Comparison of the Physiological Effects of Wearing a Dust Mask and a Breath–Synchronized Powered Air-Purifying Respirator – a Comparative Crossover Study

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ABSTRACT

Background: Few studies have examined the physiological effects of wearing respiratory protective equipment in Japan. The aim of this study was to evaluate the physiological effects of wearing a dust mask (replacement–type) and a breath–synchronized powered air purifying respirator (BS–PAPR).

Methods: Eight non-smoking healthy men aged 20 to 39 years participated in this study. We randomly divided the subjects into three groups and conducted a comparative crossover study with a counterbalanced design to control for experimental order effects. The participants underwent exercise tests under three conditions: not wearing a mask, wearing a dust mask and wearing a BS-PAPR. We measured several physiological indicators, including respiration rate, fractional gas concentration in the respirators (fraction of expired carbon dioxide ($FECO_2$) and fraction of inspired carbon dioxide ($FICO_2$)), blood pressure, heart rate, double products and New Borg scale score. These parameters were analyzed using a repeated analysis of variance.

Results: Comparison among the three conditions showed no significant difference in blood pressure, heart rate, double products, respiratory rate, or degree of subjective fatigue. However, the respiratory rate tended to be lower when wearing a BS–PAPR than when wearing a dust mask. Similarly, the New Borg scale score tended to be lower when wearing a BS–PAPR than when wearing a dust mask. $FECO_2$ and $FICO_2$ values were significantly lower when wearing a BS–PAPR than when wearing a dust mask before and after the exercise test, although there was no significant difference during exercise.

Conclusions: Our findings suggest that use of a BS–PAPR may reduce the burden on the respiratory system due to exercise loading, and improve subjective fatigue compared to a regular dust mask.

Keywords: Respiratory protective equipment, Breath–synchronized powered air purifying respirator, Dust mask, Physiological effects, Subjective fatigue

INTRODUCTION

Respiratory protective equipment is used in many workplaces to prevent exposure to occupational harmful substances. However, studies have suggested that wearing respiratory protective equipment can burden the respiratory or circulatory organs (ISO, 2012 and Miura T et al., 1958). Guidelines therefore require the conduct of respirator medical evaluation questionnaires or medical work aptitude checks when wearing respiratory protective equipment (McLellan RK, 2000 and OSHA, 1999). In Japan, the option to use respiratory protective equipment has increased in worksites since the promulgation of standards for powered air purifying respirators (PAPR) by the Ministry of Health, Labor and Welfare (MHLW) in 2014 (MHLW, 2014). In addition, use of PAPR was made mandatory for several working conditions such as asbestos-removing work in the revised regulations of MHLW in 2014 (MHLW, 1972, 1979 and 2005). Given their increased use, it is necessary to evaluate the health effects of wearing respiratory protective equipment, including PAPR.

Few studies have examined the health effects of wearing respiratory protective equipment in Japan. Miura et al. reported that ventilation resistance increased following the use of respiratory protective equipment during exercise tests (Miura T et al., 1960). Takahara et al. investigated the effects on thermal sensation and comfort when wearing various respiratory protective equipment in hot environments, and reported that PAPR helped moderate the elevation in body temperature or respiratory rate and reduced discomfort (Takahara et al, 2013). However, it is insufficient to only evaluate the effects of wearing respiratory protective equipment on respiratory or circulatory indicators. We previously reported that double products (DP), an index of myocardial oxygen consumption equivalent to the systolic blood pressure (SBP) multiplied by the pulse rate (PR) (Nelson RR, 1974 and Nordstrom LA, 1978), increased following intense exercise while wearing dust masks (replacement–type) (Hasegawa M et al, 2017). In addition, we clarified that PAPR induced a comparatively reduced physical load under the same conditions. However, our previous study had several limitations. First, we used excessive exercise loads: we conducted an exercise load experiment using 30 minutes of exercise on an exercise bike at a 100-watt load. This was approximately equivalent to 6.0 to 6.5 metabolic equivalents (METs), which corresponds to occupations with heavy or vigorous workloads such as farming or carrying 50–74-pound items (Ainsworth BE, 2011). As a result, the PR of many subjects increased to more than 140 bpm (Hasegawa M et al, 2017), which may not be realistic of changes in PR experienced during actual manual work. The second limitation was examination inaccuracy. RR was drastically changed by motion or posture due to the use of an electrocardiograph. Additionally, blood pressure (BP) measurements may not have been accurate due to the use of auscultation.

