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Human factors impact of COVID-19 face mask usage for essential workers: Engineering evaluation of mask usage

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Human factors impact of COVID-19 face mask usage for essential workers: Engineering evaluation of mask usage

by

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DEDICATION

I dedicate this thesis to:

My beloved parents, Mr. Zeyad Mgaedeh and Mrs. Iftikhar Abdel-All. My Dad, who passed away before starting my graduate program in ISU but his words of encouragement and push for consistency about my dreams still ring in my ears to be today on this track. My Mom, who is my mom, father, brother and everything in this world where she worked hard to raise us by herself. She always there to hear, push and provide me endless love and without her prays of day and night, the present study would have been a mere dream.

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Tidal volume (TV): The volume of air entering or leaving the lungs during a single breath. Average value under resting conditions = 500 ml.

Tidal volume = Minute ventilation / respiratory rate

(ml/breath) (ml/min) (breath/min)

Respiratory rate (RR) or breathing frequency: The number of breaths you take per minute. The normal respiration rate for an adult at rest is 12 to 20 breaths per minute. A respiration rate under 12 or over 25 breaths per minute while resting is considered abnormal. It can be measured by counting the number of breaths for one minute through counting how many times the chest rises.

Respiratory rate = Minute ventilation / tidal volume

(breaths/min) (ml/min) (ml/breath)

Mean inhalation/inspiratory flow (MIF): Mean flow rate during inhalation phase.

Minute ventilation (MV) or Pulmonary ventilation: The total volume of air inspired and expired each minute. It can be measured with devices such as a Wright respirometer or can be calculated from other known respiratory parameters. is tidal volume multiplied by respiratory rate. In a typical adult at rest, minute ventilation is about 6000 mL/min (MV = 12 breaths per minute × 500 mL = 6000 mL/min).

Pulmonary ventilation = tidal volume × respiratory rate

(ml/min) (ml/breath) (breaths/min)

Inspiratory:Expiratory ratio (I:E ratio): The ratio of inspiratory time : expiratory time. In normal spontaneous breathing, the expiratory time is about twice as long as the inspiratory time. This gives an I:E ratio of 1:2 and is read "one to two".

Total cycle time (TCT): Which is set by the respiratory rate, is the sum of inspiratory time (t_I) and expiratory time (t_E). [60 seconds in a minute ÷ measured respiratory rate]

$$\mathbf{TCT = 60/RR}$$

$$\mathbf{TCT = T_I + T_E}$$

(sec.)

Inspiratory time (Ti): the time over which the tidal volume is delivered or the pressure is maintained (depending on the mode) in time-cycled modes either inspiratory time or IE ratio are set (flow is adjusted to ensure that the set tidal volume is delivered in that time).

Expiratory time (Te): the time over which the tidal volume is exhaled out.

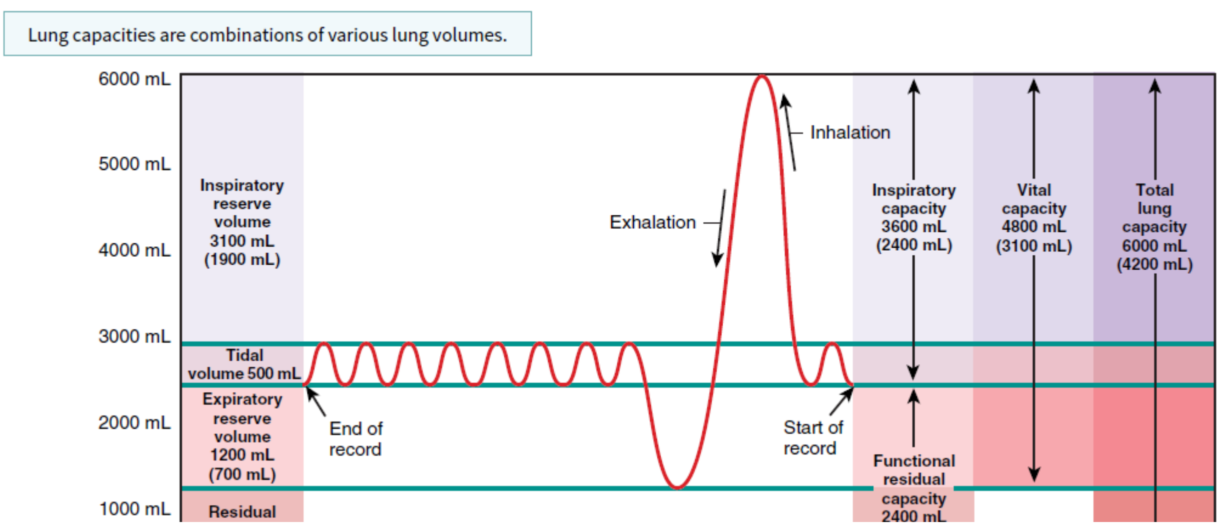

Figure 0.1. Spirogram of lung volumes and capacities. The average values for a healthy adult male and female are indicated, with the values for a female in parentheses. Note that the spirogram is read from right (start of record) to left (end of record).

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ABSTRACT

This thesis investigates the factors that affect the temperature, humidity, and heat index inside a mask (under the nose and on cheeks). Previous research found that thermal burden and stress are the leading factors to intolerances to wear a mask during work. Researchers were mainly investigating facemasks that are worn by healthcare and industrial workers. Investigating the temperature build-up inside the mask or facial skin was always done with human participation.

The work presented in this thesis, examines factors affecting retail companies' employees while wearing face masks in the COVID-19 era as the new norm of life. This study investigated the temperature, relative humidity, and heat index inside the mask without a human participant (via the use of a custom human breathing simulator). The thesis's work is divided into two studies focused on wearing different face masks and their associated impacts on different human aspects. The first study investigated how employees in retail stores use facemasks and how smoking habits, workload, athletic level, and wearing eyeglasses while using masks influence employees. It was found that these factors had impacts on human sense, psychomotor ability, psychology, cognition, work tolerance, the sensation of discomfort, and thermal sensation.

The first study's findings and the pandemic's current situation that add challenges to research humans bring the second study to the light. The second study focused on building a simulator of human breathing matching the temperature and humidity of exhaled breath. Also, build a simulator that is adjusted to several breathing rates and workloads. Moreover, this part of the work investigated the effect of the face mask types and workloads on temperature, relative humidity, and heat index inside the mask. The temperature and heat index build-up within masks is significantly affected by different face mask types and workload levels (under the nose and in front of cheeks). Overall, this work provides new insight into factors that impact employees in

retail companies. Also, this device enables the researchers to study any face mask types or face shields under different conditions without risking the individuals.

CHAPTER 1. GENERAL INTRODUCTION

Background

Respirators and face masks are the most critical component of personal protective equipment (PPE) when individuals risk exposure to fumes, vapors, gases, and particulate matters. If personnel are working in a risk position of breathing hazardous substances and doesn't commit to wearing the required face cover, substances will directly enter his lungs. Face mask-like items were dating back to the 6th century BC, and there are depictions on the doors of Persian tombs of people covering their mouths with fabric before the first occurrence of the first face mask in the 16th century (Global Times, 2020). The first face mask equipped with a whole outfit as a plague doctor suit was created by a French doctor, Charles de Lorme, in the 16th century during the later waves of the Black Death outbreak that first appeared in the early 1350s. (Tubino & Alves, 2009). As a reaction to Carl Flügge's finding that the culturable bacteria carried by the respiratory droplets (Inhalationstuberculose & Consequenz, n.d.; Luftinfection, n.d.), Johann Mikulicz wore the first surgical mask in 1987 (Gandhi et al., 2020; Strasser & Schlich, 2020). In the 1990s, the N95 was first used in healthcare settings where doctor Lien-the paved the way to respiratory mask invention by developing hard cotton masks consisting of several layers of cloths wrapped around the face (BY MARK WILSON, 2020).

Although the PPE is the last step in the hierarchy of controls when there is no profitable way to control hazards (*Hierarchy of Controls | NIOSH | CDC*, n.d.), face masks are essential protect the wearers. Researchers had studied different types of face masks in different settings of use. Face masks are mainly used in healthcare and industrial settings differing in types. Face masks with no assigned protection factor are ONE-WAY protection levels that block large-particle droplets, splashes, sprays, or splatter generated by the wearer to reach the environment and others' mouth and nose.

On the other hand, respirators are TWO-WAY of a high level of protection and filtration of airborne particles (virus and bacteria) if they properly fit with an assigned protection factor (*(5) The Difference between a Face Mask and Respirator - Why Workers Need to KNOW! | LinkedIn*, n.d.). Air-purifying respirators (APRs) and air-supplying respirators (ASRs) are the two classifications of respirators. Cloth masks are the following used mask in a low resource setting and shortage of PPE circumstances (Bartlett, 2004; Yang et al., 2011). Nowadays, the CDC recommends cloth masks to be used by the public to reserve the medical masks and respirators to first-line responders. Various face mask types had been investigated extensively as the researchers were triggered by the seriousness of filtering performance in a critical environment. Face masks were tested under various aerosols; monodisperse latex spheres and sodium chloride aerosols (Meyer et al., 1997a; Oberg & Brosseau, 2008), combustion of wood, paper, and plastic (He, Grinshpun, et al., 2013a; He et al., 2014, 2019), silica aerosol (Brossea et al., 1990), polydisperse corn-oil aerosol (Tuomi, 1985), and monodisperse dioctyl phthalate (Cooper et al., 1983). FFP2 had shown a significant efficiency performance compared to surgical masks in protecting the wearer from the environment in both short and long-term laboratory experiments (van der Sande et al., 2008). Despite the finding that all masks reduced inward particle penetration, cloth masks were the least effective in terms of protection. The finding coincided with the first randomized clinical trial of cloth masks by MacIntyre et al.. Particles penetrated nearly 97% of fabric masks and 44% of medical masks (MacIntyre et al., 2015).

On account of the discomfort, physiological and psychological effects associated with wearing a facemask, the protectiveness of face masks declined as a result of less tolerance to adhere to mask till the end of the work (Martel et al., 2013; Moore et al., 2005; Pourbohloul et al., 2005; Shenal et al., 2012). The thermal stress burden was the primary source of the subjects' discomfort (Hayashi & Tokura, 2004; Li et al., 2005). The heat build-up in the face's skin was the leading cause to terminate the study before 8 hours is over (Radonovich et al., 2009). Wearing N95 FFR for 2 hours at a low-moderate work rate significantly increased the facial skin temperature but not the core temperature (R. Roberge et al., 2012b). A comparison between surgical mask and N95, Li et al. found that the skin temperature and microclimate inside the N95 were higher than the surgical mask while simulating work by healthcare workers. Under normal conditions, the surrounding air temperature and humidity affect the facial skin temperature (Nielsen et al., 1987). Adding physical barriers such as wearing respirators or face masks created a microenvironment. The microenvironment or protective face mask dead space is the new breathing environment for the wearers, which was the critical factor for thermal stress (Li et al., 2005). Thus, the increasing facial temperature is a body adjustment to the thermal stress (Johnson, 2016). An increase in the body temperature could cause heavy sweating, clammy skin, dehydration, tiredness, headache, dizziness, nausea, cramps, and a quick, weak pulse (*Heat Wave 2019: How Summer Heat Affects the Body and Brain*, n.d.). However, a recent study conducted by (Morris et al., 2020) to investigate the effect of prolonged facemask use found that only dyspnea aggregated over time without impacting motor-cognitive performance. Besides the heat build-up inside face masks, researchers found other factors contributed to discomfort and tolerability issue: facial pressure or pain, skin irritation, difficulty breathing, and difficulty communicating (Li et al., 2006a; Nichol et al., 2008; Radonovich et al., 2009; R. J. Roberge, Coca, Williams, Powell, et al., 2010). Moreover, respirators and face masks had shown to impact human psychology (Johnson et al., 1995; Wu et al., 2011). Wearing masks aggregated the anxiety level and cut down the tolerability to work.

Motivation

Researchers had heavily studied various respirators and face masks in healthcare and industrial settings where they are primarily used to protect the wearers from hazardous and dangerous particles. The research's main focus was the face masks' efficiency and extended cover of the physiological, psychological, and thermal burden caused by covering the mouth and nose. During the COVID-19 pandemic, wearing a face mask in public settings was recommended globally and mandatory in some countries such as Venezuela, Vietnam, United Arab Emirates, Turkey, etc. (*Which Countries Have Made Wearing Face Masks Compulsory? | Coronavirus Pandemic News | Al Jazeera*, 2020), for all people who are two years old or older. Wearing a face mask is one path of others to hinder the spreading of respiratory droplets(*COVID-19: Considerations for Wearing Masks | CDC*, 2021). They are the primary mode of spreading covid-19 from an individual's mouth and nose to others while sneezing, coughing, singing, or shouting (Kutter et al., 2018; Milton et al., 2013; Stelzer-Braid et al., 2009). Throughout the pandemic, several behaviors were observed while wearing the mask among people, such as: donning off the mask to take a breath, hear well, speak comfortably, cool down the face, or stabilize the mask below the nose during work. The previous research lacks investigating wearing face masks for a long time during work considering face masks beyond the respirators and medical masks. Thus, there is a strong motivation to study the impact of workload levels, face mask types, smoking status, athletic levels, caffeine intakes, wearing eyeglasses on human perception of sensation and temperature of different body regions (body, lips, and cheeks under mask temperature).

The first motivation triggered the second one to build a human breathing simulator. COVID-19 pandemic had imposed numerous restrictions on human interactions such as social distancing, mandate faces covering, virtually working when it's critical, travel restriction, etc. Also, the research area had been significantly impacted by COVID-19, particularly where human participation is required. Building a human breathing simulator matching the exhaled breath's temperature and humidity will serve in COVID-19 such circumstances. Furthermore, the literature showed that thermal burden and stress were the leading factors to discomfort and work inconsistency. In that context, researchers' main focus was on respirators and medical masks. Also, the conditions where masks were tested were limited to avoid exposing participants to risk. Therefore, having a breathing simulator will help investigate various face masks, respiratory rates, and workloads.

Research Objectives

Three areas are the main focus of this research: 1) the impact of wearing face masks on workers in retail companies during the Covid-19 era, 2) development of a human breathing simulator, 3) impact of different types of facemasks, job demand, and respiratory rates on temperature, humidity, and moisture build-up inside the mask.

This study's first objective is to investigate the impacts of workload, facemask type, athletic level, caffeine intake, smoking status, and wearing eyeglasses while retail staff wears face masks. This study will analyze these characteristics impact human sense, psychology, perception, the sensation of discomfort, psychomotor capacity, and work tolerance during the COVID-19 era.

The second objective of this study is to build a human breathing simulator. The simulator simulates the temperature and humidity of exhaled breathing air. Also, the breathing simulator is adjustable for different breathing volumes and respiratory rates.

This research's third objective focuses on testing different facemask types and workloads, affecting the temperature, humidity, and heat index build-up inside the mask. The results of this testing will be compared with the workers' in retail companies' results.

Thesis Organization

This thesis is divided into five chapters. Chapter 1 presents a brief background of the research topic, highlights the motivation toward this topic, and presents the objectives. Chapter 2 consists of literature reviews starting by illustrates the history of face mask along the time, reviews all topics that had been studied in the context of face masks, such as the efficiency of face mask, the effect of face mask on human physiology, sense, performance, cognitive ability and shortage of respirators and facemasks. A self-administrated survey study on the impact of workload, facemask type, athletic level, caffeine intakes, smoking status, and wearing eyeglasses while wearing face masks on workers in retail companies in terms of human sense, psychology, perception, the sensation of discomfort, psychomotor capacity, and work tolerance during the Covid-19 era is presented in a journal paper format in Chapter 3. The development of a breathing simulator to estimate the effect of mask type, job demand, and respiratory rate on the build-up temperature, humidity and moisture will be presented in Chapter 4. The final chapter wraps up the conclusions drawn from this research, spotlights contributions in this area, and specifies this study's limitations as a direction for future work.

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CHAPTER 2. RELATED WORK

History

Despite the varieties of design, material, and using purposes of face mask nowadays, face mask had been developed and changed throughout history and across the globe. Ahead of the first occurrence of the first face mask in 16th century, there were face mask-like objects dated to the 6th century BC and there are images on the door of Persian tombs of people covered their mouth by cloth (Global Times, 2020). In 13th century from 1279 to 1368, Marco Polo recorded that the servants were covering their mouth and nose with silk scarves to prevent their breath impacting the food's smell and taste while serving the meal for the emperor in Yuan Dynasty in China (Global Times, 2020). In 16th century during the later waves of the black death epidemic that first occurred in early 1350s, the first face mask associated with full outfit as plague doctor costume developed by a French doctor, Charles de Lorme (Tubino & Alves, 2009). The costume consisted of large leather tunic, gloves, boots, hat, and a bird's beak mask as shown in figure 1. Plague doctors filled the half foot long nose with fragment herbs and spices to filter and ward off the exhaled air from miasma which know as bad odor or air as they believed at that time it causes the disease (O'donnell et al., 2020; Strasser & Schlich, 2020). In 1897, the first surgical mask was worn by Johann Mikulicz who was head of the surgery department of the University of Breslau (now Wroclaw, Poland) as a response to experimental findings of the German bacteriologist Carl Flügge's that the culturable bacteria carried by the respiratory droplets (Gandhi et al., 2020; Strasser & Schlich, 2020). The born mask was described as "a piece of gauze tied by two strings to the cap, and

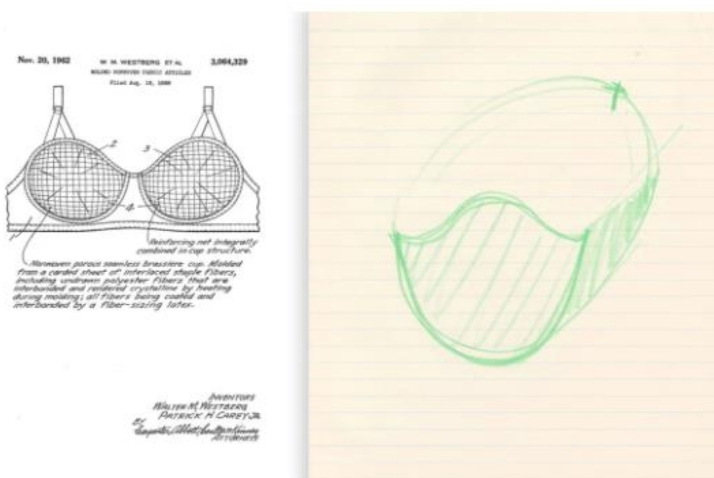
Figure 2.1.Plague doctor outfit. Right: plague doctor mask displayed in Berlin's Deutsches Historisches Museum in Germany

sweeping across the face so as to cover the nose and mouth and beard". Then surgeons started wearing masks inside the operating room and the mask widely spread and developed afterwards.

The first milestone toward the inventing the respiratory mask was by the doctor Lien-teh Wu, who elaborated the surgical mask that prevent the transmit of user's breath droplet into hardier cotton mask that filter the inhalation air by adding several layers of cloths and wrapped around the face securely (Figure 3) during Manchurian plague (Northern China) between 1910 and 1911 (BY MARK WILSON, 2020). Wu's mask spread significantly ever then and was used during the Spanish flu in 1918 and companies produced the same mask to fight the flu. During 1930s, the disposable papers masks started to replace the washable and reusable mask for a single use only (O'donnell et al., 2020). In 1961, a new bubble surgical mask invention released by 3M that was used later as dust mask as they found it didn't block pathogens (BY MARK WILSON, 2020). The model was designed by Sara Little Turnbull inspired from the cup of bra where she was designing the molded bra. In 1972, the first single-use N95 "dust" developed by 3M was approved. For decades, the N95 was used mainly in industries till 1990s where N95 standards were adjusted to fit healthcare settings (BY MARK WILSON, 2020). The face mask was limited to be used inside the operating room until the Manchurian plague (1910-1911) and influenza pandemic (1918-1919), where the medical workers and patients started wearing it as a mean of protective guard against the infectious disease. Nowadays, the most common used personal protective equipment in the health care fields are respirators and surgical mask (*Use of Respirators and Surgical Masks for Protection | NIOSH | CDC*, n.d.)

