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Experimental investigation of the effect of thermal comfort parameters on cervical range of motion

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ABSTRACT

The most well-known ailment affecting the neck muscles is neck stiffness, caused by sharp changes in temperature, chilling of the muscles by air conditioning or drafts, and consequent painful muscle contractions. A stiff neck is typically characterized by soreness and difficulty in moving the neck – especially when trying to turn the head to the side. A stiff neck may also be accompanied by a headache, neck pain, shoulder pain and/or arm pain. Reduced cervical range of motion (ROM) is a common finding in people with neck pain. Musculoskeletal disorders continue to represent a major source of pain and discomfort as well as a significant source of workday loss and workers' compensation costs.

In this study, the effects of parameters in air conditioning such as temperature, humidity and air velocity on cervical ROM have been investigated experimentally. In this investigation, each of the three parameters was used as a variable while the others were kept constant in a controlled laboratory room, and the effects of the parameter variations were investigated. Based on the observation that individuals often enter the air conditioned room perspiring in summer conditions, both dry and sweaty conditions were examined. Finally, experimental data were assessed with ANOVA analyses, and cervical rotation was found to be influenced by temperature and air velocity, but not humidity. It was also determined that parameters (temperature, air velocity and humidity) are not effective factors on cervical motion limitation provided that indoor air conditions remain within comfort limits which are prescribed in current standards of ASHRAE Standard 55 – 2004 and ISO 7730.

1. Introduction

When examining the indoor air conditions in the air-conditioned space, it is necessary to consider human health in addition to thermal comfort. The purpose of currently used Heating, Ventilation and Air-Conditioning Systems *(HVAC)* systems is to maintain thermal comfort and good air quality within indoor environments. The main reason of a mechanically ventilated office building is to supply comfortable and healthy living environments for occupants, while maintaining minimum energy consumption.

The upper and lower parameter limits are prescribed in standards and guidelines for the indoor environment (ASHRAE Standard 55 – 2004 and ISO 7730). Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" which is assessed by the subjective evaluation. According to current standard of ISO 7730, the operative temperature shall be between 23 °C and 26 °C (i.e. 24,5 °C + 1,5 °C), the relative humidity shall be between 30% and 70% at light, mainly sedentary activity (office, dwelling, school, and laboratory) during summer conditions (cooling period). The mean air velocity shall be approximately between 0.2 m/s and 0.3 m/s at the range of 10%–20% turbulence intensity in the recommended temperature range. If the environmental conditions are inside the comfort limits recommended in this standard, it is estimated that more than 80% of the occupants will find the thermal conditions acceptable. ASHRAE Standard 55 – 2004 also involves similar proposals for comfort limits.

Recently, several studies dealing with these topics have also been carried out both experimentally and theoretically by researchers. Existing ISO standards and current activity associated

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with thermal comfort including draught, vertical air temperature difference, floor temperature and radiant asymmetry which cause mostly local thermal discomfort are described (Olesen and Parsons, 2002). Experimental investigation on human reaction to local air movements revealed that the exposure duration to air movements plays a fundamental role on air flow sensitivity (Todde, 2000). Many studies investigating the effects of thermal comfort parameters on ergonomics can be found in the literature (Broday et al., 2014; Kolb et al., 2012; Skandfer et al., 2014; Song et al., 2012).

A violent movement of the spinal column may also produce temporary whiplash. Neck pains often result from emotional tension or from working in one position for long periods (like in front of a computer screen). Musculoskeletal complaint rates continue to be high among computer users. Studies have reported musculoskeletal disorder prevalence rates of 20% to over 75% among these types of workers (Hsu and Wang, 2003; Ming et al., 2004; Hoyle et al., 2011). Available studies related to this topic can be found in the literature (Puranen et al., 2003; Reeves et al., 2005; Szeto and Sham, 2008).

Neck stiffness is typically characterized by soreness and difficulty in moving the neck – especially when trying to turn the head to the side. Neck stiffness may also be accompanied by a headache, neck pain, shoulder pain and/or arm pain, and may force the individual to turn the entire body, not only the neck, when trying to look sideways or backwards. Reduced cervical ROM is a common finding in people with neck pain (Woodhouse and Vasseljen, 2008; De Loose et al., 2009).