Here, we aimed to clarify the physiological effects of wearing a dust mask and a breath–synchronized PAPR (BS–PAPR); specifically, the effect of wearing a BS–PAPR on reducing respiratory and circulatory physiological burden. We investigated changes in several physiological indicators and subjective fatigue between wearing and not wearing these two types of respiratory protective equipment during exercise loading that was reflective of that experienced during general manual work. In addition, we monitored BP during exercise loading to obtain accurate BP values during exercise loading. This study was expected to be useful for identifying suitable respiratory protective equipment and promoting the effective use of BS–PAPR among individual workers and workers with health problems.

METHODS

Study Design and Setting

This study was a randomized controlled crossover study with a counterbalanced design to control for experimental order effects. We divided participants into three groups and the participants underwent exercise tests under three conditions: not wearing a mask, wearing a dust mask (replacement–type) or wearing a BS–PAPR, in different orders. The conditions were switched such that all participants were tested under all three conditions during the study period. This study was conducted at the University of Occupational and Environmental Health, Japan, between October 2017 and May 2018. We performed these experiments in an artificial climate chamber where the air temperature was fixed at 20°C and the humidity at 50% to avoid variations in air temperature and humidity affecting physiological indicators.

Participants

It is well–known that age, sex, present illness and smoking habit influence respiratory or circulatory indicators. We therefore only recruited male participants aged 20 to 39 years with no smoking habit and no present illness for this study. Eight participants provided consent and were enrolled in this study. Withdrawal criteria were a complaint of poor general condition, and abnormal findings in the electrocardiogram or blood pressure following exercise testing. However, all participants completed this study and no data were excluded. Participants' mean age (SD, minimum–max) was 25.4 (6.0, 21–39) years and mean body mass index (SD, minimum–max) was 21.8 (1.5, 19.2–24.2) kg/m^2.

Procedures

We evaluated various respiratory and circulatory physiological indicators and subjective fatigue before, during and after the exercise test under the three conditions, not wearing a mask, wearing a dust mask, and wearing a BS–PAPR (Fig. 1). The experiment was conducted in the following order: 15 minutes of rest before exercise, 30 minutes of exercise, and 15 minutes of rest after exercise. We used a bicycle ergometer (Health Guard Active 10II; Takei Scientific Instrument Co. Ltd., Fukuoka, Japan) set to a workload of 80 watts for 30 minutes for the exercise test. This exercise was approximately equivalent to 4.0 to 4.5 METs, which corresponds to occupations with moderate workloads such as general manual or unskilled labor or lifting 10–20-pound items continuously for one hour (Ainsworth BE, 2011). The dust mask was a disposal filter–type for liquid particles, with a dioctyl phthalate (DOP) particle–collecting efficiency rate of 95% or greater (model: 1005R; KOKEN Ltd., Tokyo, Japan). The BS–PAPR was a disposable filter–type for liquid particles, with a DOP particle–collecting efficiency rate of 95% and air flow of 138 L/min or greater (model: BL–321; KOKEN Ltd). Two days were left between switching of conditions to avoid any physiological carryover effects due to residual exhaustion from the exercise test.

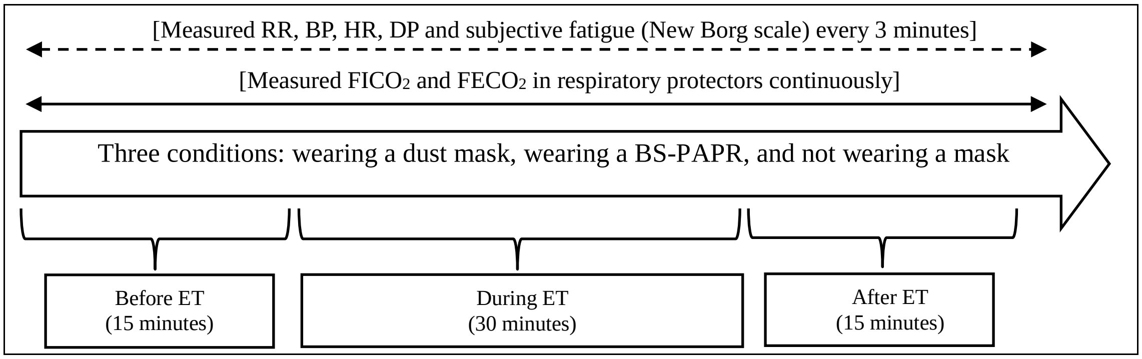

Fig. 1. Study protocol. RR: respiratory rate, BP: blood pressure, HR: heart rate, DP: double product, $FICO_2$: fractional concentration of inspired carbon dioxide, $FECO_2$: fraction of expired carbon dioxide, ET: exercise test.