Healthcare workers in "anti-plague masks" during the 1911 Manchurian plague. [Photo: courtesy University of Cambridge/Centre for Research in the Arts, Humanities and Social Sciences (CRASSH, The University of Cambridge)/The University of Hong Kong Libraries]

Figure 2.2. Wu's mask during the Manchurian plague



Trumbull's sketch for a surgical mask, stemming from her 3M bra design. [Image: © Center for Design Institute]

Figure 2.3. First design on N95 mask by <u>Sara Little Turnbull</u>

Respirators' efficiency and fit test

Both of the respirators and surgical mask are the means of controlling the contagion. Particles' sizes and types that blocked by the respirators and surgical mask are different. Surgical mask shields the mouth and nose by hindering the reach of large droplets, splashes, sprays, or splitter that may contain germs (*N95 Respirators, Surgical Masks, and Face Masks | FDA*, n.d.-a). On the other hand, respirators block inhaling dusts, fumes, vapors, small and large droplets that carried infectious agents (*1910.132 - General Requirements. | Occupational Safety and Health Administration*, n.d.; *Respiratory Protection. - 1910.134 | Occupational Safety and Health Administration*, n.d.). Researchers studied the efficiency of the surgical mask and respirators filtration in different conditions and scenarios. In 2013, He et al. investigated the performance of the N95 respirator and surgical mask (SM) as a function of particle size under four different values of mean inspiratory flow (MIF) and five values of breathing frequency measuring the filter penetration (P_{filter}) and total inward leakage (TIL). P_{filter} is the ration of concentration of the particles inside and outside the N95/SM. TIL reflects the total particles penetrated the respirator or the surgical mask. As a result of testing N95 and SM on advanced manikin head, the particle size and MIF affect the P_{filter} and TIL more significantly than the RR. Researchers defined that there are two ways that the particles can go inside the mask: filter medium and faceseal leakage (Grinshpun et al., 2009). It was found that faceseal leakage penetration exceeded the penetration through the filter medium while testing N95 respirator and SM on breathing manikins that used the prerecorded human breaths that provide deep understanding in compared to the constant flow (Grinshpun et al., 2009). Grinshpun et al. illustrated that number of factors contributed to the faceseal leakage penetration such as facial/body movement, breathing intensity and facial dimension. Proceeding from the two main approaches of NIOSH and OSHA that knowing the filter efficiency of respiratory protection and ensuring the proper use and device selection are the two main factors of respiratory protection, Oberg and Brosseau (2008) studied 9 different surgical masks (Types: surgical, laser, and procedure. Models: cup, flat, and duckbill) that are representative of hospital and dental settings in terms of filter efficiency and fit performance. They found that the surgical mask doesn't have the criteria to be used as respiratory protective device and the dental masks settings collected more particles compared to hospital masks settings. Also, they figured out an outward leakage while measuring the inward leakage. They recommended the use of surgical N95 respirators for respiratory and wound infection in hospital care settings as they are certified by both FDA and NIOSH. Investigating the filter efficiency extended to cover cloth mask and more widely in 2020 during the COVID-19 pandemic. As the CDC recommended the uses of cloth mask to cover mouth and nose while being in public because of the N95 respirators shortage that must be reserved for the front line health care workers (*N95 Respirators, Surgical Masks, and Face Masks | FDA*, n.d.-b) where the shortage in personal protective equipment (PPE) in Asian countries and West Africa during the arising of infectious diseases enforce the health workers to wear cloth mask. Prior the merging of medical mask in mid-19th and later replaced by respirators, cloth/cotton mask (Quesnel, 1975; *Use of Cloth Masks in the Practice of Infection Control - Evidence and Policy Gaps | Semantic Scholar*, n.d.) had been used by health care workers to protect themselves (Dis, 2016; Yang et al., 2011). The reusability and cleaning options of cloth masks candidate it to be the choice in resource-poor setting in contrast of high resource setting where all cloths masks had been replaced by disposal medical masks and respirators.

Home-made cloth mask reduce the aerosol exposure but in less effective way compared to surgical mask which is less effective than respirators (Davies et al., 2013; Quesnel, 1975; van der Sande et al., 2008; Yang et al., 2011). However, the highest infection was for healthcare workers wearing cloth mask (MacIntyre et al., 2015). MacIntyre et al. (2015) measured the Clinical respiratory illness (CRI), influenza-like illness (ILI) and laboratory- confirmed respiratory virus infection among 1607 hospital workers working in high-risk wards randomly assigned to medicals masks and cloth masks over 4 consecutive weeks.

Respirators impact on human physiology, sense, performance, and cognitive ability

Filter efficiency and facial test of the respiratory protective equipment (RPE) are well documented area because of their critical role as a barrier between wearers and contaminated air whether it has virus, bacteria or pollutants. For instance, during the SARS outbreak in 2003, it had been suggested that wearing facemask aid in reducing the contagion (Wong et al., 2004). However, other researchers found that the respiratory protective equipment's had effect on respiratory, breathing pattern, wave shape, anaerobic threshold (Louhevaara, 1984), cardiovascular and musculoskeletal systems, human thermoregulation, moisture retention, subjective sensations, and work tolerance.

In 2005, a study conducted by Li et al. measured the effect of the N95 and surgical facemask with and without nano-functional treatments on heart rate, thermal stress and subjective sensations while subjects walked on treadmill in intermittent exercises at 25ºC and 70% RH simulating hospitals conditions. They found that the microclimate, skin temperatures and absolute humidity were lower inside the both types of the surgical mask compared to the both type of N95. N95 recorded higher participants' heart rate and overall discomfort compared to the surgical mask as well as the feeling of unfit, tight, itchy, fatigued, odorous and salty. Increasing the heart rate explained by the shortage of oxygen delivery (Ganong, 1997) because of breathing resistance as the impact of the microclimate temperature, humidity and skin temperature inside the mask (Li et al., 2005). Significant increase in heart rate was associated with three different levels of work load sorted as light, moderate and heavy workload performed on treadmill for four settings for each:

without RPE, valve RPE, half-face RPE and full-face RPE. Full-face RPE reported a significant increase in heart rate compared to other RPE (Khodarahmi et al., 2013). However, there is no significant change in heart rate while wearing valve and half-face RPE.

Discomfort recorded by the subjects was mainly caused by the thermal stress burden (Hayashi & Tokura, 2004; Li et al., 2005; White et al., 1991). Louhevaara (1984) found that "All types of respirators alter the user's natural breathing pattern and cause at least subjective sensations of discomfort" as a result of reviewing the effect of respirators on human physiology. Thermal heat built up in the face's skin recorded 58 complaints as the leading reason to terminate the session before complete 8 hours (Radonovich et al., 2009). Followed by pressure or pain (25), dizzy or difficulty concentrating (19) then visual degrading included fogging (15). Studies by Jones (1991), White et al. (1991), Laired et al. (2001), Laired et al. (2002), and Radonovich et al. (2009) coincided with the findings that thermal discomfort associated with facial heat that cause work intolerances and lack of sticking to the RPE till the end of the shift.

The difference between high humidity and heat of the expired air inside the mask and the environment affect the moisture of respirators (Li et al., 2006). Maclntyre et al. (2015) reported that infection exaggerated by using the cloth mask because of poor filtration and moisture retention. In another study, Roberge et al. (2010) found that the existence of exhalation valve in filtering face respirator didn't affect the moisture retention where the moisture gain for FFR with and without valve is 0.11g and 0.13g respectively explained by the short duration of use session and low exertion. Khaw et al. (2008) found that breathing resistance could increase because of the moisture retention in FFR after prolong use.

Shortage of respirators and facemasks

Protecting the front-line workers by supplying them with the required PPE had been always the most important concern during airborne infectious outbreaks and pandemics. The most critical component of the PPE for health care workers is filtering facepiece respirators where N95 FFR is the most used FFR and had been certified by NIOSH followed by surgical mask which slower the transmission of the infectious particles. In 2006, CDC had estimated the need of at least 1.5 billion medical masks for healthcare workers and 1.1 billion for the public in case of sever influenza pandemic. Thus, researchers were always looking for solutions to extend the useful life of the N95 FFR and found that wearing surgical mask as outer barrier extend N95 useful life as found by the Institute of Medicine (Dis, 2016). As previously summarized that wearing respirators standing alone had physiological impact, by adding surgical mask as outer layer R. J. Roberge et al. (2010) found that there is no significant increase in physiological variables, comfort scores, exertion scores, and moisture retention. However, the oxygen concentrations decreased in the dead space for FFR with and without exhalation valve at simulated stationary work and bedside nursing patient care activities, respectively. Currently, the world is overwhelmed with the shortage of N95 respirators due to the coronavirus disease. Researchers had suggested a low cost and fast decontamination protocol to facilitate the reuse of N95 (Daeschler et al., 2020). They found that at 70ºC, 0% humidity for 60 min, thermal disinfection deactivated SARS-Cov-2 without destroying the function and structural integrity of four different types of N95 respirators. N95 respirators' microfibers degrade at 130ºC and SARS-CoV-2 inactivated by heating for 5 minutes at 70ºC (Guillory, 2007). Moreover, thermal disinfection was successful to eliminate E-coli colonies when respirators exposed to 70ºC, 50% humidity for 60 min (Daeschler et al., 2020).

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CHAPTER 3. COVID-19 FACE MASK SURVEY

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Abstract

Wearing a face mask in public settings has been recommended internationally and made mandatory in some countries after the World Health Organization declared the COVID-19 outbreak a pandemic. It rapidly became the new norm of human interaction. This study investigated how employees in retail stores use facemasks and how smoking habits, workload, athletic level, and wearing eyeglasses while using masks influence employees. Surveys were distributed to retail employees via emails. Results showed that smoking and workload interaction led significantly to slower motion response, cause itchiness and tightness. Also, smokers showed less tolerance to work till the end of the shift and higher body, lip, and cheeks temperature when compared to nonsmokers. The workload was found to have a negative impact on the heat build-up within the mask. Also, vision ability significantly declined while wearing eyeglasses and having the mask on. Stress is slightly significantly affected by the interaction of wearing eyeglasses and face mask types. A significant effect was found between athletic employees and not in rating overall discomfort.

Keywords: smoking, wearing eyeglasses, workload, Retail Company, face mask, COVID-19

Introduction

During the COVID-19 pandemic, wearing a fitted face mask covering the mouth and nose in public settings for people ages two years and older was recommended globally and mandatory in many countries, such as Venezuela, Vietnam, United Arab Emirates, Turkey, etc. (Al Jazeera., 2020). Wearing a face mask is one path to hinder the spread of respiratory droplets, which is the primary mode of spreading COVID-19 from an individual (CDC, 2020). This droplet spread can transmit to others during sneezing, coughing, singing, or shouting (Milton et al., 2013; Stelzer-Braid et al., 2009). Besides using the face mask, the Centers for Disease Control and Prevention (CDC) recommends handwashing with soap for twenty seconds or hand sanitizing with 60% alcohol and six-foot physical distancing (MacIntyre et al., 2020) from others (CDC, 2020). From the beginning of the COVID-19 pandemic to February 24, 2021, more than 111 million confirmed cases had been reported to the World Health Organization (WHO), with more than two million global deaths. Before the vaccine, nations worldwide applied various measures to slow down the number of infectious cases and "flatten the curve.

Covering the mouth and nose is the new normal for everyone. In contrast, previously, the face mask was only common among health care workers, front-line responders, and individuals at risk of exposure to fumes and vapors gases and particulate matters. If personnel is working in a risk position of breathing hazardous substances and do not commit to wearing the required face cover, substances will directly enter their lungs.

Investigations for the impacts of face masks on workers within health care and industrial settings are well documented. Researchers found that the respiratory protective equipment (RPE) affects respiration, breathing patterns, wave shape, and anaerobic threshold. Further, they impact cardiovascular and musculoskeletal systems, human thermoregulation, moisture retention, subjective sensations, and work tolerance. Studies by Jones (1991), White et al. (1991), and Laired et al. (2002) coincided with the findings that thermal discomfort, associated with facial heat, caused work intolerances and lack of sticking to the RPE until the end of the shift.

Thus, there is no research about facemasks usage to the best of current knowledge and their impacts on employees in retail companies. Therefore, this study investigates the impacts of wearing facemask on retail employees considering their smoking habits, workload, athletic level, and wearing eyeglasses. These factors' impacts on human sense, psychomotor ability, psychology, cognition, work tolerance, the sensation of discomfort, and thermal sensation during the COVID-19 era will be analyzed.

Methods

Ethics and Informed consent

This study was an online self-administered questionnaire provided to the responders by an email titled "**Effects of wearing face masks on workers' performance, Productivity, perceptions, and senses during Covid-19 pandemic**". The institutional review board of Iowa State University approved the study protocol as exemption research where the individuals' identities were not ascertained, directly or through identifiers linked to the subjects (Appendix. IRB approval letter). Data was collected between the beginning of December 2020 and the beginning of February 2021. Individuals working in retail companies in all available positions and wearing face masks while working were the target population for this study as all workers are required to wear face masks in retail companies. Electronic consent was obtained at the beginning of the survey, where the agree option took the participant into the survey questions while the disagree option terminates the survey. The survey started with a brief description of the research and the purposes, indicating that participation is voluntary and anonymous, estimated time needed to complete the survey, contact information for questions and concerns, and eligibility criteria to participate in the study.

Instrument

The survey questions were developed based on the observations of workers' attitude in retail companies while working and based on self-experience while wearing the face mask performing our jobs. The final version of the survey is divided into five sections, a total of 49 questions (26 single choice questions, 11 text entry questions, and 12 rating scale questions) expressed in simple English language. In rating scale questions, respondents select numbers between 0 to 10 that best reflect their responses. The first section was addressing demographic and general information such as gender, race, age, education level, personal income, smoking status, having respiratory disorders or problems, and wearing eyeglasses or not. The second section covered Retail Company related information such as current position, full or part-time employment, workload, employment length, and shift. The third section consists of covid-19 related questions asking about covid-19 worries, previous mask wearing experience, and mask type used during working hours and daily life. The fourth section comprises how the mask affects human performance, psychology, perception, psychomotor ability, work tolerance, sense (hearing, vision), and method of donning off the mask during the shift. In the final section, participants were asked to self-asset and rate their perceptions of sensations of discomfort (humidity, heat, breathing resistance, itchiness, tightness, saltiness, feeling unfit, odor, fatigue, and overall discomfort) (Li et al., 2005), rate body, lip, and cheeks temperature under the mask and rate how much they like wearing a face mask. The survey ended up with an open-ended question asking, "what annoys you most about face masks?".

Statistical analysis

R software was used for statistical analysis of the survey data. For categorical groups, a chi-squared test was applied. For other data, Scheirer–Ray–Hare test was used. Further, Spearman's correlation was performed to test the correlations. Frequency analysis and cross-tabulations were also used to analyze demographic and participants' characteristic data. Shapiro-Wilk test was applied to check if the variables are normally distributed. A p-value of <0.05 was considered as a statistically significant difference among groups.

Pre-check the data

```
        Shapiro-Wilk normality test

data:  data$Heat
W = 0.8894, p-value = 3.969e-06
```

Figure 3.4.Shapiro test for heat

```
        Shapiro-Wilk normality test

data:  data$Humidity
W = 0.90426, p-value = 1.659e-05
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Figure 3.3. Shapiro test for humidity

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        Shapiro-Wilk normality test

data:  data$Ithiness
W = 0.88742, p-value = 3.307e-06
```

Figure 3.1.Shapiro test for itchiness

```
        Shapiro-Wilk normality test

data:  data$Breathing.resistance
W = 0.8984, p-value = 1.043e-05
```

Figure 3.2.Shapiro test for breathing resistance

```
        Shapiro-Wilk normality test

data:  data$Saltiness
W = 0.86398, p-value = 4.315e-07
```

Figure 3.5. Shapiro test for saltiness

```
        Shapiro-Wilk normality test

data:  data$Tightness
W = 0.87706, p-value = 1.308e-06
```

Figure 3.6. Shapiro test for tightness

```
        Shapiro-Wilk normality test

data:  data$Odor
W = 0.86217, p-value = 3.72e-07
```

Figure 3.7.Shapiro test for odor

```
        Shapiro-Wilk normality test

data:  data$Feeling.infit
W = 0.89102, p-value = 4.613e-06
```

Figure 3.8.Shapiro test for feeling unfit

```
        Shapiro-Wilk normality test

data:  data$Overall.discomfort
W = 0.89586, p-value = 7.287e-06
```

Figure 3.9.Shapiro test for overall discomfort

```
        Shapiro-Wilk normality test

data:  data$Fatigue
W = 0.88025, p-value = 1.731e-06
```

Figure 3.10.Shapiro test for fatigue

```
        Shapiro-Wilk normality test

data:  data$Lip.temp
W = 0.9297, p-value = 0.0002817
```

Figure 3.12.Shapiro test for lip temperature

```
        Shapiro-Wilk normality test

data:  data$Body.temp
W = 0.88525, p-value = 3.061e-06
```

Figure 3.11.Shapiro test for body temperature

```
        Shapiro-Wilk normality test

data:  data$Slowerinmotion
W = 0.85216, p-value = 1.914e-07
```

Figure 3.13.Shapiro test for slower in motion

```
        Shapiro-Wilk normality test

data:  data$Hearing
W = 0.79291, p-value = 2.577e-09
```

Figure 3.14.Shapiro test for hearing

```
        Shapiro-Wilk normality test

data:  data$Vision
W = 0.86845, p-value = 6.258e-07
```

Figure 3.15.Shapiro test for vision

```
        Shapiro-Wilk normality test

data:  data$Cheeks.temp
W = 0.92091, p-value = 0.000116
```

Figure 3.16. Shapiro test for cheeks temperature

```
        Shapiro-Wilk normality test

data:  data$Movementrestriction
W = 0.87759, p-value = 1.371e-06
```

Figure 3.17. Shapiro test for restriction in movement

```
        Shapiro-Wilk normality test

data:  data$doingyoujobortaskquicklytotakebreaktotakeofftheface.mask
W = 0.90447, p-value = 1.694e-05
```

Figure 3.18.Shapiro test for doing the task quickly

```
        Shapiro-Wilk normality test

data:  data$Stress
W = 0.86908, p-value = 6.598e-07
```

Figure 3.20.Shapiro test for stress

```
        Shapiro-Wilk normality test

data:  data$timetounderstandothers
W = 0.87855, p-value = 1.491e-06
```

Figure 3.19.Shapiro test for time to understand others

Results

Demographic and company-related data

A total of 88 workers received the questionnaire through an online link, among which 82 workers participated, and six workers disagreed to participate. Thus, 82 respondents were included in the descriptive and statistical analysis. The most frequent age range was 25-34 years (44%), followed by 18-24 years (40%), where 56.1% (n=46) were full-time employees and 42.68% (n=35) part-time employees. In the mean of workload level, 13.41%, 45.12%, 21.95%, and 18.29% reported that they work in low, medium, high, and strenuous workload positions, respectively. Detailed descriptive data regarding the demographic and related company information of participants are presented in table1.

Covid-19 related information

Participants showed compliance to wear a face mask out of the working hours (64.63%) with no significant differences of gender across all ages as they believe that covid-19 is a dangerous pandemic (p=0.04918) and worried about being infected with the coronavirus (p=0.02268). Deep insight, 46% were worried about getting infected or transferring it to other people if they are carrying the coronavirus without showing symptoms, 23% worried about getting infected, 15.85% worried to transfer it to others if they are carrying the virus. Surgical masks were documented as the more frequent mask used during and out of working hours. The staff chooses to use exhaled valve respirators (n=23, 28.05%) after surgical masks (n=36, 43.90%) during the working day. Cloth masks and respirators with exhaled valves, on the other hand, were stated to be used similarly out of working time (n=20 each, 24.39% each) after the surgical mask (n=32, 39.02%). Cotton fabric was found to be the most used material for cloth masks during working.

Table 3.1.Demographic and related company characteristics of the participants.

	Demographic factors	**Frequency**	**Percent**
Gender	Male Female Prefer not to answer Other, please specify NA	53 27 2 0 0	64.63% 32.93% 2.44% 0.00% 0.00%
Age range	18-24 25-34 35-44 45-54 55-64 65 and above NA	33 36 9 3 1 0 0	40% 44% 11% 4% 1% 0% 0%
Education level	Less than high school degree High school graduate (high school diploma or equivalent including GED) Some college but no degree Associate degree in college (2-year) Bachelor's degree in college (4-year) Master's degree Doctoral degree Professional degree (JD, MD) NA	5 19 5 12 33 7 1 0 0	6.10% 23.17% 6.10% 14.63% 40.24% 8.54% 1.22% 0.00% 0.00%

Table 3.1. Continued

	Demographic factors	Frequency	Percent
Smoking status	Yes No Sometimes NA	44 33 5 0	53.66% 40.24% 6.10% 0.00%
Respiratory disorders or problems	Yes No NA	15 67 0	18.29% 81.71% 0.00%
Consume caffeinated drinks	Yes No NA	71 11 0	86.59% 13.41% 0.00%
Wearing eyeglasses	Yes No Sometime	27 37 18	32.93% 45.12% 21.95%
Position	Sales Associate Cashier Customer Service Representative Visual Merchandiser Buyer Store Manager Assistant Store Manager Inventory Control Specialist Other, please specify NA	7 8 5 4 3 5 19 4 26 1	8.54% 9.76% 6.10% 4.88% 3.66% 6.10% 23.17% 4.88% 31.71% 1.22%
Working period	Less than 6 months 6 months – 1 year 1-2 years 3-5 years 6-10 years Over 10 years NA	13 9 19 27 9 2 3	15.85% 10.98% 23.17% 32.93% 10.98% 2.44% 3.66%

Face mask during the shift

Face mask type, workload level, smoking status, wearing glass or not, athletic level, consuming caffeine or no were statistically analyzed to determine if they significantly influence human sense, psychomotor ability, work tolerance, human sensation. Also, the face mask type and workload were statically analyzed their interaction with the rest of the factors.

