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Computer vision-based objective evaluation of increase in breathing resistances of respirators on human subjects

Zhongliang Yang[a,*], Yumiao Chen[b], Zhichuan Tang[c], Miao Jia[a]

[a] *College of Mechanical Engineering, Donghua University, Shanghai 201620, China*
[b] *School of Art, Design and Media, East China University of Science and Technology, Shanghai 200237, China*
[c] *Industrial Design Institute, Zhejiang University of Technology, Hangzhou 310023, China*

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ABSTRACT

The purpose of this study was to evaluate objectively the impact of wearing respirators on breathing resistances of actual human subjects. We designed a monitor of the nasal airflow, which was composed of a full facepiece mask, a pipe for gathering nasal airflow, a monitoring line and a camera. A total of 5 normal adult volunteers were recruited in this study. Wearing the monitor, the subjects were required to sit for 1 min and walk for 1 min during wearing eight different models of respirators and without a respirator. Subsequently, the swing video of the monitoring line was collected by the camera during each breath of the subjects. The mean value of maximum swing angles of the monitoring line and the swing angle ratio were calculated through the image processing of the experimental videos. The experimental results show that the swing angle ratio during exhalation and inhalation are effective for representing exhalation resistances and inhalation resistances respectively. This is the first reported study that combines computer vision and the self-developed nasal airflow monitor to demonstrate quantitatively and objectively the exhalation resistances and inhalation resistances with the use of different respirators on actual human subjects.

1. Introduction

Respirators offer protection for men and women who need to work in the atmospherically hostile environment [1,2]. While major advances have been made in recent years with respect to improved protection capability, there has been a little effort directed toward the effects of respirators on human performance and well-being [3]. Up to now, the filter quality factor is the sole indicator of filter media performance considering both aerosol penetration and breathing resistances [4]. A higher expiratory and inspiratory resistances reduces the ease of breathing and thus causes discomfort [1]. Breathing discomfort due to increased breathing resistances is known to be the main problem with the use of respirators [1]. How to balance barrier property and breathing resistances needs human factors/ergonomics (HFE) to get involved [3].

Breathing resistances can be assessed subjectively and objectively. Although the method of subjective evaluation is simple and easy to use, it is difficult to ensure the accuracy and internal consistency of the experimental data because of the individual differences among subjects and the lack of a unified psychological index and general subjective scale [5]. Thus, some researchers pointed out that quantitative objective evaluation should be prior to the subjective opinions, comments and ratings [6].

* Corresponding author.
E-mail address: yzl@dhu.edu.cn (Z. Yang).

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Table 1
The filtration efficiency and breathing resistances of tested respirators.

Respirator number	Respirator type	Filtration efficiency level	Materials of respirators	Inhalation resistances/Pa	Exhalation resistances/Pa
1	3M 9001V	N90	Nonwovens	27	15
2	3M 9501	N95	Nonwovens	40	32
3	3M 9501V	N95	Nonwovens	41	21
4	The Green Shield mask M95V	N95	Nonwovens	40	29
5	The Green Shield mask	N95	Cotton	37	11
6	Reesfort anion anti-pollution respirator	N95	Cotton	76	45
7	Zhongti By Power anion respirator (B01N95)	N95	Nonwovens	48	32
8	Zhongti By Power anion respirator (B03N95)	N95	Nonwovens	41	29

Unfortunately, there currently exist two main problems in the methods to objectively assess the breathing resistances of wearing respirators. Firstly, the breath resistances measured by the physical and objective method is always based on simulators or human surrogates [7]. For example, breath resistances can be measured by pressure drop using a manikin-based protocol with respirators sealed on manikins [8]. The simulators are difficult to completely replace the actual human, whose breathing system is far more complicated than we can imagine [9]. Secondly, some researchers tried to assess the breathing resistances of wearing respirators on actual human subjects instead of simulators or human surrogates [1]. In that study, the authors measured nasal airflow resistances during inspiration and expiration using a standard rhinomanometry and nasal spirometry to assess objectively the increased breathing resistances with the use of N95 respirators on actual human subjects. However, their method not only interferes with the breath of subjects but also costs too much.

In order to solve these two problems, we proposed a human-in-the-loop method to evaluate the increase in breathing resistances of respirators objectively based on computer vision. Recently, computer vision technology has been developed and widely used, and has gradually been the focus of many researchers, because it has many advantages, such as flexible, low cost, non-contact, easy to get large amount of information, long distance, beneficial to achieve intelligence and automation [10,11]. In this study, we conducted a series of pilot experiments using the self-developed nasal airflow monitor to assess objectively the breathing resistances of wearing respirators on actual human subjects.

2. Materials and methods

2.1. Participants

Five healthy male subjects aged from 23 to 25 years were selected to participate in the experiment. All subjects had a routine examination to exclude recent respiratory infection and nasal deformity. Before the experiment, the subjects were briefed on the nature, purpose, methods and risk of the study, and then they were required to complete a background questionnaire about personal information such as height and weight. Their height ranged from 165 to 180 cm (Mean = 170, SD = 5.23), and weight from 52 to 70 kg (Mean = 60, SD = 6.81).

2.2. Respirator selection

In the experiment, eight respirators with similar filter efficiency (N90 and N95) but different exhalation and inhalation resistances were selected. The experimental setup was in strict accordance with the standard of GB2626-2006: Respiratory protective equipment: Non-powered air-purifying particle respirator [12]. The exhalation and inhalation resistances of these eight respirators were measured by the VelociCalc® Plus Multi-Parameter Ventilation Meter 8386 [13]. The tested results of filtration efficiency and breathing resistances of the eight respirators are shown in Table 1. "V" refers to the respirator with an exhalation valve. The tested respirators are shown in Fig. 1. More detailed description of the experimental setup, protocol and procedure can be found in Liu et al. [13] and GB2626-2006 [12].

2.3. Self-developed nasal airflow monitor

To allow an easy, accurate and standardized measurement of increase in breathing resistances of respirators on human subjects, a nasal airflow monitor was designed. It mainly contains a full facepiece mask, a pipe for gathering nasal airflow, a monitoring line and a camera. The detailed components of the nasal airflow monitor are shown in Fig. 2. The full facepiece mask was composed of transparent mask, fixator, elastic clasp, frame for full facepiece mask, connect buckle, facial sealing ring and connecting belt. facial sealing ring was made from silica gel, which can fit closely to face to avoid any air leakage. The pipe for gathering nasal airflow was made of transparent plastic, the holes on which can be used to install the monitoring line and the flange can be used to connect the pipe with the full facepiece mask. The camera can be connected with the computer through the USB plug, and it can be connected with the full facepiece mask through the support frame, support rod, adjusting rod, support rod for camera. The adjusting rod can be used to adjust the position of the camera to allow an