Various tools have been used in the literature to assess cervical ROM (Haynes and Edmondston, 2002; Tousignant et al., 2000; Jordan et al., 2000). These range from simple goniometers to most sophisticated methods such as electromagnetic 3 dimensional real-time motion analyzer systems (Agarwal et al., 2005a, b). Radiographic analysis has also been reported as a reliable method to be used for this purpose (Wolfenberger et al., 2002).

Experiments have been carried out to investigate the turbulence intensity effects on local skin temperature drop, and whether subjects' dissatisfaction with draft can be correlated to the local skin temperature drop (Wang et al., 2011). Subjects have been evaluated for change in thermal sensation as well as skin physiological properties, including skin capillary blood flow (SCBF), skin moisture, transepidermal water loss (TEWL), and skin temperature over the course of acclimation (Chen et al., 2011).

The effects of parameters such as temperature, humidity, and air velocity on cervical ROM have not been adequately studied. Based on the observation that people working or residing in an air-conditioned environment often complain from cervical mobility limitations, we hypothesize that cervical ROM is influenced from environmental conditions.

In this study, the effects of the temperature, humidity and air velocity parameter on cervical ROM are investigated experimentally. In the experiments, each of these three parameters has been used as a variable, keeping the others two constant in a controlled laboratory room, and the effects of the variable parameter have been investigated. Based on the observation that individuals often enter the air conditioned room perspiring in summer conditions, both dry and sweaty conditions were examined. The main contribution of this paper is the study of the effects of indoor air conditions on cervical ROM, addressing the following questions:

- Is cervical ROM affected by environmental conditions, and if so, which parameters and which values of these parameters cause cervical mobility limitations?
- Is cervical ROM affected by human skin conditions? Are there any differences between dry and sweaty skin conditions?

2. Experimental methodology

2.1. Subjects

Experiments were carried out in climate chambers at a university laboratory in summer months. The subjects were twenty-five healthy male university students. The study was approved by Uludag University Ethical Board and all subjects provided informed consent. Only persons in good health and with almost the same physique and body shape were allowed to participate to the experiments. The anthropometric data for the subjects are listed in Table 1. All subjects were requested to wear the same type of clothing ensemble (briefs, short sleeve shirt, long trousers, and socks) made of cotton. The clothing insulation value of the ensemble was not measured, but was estimated to be approximately 0.5 clo. In addition to independent environmental and personal variables influencing thermal response of person in air-conditioning area such as air temperature, air velocity, humidity, clothing level and metabolic rate, other factors such as age, sex, individual variations, etc may also have some effect, but are generally considered to be secondary factors. Therefore, all secondary factors were held constant as much as possible (for instance, only male subjects preferred) and subjects group were formed homogeneous in order to examine only the effects of air-conditioning parameters such as temperature, humidity and air velocity on cervical ROM. The subjects were also requested to avoid physical activities such as sports or strenuous work that could cause cervical mobility limitations, and to keep away from the extremely hot and cold places and extreme conditions in daily life for a period of one week prior to and during the six-week study period. This way, other probable contributing factors were attempted to be standardized as much as possible so that only the thermal condition effects on cervical mobility could be investigated.

2.2. Facilities and procedure

The experiments were carried out in a prefabricated climate chamber ($3.7 \times 2.4 \times 1.9$ m^3) in which the air temperature, velocity and relative humidity could be controlled. The test person was seated on a chair in the climate room, his back facing towards the air-conditioner system. The positions of the subject and the experimental apparatus, and measurement points are presented in Fig. 1. In the climate chamber, each subject was exposed to various combinations of air velocity, air temperature and relative humidity for 120 min. A computer was provided for the subjects and they were allowed to watch films and/or surf on the internet. Investigated indoor air conditions were 20 °C–26 °C with 2 °C intervals for air temperature, 40% rh to 80% rh with 20% rh intervals for relative humidity and 0.2 m/s to 0.6 m/s with 0.2 m/s intervals for air velocity. These environmental conditions are typical in the

Table 1
Anthropometric data for the subjects.

Sex	Number of subjects	Age in years	Height in metres	Weight Kg	Du Bois area m^2
Male	25	22.9 ± 2.09	1.78 ± 0.07	76.99 ± 8.98	1.94 ± 0.14