Human sense (Vision, Hearing)

Respondents reported their vision and hearing sense while wearing face mask during the shift on a Likert scale from 0-10. Vision sensing is significantly influenced only by wearing eyeglasses factor ($p<0.05$) as shown in figure (5). There is a significant difference among people who are wearing eyeglasses compared to not wearing them. Of the workers, 36.59% reported that they took off the mask for reading or seeing, 36.59% didn't take off the mask to read or see, and 20.73% took off the mask sometimes to read or see more clearly. Any of the factors did not influence the ability to hear others well during the work.

Figure 3.21. Rating of vision sense during the shift

Psychomotor ability

Psychomotor ability was addressed by asking the respondents if they feel that their movements become more restricted and slower in motion while the mask is on rating from 0 to 10. Smoking status and workload levels Interaction showed a significant effect on movement restriction (p=0.03) and slower in motion responses (p=0.04). Figure (7) showed that movement becomes more restricted for smokers working in a high and strenuous, demanding job. Figure (6) revealed that smokers who are smokers tend to become slower in motion as the workload increases.

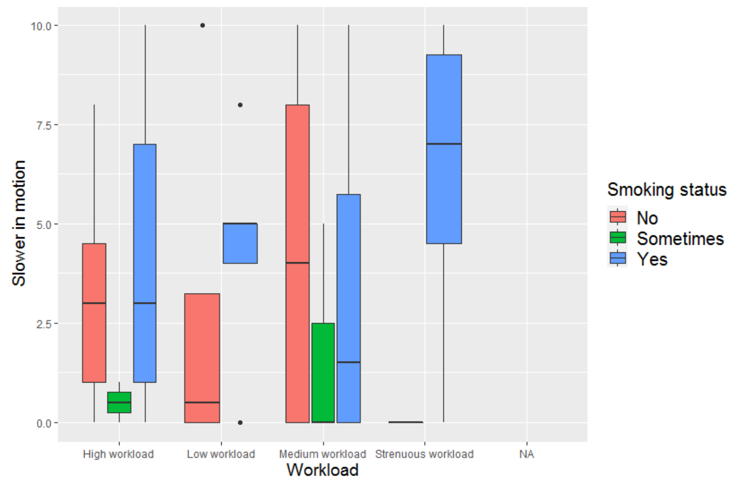

Figure 3.22.Interaction of smoking status and workload vs. rating of being slower in motion

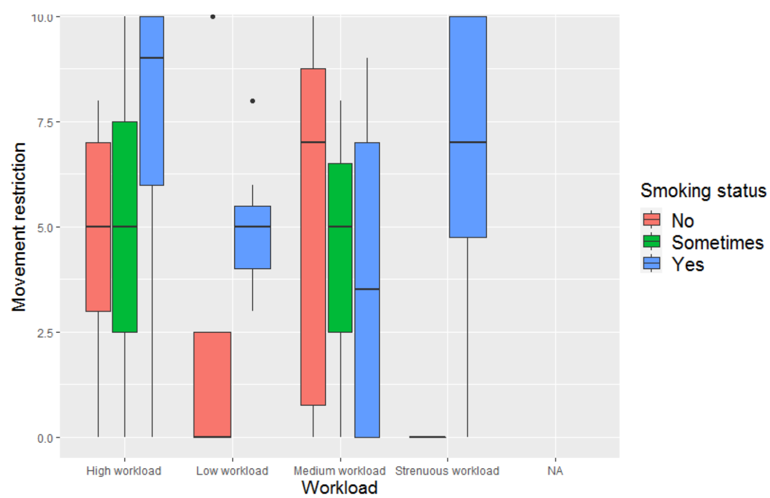

Figure 3.23. Interaction of smoking status and workload vs. rating of movement restriction

Human psychology and cognition

No significant factors affect the respondents" stress levels during their job except the interaction of face mask type and wearing eyeglasses or not (p=0.045). The same interaction showed an influence on the workers' response time to understand what others asked (p=0.029).

Figure 3.25.Interaction of wearing eyeglasses and facemask type vs. rating of stress

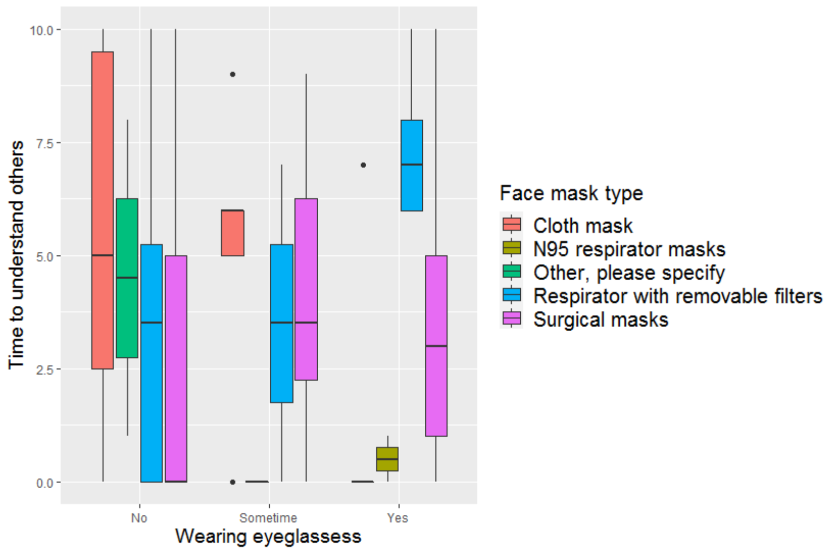

Figure 3.24.Interaction of wearing eyeglasses and facemask type vs. rating of time to understand others talk

Work tolerance

The finding indicated that facemask type and workload don't significantly affect the workers' tolerance to keep the mask on for the whole shift. However, 37.80% sometimes take a face mask off during work and then donned it back, 30.49% always take it off during the shift, and 25.61% didn't take it off. Smokers tend to do their task quickly and wrap it to take the break and don off the mask compared to nonsmokers (p=.04), as shown in figure (10). Spearman correlation test conveyed that there is significant positive correlation between the attitude of doing the work quickly to take break and humidity (p=0.0004, rho=0.38), heat (p=1.556e-05, rho=0.46), breathing resistance (p=1.999e-07, rho=0.543), itchiness (p=1.124e-06, rho=0.51), tightness (p=5.199e-10, rho=0.623), saltiness (p=5.883e-08, rho=0.5589), feeling unfit (p=2.914e-09, rho=0.60), odor (p=0.015, rho=0.269), fatigue (p=3.004e-09, rho=0.60), overall discomfort (p=3.77e-10, rho=0.627), lip temperature (p=0.0049, rho=0.311), cheeks temperature (p=0.019, rho=0.264), and stress (p=1.565e-08, rho=0.578).

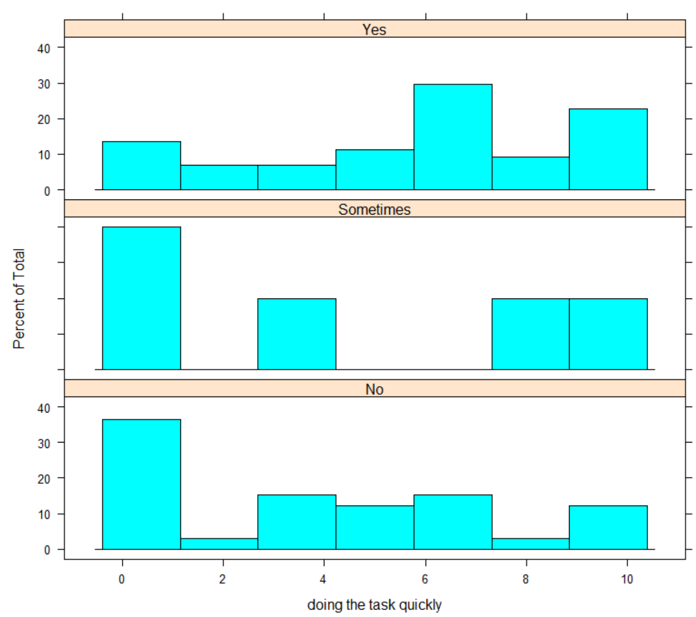

Figure 3.26. Histogram of work tolerances for smoking status

Face mask at the end of the shift

Human sensation of discomfort

Respondents were asked to rate their ten human sensations of discomfort at the end of the shift. Feeling unfit was significantly affected by the face mask type (p=0.041). Workload significantly affects heat only (p=0.011). Workload and smoking interaction significantly impact tightness (p=0.0244) and itchiness (p=0.01). Also, the itchiness was affected by smoking and face mask type interaction (p=0.016). Overall discomfort was showed significant differences in the context of athletic level (p=0.02). No significant difference was found in the subjective rating of humidity and breathing resistance.

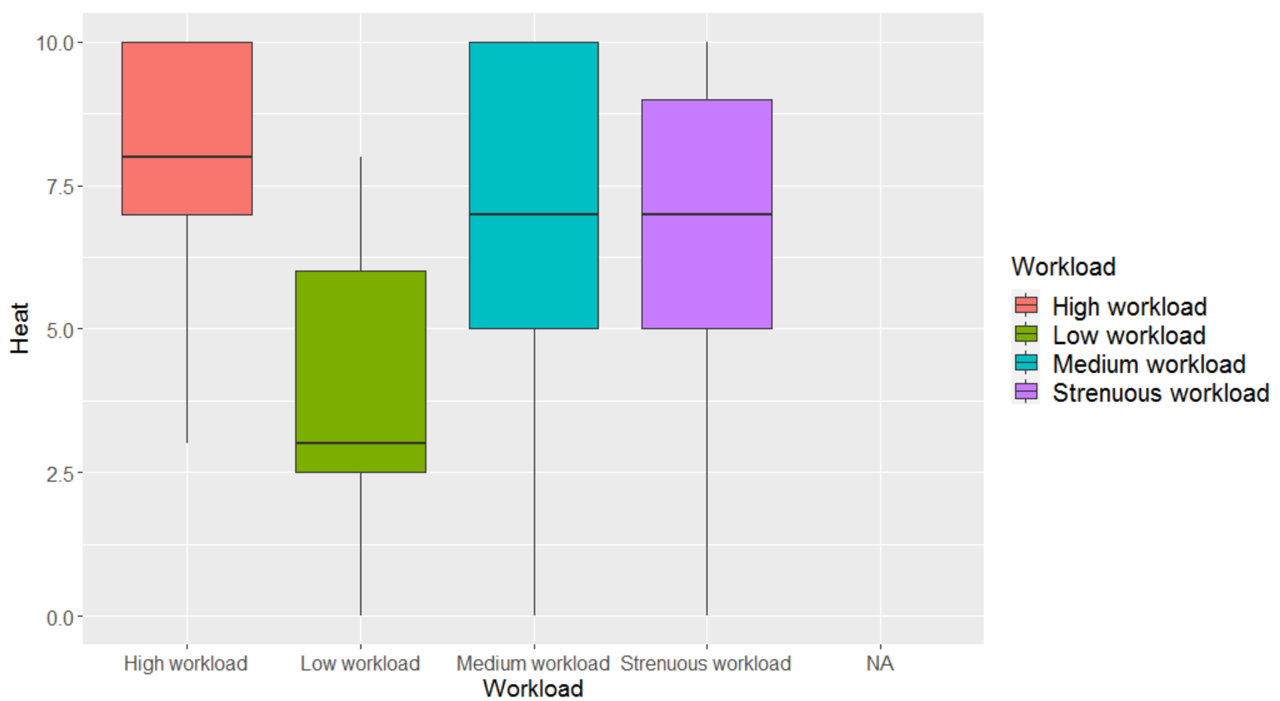

Figure 3.27.Rating of Heat inside mask at end of shift for different workloads

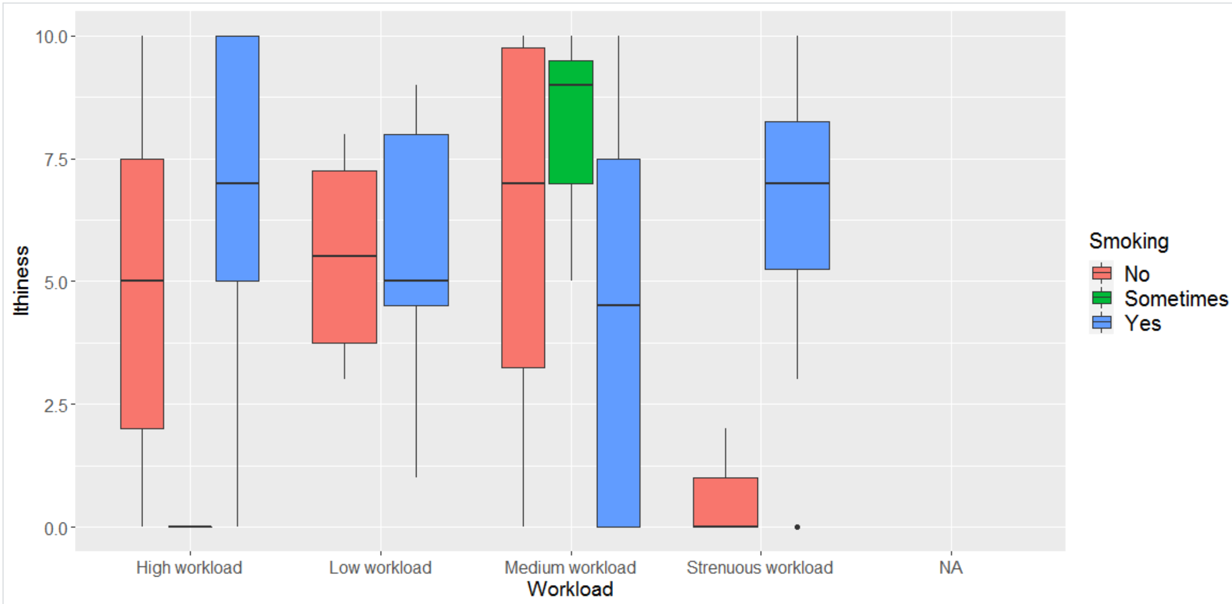

Figure 3.28.Interaction of smoking status and workload vs. rating of itchiness

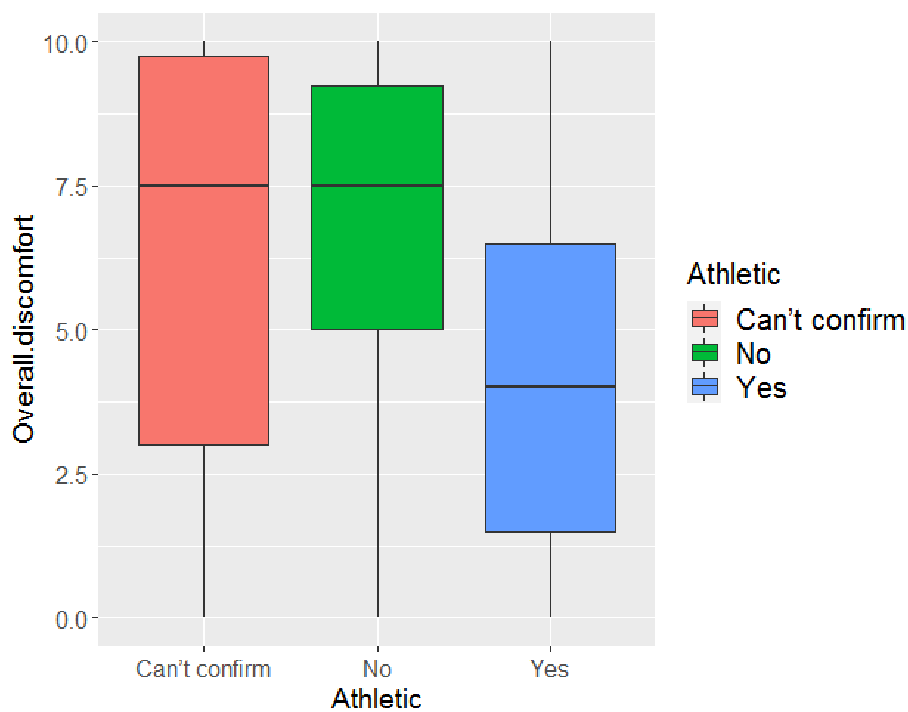

Figure 3.29. Effects of Athletic level on rating the overall discomfort

Thermal sensation

Body, lip, and cheeks temperature had a significant difference in ratings' results among smokers and nonsmokers (p=0.001, p=0.005, p=0.04, respectively). A significant difference in rating body temperature for different types of used masks (p=0.0079).

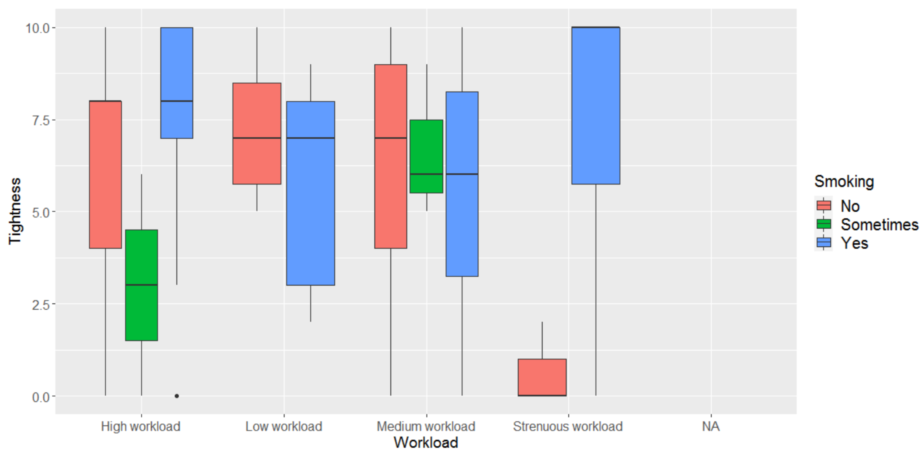

Figure 3.30.Interaction of smoking status and workload vs. rating of tightness

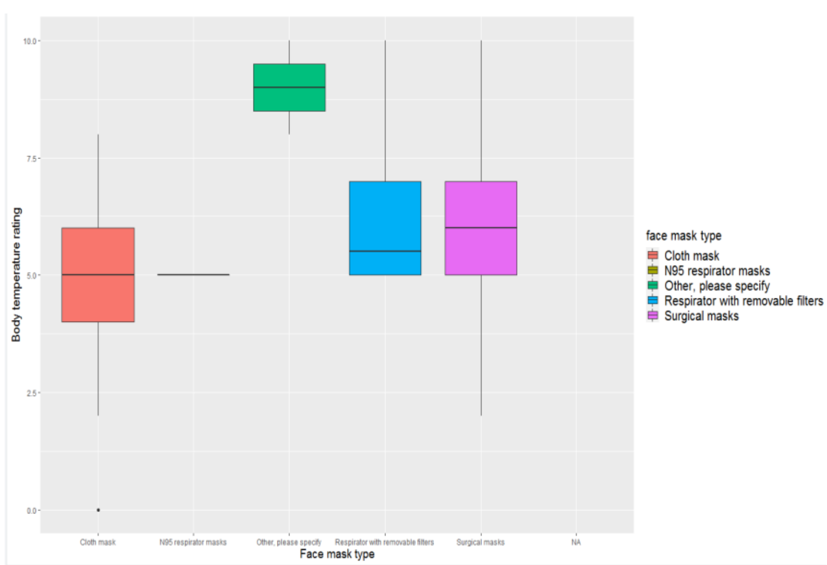

Figure 3.31. Face mask type vs. rating of body temperature

Discussion

Once the world health organization announced the COVID-19 pandemic, wearing a face mask in public settings was recommended globally and mandatory in some countries to hinder spreading respiratory droplets (*COVID-19: Considerations for Wearing Masks | CDC,* 2021; *Which Countries Have Made Wearing Face Masks Compulsory? | Coronavirus Pandemic News | Al Jazeera*, 2020) and became the new norm of human interaction. Researchers along the years well investigated the disposal of respirators in the context of healthcare workers (N95 or surgical masks, which are the most commonly used mask by healthcare workers) and reusable respirators used in industries (half-face or full-face respirators protect users from airborne particulates, gases, fumes, and vapors). However, to the best of our knowledge, the current research is the first research study using facemasks by essential workers in retail companies. The first study evaluates the effect of workload, smoking status, and wearing eyeglasses while wearing face masks on essential workers working in retail companies in the context of human sense, psychology, cognition, psychomotor ability, and work tolerance, the human sensation of discomfort.

