

Measurement of Operational Fit Factors for Soldiers Wearing the S10 Respirator

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ABSTRACT

Investigations in the industrial setting have established that mask Fit Factors (FF) achieved in the workplace often bear little resemblance to those achieved in a laboratory. Consequently, the potential impact of operational activities on the protection afforded by the S10 respirator was investigated.

Twenty-four Australian soldiers (23 male, 1 female; 17 non-smokers, 7 smokers) participated in a study to determine mask fit under a range of operational conditions. The study consisted of the following segments: initial mask FF (6 minutes), operational FF (30 minutes) and final mask FF (6 minutes). The total length of time subjects wore the S10 respirator was 3 hours.

Mask FF for non-smokers remained unchanged throughout the trial, indicating that wearing a respirator for 3 hours and completing moderate exercise (30 mins) had no adverse effect on mask FF. Operational tasks that resulted in greater facial and head movements, higher breathing and heart rates (in order of severity) tended to have the most negative influence on operational FF. Exercises requiring speech were found to have the lowest FF. Consequently, twenty-six percent of subjects (including repeats, 7/27) failed to achieve an overall operational FF greater than the minimum target of 2000.

Therefore, it was found that the Australian in-service respirator (S10) provided significantly lower levels of protection in an operational environment (5th percentile FF=620) compared to the standard mask fit test (FF>2000).

Keywords: Fit Test, Fit Factor, Respirator, Operational Effectiveness, Soldiers

INTRODUCTION

The most important piece of protective equipment a soldier has in a chemically or biologically contaminated battlefield is the General Service Respirator (GSR). The UK S10 respirator is currently in-service with the Australian Defence Force. The S10 is a full-facepiece negative pressure respirator manufactured by Avon Rubber p.l.c. When it is properly fitted the respirator offers protection against gases, vapours, particulates and liquid aerosols. Past studies have investigated the protection afforded by military respirators under laboratory conditions. In such studies, losses in protective levels have been measured under controlled laboratory conditions using artificially generated test atmospheres (including particles of known size and concentration). The equipment used in these evaluations has been highly specialised, bulky and immobile (Bancroft *et al.*, 1999).

Recent developments in particle counting devices have resulted in equipment, such as the PortaCount® Plus, that is field portable, man mountable and relatively robust. The PortaCount® Plus is based on a miniature, continuous-flow Condensation Nucleus Counter (CNC). A CNC takes particles that are too small to be easily detected, grows them to a larger more easily detectable size and then counts them with no size differentiation. Full details of the theory and operation of the PortaCount® can be found

in the user manual (TSI Incorporated October, 1996). This equipment allows measurement of Fit Factors (FF) during typical operational activities. A FF is the ratio (C_o/C_i) of the test agent concentration (C_o) divided by the concentration in the respirator due to leakage (C_i).

Assigned Protection Factors (APF) are determined by governments and/or standards organisations based on scientific results measured in the laboratory and workplace. An APF is the minimum expected workplace level of respiratory protection that would be provided by a properly functioning respirator or class of respirators, to a stated percentage of properly fitted and trained users (Capon, 1996). Studies undertaken in an industrial setting have established that mask FF achieved in the workplace often bear little resemblance to those measured in a laboratory (Myers *et al.*, 1984; Tannahil *et al.*, 1990; Spear *et al.*, 2000). Recent studies have investigated "Battlefield" FF using the PortaCount[®] Plus as the primary research tool (Richardson and Bee, 2001; van der Gijp *et al.*, 2001) with limited operational data. Richardson and Bee (2001) concentrated on the development of the man-mountable research tool, subsequently presenting only limited protection factor data for an operational task (weapon handling). Van der Gijp *et al.* (2001) provided a more detailed assessment of respirator fit using a small sample size and broader range of respirator exercises. However, both Richardson and Bee (2001) and van der Gijp *et al.* (2001) failed to record ambient particle concentration in the breathing zone. Therefore the present study differs from these studies by the inclusion of simultaneous measurement of ambient particle concentrations in the breathing zone and mask leakage (every 2 seconds). Furthermore, the present study involved continuous FF measurement over a range of operational activities providing better resolution in terms of afforded protection level of a respirator during dynamic tasks than previous reported studies.

In summary, the focus of the present study was the measurement of FF achieved by a group of volunteers from the Chemical Biological Radiological Response (CBRR) Squadron while they performed general operational activities.

METHODS

Subjects

Twenty four healthy, medically fit subjects (23 male, 1 female) from the Chemical Biological Radiological Response (CBRR) Squadron volunteered following an initial briefing on the purpose and demands of the trial. All soldiers were well trained in the use of military respiratory protective equipment and no instruction was required for the donning of respirators. Amongst this cohort, seventeen were non-smokers. Four subjects (all non-smokers) repeated the trial (initial, operational and final mask FF assessments) 48 hours after their initial test. Non-smokers were chosen for the repeated measures experiment to minimise the potential for FF contamination generally observed in smokers for this type of assessment.

