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The COVID-19 pandemic has required people to take new measures to mitigate the spread of the communicable virus. Guidelines from health organizations, government offices, and universities have been disseminated. Adherence to these guidelines cannot be more critical for flight training. This study explored the effects face masks had on CO_2, heart rate, respiration rate, and oxygen saturation while wearing a face mask at an oxygen level simulated to 5,000 feet. Thirty-two instructor pilots (IP) volunteered to participate in the study. IPs spent 90 minutes in a normobaric chamber while wearing a cloth face mask or a paper face mask. Participants were measured before entering the chamber, at the 15-minute mark, at the 45-minute mark, at the 90-minute mark, and after exiting the chamber where they briefly removed their mask for a final measurement. No differences were found between type of face mask. Wearing face masks did not present any potential health or safety issues for the IPs. However, IPs did report moderate dislikes (e.g., comfort, issues with fatigue, restriction of movement) of wearing face masks. Although face masks may be a nuisance, it does not appear to create any health or safety issues at a simulated altitude of 5,000 feet.

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The outbreak of COVID-19 has brought about some drastic changes to our way of life. As more is learned about the virus, cities and counties look to protect citizens and allow a return to normal. The Centers for Disease Control and Prevention (CDC) (2020) issued a recommendation that citizens wear cloth masks to protect themselves and others.

Many aspects of day-to-day life can be adjusted to allow for social distancing to help reduce the risk of community-based spread of COVID-19. The unique nature of flight training does not allow for social distancing in the aircraft. When Embry-Riddle Aeronautical University decided to resume flight training, face masks usage for both instructor pilots (IP) and students were one of the many safety precautions that were made mandatory.

After a few weeks of flight training some of the IPs expressed concerns about discomfort from wearing a mask and some said face masks cause them to feel fatigued. During respiration, a gas exchange occurs when oxygen is inhaled and absorbed into the body and carbon dioxide (CO_2) is exhaled. When exhaling into a mask, there is a potential to inhale a greater amount of carbon dioxide, due to the exhaled carbon dioxide being trapped between the face and mask. One symptom of an excess of carbon dioxide in the blood, or hypercapnia, is fatigue (Jewell, 2005). Carbon dioxide can be measured in the air exhaled, by using a capnograph. A normal amount of carbon dioxide when measured by a capnograph is between 35 and 45 mm HG (Sullivan, 2015). If the mask is trapping carbon dioxide rich air, it could result in not enough oxygen being brought into the lungs during respiration. Lack of oxygen being absorbed through respiration could cause hypoxia. The Cleveland Clinic lists the symptoms of hypoxia ranging from shortness of breath, to confusion and death (Hypoxemia, n.d.). The amount of oxygen in a person's blood can be measured using a pulse oximeter. A normal pulse oximeter reading will vary between 95-100% (Mayo Clinic, 2018). The effect of hypoxia due to an increase in altitude in non-pressurized aircraft has been well documented and is required to be taught at the Commercial pilot level (FAA, 2015). Pilots are trained to know what symptoms to look for and how best to react.

Relatively little research has been conducted regarding the physiological effects of wearing a mask. Roberge, Coca, Williams, Powell and Palmiero (2010) conducted a study with healthy health care workers using filtering facepiece respirators (FFR) or N95 masks. The study looked at differing workloads for a 1-hour duration and studied, CO_2 as one of the many physiological effects. The study concluded that there were no significant physiological effects of wearing an FFR for 1 hour. However, two of the participants' peak CO_2 reached 50 mm HG at the end of the 1-hour period, suggesting that use of this type of mask beyond an hour may have negative effects. It is important to note that an FFR is designed to fit tightly to the face so it can filter out 95% of airborne particles unlike a cloth or paper/surgical mask (Center for Devices and Radiological Health, n.d.).

Schmidt (2020) quoting a representative from the CDC:

> The CO_2 will slowly build up in the mask over time. However, the level of CO_2 likely to build up in the mask is mostly tolerable to people exposed to it. It is unlikely that wearing a mask will cause hypercapnia. (para. 5)

A later study by Roberge et al., (2012) considered the physiological effects of wearing a surgical mask. Participants walked on a treadmill for 1 hour wearing a surgical mask and for an additional hour without a mask while various physiological measurements were taken. In the analysis, Roberg et al. concluded that there was no physiological impact from wearing a surgical mask. There was a statistically significant rise in transcutaneous carbon monoxide; however, it would not be medically significant in a healthy individual. The CO_2 levels still remained in the normal range between 35 to 45 mm HG.