Employees in retail companies showed compliance to wearing facemasks out of the working hours. Besides, even though no rules require the use of a facemask, 80.49% of staff expressed their willingness to do so. Surgical masks were the most commonly worn mask both in and out of the workplace, followed by respirators with removable filters. Homemade cloth mask reduces the aerosol exposure but is less effective than the surgical mask, which is less effective than respirators (Davies et al., 2013; van der Sande et al., 2008). The reusability and cleaning options of cloth masks candidate it to be the choice in resource-poor settings compared to high resource settings where all cloth masks had been replaced by disposal medical masks and respirators.

Face mask during the shift

Human sense (Vision, Hearing)

Eyes glasses' users significantly had a problem in viewing or seeing others and stuff as their ratings of problem in vision is high compared to non-wearer eyeglasses. This can be directly explained by the fog-up factor that condenses on the lens. In general, visual range abilities are negatively affected by wearing full-face respirators (Zelnick et al., 1994)and full-face military respirators(Johnson et al., 1997). Respondents conveyed their masks' annoying aspects by repeating the "fog on eyeglasses," "fog up my eyeglasses," and "the vision is not clear."

Even that there is no significant effect on hearing sense, some employees reported that face mask affects their hearing and trigger them to raise their voice to convey their information to others.

Psychomotor ability

As the workload increases from low to strenuous, the rating for becoming restricted and slower in movement increases for both smokers and non-smokers categories. Rating for high and strenuous workload was almost close in ratings. Even so, smoking significantly affects the movement while wearing the mask while performing a job. According to several researches, blood pressure levels vary with physical activity, smoking, caffeine consumption, emotional state, room temperature, and season. Mayo clinic reported an immediate increase in blood pressure due to smoking or even chewing tobacco (*High Blood Pressure (Hypertension) - Symptoms and Causes - Mayo Clinic*, 2021). Increased blood pressure had a negative impact on lower limb function in older adults. A significant decline in leg function was associated with each 10mm Hg increase in systolic blood pressure ($p=0.011$). Another study conducted on older adults found that higher systolic blood pressure causes a faster rate of gait speed deterioration(Rosano et al., 2011). On the other hand, a systematic review conducted by AL-Bashaireh et al. to review the effect of tobacco smoking on musculoskeletal health found a negative effect of smoking on the musculoskeletal system. Despite the lack of research, they found that smoking was associated with decreased muscle strength, increased cartilage volume, thinner patellar and Achilles tendons, severe rotator cuff tears, and poor functional and stability scores anterior cruciate ligament (ACL) reconstruction (Al-Bashaireh et al., 2018).

Human psychology and cognition

As illustrated in figure (8), workers who wear eye glasses while using a respirator with removable filters and cloth masks become stressed during the shift compared to people who sometimes wear eyeglasses or don't wear all. Workers who wore eye glasses reported that wearing eye glasses affects their work and their vision because of the fog-up. Also, some workers stated that they couldn't see people and stuff, which stress them up. As the exhaled air is warm (35°C) (Popov et al., 2006) and has 100%RH (Bouverot, 1985)can only escape in the upward direction of eye glasses and condense on the colder lens where the condensation is a temperature function. Respirators are tight-fitting personal protective equipment, and surgical masks are loose-fitting face masks. Respirators add pressure behind the ears and around the mouth, which annoyed the workers and coincided with Snook et al. (1966) findings. Respirators' and surgical mask users reported suffering from high humidity, breathing shortage, and tightness. Anxiety rises as breathing becomes difficult (Laird et al., 1993b). According to Wu et al. (2011), Respirators increase anxiety, particularly in people who are already anxious.

Furthermore, employees who wear eyeglasses and use respirators with removable filters highly rated their cognitive process to process what others are saying, and employees who don't wear eyeglasses and use cloth mask (figure 9) s. Heat stress imposed by respirators as a thermal burden (Laird et al., 1993a) showed to degrade the cognitive ability (Guo et al., 2008; Hayashi & Tokura, 2004; Li et al., 2006a). Of cloth masks' users, cloth masks are loose-fitting. The loose-fitting feature between the face and the mask hinders from providing full protection from germs or contaminants, forcing the workers to keep enough distances away from customers or other employees, leading to difficulty in hearing and processing information. Various responses were received regarding what annoys users about face masks, such as face masks hinder to see people's smiles or showing workers' smiles, difficulty in recognizing people during essential meetings, repeating talks many times to deliver the message, and increase the employees' voice level (louder).

Work tolerance

When comparing smokers and nonsmokers' tolerances to remain until the end of the shift, the survey results revealed a significant difference. Smoking increased a person's thermal load, as shown by this research, in which smokers classified their body, lip, and cheeks under the mask temperatures as significantly higher than nonsmokers. Also, the Spearman correlation test revealed a strong positive correlation between the attitude of finishing work quickly in order to take a break and humidity, heat, breathing resistance, itchiness, tightness, saltiness, feeling unfit, odor, fatigue, overall discomfort, stress, lips and cheeks temperature. On the other hand, inhaled hot smoke raises the temperature within the lungs, which raises the core body temperature(*The Most Serious Public Health Concerns in the U.S.*, 2016). After 30 minutes of smoking, Fan et al. discovered a substantial rise in facial skin temperature, with a mean increase of 2°, and speculated that this might be a factor in premature skin aging (Fan et al., 2012). Thermal heat built up in the face's skin recorded 58 complaints as the leading reason to terminate the session before complete 8 hours (Radonovich et al., 2009). Followed by pressure or pain (25), dizziness or difficulty concentrating (19), visual degrading included fogging (15) (Khoo et al., 2005; Meyer et al., 1997b), vocal acuity (13) (Khoo et al., 2005), burning eyes (12), then itching (8). Radonovich et al. (2009) coincided with the findings that thermal discomfort associated with facial heat cause work intolerances and lack of sticking to the respirator protective equipment (RPE) till the end of the shift. Apart from completing tasks quickly for break time, staff positively responded that they permanently remove their mask during work (37.8%) and sometimes do so (30.249%). Breathing resistance of respirators had a negative effect on wearers' work efficiency, according to Caretti et al. (2001), and cause respiratory fatigue (Sinkule et al., 2013). Twenty-five of the eighty-two staff in the current study registered respiratory problems. The results of the current research matched those of several earlier studies on the sources of work tolerances. Overall discomfort (“SARS Unmasked: Celebrating Resilience, Exposing Vulnerability : Final Report ... - Google Books,” 2008), decreased visual, auditory acuity, excessive humidity or heat, headaches (Li et al., 2005), facial pressure, skin irritation or itchiness, excessive fatigue (Yassi A et al., 2004), anxiety (“SARS Unmasked: Celebrating Resilience, Exposing Vulnerability : Final Report ... - Google Books,” 2008), and other interferences with occupational duties have all been linked to problems respirator tolerability.

Face mask at the end of the shift

Human sensation of discomfort

Job demand significantly affects the heat perception reported by the employees (figure 11). As the workload increased, the heat development increased. Significance was found between low workload and medium, high and strenuous workload with no difference between medium, high, and strenuous workload. This finding agreed with Li et al.’s findings where the heat increases gradually with the increased workload. The workload could be mentally or physically demanded. Researchers found that working under mental demand jobs or high-heat/high-work conditions reduces employees’ tolerances (James et al., 1984; P. A. Hancock, 1987). Also, Hancock (1987) indicated that heat stress influences cognitive performance as a factor of the type of cognitive task.

As a consequence of increased heat perceptions by increased workload, it had been found that interaction between workload and smoking had a significant effect on tightness and itchiness perception (figure 12 and 14). As the workload increases, smokers rated their itchiness perception highly compared to nonsmokers. Several factors could trigger itch response: environmental factors, living habits, and the state of mind. However, Wahlgren (1991) found that heat or warmth could be the primary player to trigger itchiness response among all factors. In this study, it had been found that as workload increases, heat perception increases. Also, smokers rated their body, lip, and cheeks temperature highly compared to nonsmokers.

Moreover, it had been found that there is a significant effect of being athletic on overall discomfort while wearing the mask as shown in figure 13. Non-athletic employees highly rated their overall discomfort compared to athletic employees. People who work out have a lower resting heart rate than people not work out, where studies showed that wearing a face mask increase the heart rate (Li et al., 2005).

Thermal sensation

In this self-administered survey, respondents who considered themselves as smokers tend to rate their body, lip, and cheeks under mask temperature in comparison to nonsmokers. This is explained by that smoking affects almost every organ in the human's body: heart, blood vessels, lungs, eyes, mouth, bones, bladder, reproductive organs, and digestive organs. Smoking exposes the heart, blood cells, and blood vessels to being damaged by building up the plague inside the arteries. The blood flow rich in oxygen will be limited by time to reach organs as the plague piled up and hardened in the arties by time which causes the feeling of cold in hands and foot (*Smoking and Your Heart | NHLBI, NIH*, n.d.). However, inhaled hot smoke tends to increase the temperature inside the lungs, increasing the core body temperature (*The Most Serious Public Health Concerns in the U.S.*, 2016). Thus, this turns that the exhaled air is higher in temperature, raising the cheeks under mask temperature. Moreover, Fan et al. (Fan et al., 2012)found a significant increase in facial skin temperature with a mean increase of 2°C after 30 min of smoking and stated that this could be a factor in premature skin aging.

Workers use different types of masks during works which significantly affects their rating for their body temperature by the end of the shift. Workers wearing surgical masks (0.04) and respirators with a removable filter ($p=0.04$) rated their body temperature higher than workers wearing cloth masks. Yip et al. investigated the effect of wearing a face mask on body temperature. They found a significant increase in oral temperature when wearing a face mask (N95 and surgical mask) contrasted to not wearing (Yip et al., 2005). Increased perception of facial skin and total body heat was reported as the most common complaints of N95 FFR users due to the additional energy expenditure (Baig et al., 2010; Guo et al., 2008; Li et al., 2005). Energy expenditure increased because of increased breathing resistance, brain warming, psychophysiological perceptions, respiratory heat loss impairment, and intrusion with facial skin heat convection and evaporation (R. Roberge et al., 2012a). The cotton mask was considered the most used fabric for workers who use cloth masks. Cotton fabric is smooth and soft, which makes it cool and breathable while touching the face. Also, surgical masks are more breathable than N95 facemasks as surgical masks thinner and permit air and moisture to flow (Li et al., 2005). This explained why surgical and respirators with removable filters increase the body temperature compared to cloth masks. In other words, as the mask layers increase, the moisture and air permeability decrease.

An option of text entry for other masks used was provided. However, respondents didn't mention what types of masks they used that are not in the questions' options. Nevertheless, a significant difference in rating was found between the cloth mask, respirator with removable filters, and other masks.

Conclusions

To the author's knowledge, the current study is the first to look at the use of facemasks by staff in retail companies. Also, this is the first research to look at the impact of workload, facemask type, athletic level, caffeine intakes, smoking status, and wearing eyeglasses while wearing face masks on staff in terms of human sense, psychology, perception, the sensation of discomfort, psychomotor capacity, and work tolerance. According to the findings, the interaction of smoking and workload had a major impact on movement restriction, slower in motion response, tightness, and itchiness. Smokers had a lower tolerance for working until the end of the change and a higher body, lip, and cheek temperature. The workload directly influenced the heat build-up inside the mask.

Additionally, wearing eyeglasses reduces vision capacity dramatically. This study's finding guides the main factors that affect employees' workers' performance, productivity, perceptions, and senses while wearing facemasks. Moreover, findings present different factors on employees that can help position employees on suitable position fit to their characteristics.

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Appendix. IRB approval Letter

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Ethics
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 11/03/2020

To: Richard T Stone

From: Office of Research Ethics

Title: **Effects of wearing face mask on workers' performance, productivity, perception and senses during Covid-19 pandemic**

IRB ID: 20-402

Submission Type: Initial Submission **Exemption Date:** 11/03/2020

The project referenced above has been declared exempt from most requirements of the human subject protections regulations as described in 45 CFR 46.104 or 21 CFR 56.104 because it meets the following federal requirements for exemption:

2018 - 2 (i): Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) when the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects.

The determination of exemption means that:

- **You do not need to submit an application for continuing review. Instead, you will receive a request for a brief status update every three years. The status update is intended to verify that the study is still ongoing.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any *modifications to the research procedures* (e.g., method of data collection, nature or scope of information to be collected, nature or duration of behavioral interventions, use of deception, etc.), any change in *privacy or confidentiality protections*, modifications that result in the *inclusion of participants from vulnerable populations*, removing plans for informing participants about the study, any *change that may increase the risk or discomfort to participants, and/or* any change such that the revised procedures do not fall into one or more of the regulatory exemption categories. The purpose of review is to determine if the project still meets the federal criteria for exemption.
- All *changes to key personnel* must receive prior approval.
- **Promptly inform the IRB of any addition of or change in federal funding for this study.** Approval of the protocol referenced above applies only to funding sources that are specifically identified in the corresponding IRB application.

Detailed information about requirements for submitting modifications for exempt research can be found on our website. For modifications that require prior approval, an amendment to the most recent IRB application must be submitted in IRBManager. A determination of exemption or approval from the IRB must be granted before implementing the proposed changes.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Additionally:

- All research involving human participants must be submitted for IRB review. **Only the IRB or its designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

- **Please inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an eligible PI to remain open.

- **Immediately inform the IRB of (1) all serious and/or unexpected** adverse experiences involving risks to subjects or others; and (2) any other unanticipated problems **involving risks to subjects or others.**

- **Approval from other entities may also be needed.** For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

- Your research study may be subject to post-approval monitoring **by Iowa State University's Office for Responsible Research.** In some cases, it may also be subject to formal audit or inspection by federal agencies and study sponsors.

- Upon completion of the project, transfer of IRB oversight to another IRB, or departure of the PI and/or Supervising Investigator, please initiate a Project Closure in IRBManager to officially close the project. For information on instances when a study may be closed, please refer to the IRB Study Closure Policy.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

CHAPTER 4. HUMAN BREATHING SIMULATOR

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Modified from a manuscript to be submitted in Human Factors Journal

Abstract

A human breathing simulator was developed to measure the effect of wearing different mask types (N95, KN95, surgical mask, cotton mask with exhalation valve, cotton mask) and workloads (medium, high, strenuous) on temperature relative humidity and heat index build up inside mask. The machine was built to simulate the temperature and humidity of exhaled air, adjustable to various breathing rates and cyclic mean inhalation flow without human participation. Face masks were fully sealed on manikin's head breathing out of the tube connected to the simulator. Different face mask types and workload levels had significant effects on temperature and heat index build-up inside masks (under the nose and in front of cheeks). Results showed that the N95 mask aggregated the highest temperature and heat index over time and the cotton mask with exhalation valve is the lowest. Also, medium workload showed higher temperature and heat index compared to high and strenuous workload. The relative humidity was 99.9% over the time where it reached saturation.

Keywords: face mask, respiratory rate, workload, breathing simulator

Introduction

COVID-19 pandemic had extensively affected our ordinary life. It posed various restrictions on human interactions and daily life activities such as social distancing, mandate faces covering, virtually working when it's critical, travel restriction, etc. More than 124 million confirmed cases had been registered to the World Health Organization by the start of the Covid-19 pandemic until March 26, 2021, with more than 2 million deaths worldwide (*WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus Disease (COVID-19) Dashboard*, n.d.). When sneezing, coughing, talking, or yelling, nasal droplets are the primary mode of transmitting covid-19 from an individual's mouth and nose to others. Covering the mouth and nose is the primary way of many ways to prevent this (*COVID-19: Considerations for Wearing Masks | CDC*, n.d.). Wearing face masks during work and interactions for a long time is new behavior for the public where it has become mandatory in some countries around the world. Previous researches in healthcare and industry settings showed that less tolerance to adhere to masks till the end of the work because of the associated discomfort, physiological and psychological effects while wearing the mask (Martel et al., 2013; Moore et al., 2005; Pourbohloul et al., 2005; Shenal et al., 2012). The build-up of heat in the face's skin was the primary reason for terminating the study before the 8-hour mark (Radonovich et al., 2009). In a study of surgical mask and N95, Li et al. discovered that when simulating healthcare worker work, the skin temperature and microclimate within the N95 were higher than the surgical mask. The face mask's thermal stress triggered the facial temperature increase as an adjustment (Johnson, 2016). These findings triggered the execution of the previous presented study in this research as researchers' main focus was for healthcare and industrial workers. Also, the conditions where masks were tested were limited to avoid expose participants to risk. Therefore, having a breathing simulator will help investigate various combinations of face masks, respiratory rates, and workloads.

Therefore, this study aims to build a human breathing simulator that simulates the exhaled air in temperature and humidity and adjustable for various breathing rates and cyclic mean inhalation flows. Also, to investigate the effect of different mask types and workloads on the temperature, humidity, and heat index build-up inside the mask. The results will be validated by comparing them to the previous study of employees in retail companies and previous research in this area.

Methods

Human breathing simulator

The current study aims to build a human breathing apparatus that simulates the human breathing in temperature, the humidity of the exhaled air, adjustable to various breathing rates, and mean inhalations flow.

A piston crank slider mechanism was applied (figure 15) to simulate the exhalation and inhalation of human breathing. The piston was 3d printed that fit inside the mobile dispenser and has a hole in the middle of diameter 2.54 cm (He et al., 2019). A tube of 2.54 cm extended from the piston opening to the manikin's upper and lower lips.

The normal breathing rate (reparation rate) for an adult varies among individuals from 12 to 20 breaths/min. However, adults' average breathing rate is 15 and 25 breaths/min was based. A DC motor connected with a speed controller controlled by Arduino code was used to simulate the breathing rate. Moreover, studies showed that the mean inhalation flow varied as the workload varied (Yuasa et al., 2015). The mean inhalation flow is presented by the distance the piston traveled. Two links were 3d printed with several holes in each, where each hole moves the piston at different distances.

It had been shown that the exhaled breathing temperatures (EBT) are affected by BMI, physical activity, residential proximity to traffic, sex, age, and ambient temperature. Previous studies had found the EBT from mouth equal to 31.5 C when conducting a comparison between the mouth and nose breathing in human, 35.02 ± 0.02 in control subjects while assessing the changes in airway inflammation (Popov et al., 2006), 33.82 C on average (21-25 years old) while investigating the EBT values between asthmatic and healthy subjects after an exercise test, 34.45 C on average (30-40 years old) while studying the correlation between exhaled breath temperature and bronchial blood flow, and 31.4-35.4 °C for Haifa's participants, 31.4-34.8 °C for Parisian participants when investigating the effect of the geographical differences on the EBT and relative humidity in exhaled breath. A cylinder device was used, which heats up, and the temperature was controlled using humidity and temperature controller.

Similar to the EBT variable, the EBRH has two levels. The first level is 91%, and the second level is 100%. There is little knowledge about the EBRH, which is almost assumed to be as high as 100%. However, a recent study conducted in two different countries designed an apparatus to consolidate a range for the EBT and EBRH. They found that EBRH is 65.0-88.6% for Haifa's participants 41.9-91.0% for Parisian participants. They explained the result as the room RH levels were 29% and 45% in Paris's and Haifa's sites, respectively. An external warm humidifier with an adjustable mist level was used as a humidity source while breathing.

On the manikin head, three humidity and temperature sensors were placed in three places: under the nose, left, and right cheeks. The data was collected each second.

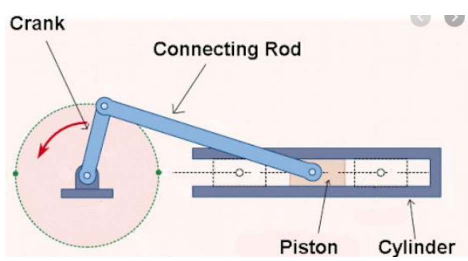


Figure 4.1. Crank slide mechanism

Figure 4.3.Front view of the simulator

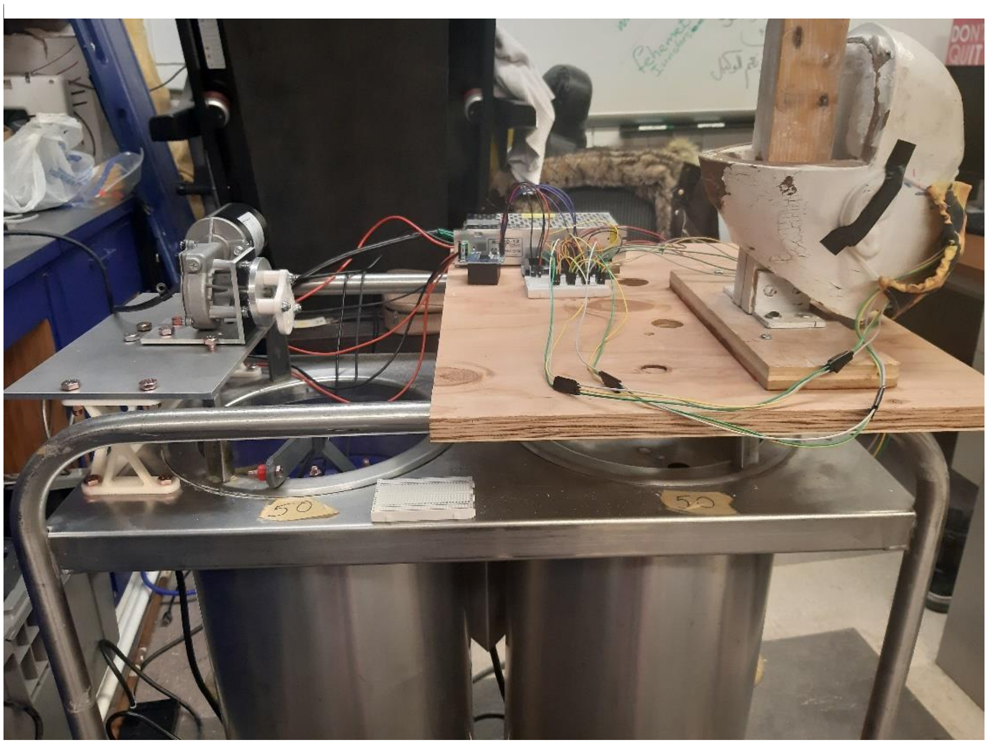


Figure 4.2. Side view of the simulator

Tested Respirator and Mask

Face masks were classified into three categories to draw a clear conclusion: cloth face mask, surgical mask, and respirator. No doubt that all of them cover a wearer's mouth and nose. Five types of widely used and commercially available masks and respirators were used in this study. Table (4.1) illustrates the tested respirators and masks and their features.

