part II of the study the inhalation resistances and exhalation resistances were also measured. In addition, the breathing pressure curves were recorded in the fifth, respectively the sixth minute of stress.

In both parts of the study more than 100,000 personal facts were recorded in computerized form.

The test runs were made on two consecutive days at the same time of the day. A test run lasted 12 minutes and was divided as follows:

2 minutes adjustment time at rest

7 minutes adjustment at the treadmill ergometer, 90 watt, and

3 minutes recovery time at rest.

RESULTS AND DISCUSSION

General

It is generally accepted that each type of work stress results in specific changes on the stress characteristics of heart, circulatory system and lungs. As the test showed, the wearing of respiratory protective equipment results in additional stress factors which then influence these characteristics. The following will illustrate and discuss the changes on the average curves of the individual characteristics, with and without respiratory protective equipment.

An evaluation with regard to the different age groups was made. Dispersion diagrams were made and regression curves in relationship to age were determined here.

Stress on Heart-Circulatory System

For this discussion, the only characteristics used for stress on the heart-circulatory system is the heartbeat frequency (HSF).

During stress, this increases at first rapidly, then gradually to a level of maximum approximately 117 heartbeats per minute. At the end of stress, the decrease is rapid. Three minutes after the stress period, an average of 92 heartbeats per minute was measured.

With the additional influence of a facepiece, consisting of a full facepiece and a gas gauge, there is only a slight increase of the heartbeat frequency during and after the stress period of an average of maximum 3 heartbeats per minutes.

Primarily this increase is the result of the dynamic deadspace of the full facepiece and to a lesser degree due to the existing breathing resistance (see picture 9). Since modern full facepieces were used which were equipped with nose cups, this influence was not too great.

However, the additional influence of a combination filter cartridge before, during and after stress period resulted in an additional increase of an average of seven heartbeats per minute to the heartbeat frequency.

Therefore, with the gas mask system (full facepiece with combination chemical/aerosol filter cartridge) and gas gauge, the total influence during the selected, sub-maximum stress was approximately 11 additional heartbeats per minute at a maximum average heartbeat frequency of approximately 128 per minute. This corresponds to an increase of approximately 9.5 percent.

For a comparative examination of the additional influence of the weight of approximately 16 kilogram of a compressed air breathing apparatus, measuring of the heartbeat frequency is possible only with facepiece (picture 6).

Before, during and after the stress period there is an increase in the heartbeat frequency due to the weight. The maximum was reached in the seventh minute of the stress and on the average it was about 13 heartbeats per minute. With compressed air breathing apparatus and facepiece the average heartbeat frequency was maximum approximately 141 per minute, compared to the approximately 128 per minute when using facepiece and combination filter cartridge. The heartbeat frequency increase, caused by the 16 kilogram weight of the apparatus, therefore is about twice as high as the increase caused by the combination filter cartridge. Also, compared with the gas mask, the recovery behavior of the heartbeat frequency is markedly slower with compressed air breathing apparatus.

Comparing the total influence of the compressed air breathing apparatus and gas gauge system against the corresponding values when using no respiratory protective equipment at all (even though this is not entirely correct, since there was a different group of persons), there is an increase of 24 heartbeats per minute, corresponding to 20.5 percent.

Stress on the Lungs

Breathing minute volume

On the various aspects of stress on the lungs which were examined, let us first look at the behavior of the air volume that is breathed in a minute, known as breathing minute volume (AMV). An additional influence on the use of breathing air is not noticeable during the stress due to wearing a combination filter cartridge (Picture 7).

The situation differs with the wearers of compressed air breathing apparatus under the same stress (Picture 8). For facepiece without compressed air breathing apparatus the average original values of the breathing minute volume were at 13 liters per minute, and with compressed air breathing apparatus at 16 liters per minute. The increased air consumption due to the additional weight of approximately 16 kilogram is up to seven liters per minute in the seventh minute of stress.

With facepiece, gas gauge and compressed air breathing apparatus the average breathing minute volume reached a maximum of about 45 liters per minute, compared with about 38 liters per minute for facepiece and gas gauge but without the weight load. Comparing picture 7 and picture 8, it becomes evident that it is the weight of the compressed air consumption per minute under dosed work stress. With this measurement the influence of the filter cartridge cannot be assessed.

Breathing Resistance

For wearers of respiratory protective devices with combination filter cartridges the most important stress factors during inhalation and exhalation are the negative and positive pressures that must be overcome, the so-called breathing resistances. For this reason these values were also taken into account in part II of the study.

Picture 9 shows that the positive pressure required to open the exhalation valve during the work stress is on the average 2 mbar .

During inhalation the negative pressure from the full facepiece and gas and gas gauge was a maximum of - 2.8 mbar. This figure includes a pressure loss of - 1 mbar which is caused by the gas gauge. This could not be avoided for technical reasons.

The facepiece with combination filter cartridge results in a negative pressure about four times as high as the wearer inhales. Already before the work stress period the average is - 3 mbar and during the dosed work in the seventh minute of the stress up to almost - 10 mbar.

The breathing work required to overcome such positive and negative pressures and its influence on the respiratory organs must be considered as additional stress factor to the weight of the breathing apparatus. This must be taken into consideration during medical examinations of wearers of respiratory protective equipment.

Breathing time quotient

During the execution of part II of the study the breathing pressure curves were recorded without inherent delay during the fifth, respectively the sixth minute of the stress period. From the breathing times of inhalation and exhalation which are recorded on these curves, the influence of resistance on the natural breathing curve is evident.

By designating the average exhalation time t_{EX} and the average inhalation time t_{IN} , one obtains the breathing time quotient (AZQ) with the following formula:

$$AZQ = \frac{t_{EX}}{t_{IN}}$$

While during the test run with facepiece without filter (little inhalation resistance) the exhalation time on the average was greater than the inhalation time by a factor of 1.3 (AX 1.3), this relationship in the test run with facepiece and combination filter (high inhalation resistance) changes to such an extent that the inhalation time and exhalation time are almost equal. The breathing time quotient becomes approximately 1.

The wearers of respiratory protective equipment perceive this disorder of the natural breathing as very unpleasant.

CONCLUSION

A research project was conducted with two common respiratory protective devices involving a large group of 422 participants. In this project, where more than 100,000 individual data were measured, it was attempted to abstract from these the influences of the respiratory protective equipment factors on the wearers of such equipment, such as apparatus weight, breathing resistances and dynamic dead space in the equipment. Basic knowledge has been obtained from which the real stress can be judged to which workers are subjected when wearing respiratory equipment under real life conditions.

It can be expected that in the future this knowledge will be taken into consideration not only for medical examinations of wearers of respiratory protective equipment, but also when setting performance standards for tests on respiratory protective equipment.