No studies relating to physiological effects of face mask use in an aviation context have been found. This study looked at the amount of carbon dioxide exhaled over time at a simulated altitude of 5,000 feet. Additionally, a comparison was made between paper/surgical masks and cloth masks.

Methodology

Participants

Thirty-two (26-male, 6-female) instructor pilots volunteered to participate in this study. Mean age of participants was 24.31 years ($SD = 2.98$). All participants were currently employed and received the IP hourly rate for the 2 hours in the study. Half the participants wore a cloth face mask during the study and the other half wore a paper/surgical face mask.

Materials

The Smiths Medical 8401 Capnocheck II capnograph (see Figure 1) with cannula was used to measure End-tidal CO_2, heart rate (HR) respiration rate (RR), and O_2 saturation. Cloth face masks and paper face masks were provided to participants, if necessary, to assure an equal distribution of face mask types per group. A normobaric altitude chamber was used to reduce oxygen levels from 20.9% at sea level to 17.61% —the typical oxygen level at an altitude of 5,000 feet. To simulate activities that may occur in an aircraft, aeronautical charts were provided, as well as a nut and bolt to simulate any turning of knobs. A survey (see Appendix A) included self-reports of opinions concerning wearing face masks.

Figure 1. Capnograph device.

Procedure

Eight sessions were scheduled to accommodate four participants at a time. Guidelines as directed by the CDC and as mandated by the University were strictly followed. There were two empty seats between each participant in the normobaric chamber. Participants were provided with hand sanitizer and were required to wear masks at all times — except for a few minutes before entering the chamber and for a few minutes after exiting the chamber.

After signing the consent form, each participant's CO_2, HR, RR, and O_2 saturation were measured with the capnograph – first with the face mask off, then with the face mask on. Participants were provided with their own cannula. Participants entered the normobaric chamber at a simulated altitude at 2,000 feet, when it was then raised to a simulated altitude of 5,000 feet. At the 15-minute, 45-minute, and 90-minute mark in the chamber, participants' CO_2, HR, RR, and O_2 saturation were again measured. Face masks were never removed inside the chamber. Throughout the 90-minute session, participants were periodically instructed to look up airport identifiers and runway elevations on an aeronautical sectional chart, raise their arms for 10 seconds to simulate adjusting navigation/communications controls, read a check-list, and twist a nut on and off a bolt. Participants were not aware of the exact moment physiological measurements were taken or, the time when they were to exit the normobaric chamber.

After 90 minutes, participants exited the chamber. Participants then completed the survey. Before completing the study, participants' CO_2, HR, RR, and O_2 saturation were measured again (one at a time) with the face mask off.

Results

A 2 (Type of face mask) x 6 (Time of collection) Mixed ANOVA was conducted for CO_2 level, HR, RR, and O_2 saturation. Main effects for Time of collection were found for all four measurements: CO_2: $F(5, 150) = 2.969$, $p = .014$, $\eta_p^2 = .090$; HR: $F(5, 150) = 11.782$, $p < .001$, $\eta_p^2 = .282$; RR: $F(5, 150) = 2.347$, $p = .044$, $\eta_p^2 = .073$; O_2: $F(5, 150) = 10.412$, $p < .001$, $\eta_p^2 = .258$ (See Figures 2 a, b, c, and d). No other effects were found.

CO_2 levels were significantly higher before entering the normobaric chamber when the face mask was off, as well as after donning the face mask, but immediately before entering the chamber when compared to the 45-minute mark inside the chamber when the face mask was on and when immediately tested after exiting the chamber (See Table 1). LSD post hoc analyses showed higher HR before entering the chamber (both with face mask off and after donning the face mask) compared to all other time measurements when in the chamber and when tested after exiting the chamber. LSD post hoc analyses showed RR was higher after exiting the chamber compared to after donning the mask before entering the chamber, at the 15-minute mark, and at the 45-minute mark. Post hoc analyses found O_2 saturation to be lowest at the 15-minute mark when compared to all other measured times. In addition, O_2 saturation was highest after exiting the chamber when compared to all other measured times.