Table 4.1. Investigated masks characteristic

Mask type	**Model**	**Size (cm)**	**Materials**	**Exhalation valve**
N95	Molded Cup	12.5×13.2	* Filter – Polypropylene * Shell – Polyester * Coverweb - Polyester	No
KN95 (VIC 951)	Molded Cup	13.208×12.7×6.35	Polypropylene	No
Disposable mask (jumbo pack)	Loose-fitting	17 × 9	70% non-woven, 30% melt-blown fabric 3 Ply	No
Cotton Mask Activated Carbon	Loose-fitting	22 × 14	100% Cotton	Yes
Cotton mask	Loose-fitting	16 × 8.8	Soft 3 Ply	No

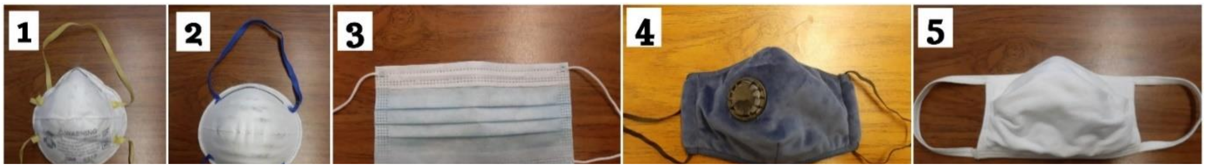


Figure 4.4. Investigated mask, 1) N95 mask, 2) KN95 mask, 3) surgical mask, 4) cotton mask with exhalation valve, 5) cotton mask

A cloth face mask was recommended to be worn by the public recently as recommended by the CDC (*COVID-19: Considerations for Wearing Masks | CDC*, n.d.). Two cotton masks were investigated in this study. One cotton mask that has exhalation valve and the other without exhalation valve.

Surgical masks (medical procedure, dental, isolation masks) filter the large-particle droplets, splashes, sprays, or splatter that may contain germs (viruses and bacteria) to block them from reaching the mouth or nose. On the other hand, surgical masks can't block or filter the sneezing or coughing particles small in size. The loose-fitting feature between the face and the mask hinders providing full protection from germs or contaminants (*N95 Respirators, Surgical Masks, and Face Masks | FDA*, n.d.-b).

Respirators are tight-fitting personal protective equipment that provides a high level of protection and filtration of airborne particles (virus and bacteria) if they properly fit. Air-purifying respirators (APRs) and air-supplying respirators (ASRs) are the two classifications of respirators. APRs filter and remove the air's contaminants and categorized into three types: filtering facepiece respirators (FFRs), elastomeric facepiece respirators, and powered air-purifying respirators (PAPRs). FFR is one facepiece made of the filter material and disposal upon excessive resistance or physical damage (*Approved Respirators, What Are They? | NPPTL | NIOSH | CDC*, n.d.). In this study, we investigated the N95 respirator.

KN95 mask is similar to N95 masks, a filtering facepiece of 95% of particles (Improve the Fit and Filtration of Your Mask to Reduce the Spread of COVID-19 | CDC. KN95 masks are made in China and are not approved by NIOSH, and N95 masks are commonly used in the USA and approved by NIOSH.

Experimental Design and Test Conditions

Independent variable

This study manipulated two independent variables at different levels. The first independent variable is the mean inhalation flow (MIF) rate varying the values at 30, 85, and 135 L/min. The values simulate the human breathing at medium, high and strenuous workloads, respectively (He, Grinshpun, et al., 2013b).

The second independent variable is the type of mask and respirator. One cotton mask, one cotton mask with exhalation valve, 1 surgical mask, 1 KN95 respirator, and 1 N95 respirator were investigated in this study.

Dependent Variable

The current study aims to demonstrate the temperature and relative humidity build-up inside the different mask types while wearing them for time. The temperature and humidity were measured using sensors connected through Arduino. The temperature accuracy is ±0.3°C and the relative humidity accuracy is ±2% for RH% range 10% -95%. The sensor measures the temperature range from -40°C to 105°C and the RH% from 0-100%. The data were collected for each 1s.

The heat index was also calculated throughout the experiment that reflects the temperature that the body feels when the temperature and relative humidity combined.

Constants

The exhaled breathing temperatures (EBT) were controlled to be around 32ºC, and the exhaled breath relative humidity (EBRH) was controlled to be 99.9%. The breathing rate was adjusted to 25 breaths/min. The selection of the 25 breaths/min was based on the average respiratory rate in healthy adults.

Data Analysis

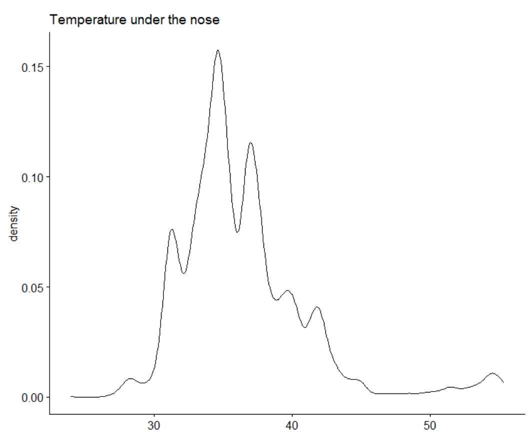
A Welch's ANOVA and the Kruskal Wallis test were applied to investigate the effect of the face mask types and Workload levels on temperature and heat index for both microenvironments under the nose and in front of the cheeks. Games-Howell test and Dunn tests were applied as post-hoc analyses to locate the specific differences. A p-value of <0.05 was considered as a statistically significant difference among groups.

Table 4.2. Independent variables levels

Variable	**Levels**
Mean Inhalation flow (MIF)	3 (30, 85, 135 L/min)
Mask and Respirator types	5 (Face mask: one cotton cloth mask, one cotton mask with exhalation valve, Surgical mask, N95 and KN95)

Pre-Check the data

The sample size is large (n>30). The data were checked visually by normal plots (histogram) and density plot.



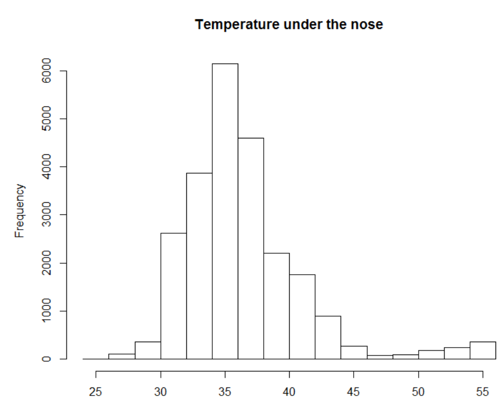


Figure 4.5. Density plot (right) and histogram (left) for temperature under

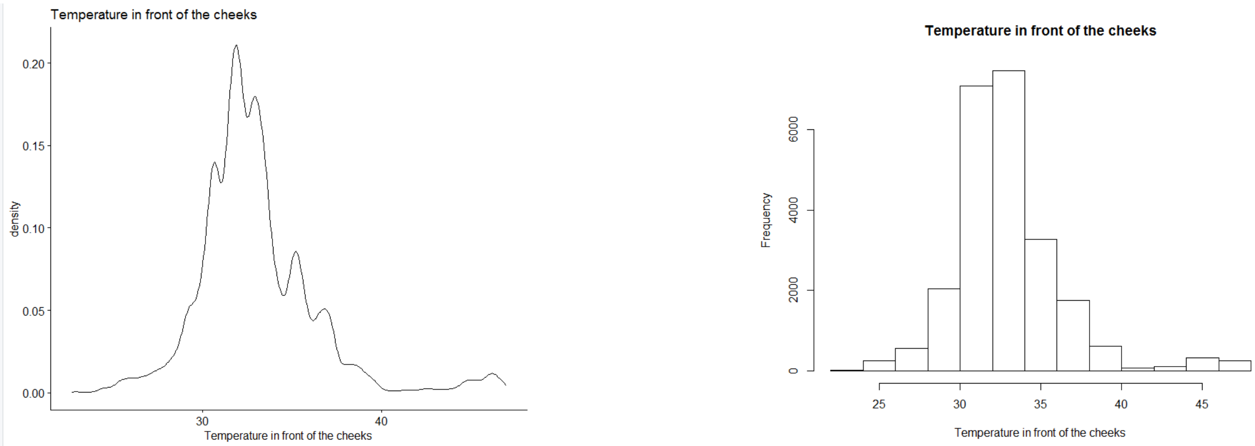


Figure 4.8.Density plot (right) and histogram (left) for temperature in front of the cheeks

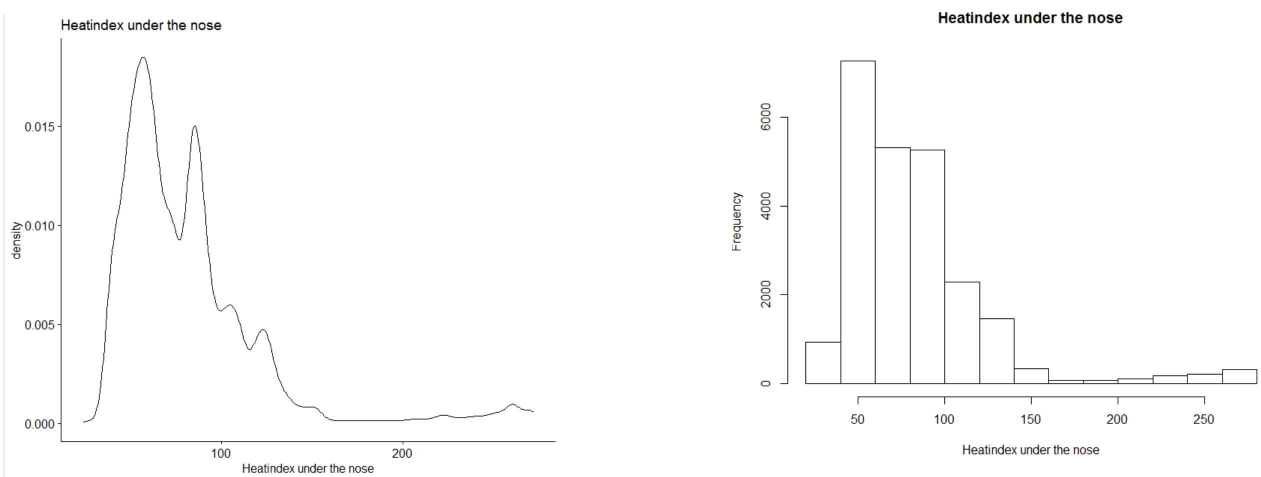


Figure 4.7.Density plot (right) and histogram (left) for heat index under the nose

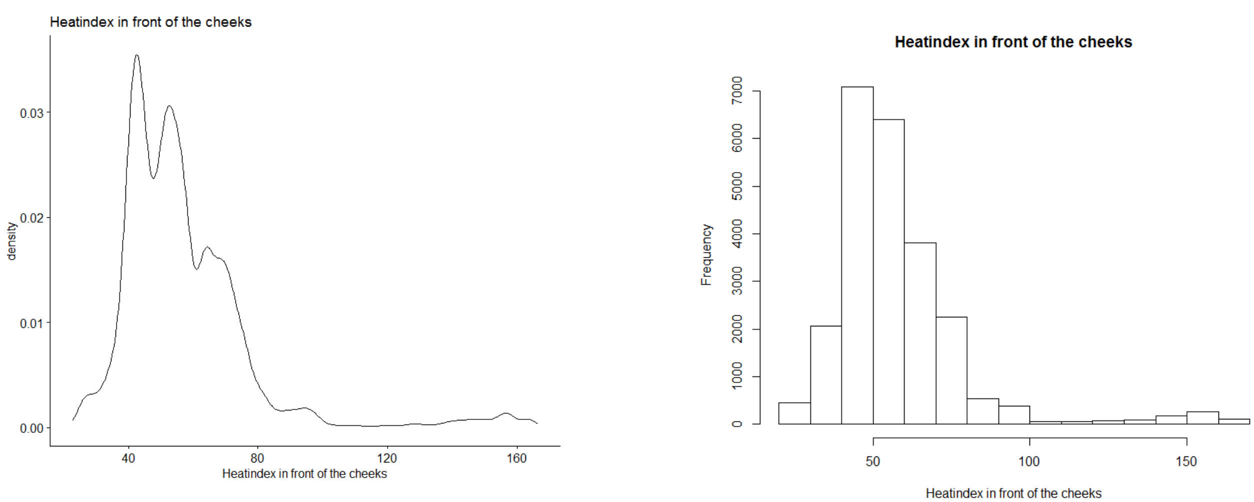


Figure 4.6.Density plot (right) and histogram (left) for heat index in front of the cheeks

As shown in figures 20&21 that temperature under nose and in front of the cheeks has normal distribution. On the other hand, heat index under the nose and in front of the cheeks doesn't had normal distributions (figure 22 & 23). Levene's test was used to check the homogeneity of variances for normally distributed data (temperature under the nose and temperature in front of the cheeks). Based on the Leven's test, it showed that the assumption of equal variances is violated.

```
Levene's Test for Homogeneity of Variance (center = median)
         Df F value    Pr(>F)
group     4  755.74 < 2.2e-16 ***
      23785
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 4.10. Leven's test for face mask types and temperature under the nose

```
         Df F value    Pr(>F)
group     4  852.57 < 2.2e-16 ***
      23785
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 4.9.Leven's test for face mask types and temperature in front of the cheeks

```
         Df F value    Pr(>F)
group     2  3155.9 < 2.2e-16 ***
      23787
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 4.12.Leven's test for workload and temperature under the nose

```
Levene's Test for Homogeneity of Variance (center = median)
         Df F value    Pr(>F)
group     2  2741.2 < 2.2e-16 ***
      23787
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 4.11.Leven's test for workload and temperature in front of the cheeks

Results

Temperature

Figure (48) and figure (49) show that the univariate factors affect the temperature under the nose and in front of the cheeks, respectively. The mean of the temperature under the nose and in front of the cheeks seems to change with different mask types. Also, different levels of the workload seem to influence the temperature.

Mask type

Regarding the temperature under the nose, significant differences were found among the five types of face masks at the level of P<2e-16. The highest temperature build-up was for N95 respirator then KN95 respirator, surgical mask, cotton mask, and cotton mask with exhalation valve as shown in the table (5). All combinations of face masks showed significant except for cotton and surgical masks.

Regarding the temperature in front of the cheeks, significant differences were found among the five types of face masks at the level of P<2e-16. The temperature inside the N95 respirator and KN95 respirator was significantly higher than the cotton mask, surgical mask, and cotton mask with exhalation valve, as shown in table (7).

Workload

Welch's ANOVA showed that workload levels had a significant effect on both temperature build-up under the nose and in front of the cheeks at a level of P<2e-16. Games-Howell post-hoc tests (Table 9&11) revealed that the temperature build-up inside the mask for medium workload was higher than high Workload and strenuous Workload (nose and cheeks: P<0.05). The high workload showed higher temperature build-up than the strenuous workload (nose and cheeks: P<0.05).

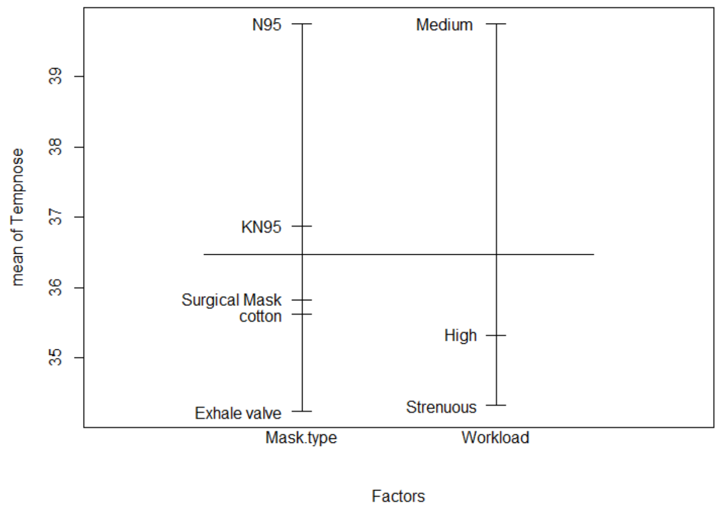


Figure 4.14.univariate factors effects on temperature in front of cheeks

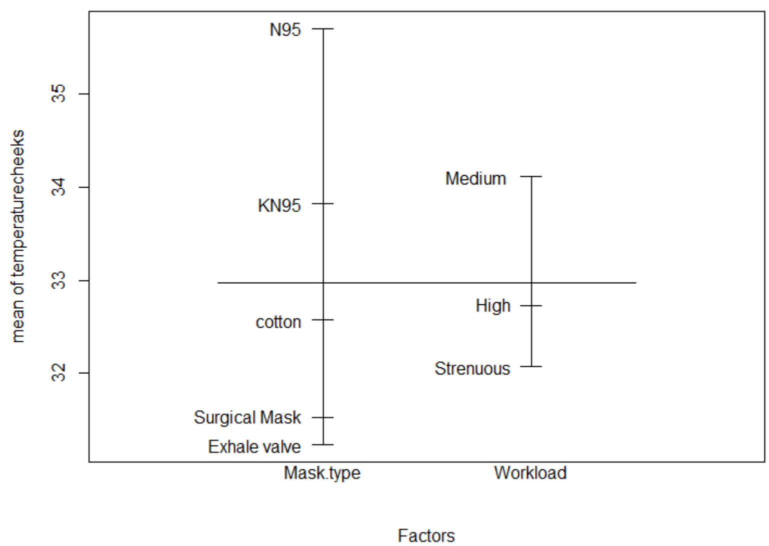


Figure 4.13.univariate factors effects on temperature under nose

Heat index

The effects of univariate influences on the heat index under the nose and in front of the cheeks are seen in figures (50) and (51). For various face mask types, the average temperature under the nose and in front of the cheeks tends to change. Moreover, the heat index tends to be determined by varying degrees of workload.

Mask type

Kruskal-Wallis Test was conducted to investigate the differences in heat index under the nose according to the types of face masks. Significant differences (P< 2.2e-16) were found among the five categories of face masks (N95, KN95, cotton mask, surgical mask, cotton mask with exhalation valve). The Dunn test post hoc test (Table 13) revealed that the heat index under the nose was highest for the N95, then KN95, cotton, surgical mask, and last for cotton with exhalation valve.

Regarding the heat index in front of the cheeks, significant differences were found among the five types of face masks at the level of P<2e-16. The heat index inside the N95 respirator and KN95 respirator was significantly higher than the cotton mask, surgical mask, and cotton mask with exhalation valve, as shown in table (15).

Workload

Kruskal-Wallis Test showed that significant differences (P< 2.2e-16) among the three levels of workload (medium, high, and strenuous workload). The Dunn test post hoc test (Table 17) revealed that the heat index under the nose was highest for the medium, then high, and last for the strenuous workload.

A significant effect on heat index in front of the cheeks was found by conducting Kruskal-Wallis Test at a level of P<2e-16. The Dunn test post hoc test (Table 19) revealed that the heat index in the mask for medium workload was higher than high workload and strenuous workload (cheeks: $P<0.05$). Also, the high workload showed higher temperature build-up than the strenuous workload (cheeks: $P<0.05$).