Evaluation

Respiratory physiology - RR was measured using an electrocardiogram or a breathing pattern and respiration rate tracker (SpireTM; Spire Inc., California, US), which is an activity tracker worn on a waistband or bra strap designed to analyze breathing rate to determine levels of tension, calm, or focus. The concentration of carbon dioxide (CO_2) in the masks was measured using a mass spectrometer for respiratory analysis and bioprocess monitoring (ARCO–2000; ARCO SYSTEM Inc., Chiba, Japan) at 0.1 second intervals. To measure the CO_2 concentration in the masks, a gas suction tube was pierced and inserted into the region of the respiratory protective equipment that would come into contact with the wearer's face, and the tip of the gas suction tube was placed in front of the nose and mouth. We defined the maximum concentration of carbon dioxide in one breath as the fraction of expired carbon dioxide ($FECO_2$) and the minimum concentration of carbon dioxide in one breath as the fraction of inspired carbon dioxide ($FICO_2$).

Circulatory physiology - SBP, diastolic BP (DBP), heart rate (HR), and DP were measured using an automated exercise loading BP manometer (Tango M2; Suntech Medical Inc.) at three minute intervals. We stopped the exercise test when DP exceeded 25000 according to the criteria of the Japanese Society of Nuclear Cardiology for ceasing exercise loading, and that of the Civil Aviation Bureau Japan, which states that DP greater than 20000 indicates a state of high burden on the myocardium during an exercise loading test involving pilots' aptitude test (MLIT, CAB, 2013).

Subjective fatigue - Subjective fatigue was measured using the New Borg scale (Borg GA, 1982 and Borg E, 2006) at three minute intervals. The New Borg scale is a method for measuring perceived physical exertion. Participants rated their subjective exertion level on a scale from zero to 10 (0: no exertion, 1: very weak, 5: strong, 10: very, very strong).

Statistics

Data were evaluated using a repeated measures analysis of variance (ANOVA), with respiratory and circulatory indicator values or New Borg scale scores as dependent variables and the three conditions (wearing a dust mask, wearing a BS–PAPR, and not wearing a mask) as independent variables. When the hypothesis of sphericity was rejected in the repeated measures ANOVA, a Greenhouse–Geisser correction for degrees of freedom was performed. Post-hoc multiple comparisons were performed using the Bonferroni method. Statistical analysis was performed using IBM SPSS ver. 25.0 (IBM, New York, US). A P value below 0.05 was regarded as statistically significant.

RESULTS

Respiratory Physiological Indicators

The mean RR (SD) of participants not wearing a mask, wearing a BS–PAPR, and wearing a dust mask were 17.8 (1.1), 16.4 (1.0), and 18.3 (1.0) times per min before the exercise test; 26.9 (2.0), 27.5 (1.3), and 29.9 (1.6) times per min during the exercise test; and 17.6 (1.3), 17.5(0.7), 18.5 (0.8) times per min after the exercise test, respectively. The mean RR tended to be lower when not wearing a mask and wearing a BS–PAPR than when wearing a dust mask before, during, and after the exercise test (Fig. 2). However, there was no significant difference in RR among the three conditions (F[1, 14]=0.364, p=0.699) or among the three conditions over time (F[9.0, 94.4]=0.565, p=0.882) using a repeated measures ANOVA.

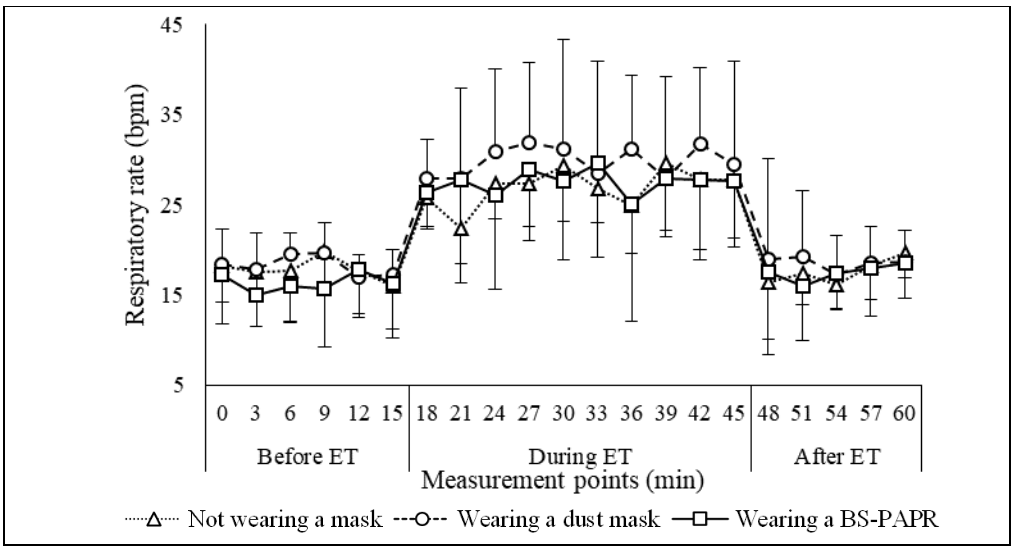

Fig 2. **Changes in respiratory rate before, during and after the exercise test among those not wearing a mask, wearing a dust mask, wearing a BS-PAPR. Error bars show the standard deviation. ET: exercise test, BS-PAPR: breath–synchronized powered air purifying respirator.**