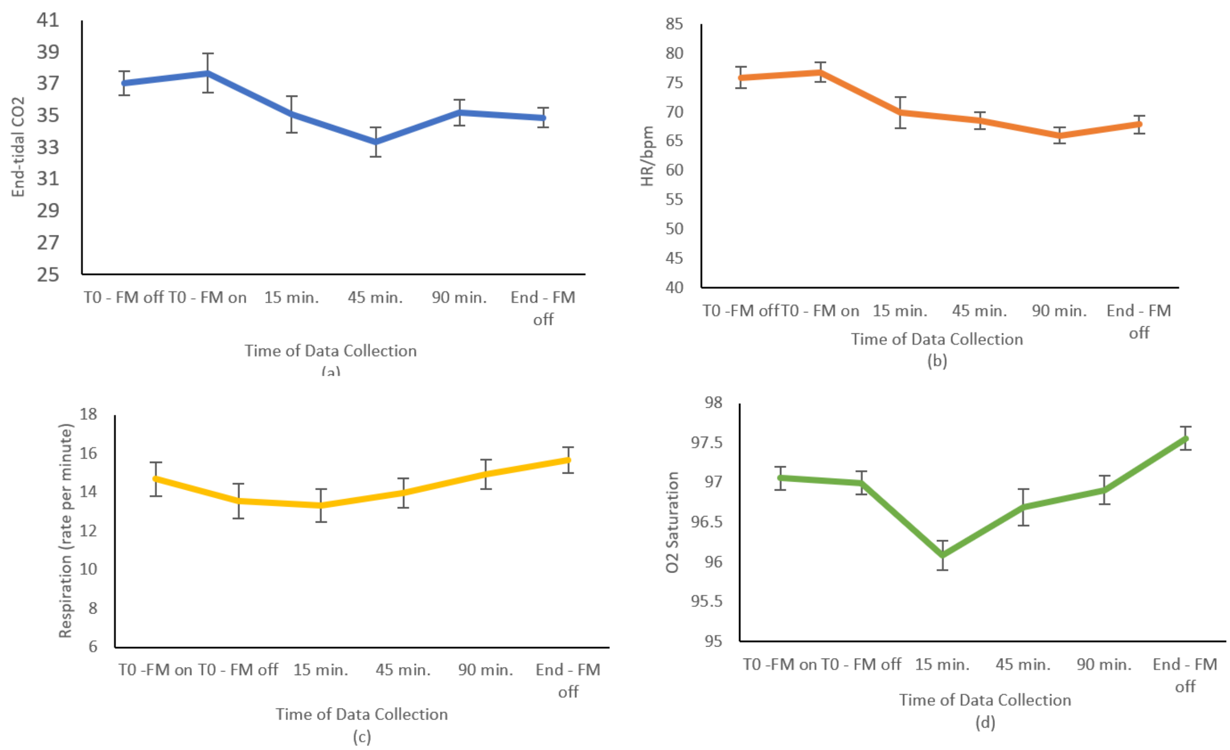

Figure 2(a)-(d). Changes in CO_2, Heart Rate, Respiration Rate, and O_2 Saturation Over Time of Data Collection.