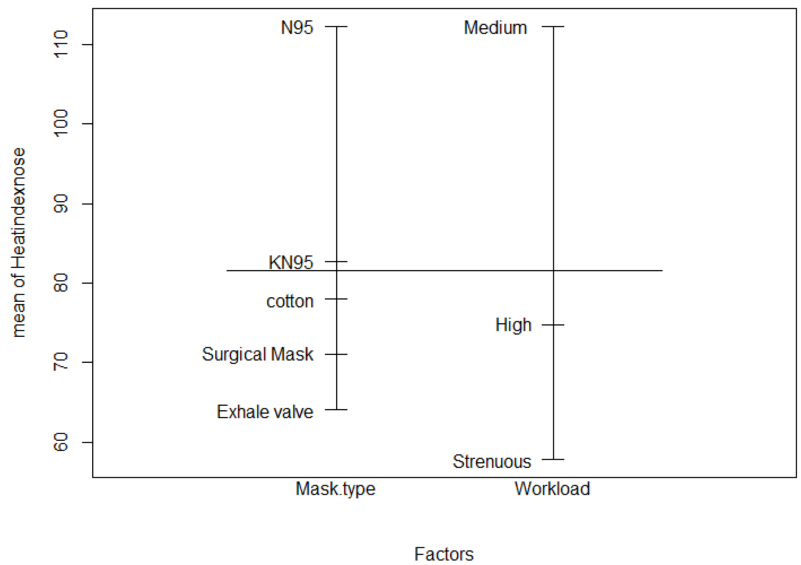


Figure 4.16.univariate factors effects on heat index under nose

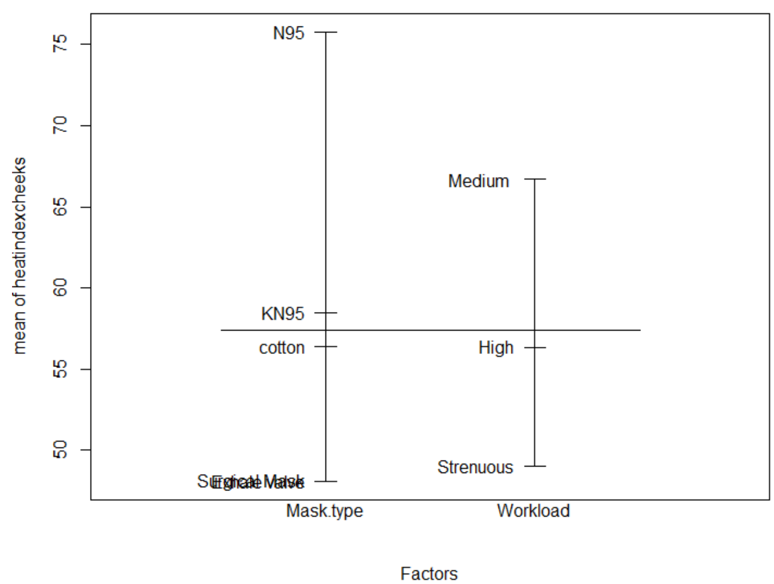


Figure 4.15.univariate factors effects on heat index in front of cheeks

Table 4.3.Temperature under the nose **Welch one-way test** for mask types

One-way analysis of means (not assuming equal variances)			
F	**num df**	**denom df**	**p-value**
799.17	4	11691	< 2.2e-16

Table 4.4. Games-Howell post-hoc test for Temperature under the nose for mask types

Groups	**Mean Difference**	**Standard Error**	**t**	**df**	**p**	**upper limit**	**lower limit**
1 cotton : Exhale valve	-1.375	0.048	20.110	9148.425	0.000	-1.189	-1.562
2 cotton : KN95	1.262	0.055	16.156	9452.554	0.000	1.475	1.049
3 cotton : N95	4.136	0.080	36.395	7208.635	0.000	4.446	3.826
4 cotton : Surgical Mask	0.215	0.046	3.319	8531.118	0.008	0.391	0.038
5 Exhale valve : KN95	2.637	0.051	36.685	8840.212	0.000	2.834	2.441
6 Exhale valve : N95	5.512	0.077	50.353	6459.376	0.000	5.810	5.213
7 Exhale valve : Surgical Mask	1.590	0.040	27.872	9305.510	0.000	1.746	1.434
8 KN95 : N95	2.874	0.082	24.820	7562.089	0.000	3.190	2.558
9 KN95 : Surgical Mask	-1.047	0.048	15.307	8151.340	0.000	-0.861	-1.234
10 N95 : Surgical Mask	-3.921	0.076	36.577	6035.268	0.000	-3.629	-4.214

Table 4.5.Temperature in front of cheeks **Welch one-way test** for mask types

One-way analysis of means (not assuming equal variances)			
F	**num df**	**denom df**	**p-value**
1684.5	4	11649	< 2.2e-16

Table 4.6. Games-Howell post-hoc test for Temperature in front of cheeks for mask types

groups	**Mean Difference**	**Standard Error**	**t**	**df**	**p**	**upper limit**	**lower limit**
1 cotton : Exhale valve	-1.341	0.034	28.286	8041.320	0	-1.211	-1.470
2 cotton : KN95	1.243	0.039	22.391	9497.675	0	1.394	1.091
3 cotton : N95	3.125	0.055	40.182	7795.110	0	3.337	2.913
4 cotton : Surgical Mask	-1.053	0.034	22.197	8047.879	0	-0.923	-1.182
5 Exhale valve : KN95	2.584	0.033	56.124	8238.524	0	2.709	2.458
6 Exhale valve : N95	4.466	0.050	62.614	6104.483	0	4.661	4.271
7 Exhale valve : Surgical Mask	0.288	0.025	8.034	9513.982	0	0.386	0.190
8 KN95 : N95	1.882	0.054	24.462	7603.385	0	2.092	1.672
9 KN95 : Surgical Mask	-2.295	0.033	49.842	8245.073	0	-2.170	-2.421
10 N95 : Surgical Mask	-4.178	0.050	58.563	6108.055	0	-3.983	-4.372

Table 4.7.Temperature under the nose **Welch one-way** test for workload

One-way analysis of means (not assuming equal variances)			
F	**num df**	**denom df**	**p-value**
2860	2	14349	< 2.2e-16

Table 4.8. Games-Howell post-hoc test for Temperature under the nose for workload

groups	Mean Difference	Standard Error	t	df	p	upper limit	lower limit
1 Medium : High	-4.428	0.053	58.783	10835.119	0	-4.252	-4.605
2 Medium : Strenuous	-5.425	0.051	74.592	9636.756	0	-5.254	-5.595
3 High : Strenuous	-0.997	0.027	26.397	14775.254	0	-0.908	-1.085

Table 4.9.Temperature in front of cheeks **Welch one-way** test for workload

One-way analysis of means (not assuming equal variances)			
F	**num df**	**denom df**	**p-value**
803.39	2	13157	< 2.2e-16

Table 4.10. Games-Howell post-hoc test for Temperature in front of cheeks for workload

groups	Mean Difference	Standard Error	t	df	p	upper limit	lower limit
1 Medium : High	-1.379	0.043	22.632	11921.765	0	-1.236	-1.522
2 Medium : Strenuous	-2.037	0.040	36.419	9032.501	0	-1.905	-2.168
3 High : Strenuous	-0.658	0.022	20.858	11775.886	0	-0.584	-0.731

Table 4.11. Kruskal-Wallis: Heat index under nose versus face mask type

chi-squared	df	p-value
2840.2	4	< 2.2e-16

Table 4.12.Dunn (1964) Kruskal-Wallis multiple comparison for heat index under nose versus mask type

Comparison	Z	P.unadj	P.adj
1 cotton - Exhale valve	28.7287349	1.670128e-181	4.175321e-181
2 cotton - KN95	-0.5982501	5.496731e-01	5.496731e-01
3 Exhale valve - KN95	-29.3269850	4.697823e-189	1.565941e-188
4 cotton - N95	-21.2457954	3.605446e-100	7.210893e-100
5 Exhale valve - N95	-49.9745302	0.000000e+00	0.000000e+00
6 KN95 - N95	-20.6475452	1.027077e-94	1.711794e-94
7 cotton - Surgical Mask	15.6339631	4.273749e-55	5.342186e-55
8 Exhale valve - Surgical Mask	-13.0947718	3.527330e-39	3.919256e-39
9 KN95 - Surgical Mask	16.2322132	2.984996e-59	4.264279e-59
10 N95 - Surgical Mask	36.8797585	9.755946e-298	4.877973e-297

Table 4.13.Kruskal-Wallis: Heat index in front of cheeks versus face mask type

chi-squared	df	p-value
5044.9	4	< 2.2e-16

Table 4.14.Dunn (1964) Kruskal-Wallis multiple comparison for heat index in front of cheeks versus mask type

Comparison	Z	P.unadj	P.adj
1 cotton - Exhale valve	31.0184180	3.043223e-211	6.086446e-211
2 cotton - KN95	-4.0811004	4.482298e-05	4.980331e-05
3 Exhale valve - KN95	-35.0995184	6.855756e-270	2.285252e-269
4 cotton - N95	-27.8871755	3.817256e-171	5.453222e-171
5 Exhale valve - N95	-58.9055935	0.000000e+00	0.000000e+00
6 KN95 - N95	-23.8060751	2.889380e-125	3.611725e-125

Table 4.14. Continued

Comparison	Z	P.unadj	P.adj
7 cotton - Surgical Mask	30.7098606	4.203485e-207	7.005808e-207
8 Exhale valve - Surgical Mask	-0.3085575	7.576582e-01	7.576582e-01
9 KN95 - Surgical Mask	34.7909610	3.332068e-265	8.330171e-265
10 N95 - Surgical Mask	58.5970361	0.000000e+00	0.000000e+00

Table 4.15. Kruskal-Wallis: Heat index under nose versus workload

chi-squared	df	p-value
8597.7	2	< 2.2e-16

Table 4.16.Dunn (1964) Kruskal-Wallis multiple comparison for temperature under nose versus workload

Comparison	Z	P.unadj	P.adj
1 High - Medium	-44.36630	0	0
2 High - Strenuous	48.32923	0	0
3 Medium - Strenuous	92.69553	0	0

Table 4.17.Kruskal-Wallis: Heat index in front of cheeks versus workload

chi-squared	df	p-value
2323.5	2	< 2.2e-16

Table 4.18.Dunn (1964) Kruskal-Wallis multiple comparison for temperature in front of cheeks versus workload

Comparison	Z	P.unadj	P.adj
1 High - Medium	-15.51044	2.948439e-54	2.948439e-54
2 High - Strenuous	31.76968	1.698362e-221	2.547543e-221
3 Medium - Strenuous	47.28012	0.000000e+00	0.000000e+00

Discussion

Temperature

Mask type

According to the results, it had been found a strong significant effect of all face mask types on the temperature build-up under the nose inside the mask. N95 respirator recorded the highest accumulated temperature inside the mask, followed by KN95, surgical mask, cotton mask, and cotton mask with exhalation valve. The surgical mask has higher air permeability and water vapor permeability than N95 (Lee et al., 2020; Li et al., 2006b). Good air permeability means good airflow passed through a specific area and consequently lowered thermal insulation (Kucukali Ozturk et al., 2018). Also, water vapor permeability is a critical aspect of fabrics to transmit moisture to the environment to maintain thermal body equilibrium. Significant temperature difference was shown between surgical masks and cotton masks. A negative relationship had been found between the cotton fabric's water vapor permeability and fabric cover and solid content (Das & Kothari, 2012). The cotton mask with an exhalation valve is made of ultra-soft cotton fabric. During the inhalation, the valve closed and allow the air to pass through the filter, while during exhalation, the valves open, and the air is pushed out through the filter and the valve (Respirators et al., 2020). The extra exit for the exhaled air enables it to escape, reducing the thermal insulation and effectively reducing the mask's temperature and humidity (Hayashi & Tokura, 2004).

KN95 and N95 respirators showed high thermal insulation over time compared to other face masks. The difference between the KN95 and N95 is the breathability criteria, not the filter efficiency. Both of them capture 95% of particles (*Improve the Fit and Filtration of Your Mask to Reduce the Spread of COVID-19 | CDC*, n.d.). CDC reported that the KN95 is uncomfortable and adds more effort to breath than N95, which is aligned with high and robust breathability standards.

However, KN95 showed more breathability compared to N95 and explained by the shape of the cup where N95 was closer to the face compared to KN95.

This research's first study showed no significant effect of face mask type wear by employees in retail companies on heat sensation. However, the heat was rated highly by the employees. A post hoc test showed that in terms of z differences order descending as follows: respirator with a removable filter, N95, surgical mask, cloth mask, other. In the second study, the cotton mask with the exhalation valve was the lowest in terms of temperature accumulated, which is contracted with the survey but can be explained as the first study has low participants compared to the second study's data size. Also, there is a possibility that the mask with removable filter wear by the employees didn’t have an exhalation valve. N95 respirator was higher in heat rated than cloth and surgical mask, which coincided with the second study.

Also, temperature build-up inside the mask in front of the cheeks significantly affected by the mask type is the same trend of the temperature under the nose except for two combinations. In the case of cheeks, the N95 respirator showed higher temperature insulation than KN95. This is explained by the shape of the two respirators where KN95 is wider and far from the cheeks. On the other hand, the N95 respirators are tighter from the side and closer to the cheeks. Also, the cotton mask aggregated more heat compared to the surgical. The cotton mask consists of three knitted cotton layers and a surgical mask consisting of three nonwoven fabric layers. However, the surgical mask is thinner and broader in front of the cheeks. As the thickness of cotton and nonwoven fabric increase, the thermal resistance increase (Kucukali Ozturk et al., 2018; Ukponmwan, 1993).

Workload

The results showed a strong significant effect of different workload levels on the temperature build-up under the nose. This study had recorded new findings that contradicted previous researches. It had been found that as the workload decreased, the temperature build-up increased. As the workload increases, the volume of exhaled or inhaled air increases too, where more volume blowing over a surface increases the temperature. In our case, the relative humidity under the nose reached saturation and was constant at 99.9%, where warm air can hold high water vapor concentration. Also, the respiratory rate was constant at 25 breath/min which reflect the speed of breathing. In combination with these factors, where humidity and speed of air constant but the temperature is increasing, the rate of evaporation increased. Evaporation rates are faster at higher temperatures because the amount of energy required for evaporation reduces as temperature rises (*Evaporation and Climate*, n.d.; *Rate of Evaporation | Science Project | Education.Com*, n.d.). However, wearing a face mask beside the original workload is an added workload to the individuals. Thus, there is less productivity and work tolerances (*Effects of an SCBA on Breathing Pattern, Gas Exchange, and Heart Rate during Exercise - PubMed*, n.d.).

Moreover, finding the significant effect of the workload on temperature build-up under the nose coincided with our previously presented study findings. In the previous study, significance was significant for low workload compared to other workload levels only. However, post hoc analysis showed the same trends for the different workloads for the z difference where the z was higher for the medium workload than the strenuous workload, z difference higher for the high workload than the strenuous didn’t match with high compared to medium workload. This could be explained by how the employees estimated the workload.

Besides, the temperature build-up within the mask in front of the cheeks is greatly influenced by the workload levels and followed the same temperature pattern under the nose. As the workload increased, the tidal volume for exhaled or inhale breath increased, and the accumulated temperature in front of cheeks decreased.

Heat index

Mask type

The heat index is the combination of temperature and relative humidity, which indicates the body's temperature. A positive direct relationship connects the air temperature (increase), and relative humidity (increase), and the heat index (increase). The heat index has a critical impact on human body comfort. The body will start perspiration as a way of body thermoregulation in a hot environment or exerted muscles. Perspiration becomes more challenging and slower in high humid conditions where the surrounding air can hold no further water. Consequently, the body temperature increases and heat up, which makes individuals feel hotter. Overheating the body combined with strenuous activity causes heat exhaustion.

The humidity over the time under the nose was 99.9% and almost saturated. Therefore, the heat index under the nose and in front of the cheeks is the temperature factor. Results showed that the heat index was significantly affected by the Mask type. N95, under high relative humidity, had the highest heat index, followed by KN95, cotton mask, surgical mask, and cotton mask with exhalation valve. The same trend of significant affected showed by the temperature under the nose.

Workload

As discussed previously, as the workload increased, the volume of exhaled or inhaled air increased. Similarly, the heat index for both microenvironments under the nose or in front of the cheeks was higher for medium, then high, followed by strenuous workload.

Conclusions

Different face mask types and workload levels significantly affected the temperature and heat index inside the mask for a breathing rate of 25 breaths/min. The humidity inside the mask was 99.9% over time, reaching saturation. The effect of the mask type on temperature build-up inside the mask agreed with previous research. On the other hand, the workload's effect on the temperature inside the mask was confounded with previous research findings that stated that the temperature inside the mask increased as the workload increased. However, this finding coincided with our first study in this work, that there is no significant effect of heat inside the mask among medium, high, and strenuous workload as rated by the employees. Although the face mask is a breathing barrier for respiratory system and increase the breathing resistance, the heat build-up inside the mask decreased as the workload increased explained by the evaporating effect.

Further research to investigate the effect of the workload on the temperature build-up inside the mask is needed. Having a breathing simulator that adjustable to various workload levels, breathing rate, and exhaled air temperature where it can be used to test any mask interested is valuable when the participants are not reachable. Also, valuable in studying strenuous workload and high breathing rates, which could expose the participants to risk.

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Appendix. SolidWorks drawing of the breathing machine

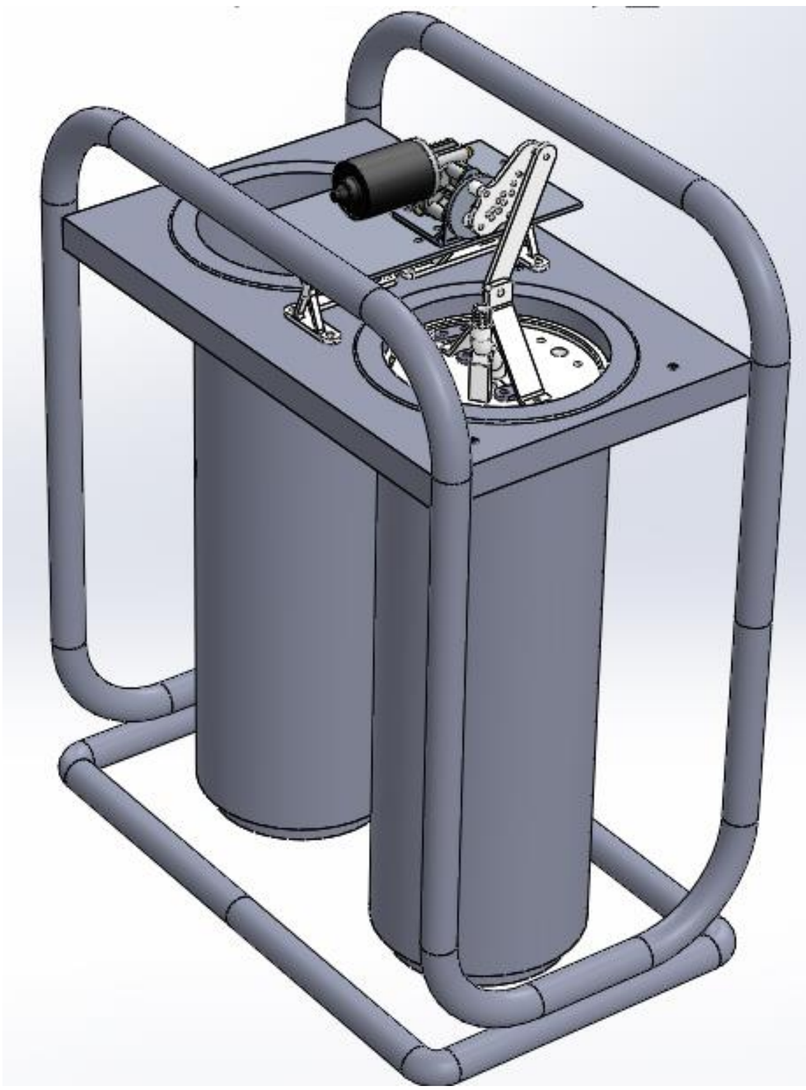

Figure 4.17. Breathing Simulator Device (Isometric View).

