TECHNICAL SPECIFICATION

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Respiratory protective devices — Human factors —

Part 6: Psycho-physiological effects

Appareils de protection respiratoire — Facteurs humains — Partie 6: Effets psycho-physiologiques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

ISO/TS 16976 consists of the following parts, under the general title *Respiratory protective devices — Human factors*:

— *Part 1: Metabolic rates and respiratory flow rates*

— *Part 2: Anthropometrics*

— *Part 3: Physiological responses and limitations of oxygen and limitations of carbon dioxide in the breathing environment*

— *Part 4: Work of breathing and breathing resistance: Physiologically based limits*

— *Part 5: Thermal effects*

— *Part 6: Psycho-physiological effects*

— *Part 7: Hearing and speech*

— *Part 8: Ergonomic factors*

Introduction

This part of ISO/TS 16976 addresses the psychological factors that can trigger physiological effects (psycho-physiology effects) that contribute to user acceptance, or the ability to tolerate wearing respiratory protective devices (RPD) for the duration needed. This part of ISO/TS 16976 takes the position that the psychological state has a physiological correlate (e.g. anxiety is accompanied by an increase in heart rate) and that the physiological responses to wearing an RPD have an impact on the psychology of the wearer (e.g. difficulty in breathing will result in anxiety). The following sections focuses on a separate psycho-physiological situation that can impact user acceptance or contribute to the likelihood of the wearer removing the RPD prematurely and, thus, being exposed to a respiratory hazard. The physiological responses to wearing an RPD is addressed first followed by a discussion on the psychological responses to wearing RPD. The discussion then turns to the methodologies used to measure the psycho-physiological responses and how these measurements are used to predict whether an individual will have difficulty wearing an RPD. Finally, this part of ISO/TS 16976 addresses the selection criteria that can be used to determine who is best suited to engage in an occupation requiring the use of RPD.

The following definitions apply in understanding how to implement an ISO International Standard and other normative ISO deliverables (TS, PAS, IWA).

— “shall” indicates a requirement.

— “should” indicates a recommendation.

— “may” is used to indicate that something is permitted.

— “can” is used to indicate that something is possible, for example, that an organization or individual is able to do something.

3.3.1 of the ISO/IEC Directives, Part 2 (sixth edition, 2011) defines a requirement as an “expression in the content of a document conveying criteria to be fulfilled if compliance with the document is to be claimed and from which no deviation is permitted.”

3.3.2 of the ISO/IEC Directives, Part 2 (sixth edition, 2011) defines a recommendation as an “expression in the content of a document conveying that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.”

Respiratory protective devices — Human factors —

Part 6: Psycho-physiological effects

1 Scope

This part of ISO/TS 16976 provides information on the psycho-physiological effects related to the wearing of respiratory protective devices (RPD) and it is intended for the preparation of standards for selection and use of RPD.

It specifies for the writers of RPD standards, principles relating to

— the interaction between RPD and the human physiological and psychological perception,

— the acceptance by the wearer, and

— the need for training to improve acceptance of the RPD by the wearer.

This part of ISO/TS 16976 does not cover requirements related to the specific hazard for which the RPD is designed.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16972, *Respiratory protective devices — Terms, definitions, graphical symbols and units of measurement*

3 Terms and definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 16972 and the following apply.

3.1
aetiopathology
cause of the pathological state or disorder, pathogenesis

3.2
anxiety
state of being uneasy, apprehensive, or worried about what might happen, misgiving

3.3
BP
arterial blood pressure (mmHg)

3.4
cardiac arrhythmia
variation from the normal rhythm of the heart beat

3.5
claustrophobia
abnormal fear or dread of being in an enclosed or confined space

3.6
dysphoria
sensation of disquiet, restlessness, or malaise

3.7
dyspnoea
sense of air hunger, difficult or laboured breathing, or a sense of breathlessness

3.8
HR
heart rate (beats·min^{-1})

3.9
hypercapnia
excess amount of CO_2 in the blood

3.10
hyperventilation
increase in overall respiration resulting from an increase in both the depth and frequency of breathing

Note 1 to entry: This can be voluntary or result from an increase in activity, fear, or breathing excess carbon dioxide (CO_2).