Table 1
Means for CO_2, HR, RR, and O_2 Saturation by Type of Face Mask

Time	CO_2			HR			RR			O_2 Saturation		
	Cloth	Paper	Total	Cloth	Paper	Total	Cloth	Paper	Total	Cloth	Paper	Total
T_0 – Mask off	37.31 (4.48)	35.28 (4.05)	36.30^{A} (4.32)	77.50 (10.46)	74.38 (9.47)	75.94^{C} (9.94)	15.88 (4.73)	13.50 (5.19)	14.69 (5.03)	96.75 (.93)	97.38 (.72)	97.06^{Fg} (.88)
T_0 – Mask on	37.22 (9.33)	38.09 (3.52)	37.66^{B} (6.95)	78.19 (10.11)	75.5 (8.33)	76.84^{D} (9.21)	13.88 (4.49)	13.25 (5.70)	13.56^{e} (5.05)	97.06 (.77)	96.94 (.85)	97.00^{Fg} (.80)
15-minute mark	35.75 (6.33)	34.38 (6.97)	35.06 (6.58)	74.44 (11.32)	65.56 (18.0)	70.00^{cd} (15.5)	14.06 (4.14)	12.56 (5.39)	13.31^{e} (4.79)	95.75 (1.13)	96.44 (.96)	96.09^{fg} (1.09)
45-minute mark	34.84 (4.79)	31.84 (5.67)	33.34^{ab} (5.39)	68.88 (9.53)	68.31 (6.44)	68.59^{cd} (8.00)	14.75 (3.44)	13.19 (5.10)	13.97^{e} (4.35)	96.63 (1.31)	96.75 (1.29)	96.69^{Fg} (1.28)
90-minute mark	35.75 (4.64)	34.63 (4.65)	35.19 (4.60)	65.88 (9.70)	66.25 (6.08)	66.06^{cd} (7.97)	15.38 (3.63)	14.50 (4.89)	14..94 (4.26)	96.94 (1.00)	96.88 (1.02)	96.91^{Fg} (1.02)
After exiting chamber (Mask off)	35.78 (3.23)	33.94 (3.68)	34.86^{ab} (3.53)	69.56 (9.59)	66.25 (6.96)	67.91^{cd} (8.41)	16.69 (4.25)	14.63 (3.20)	15.66^{E} (3.85)	97.31 (.95)	97.81 (.66)	97.56^{FG} (.84)

Mean (*SD*)
Subscripts = pairwise comparison differences (Capital letter indicates higher than respective lower-case letter)

A post study six-question survey was conducted. Questions asked about how secure the face mask was to the face (Range: 1 - extremely loose to 10 - extremely tight); comfort level (Range: 1 - no effect on comfort to 10 - extremely uncomfortable); if face mask made participant feel warmer/hotter (Range: 1 - no effect on perceived body temperature to 10 - feeling extremely hot); if face mask restricted movement (Range: 1 - no effect on movement to 10 - greatly restricted movement; if face mask contributed to overall fatigue (Range: 1 - no impact on fatigue to 10 - very fatigued); and if face mask contribute to fogged glasses (1 - Range no fogging occurred to 10 - extreme fogging occurred).

A MANOVA of all survey questions, except for the question of fogging the glasses (due to low *n*) comparing groups (cloth face mask and paper face mask) was conducted. An independent means *t*-test showed no differences between groups for the glass fogging question. See Table 2 for descriptive statistics. No differences between groups were found for any of the variables.

Table 2
Descriptive Statistics for Survey

Question	Cloth FM	Paper FM	Total
FM Secure	6.66 (1.38)	6.56 (1.97)	6.61 (1.67)
Comfort	5.44 (2.28)	5.44 (1.66)	5.44 (2.05)
Warmer/Hotter	4.69 (2.70)	4.56 (2.37)	4.63 (2.50)
Movement Restricted	2.63 (2.06)	2.5 (2.16)	2.56 (2.08)
Fatigue	3.945 (2.46)	4.25 (2.72)	4.09 (2.56)
Fog	4.8 (3.93)	7.0 (3.39)	5.9 (3.66)
	$n = 5$	$n = 5$	$n = 10$

Correlations were conducted among responses for all six questions. Table 3 shows that comfort, feeling warm or hot, and restriction of movement and fatigue all positively correlated with each other. Restriction of movement is also positively correlation with fogging of glasses.

Table 3
Correlations of Survey Questions

	2	3	4	5	6
1. FM Secure	-.057	-.203	-.153	-.112	-.058
2. Comfort	-	.601**	.471**	.585**	.165
3. Warmer/Hotter	-	-	.396*	.642**	.303
4. Movement Restricted	-	-	-	.585**	.659*
5. Fatigue	-	-	-	-	.364
6. Fog (*n* = 10)	-	-	-	-	-

*< .05
**< .01

All four physiological measurements (CO_2, HR, RR, and O_2 saturation) were averaged for each time effect. A correlation was conducted for the four averaged physiological measurements. CO_2 and O_2 saturation were negatively correlated $r(32) = -.57$, $p = .001$. CO_2 was also negatively correlated with the survey question about how secure the face mask fit $r(32) = -.364$, $p = .041$ where the tighter a fit the participant reported the face mask, the lower the CO_2. Participants who reported greater discomfort wearing the face mask showed higher heart rate $r(32) = .476$, $p = .005$.