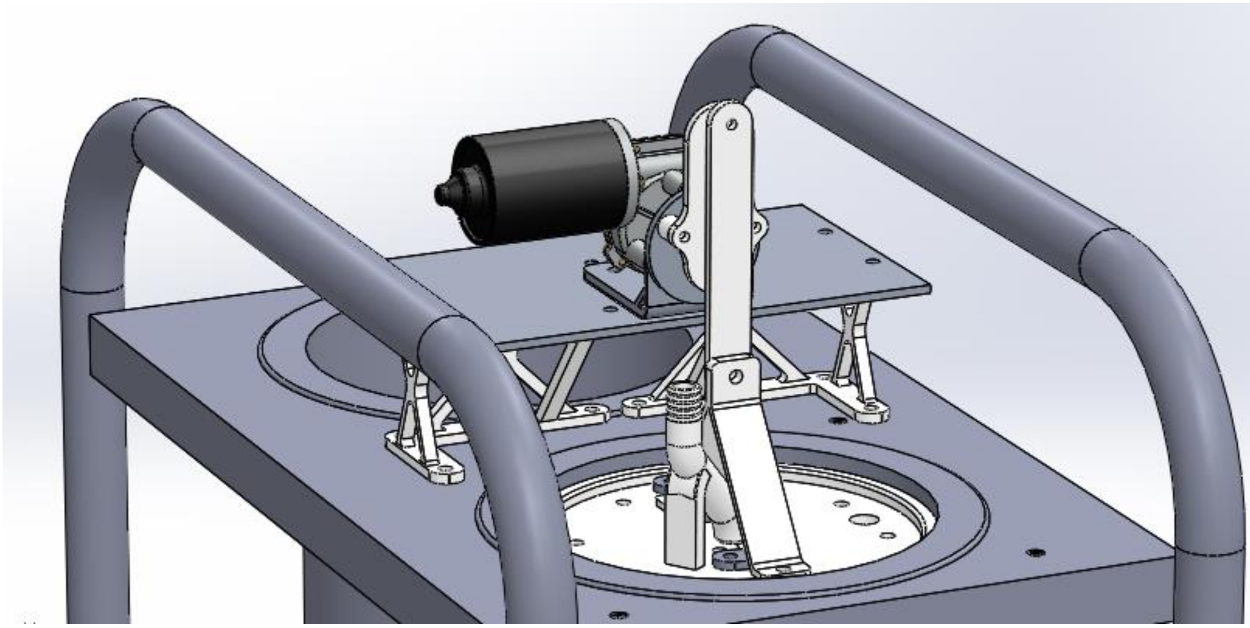

Figure 4.18. Breathing Simulator Device (Isometric View).

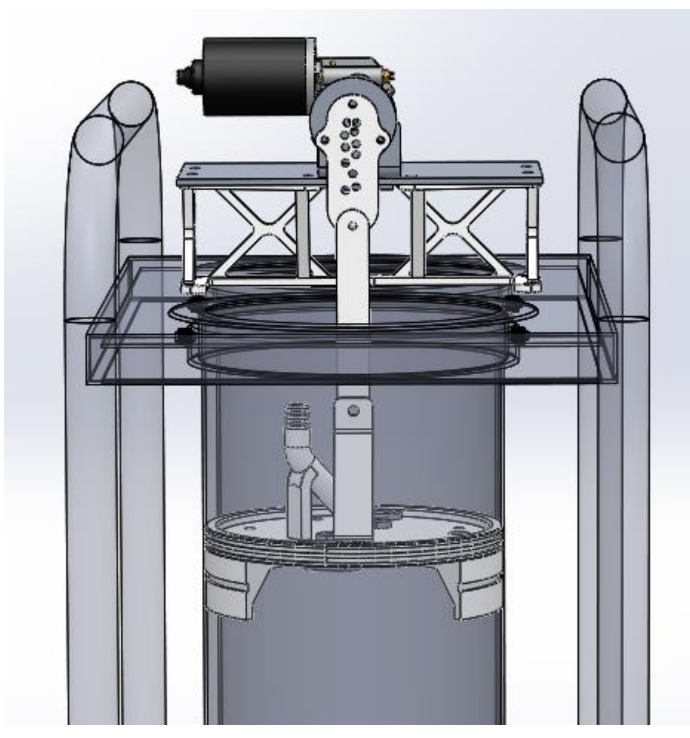

Figure 4.19. Breathing Simulator Device (Front View).

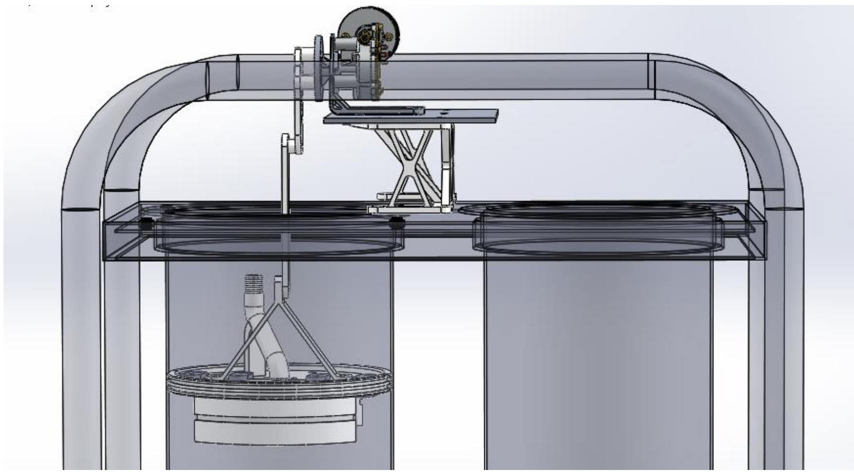

Figure 4.20. Breathing Simulator Device (Side View).

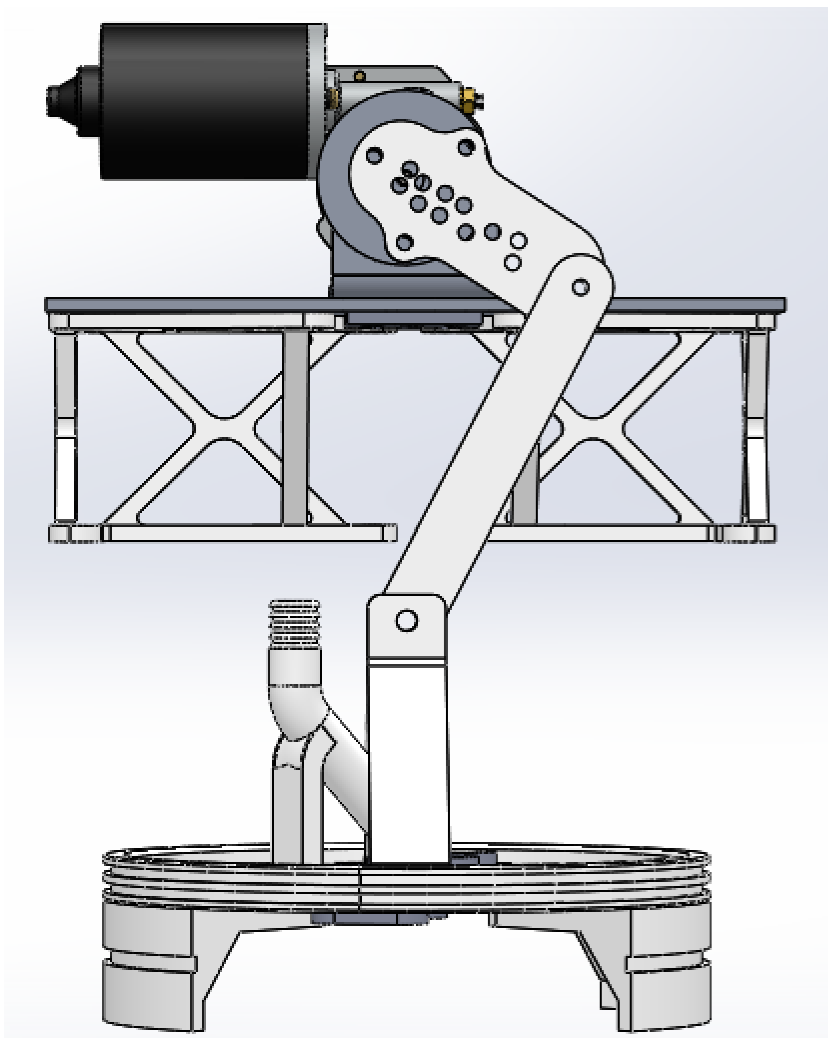

Figure 4.21. Components of Breathing Simulator Device (Front View).

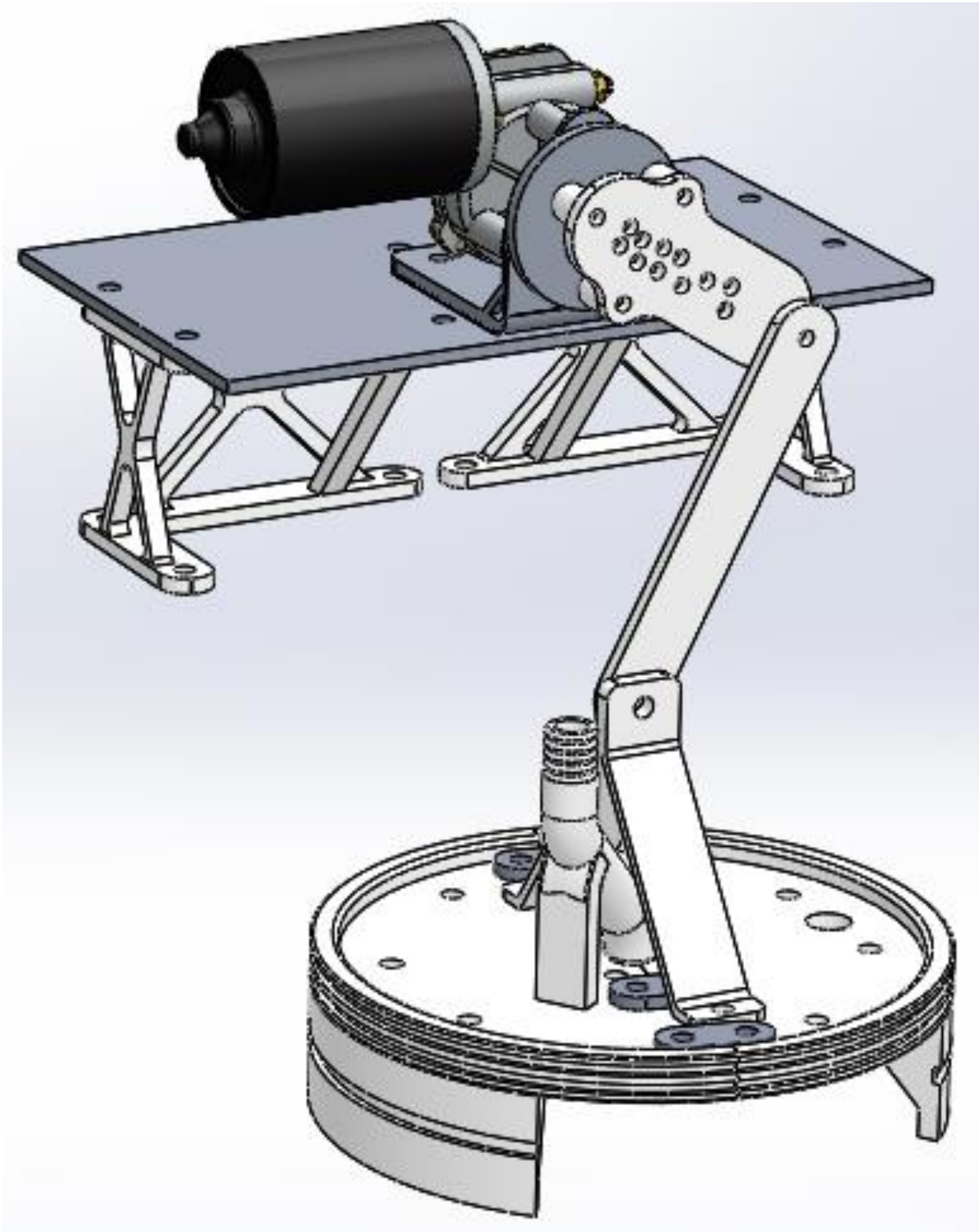

Figure 4.22. Components of Breathing Simulator Device (Isometric View).

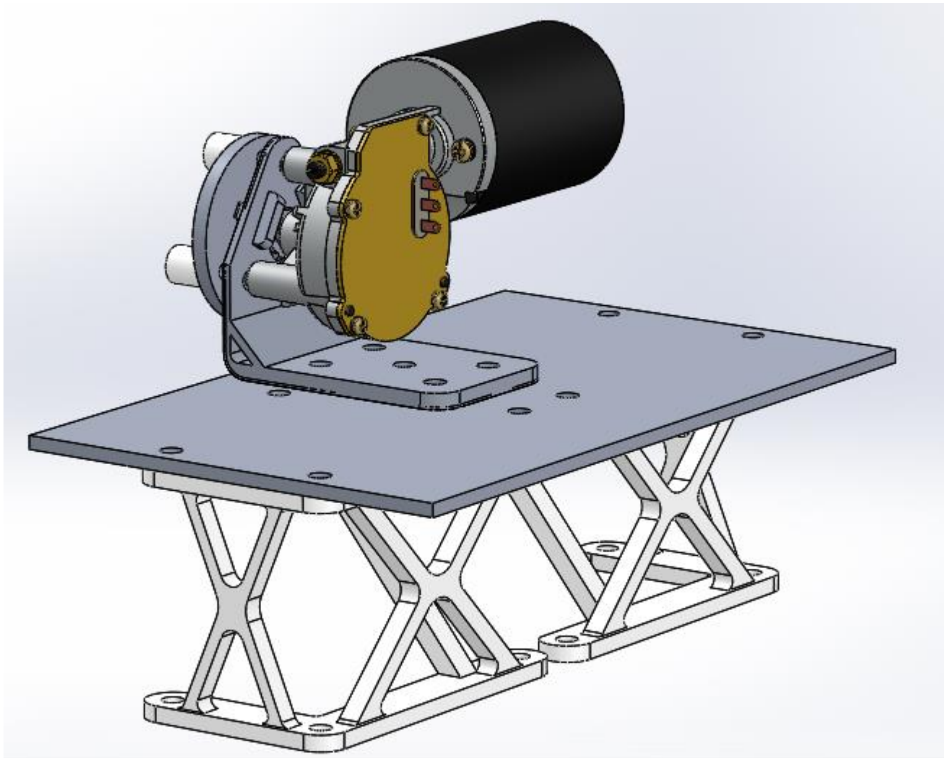

Figure 4.23. DC Motor with Mountings (Rear View)

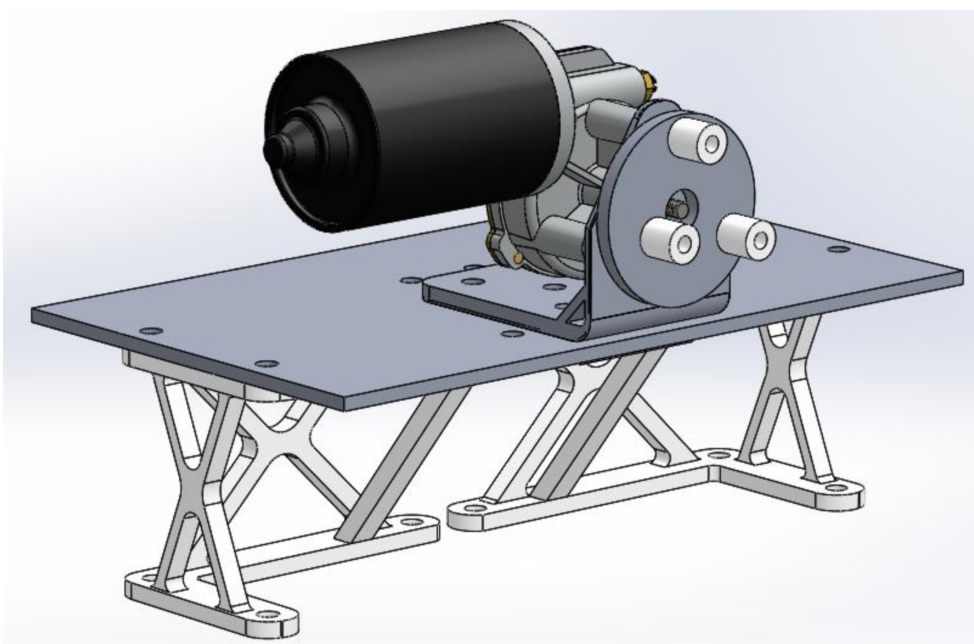

Figure 4.24. DC Motor with Mountings (Front View)

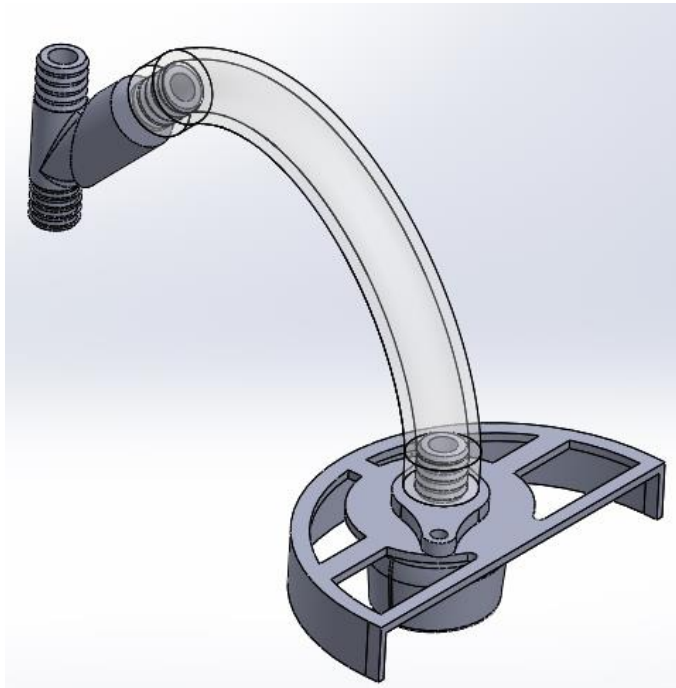

Figure 4.25. Humidifier Cap with the Connected Hose and Fittings (Isometric View)

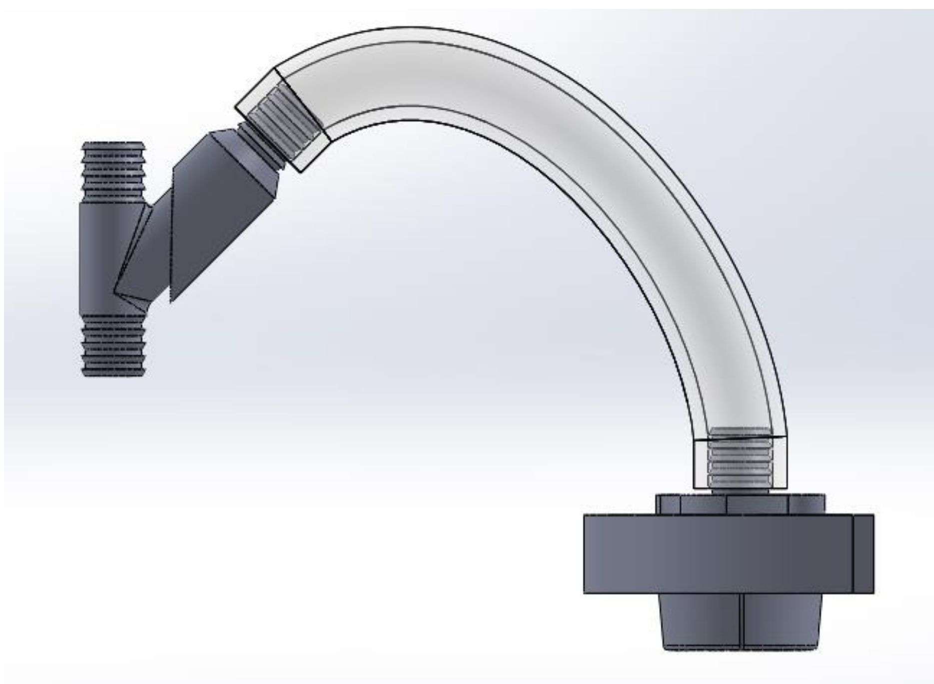

Figure 4.26. Humidifier Cap with the Connected Hose and Fittings (Side View)

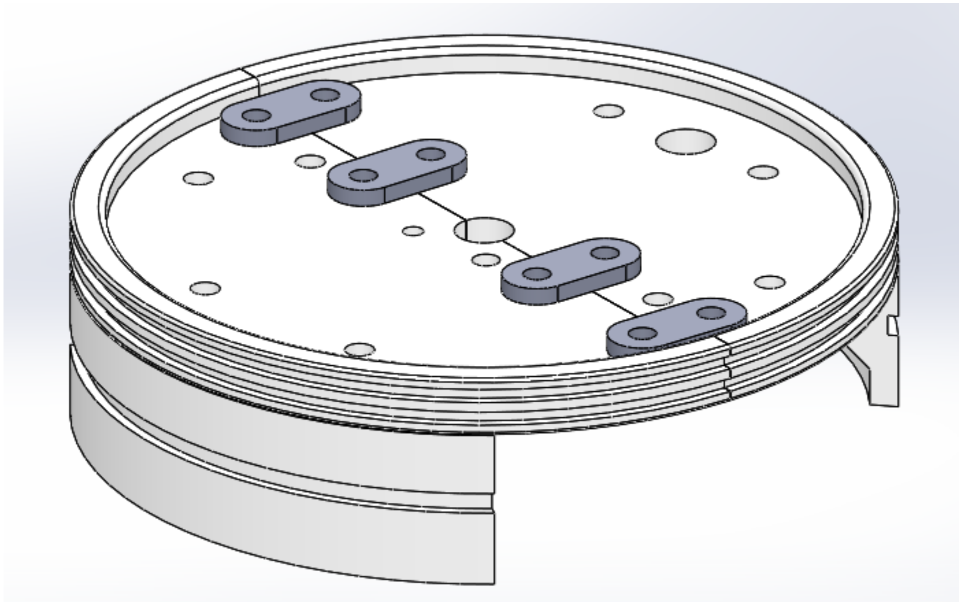

Figure 4.27. Two Parts of the Piston Assembled with Piston’s Guides (Isometric View)