There were significant differences in $FECO_2$ between wearing a dust mask and wearing a BS–PAPR (F[1, 14]=26.5, p<0.001) and between these two conditions over time (F[3.3, 45.3]=17.9, p<0.001) using a repeated measures ANOVA. Additionally, there were significant differences in $FICO_2$ between wearing a dust mask and wearing a BS–PAPR (F[1, 14]=14.6, p=0.511) and among the three conditions over time (F[3.1, 44.0]=5.99, p=0.001) using a repeated measures ANOVA. $FECO_2$ and $FICO_2$ were significantly lower when wearing a BS–PAPR than when wearing a dust mask. A post-hoc test of the three conditions over time showed that $FECO_2$ and $FICO_2$ were significantly lower when wearing a BS–PAPR than when wearing a dust mask before and after the exercise test, but were not significantly different during the exercise test (Fig. 3).

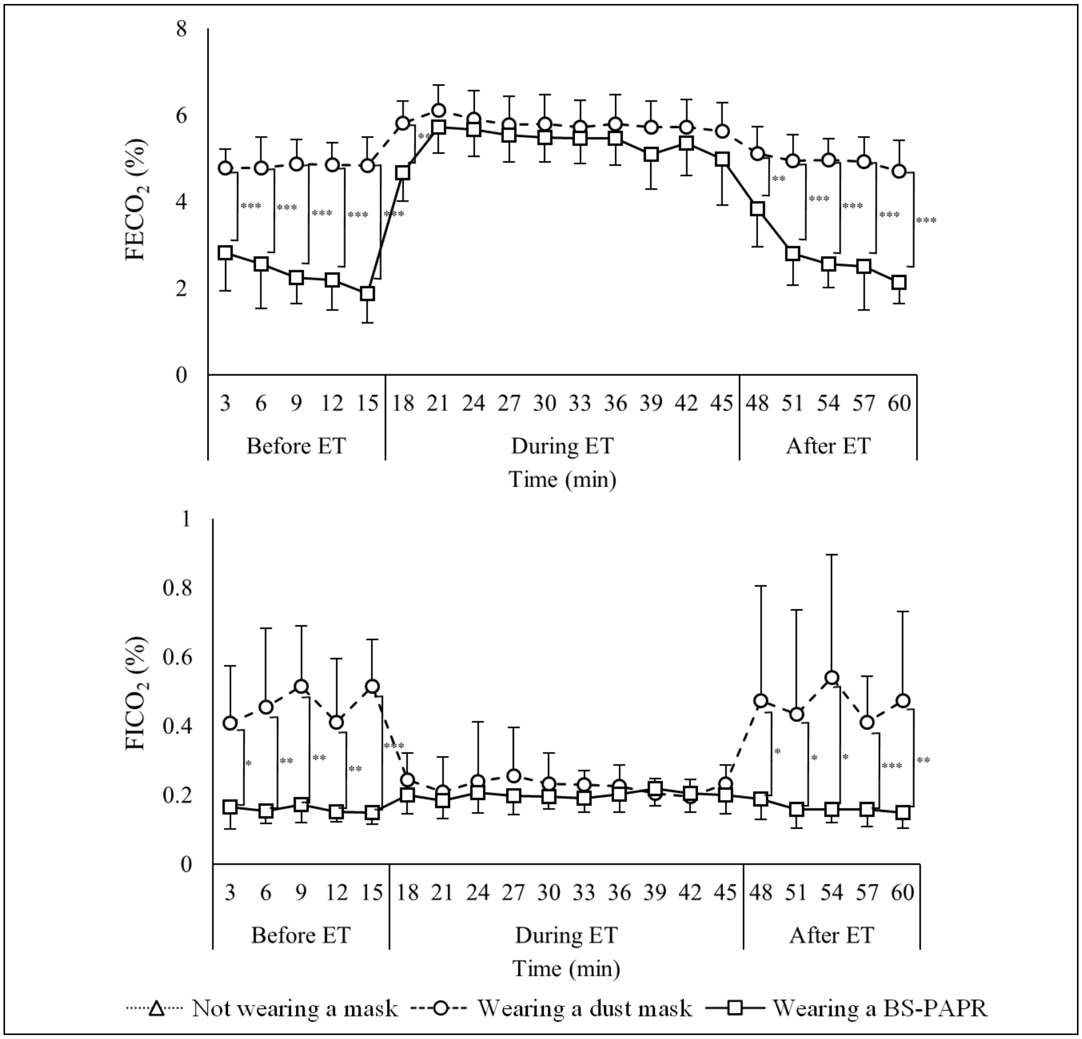

Fig 3. Changes in the fractional concentration of inspired carbon dioxide and fraction of expired carbon dioxide before, during and after the exercise test between those wearing a dust mask and wearing a BS–PAPR. Error bars show the standard deviation. $FECO_2$: fraction of expired carbon dioxide, $FICO_2$: fraction of inspired carbon dioxide, ET: exercise test, BS–PAPR: breath–synchronized powered air purifying respirator. *p<0.05, **p<0.01, ***p<0.001, significant differences in multiple comparisons between those wearing a dust mask and those wearing a BS–PAPR.

Circulatory Physiological Indicators

The mean SBP and DBP (SD) of participants not wearing a mask, wearing a BS–PAPR, and wearing a dust mask was 125.2 (1.4) and 60.3 (1.2) mmHg, 123.1 (1.7) and 71.6 (3.3) mmHg, and 121.4 (1.6) and 63.4 (0.7) mmHg before the exercise test; 155.3 (2.5) and 64.7 (1.2) mmHg, 153.7 (1.9) and 66.3 (1.6) mmHg, and 143.7 (2.5) and 63.5 (1.7) mmHg during the exercise test; and 124.6 (3.9) and 71.5 (1.2) mmHg, 126.5 (1.9) and 73.3 (0.9) mmHg, and 124.6 (2.8) and 65.2 (0.9) mmHg after the exercise test, respectively. The mean SBP and DBP tended to be higher when not wearing a mask and wearing a BS–PAPR than when wearing a dust mask before, during and after the exercise test. However, there was no significant difference in SBP or DBP among the three conditions (SBP: F[2, 21]=0.665, p=0.525; DBP: F[2, 21]=0.665, p=0.525) or among the three conditions over time (SBP: F[11.7, 122.5]=0.914, p=0.533; DBP: FF[10.0, 104.5]=1.006, p=0.443) using a repeated measures ANOVA (Fig. 4).