Discussion

Although there were some variations in the measurements of CO_2, O_2, HR and RR; at no point did the CO_2 rise above the normal range of 35 to 45 mm HG. Additionally, O_2 saturation did not fall below 95%, the generally accepted minimum normal percentage. There were no significant differences between mask types.

In terms of IP perception of the security of the mask, comfort, feeling hot or warm from the mask, restricted movement from the mask and fatigue; there was no significant differences between the two mask types. However, these variables were positively correlated with each other. The self-report of discomfort, but with little change in physiological measurements and performance is supported by previous studies in health care (Shenal, Radonovich, Cheng, Hodgson, & Bender, 2012) and education (Coniam, 2005).

Interestingly at the 45-minute measurement the CO_2 measurement dropped to 33 mm HG. This is often associated with a condition called Respiratory Alkalosis, which can be an effect of hyperventilation. The respiration rates for the participants at the 45-minute mark were normal. There appears to be a lull for all physiological measurements at the 45-minute mark, as well as a lull in conversation between IPs in the normobaric chamber at the 45-minute mark, which could explain slower breathing and HR that would lower CO_2 reading. Nonetheless, CO_2 rose back above 35 mm HG by the 90-minute mark.

Limitations

The chamber used to simulate 5,000 feet is a normobaric chamber, therefore the amount of oxygen present was decreased, but the pressure was maintained at sea level. The possible error this may cause is thought to be minimal. Additionally, the temperature remained constant in the normobaric chamber. On a climb from sea level to 5,000 feet, the temperature may change by 15° to 20°F. We do not know how differences in ambient temperature affect these physiological measurements. However, on a typical summer day, the temperature at 5,000 feet would be close to room temperature.

The activity level between the participants varied. Some groups talked animatedly amongst themselves and other groups were almost silent. This could have induced variations in the physiological readings. As in most behavioral studies, participants are aware they are being observed. The Hawthorne Effect (Snow, 1927) states that participants may change their behavior just because they know they are being observed, which consequently can confound internal validity. One issue that could have potentially affected the outcome of this study is that participants adjusted their breathing because they knew they were being observed. However, there are three reasons why it is unlikely that participants' behavior was affected in such a way to confound the results of this study. First, many of the participants were engaged in conversation, which would have decreased their focus of being observed. Second, participants were not told of the exact times measurement would be taken and the exact time the study would end. Third, there is evidence that the Hawthorne Effect has never been or has infrequently contributed to confounding effects in behavioral studies (Levitt & List, 2011).

Conclusions

The type of mask worn during an average 90-minute flight-training mission does not appear to increase the amount of CO_2 retained by the body. Additionally, face masks do not appear to hinder the body's ability to attain oxygen. IP perception about the adverse effects of the face mask appears to be moderate. However, with greater use and more familiarity wearing face masks, it is expected that this nuisance factor of the face mask will attenuate. Further testing in a flight simulator, where pilots are actively engaged with all aspects of flight (e.g., moving controls, communicating with Air traffic Control) is warranted. This study could also be repeated in flight with an observer monitoring physiological measurements.

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Appendix A

Please answer the following questions.

Please select your gender _______Male ________Female

Please provide your Age___________

What type of mask did you wear today? ______Cloth ______Paper

Please respond to the following questions based on a range of 1 to 10.

1. How well did the mask secure to your face?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

Extremely loose   Extremely tight

2. How did wearing the mask affect your overall comfort level?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

Had no effect on my comfort level   Made me extremely uncomfortable

3. Do you feel that wearing the mask made your body feel warmer/hotter?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

Wearing the mask had no effect
On my perceived body temperature   Wearing the face mask made
feel extremely hot

4. Did wearing the mask restrict your physical movement (e.g., reaching for controls, turning your head) in any way?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

Had no effect on my movement   Greatly restricted my movement

5. Do you feel that wearing the mask contributed to your overall fatigue?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

Mask had no impact on my fatigue   Mask made me very fatigued

6. If you wear glasses, did wearing the mask result in your glasses fogging?

1----------2----------3----------4----------5----------6----------7----------8----------9----------10

No fogging at all occurred   Extreme fogging of
my glasses occurred

Thank you for completing the survey. Please feel free to add any additional comments._______________