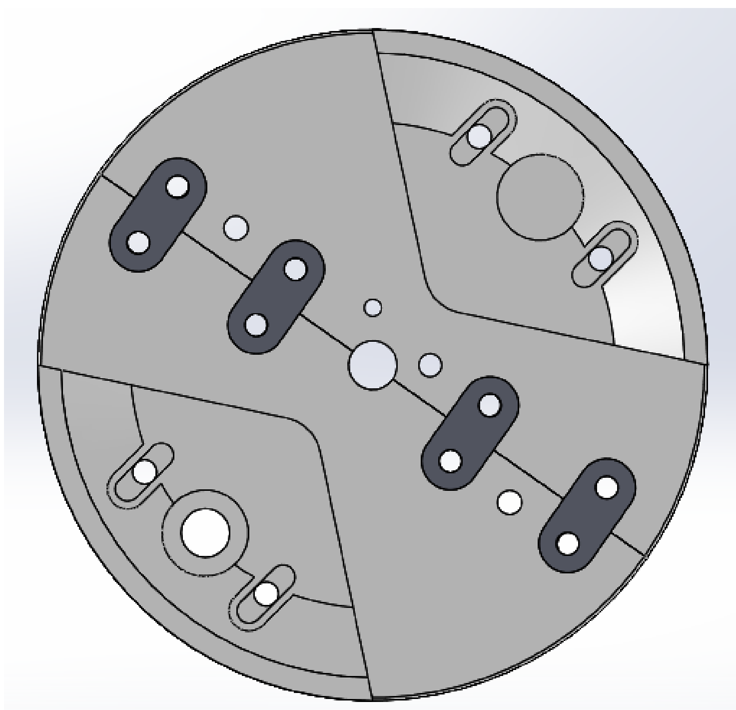

Figure 4.28. Two Parts of the Piston Assembled with Piston’s Guides (Bottom View)

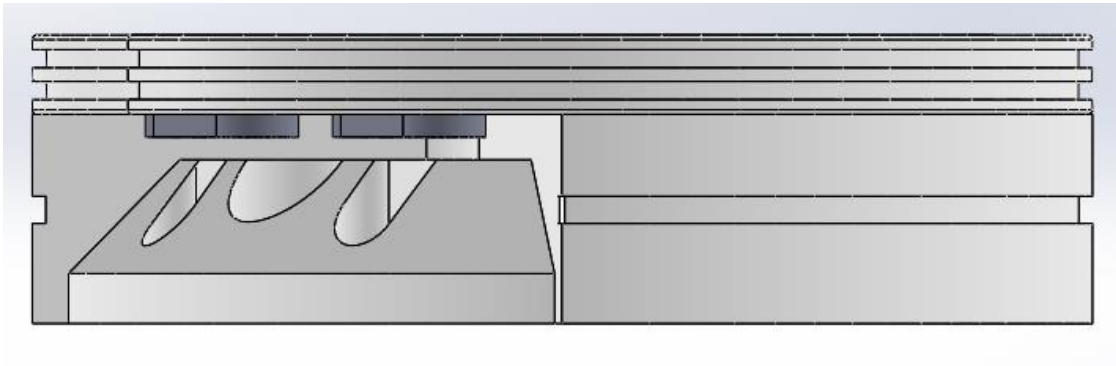

Figure 4.29. Two Parts of the Piston Assembled with Piston’s Guides (Side View)

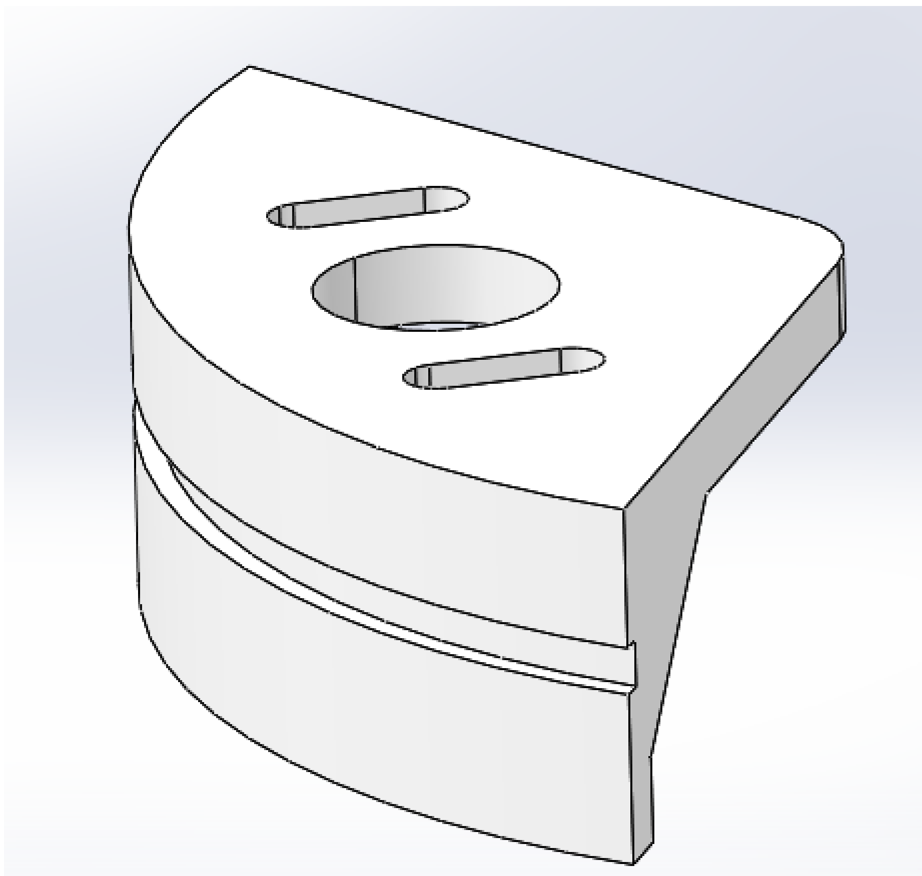

Figure 4.30. Piston’s Guides (Isometric View)

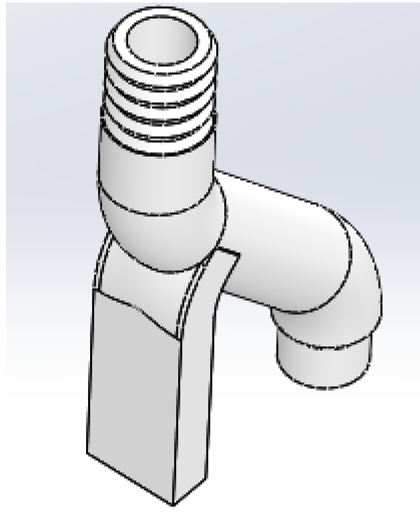

Figure 4.31. Main Hose Fitting (Isometric View)

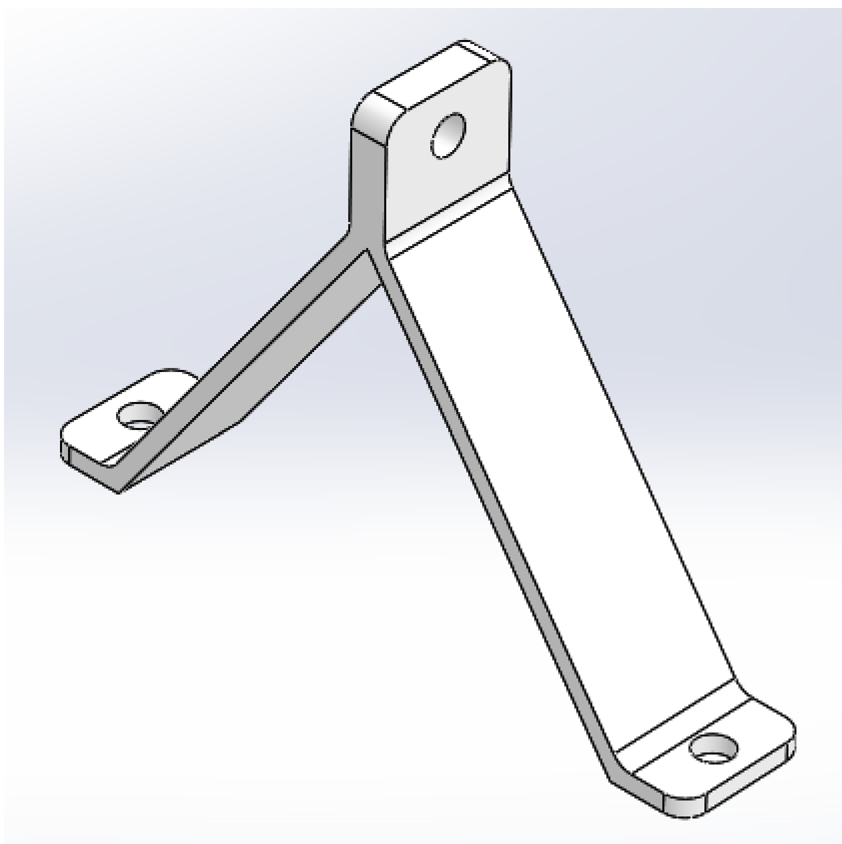

Figure 4.32. Piston’s Holder (Isometric View)

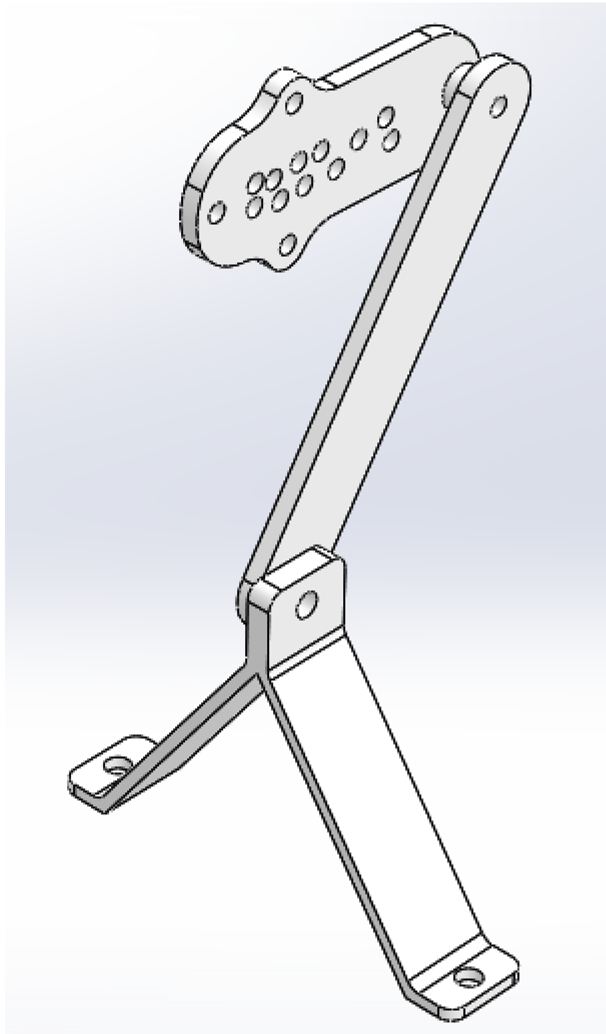

Figure 4.33. Piston’s Holder Connected with the Volume’s Link

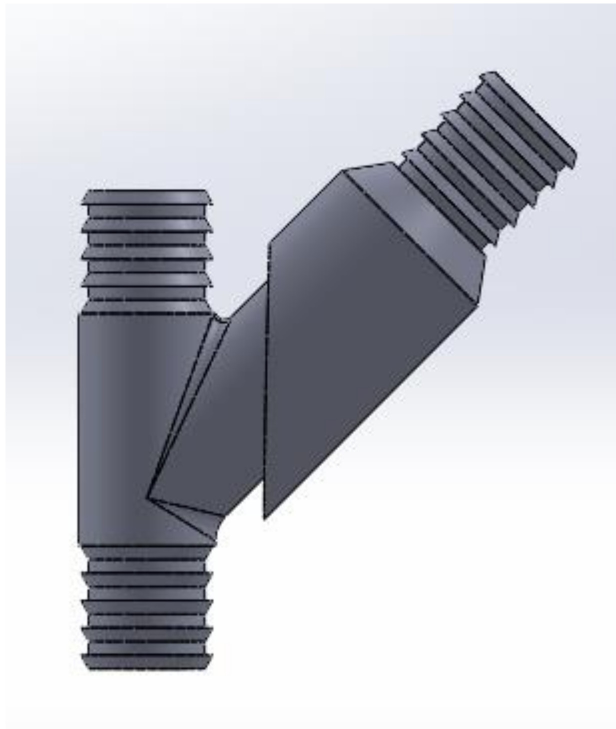

Figure 4.34. Y-Connecter with the Humidifier Hose's Fitting

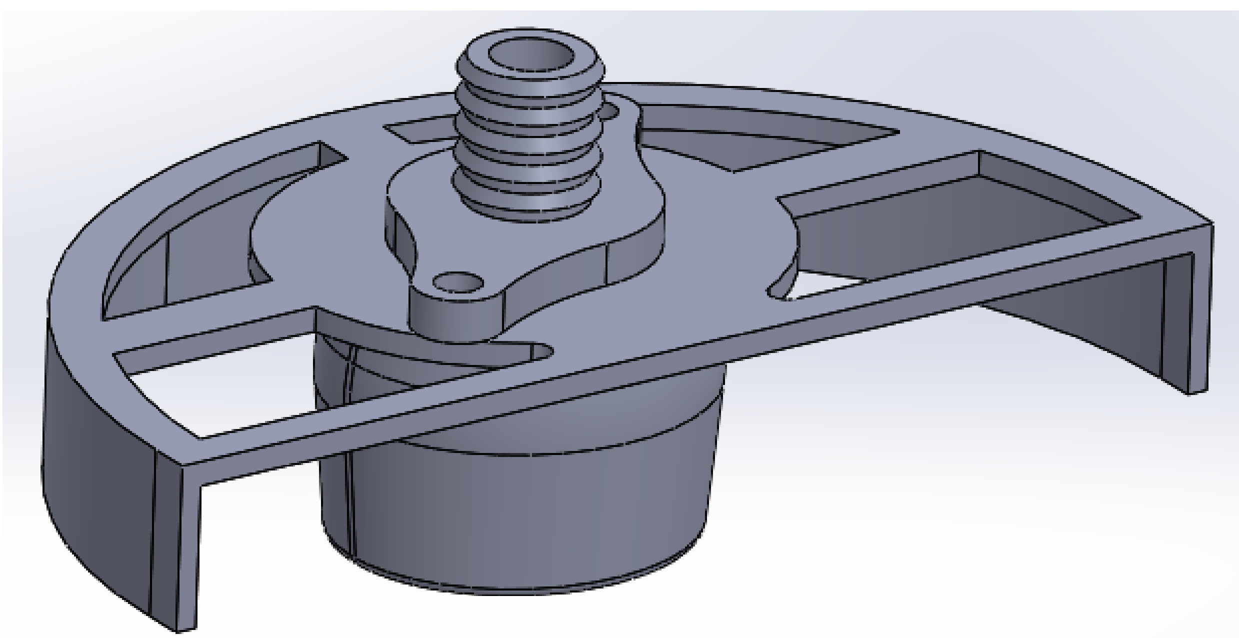

Figure 4.35. Humidifier Cap connected with Humidifier Hose's Fitting (Isometric View)

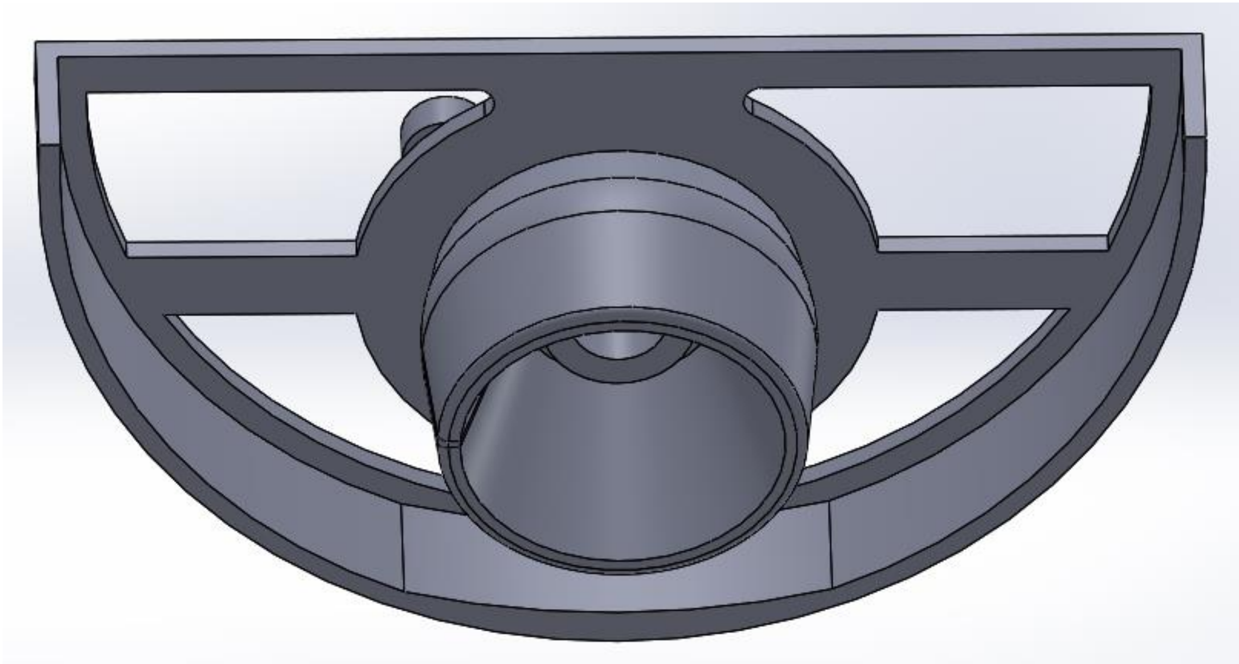

Figure 4.36. Humidifier Cap (Isometric View)

CHAPTER 5. GENERAL CONCLUSION

Conclusion and Limitations

This thesis investigated three areas; factors' impacts on human sense, psychomotor ability, psychology, cognition, work tolerance, the sensation of discomfort, and thermal sensation during the COVID-19 era, developed human breathing simulator, and the effect of different mask types and workloads on temperature, relative humidity, and heat index inside the mask.

Surveys were distributed to retail employees via emails. This study is the first in which confirmed that wearing eyeglasses affect the visual sense and the ability to read or see where the employees take off the mask to read. Consequently, taking off the mask while works will expose the employee to the risk of being infected. Also, it had been found that being fit reduced the overall discomfort of wearing a mask compared to a non-fit employee. Thus, working out and being in good shape enhance to tolerate wearing a face mask. Significant findings were found regarding smokers. Smokers were less adhere till the end of the shift as they had higher body, lip, and cheek temperatures than nonsmokers. Moreover, the interaction of smoking and workload resulted in a slightly slower motion response, itchiness, and tightness.

Regarding the second study, the temperature and heat index build-up within masks is significantly affected by different face mask types and workload levels (under the nose and in front of cheeks). The N95 mask had the highest average temperature and heat index over time, while the cotton mask with the exhalation valve had the lowest, which coincided with previous research.

On the other hand, it had been found that as the workload increased, the temperature and heat index decreased and agreed with the employees in retail companies rating, but confounded with the previous studies. Thus, the temperature and heat index inside the mask reached the Plateau effect where didn't affect by increasing workload.

There are some limitations in this work that could be addressed in the future. The number of respondents to the survey can be increased. Also, provide more clarification to the respondents on how to evaluate their workloads. Expand on the question of mask types used in retail companies. Regarding the second study, the room's temperature and humidity should be considered for the following research, affecting the output if it's varying. Also, increase the number of replicates for each set to increase the data validity.

Future Work

Although both studies presented in this thesis is some of the first of their kind, there are aspects were could be expanded:

1. Test more different mask types or any forms of mouth and nose covering.
2. Test the effect of face masks under different breathing rates.
3. Test the interaction of different mask types, breathing rates, and cyclic mean inhalation flows (workloads).