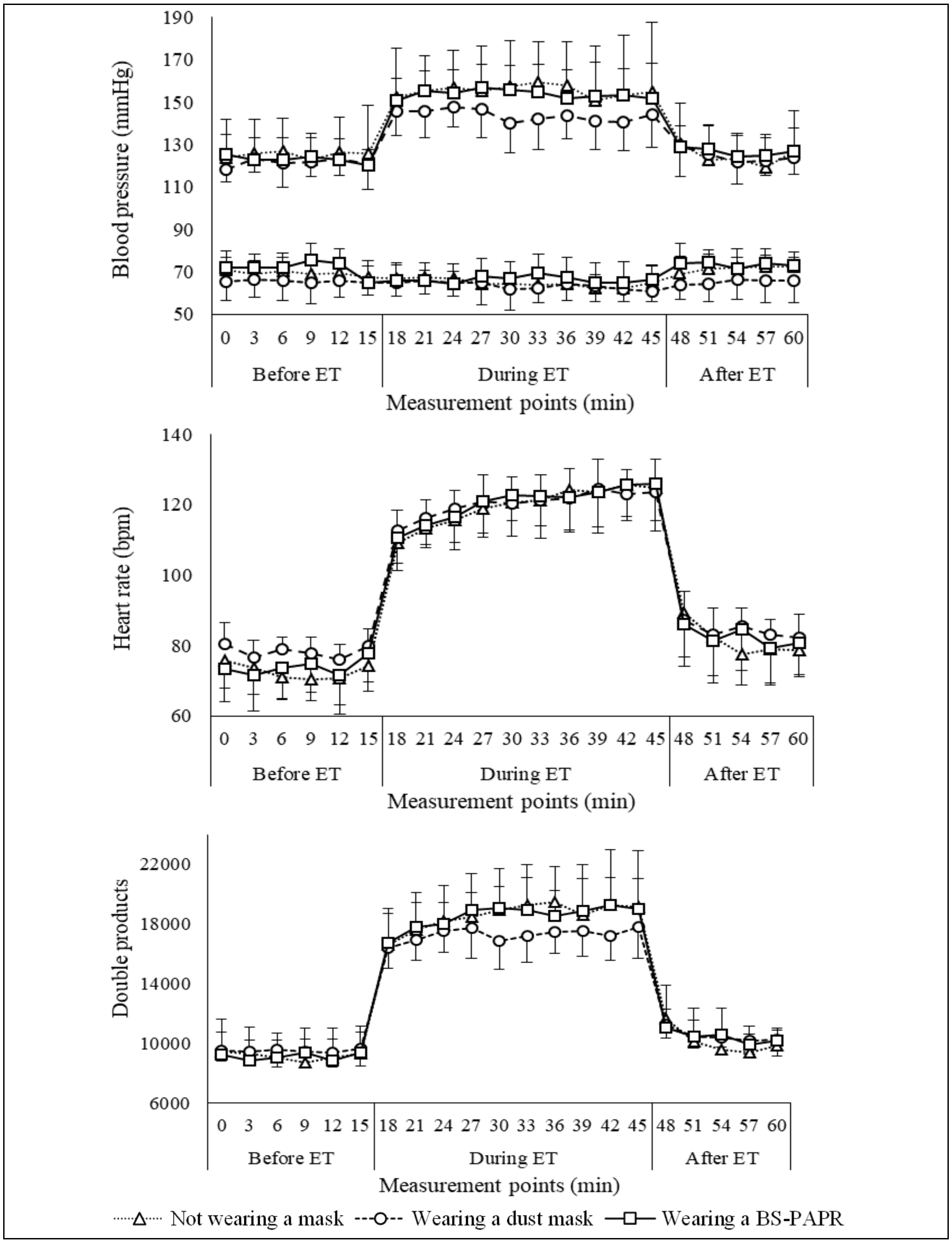

Fig 4. Changes in blood pressure, heart rate, and double products before, during and after the exercise test among those not wearing a mask, wearing a dust mask, and wearing a BS–PAPR. ET: exercise test, BS–PAPR: breath–synchronized powered air purifying respirator.

The mean HR (SD) of participants not wearing a mask, wearing a BS–PAPR, and wearing a dust mask was 72.6 (2.0), 73.9 (2.1), and 78.3 (1.6) bpm before the exercise test; 119.7 (5.2), 120.5 (4.8), and 120.4 (3.4) bpm during the exercise test; and 81.5 (4.2), 82.5 (2.5), and 84.3 (1.9) bpm after the exercise test, respectively. There was no significant difference in HR among the three conditions (F[2, 21]=0.268, p=0.768) or among the three conditions over time (F[7.2, 75.1]=0.992, p=0.444) using a repeated measures ANOVA (Fig. 4).

There was no significant difference in DP among the three conditions (F[2, 21]=0.224, p=0.801) or among the three conditions over time (F[11.0, 115.1]=1.584, p=0.113) using a repeated measures ANOVA (Fig. 4).

Subjective Fatigue

The mean New Borg scale score of participants was the same among the three conditions before the exercise test. The mean New Borg scale score (SD) of participants not wearing a mask, wearing a BS–PAPR, and wearing a dust mask was 3.6 (1.1), 3.9 (0.7), and 4.4 (1.2) during the exercise test; and 1.2 (0.2), 1.3 (0.3), and 1.6 (0.4) after the exercise test, respectively. The mean New Borg scale score tended to be lower when not wearing a mask and wearing a BS–PAPR than when wearing a dust mask during and after the exercise test. However, there was no significant difference in the New Borg scale score among the three conditions (F[2, 21]=0.154, p=0.768) or among the three conditions over time (F[5.9, 62.2]=1.157, p=0.341) using a repeated measures ANOVA (Fig. 5).