3.11
hypoxia
volume fraction or partial pressure of oxygen in the breathing atmosphere below that found in the atmosphere at sea level

3.12
metabolism/metabolic rate
energy produced in human cells by aerobic or anaerobic processes

3.13
minute ventilation
$\dot{V}_E$
total volume of air inspired (or expired) in the lungs during 1 min, in L·min^{-1} (BTPS)

3.14
paresthesia
abnormal sensation without objective cause such as numbness, prickling, and tingling; heightened sensitivity

3.15
psycho-physical effect
pertains to the mind and its relation to physical manifestations

3.16
psycho-physiological effect
psychological trait(s) and responses to a given situation which can provoke a physiological response and the physiological responses to a given situation which can provoke a psychological reaction

3.17
RR
respiratory rate (breaths·min^{-1})

3.18
SaO_2
degree of saturation of haemoglobin with oxygen in arterial blood (expressed as a % of total saturation)

3.19
stereoacuity
visual clarity in three dimensions

3.20
tachycardia
increased heart rate due to exercise, pain, anxiety, or pathophysiological state

3.21
tcCO_2
measured transcutaneous carbon dioxide

Note 1 to entry: The level of carbon dioxide in tissue vasculature, as measured by a transcutaneous CO_2 detector attached to the earlobe.

3.22
phobia
any persistent and irrational fear of a specific object, activity, or situation that results in a compelling desire to avoid the feared stimulus

3.23
State-Trait Anxiety Inventory
psychological assessment tool used to determine the presence and type of anxiety in an individual and is used to differentiate between situational anxiety (state anxiety) and chronic feelings of anxiety as part of the overall personality structure (trait anxiety)

4 Symbols and abbreviated terms

RPD	respiratory protective device
$\dot{V}_E$	minute ventilation
BP	blood pressure
STAI	State-Trait Anxiety Inventory
FFR	filtering facepiece respirator
HR	heart rate
RR	respiratory rate
SaO_2	arterial oxyhaemoglobin saturation
SARS	severe acute respiratory syndrome
WoB	work of breathing
Pa	pascal
SCBA	self-contained breathing apparatus
T_{sk}	skin temperature
SA	state anxiety
TA	trait anxiety
IDLH	immediately dangerous to life and health

$\dot{V}\,O_2$ rate of oxygen consumption during breathing

$\dot{V}\,CO_2$ rate of carbon dioxide production during breathing

5 Psycho-physiological effects influencing user acceptance of RPD

5.1 General

Many occupations require workers to wear RPD to protect them from hazardous atmospheres. However, a small but significant fraction of the workers find it difficult or even impossible to wear RPD for longer than a few minutes. This might be due to the physical discomfort of a poorly fitting RPD or due to dangerous situations under extreme circumstances or might be due to the particular psychological traits of the wearer's personality. Wearing an RPD provokes physiological responses in essentially all wearers and it appears to be the psychological response to the physiological sensations (air hunger, heat, narrowing of the visual field) that might provoke a psychological reaction that renders the individual incapable of wearing the RPD. The following sections address first the physiological responses to wearing RPD and the potential psychological reactions to those physiological responses.

5.2 Physiological responses to wearing RPD and impact on performance of work

The simple act of donning an RPD can elicit a number of psychological responses that can be independent of the environment in which the RPD is used. Wearing an RPD can alter the concentration of oxygen (O_2) and carbon dioxide (CO_2) in the breathing space that, if of sufficient magnitude, significantly affect gross respiratory function (e.g. increase or decrease in minute ventilation). In addition, wearing an RPD is associated with changes in cardiovascular function in response to sympathetic nervous system stimulation, reduction in physical performance, work of breathing, changes in $\dot{V}_E$ (e.g. dyspnoea) as a result of increased resistance to airflow, and sensation of heat. In most, if not all people, there will be a psychological response to the physiological sensations that are experienced by the wearer of the RPD. The psychological responses will determine the degree of wearer acceptance of the RPD and compliance with the requirements of RPD necessary in providing an appropriate level of protection. Each of the physiological responses is discussed in the following paragraphs.

5.2.1 Oxygen (O_2) and carbon dioxide (CO_2) in the breathing space

The physiological responses to O_2 and CO_2 in the breathing space have already been addressed in detail in ISO 16976-3 and in a recent review article.[62] Briefly, changes in the concentration of either O_2 or CO_2 in the breathing space might significantly alter the cardiorespiratory system as evidenced by changes in heart rate (HR), blood pressure (BP), $\dot{V}_E$, blood pH, and other physiological parameters. Reduced atmospheric O_2 (hypoxia) results in an increased ventilatory response[10] and increased cardiac output due to stimulation of the central nervous system[13] in order to ensure adequate oxygenation of the blood and elimination of metabolically produced CO_2. Severe hypoxia results in a constellation of signs and symptoms including a decrease in exercise tolerance, a decrease in cold tolerance, dizziness, euphoria, loss of consciousness, and if oxygen is not administered quickly, death from asphyxiation.[32] Mild hypoxia results in little change in the healthy person[11] and results in an initial mild respiratory depression followed by an increase in $\dot{V}_E$.[13] Breathing hyperoxic gas mixtures under higher atmospheric pressure (underwater diving, caisson work) can result in generalized seizures, hallucinations, involuntary movements, paresthesias, psychological changes (dysphoria, amnesia), and problems with some autonomic (involuntary) nervous system function.[55]