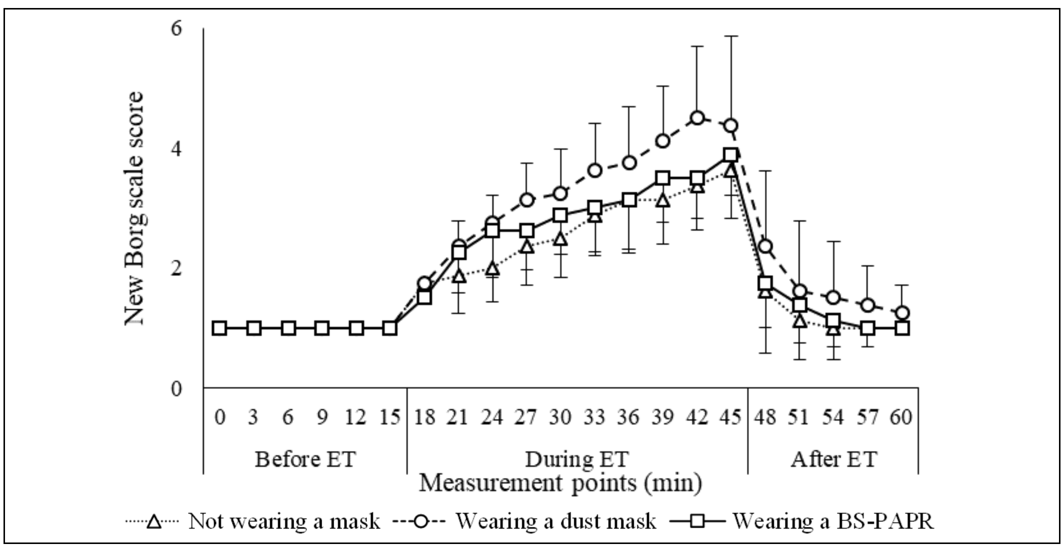

Fig 5. Changes in the New Borg scale score before, during and after the exercise test among those not wearing a mask, wearing a dust mask, and wearing a BS-PAPR. ET: exercise test, BS–PAPR: breath–synchronized powered air purifying respirator.

DISCUSSION

Mean RR was slightly lower in participants not wearing a mask and wearing a BS–PAPR than in those wearing a dust mask. In addition, $FECO_2$ and $FICO_2$ values were significantly lower among participants not wearing a mask and wearing a BS–PAPR than among those wearing a dust mask before and after the exercise test, but were not significantly different during the exercise test. Monitoring of air flow volume control using the pressure sensor attached the BS–PAPR showed that the BS–PAPR maintained positive pressure inside the mask. Specifically, the electric fan inside the mask for breathing support turned off when participants were expiring and turned on when they were inspiring to maintain positive pressure inside the mask (Yuasa et al., 2008). Therefore, according to the increased RR and ventilatory volumes, the frequent stopping of the electric fan may reduce ventilation efficiency. We observed significant differences in both $FECO_2$ and $FICO_2$ values between participants wearing a dust mask and wearing a BS–PAPR before the exercise test, but comparable $FECO_2$ and $FICO_2$ values during the exercise test. Among those who wore a BS–PAPR, the mean RR between zero to 15 minutes before the exercise test was approximately 15 times/min, and the mean RR 18 minutes after the exercise test was approximately 26 times/min. We speculate that the ventilation efficiency of the BS–PAPR becomes similar to that of the dust mask after a workload that results in an RR of 25 times/min or greater. However, a previous study reported that the dust protection and breathing support capabilities of PAPRs are maintained even following marked increases in RR (Yuasa et al., 2008). Similar to this previous study, the present study found that the mean RR when wearing a BS–PAPR was lower than that observed when wearing a dust mask during the exercise test. In addition, high–load work at an RR greater than 25 times/min is likely to be temporary or intermittent rather than continuous in actual regular work. Therefore, the decrease in ventilation efficiency owing to an increase in RR may not affect the usefulness of BS–PAPRs. Many working roles likely alternate between high workloads and rest. This suggests that the BS–PAPR device may be more effective for reducing the load on the respiratory system than a regular dust mask.

There were no significant differences in BP, HR, or DP among the three conditions. We previously reported a marginally significant difference in DP among the same three conditions under a higher exercise load than that used in the present study (Hasegawa M et al., 2017). In our previous study, we observed the highest DP values among participants who wore a dust mask, followed in order by those who wore a BS–PAPR and those who did not wear a dust mask. The discrepancy between the results of our two studies may suggest that the effects of mask devices on the circulatory system are dependent on exercise load. BS–PAPRs may be most effective for reducing the burden on the circulatory system following greater increases in exercise load. Further, in our previous study, we manually measured subjects' BP using the auscultation method, which may have resulted in lower accuracy measurements compared to those obtained using an automated exercise loading BP manometer, such as that used in the present study.

There was no significant difference in the New Borg scale score among the three conditions. However, mean scores tended to be lower when not wearing a mask and wearing a BS–PAPR than when wearing a dust mask during and after the exercise test. In fact, the mean score among those who wore a BS–PAPR was almost the same as that among those who did not wear a mask during the second half of the exercise test and after the exercise test. This suggests that the BS–PAPR may improve subjective fatigue with exercise load by supporting the wearer's breathing.

Limitations

There were some limitations in this study. First, there may have been considerable type II errors because of the small sample size. Second, we evaluated the physiological effects of wearing only two types of respiratory protective equipment devices. However, these are popular and standard respiratory protective equipment devices, and comparison of the physiological effects following the use of these two devices is expected to be useful for a large proportion of workplaces that require wearing respiratory protective equipment. Third, there was a selection bias because only healthy, no smoking males aged 20 to 39 years were selected for this study. Potential physiological effects of wearing respiratory protective equipment may have been less obvious due to the high physical function of these healthy participants. Therefore, these findings may not be applicable to all workers using respiratory protective equipment. Fourth, we conducted this study in an artificial climate chamber where the environmental conditions were fixed. Future studies should examine the effects of wearing respiratory protective equipment on various worker populations and health conditions, such as elderly workers and workers with present illness, particularly respiratory disease, in actual work environments, including hot and humid environments. We will continue to investigate the effects of various types of respiratory protective equipment.

CONCLUSIONS

We compared the physiological effects of wearing a dust mask and a BS–PAPR. We clarified that BS–PAPR reduced the burden on the respiratory system before and after exercise loading compared to a regular dust mask. Additionally, wearing a BS–PAPR may improve subjective fatigue during exercise loading.

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Disclaimer

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REFERENCES

Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor–Locke C, Greer JL, Vezina J, Whitt–Glover MC, Leon AS. (2011) 2011 Compendium of Physical Activities: a second update of codes and MET values. Med Sci Sports Exerc. 43:1575–1581

Borg GA. (1982) Psychophysical bases of perceived exertion, Med Sci Sports Exerc. 14: 377–381.

Borg E, Kaijser L. (2006) A comparison between three rating scales for perceived exertion and two different work tests, Scand J Med Sci Sports. 16:57–69.

Hasegawa M, Ikegami K, Ando H, Nozawa H, Sugano R, Michii S, Kitamura H, Kawanami S, Ogami A, Myojyo T. (2017) Physiological effects of wearing respiratory protective equipment, J ISRP Japan Sector Resp Protect. 44:1–12 (In Japanese).

International Organization for Standardization (ISO) (2012) Respiratory protective devices — Human factors — Part 4: Work of breathing and breathing resistance: Physiologically based limits 16976.

McLellan RK, Schusler KM. (2000) Guide to the Medical Evaluation for Respirator Use. OEM Press Beverly Farms, Mass.

Ministry of Health, Labor and Welfare, Japan. (MHLW) (2014) Standards for Powered–Air Protective Respirator. The Ordinance of Ministry of Health, Labor and Welfare No. 455 (In Japanese).

Ministry of Health, Labor and Welfare, Japan. (MHLW) (1972) Ordinance on Prevention of Hazards Due to Specified Chemical Substances. Ministry of Labour Ordinance No. 39. Retrieved from https://www.jniosh.go.jp/icpro/jicosh-old/japanese/country/japan/laws/03_rel/08_ selectedchemicals_reg/index.html (accessed 20 May 2018).

Ministry of Health, Labor and Welfare, Japan. (MHLW) (1979) Ordinance on Prevention of Hazards Due to Dust. Ministry of Labour Ordinance No. 41. Retrieved from https://www.jniosh.go.jp/icpro /jicoshold/japanese/country/japan/laws/03_rel/13_dust_reg/index.html (accessed 20 May 2018).

Ministry of Health, Labor and Welfare, Japan. (MHLW) (2005) The ordinance on Prevention of Health Impairment due to Asbestos, The Ordinance of the Ministry of Health, Labour and Welfare No. 21 (In Japanese). Retrieved from https://www.jniosh.go.jp/icpro/jicosh-old/english/law/asbestos /index.html. (accessed 15 May 2018).

Ministry of Land, Infrastructure and Transport, Civil Aviation Bureau, Japan. (MLIT, CAB) (2013) About exercise loading electrocardiogram test. Issued by Ministry of Land, Infrastructure and Transport, Civil Aviation Bureau, No.688 (In Japanese).

Miura T, Kimura K. (1958) Effect of increase in respiratory resistance on the pattern of respiration Studies of respiratory protective devices (rep.5). The Journal of Science of Labour. 34:720–727 (In Japanese).

Miura T, Kimura k. (1960) Studies on the respiratory resistance of the protective devices –studies on the respiratory protective devices (Rept. 7) –. Sangyo Igaku.2:1–9. (In Japanese)

Nelson RR, Gobel FL, Jorgensen CR, TAYLOR HL. (1974) Hemodynamic predictors of myocardial oxygen consumption during static and dynamic exercise. Circulation. 50:1179–1189.

Nordstrom LA, Nelson RR, Jorgensen CR, Wang, Y. (1978) The rate–pressure product as an index of myocardial oxygen consumption during exercise in patients with angina pectoris. Circulation. 57:549–556.

Occupational Safety and Health Administration (OSHA) (1999). Respiratory protection. U.S. Government Printing Office, Office of the Federal Register, Washington DC. Code of Federal Regulation Title 29, Part 1910.134.

Takahara S, Sunada K, Kawanami S, Inoue J, Horie S, Myojyo T. (2013) Changes of body temperature and exhalation gas when wearing five types of dust mask in hot environment. J UOEH. 35:75 (In Japanese).

Yuasa H, Shimizu E, Kimura K, Emi H, Nozaki K. (2008) Performance of Breath–Synchronized Powered Air–Purifying Respirator under Simulated Usage Condition, J Int Soc Resp Protect. 25:107–117.