Breathing elevated CO_2 might result in changes in stereoacuity and perception of coherent motion[56] [64] reduced retinal blood flow[31] increased rate of body heat loss during snow burial[15] decreased performance on reasoning tasks, subjective increases in both irritability and discomfort,[45] and reduced ability to exercise during simulated emergency escape procedures[6], an increase in resting $\dot{V}_E$ of up to 75 L·min^{-1},[49] induction of anaesthesia, as well as inert gas narcosis[32]. Increased partial pressure of CO_2 (PCO_2) affects pulmonary $\dot{V}_E$ disproportionate to the level of exercise, thus, increasing the metabolic

cost of breathing as well as inducing a sense of “air hunger” (dyspnoea) that limits exercise tolerance[6] and can increase the potential to induce cardiac arrhythmias[32].

For some workers, the RPD does not seem to present a significant problem during relatively short-term use[43]. Roberge et al.[44] found that O_2 and CO_2 in the breathing space remained relatively unchanged but retention of CO_2 (increased $tcCO_2$) occurred after about one hour of wear. This level of $tcCO_2$ did not result in symptomatology but might be a cause for concern if the worker wore the RPD for longer than an hour. It is interesting to note that there were small but statistically significant differences in SaO_2 between filtering facepiece respirator (FFR) RPD with and without an exhalation valve.

5.2.2 Metabolic rate during RPD use

Wearing an RPD generally results in an increase in the metabolic rate of the wearer over and above the increase resulting from performing physical work alone. Clinically significant increases in metabolic rate as measured by increased HR, BP, RR, and elevated T_{sk} in the immediate proximity underneath the RPD have been noted at moderate and higher workloads and attributable to increased breathing resistance of the FFR[22]. In other studies in which ventilator resistance was varied, exercise tolerance to increased breathing resistance decreased[17]. These general physiological responses were also noted by Smith et al.[50] Raven et al.[40] noted a 17 % to 21 % decrement in function, a 37 % increase metabolic rate, a 24 % increase in BP, and a 27 % increase in submaximal HR. Increased breathing resistance in RPD also resulted in a decrease in O_2 uptake leading to increased O_2 deficiency during exercise, and a decrease in $\dot{V}_E$ [40]. In studies by White et al.,[62] subjects wearing protective clothing including RPD also experienced an increased physiological burden as manifested by increased HR and decreased work tolerance that worsened at higher work intensities. The increased HR and RR have also been measured in subjects wearing FFR[25]. These responses are a clear indicator of an increase in the physiological cost of wearing respirators and the greater resistance to air flow, the greater the workload and the greater the physiological effect.

5.3 Subjective feelings of discomfort

A commonly reported type of discomfort related to wearing RPD is headache. In a report by Lim et al.,[29] 37,3 % of respondents reported headache associated with wearing FFR during an epidemic of severe acute respiratory syndrome (SARS) in Asia and Canada that required analgesic medication and sick leave. Although some respondents reported that they had chronic headache that was exacerbated by RPD use, others reported that the use of the RPD alone caused headache. Lim et al.[29] suggested that the aetiopathology could be hypoxemia, hypercapnia, mechanical factors (e.g. poor-fitting respirator), or stress associated with the circumstances of use (dangerous epidemic). However, neither the gas concentrations in the breathing space of the RPD nor blood gases were measured. Therefore, it is difficult to determine the specific cause of RPD-associated headache in this study. Others have suggested that excessive pressure on superficial nerves in the head, poor RPD fit, or pulling FFR straps too tightly might be the root cause of the headaches[28].

Reports of headache during and after RPD use might also be due to exposure to an elevated level of CO_2 in the breathing environment. A report by NIOSH[2] summarized 19 studies on the effects of CO_2 on human subjects. Both the physiological responses to acute and longer term exposure were described. The results of these studies have been integrated into ISO 16976-3. In this summary, studies supported the notion that breathing CO_2 at sufficient concentrations usually resulted in a CO_2-induced headache. As mentioned in 5.2.1, breathing gas mixtures containing >6,5 % CO_2 decreased performance on reasoning tasks and subjectively increased both irritability and discomfort[45]. The discomfort experienced by breathing elevated levels of CO_2 can also influence RPD use in hazardous environments. Nevertheless, given the wide range of human tolerance to CO_2, it is likely that inhalation of even relatively low concentrations of CO_2 in the breathing space of an RPD might be responsible for headache and other discomforts in the sensitive individual[43].

Although nearly everyone who wears an RPD experiences some level of discomfort, and the tolerance to discomfort varies greatly among people,[12] there is no question that the correct fitting of an RPD is critical to wearer comfort and acceptance especially when the RPD is worn in an extreme environment[37]. An RPD that is too tight on the face, has straps or other features that create pressure on the skin might cause