Respirators

The subjects had all been issued with an S10 respirator prior to the trial. The S10 respirator is available in four sizes with 1 being the largest and 4 the smallest. The subjects had been previously qualitatively fit tested using an irritant gas in a gas chamber. The soldiers were responsible for the maintenance of their own respirators. No subjects had previously undergone quantitative fit test assessments prior to this trial. No assessment of the subject's respirators in terms of serviceability was made prior to this study. Hence, the intention of this study was to assess fit factors in an operational setting, which includes the influence of dysfunctional components and incorrect fitting of the S10 that would normally occur within a military unit. The most common size of S10 respirator worn in this trial was size 2.

Experimental Procedures

Subjects were assigned to six groups of four, and two groups were tested each day, one group was tested in the morning (0900 hrs) and the second in the afternoon (1300 hrs). Subjects wore their standard

issue Disruptive Pattern Combat Uniform (DPCU), and smokers were instructed to refrain from smoking for an hour prior to their trial¹. Subjects were asked to remove the internal drinking tube, canteen-coupling valve and open the drinking valve of their S10 respirators to facilitate sampling from inside the S10 respirator. Subjects replaced their Nuclear Biological Chemical (NBC) canisters with NBC canisters that had been modified by reversing the order of gas and particulate filters. This was achieved by gluing the thread mounting and canister casing to the inlet side of a new NBC canister. The original canister thread was then removed using a band saw. The canister was then checked for leaks under positive pressure (2.5 pounds per square inch) whilst immersed in water. The particulate efficiency of the NBC canisters was not assessed before or after the modifications, since modifications did not affect the function of the filter, only the orientation of airflow. The NBC canister should have a particulate efficiency of greater than 99.99% based on the Australian Defence Specification (DEF(AUST)5686, 2001) equating to a FF of 10,000. The order of the gas and particulate filters was reversed to prevent the PortaCount[®] from counting dislodged carbon particles from the gas filter.

The group of four subjects was then asked to don their S10 respirators simultaneously. Subjects were asked to keep the S10 respirator on for the duration of the trial, although they were permitted to remove it to drink if required. Removal of the S10 respirator for drinking was not documented since operationally it is the soldiers' responsibility to ensure that the S10 respirator is fitted and adjusted correctly at all times. The influence that refitting may have on mask FF is assumed to occur operationally and we assume this to be reflected in the results and independent of smoking status.

Two subjects were assessed at a time for their initial mask FF using a PortaCount[®] Plus 8020 (TSI, St. Paul MN, USA; protocol TB 29CFR1910.139). The TB 29 CFR1910.139 protocol consisted of six 1-minute exercises (normal breathing, deep breathing, head side-to-side, head up and down, talking, and normal breathing), which were weighted to give an overall FF. The individual exercises included an ambient sample (5 sec), ambient purge (4 sec), mask purge (11 sec) and a mask sample (40 sec) from which an averaged FF for the exercise was calculated. The individual exercise FF and overall mask FF were recorded.

Once the initial mask FF of the four subjects was determined, each subject's operational FF was calculated in turn. To determine the operational FF two PortaCounts[®] were used simultaneously. One PortaCount[®] was used to sample the ambient particle concentration and the second to sample the particle concentration inside the S10 respirator. This was achieved by connecting the PortaCount[®] sampling tube to the external drinking tube of the S10 respirator. Both PortaCounts[®] were operated in the two second count mode, that is, the recorded particle concentration is the average of a two second period. The recorded particle concentrations are not presented in real time, but are delayed due to the length of sampling tube and the averaging mode in which the PortaCounts[®] were operated. Each PortaCount[®] was connected to a HP 200LX Palmtop (200LX Palmtop PC, Hewlett Packard, Singapore) for data collection. The two PortaCounts[®] were mounted to a backpack and the palmtops were placed in the front trouser pocket of the subject's DPCU.

Once test-subjects had donned the backpack and equipment (Figure 1) they were asked to complete a range of exercises:

- i. Jogging – subjects jogged over a level 50 metre course.
- ii. Lift and carry – objects varying in size and weight were picked up one at a time and carried 50 metres.
- iii. Stair climb – subjects walked briskly up and down two flights of stairs.
- iv. Walk and command – subjects walked while counting out loud.
- v. Run and dodge – subjects jogged while weaving between marker cones.
- vi. Taking cover – subjects sprinted twenty metres, crouched down as if taking cover then waited 20 seconds before repeating the exercise.

¹ Smokers have been shown to exhale smoke particles from their lungs for up to 1 hour after their last cigarette. The PortaCount[®] will count these smoke particles as mask leakage resulting in an artificially lower FF

The duration of each exercise was 5 minutes and the overall task took 30 minutes to complete. The order of tasks was partially randomised between subjects. That is, the first subject started with exercise number one and finished on exercise number six, the next subject started on exercise two and finished on exercise one, the third subject started with exercise three and finished with exercise two. This pattern was continued throughout the evaluation. This experimental design does not control for carry-over effects of a previous task. However, due to logistical issues, this sequence was the only practical solution under the given circumstances. On completion of the exercise the next subject's operational FF was calculated. Subjects associated with the repeated trials started on the same exercise as their initial assessment at the same time of the day (plus 48 hrs). When the 4 subjects had completed the operational FF task their final mask FF were calculated in the same manner as their initial mask FF.

In summary, the subjects' initial mask FF (6 mins), operational FF (30 mins) and final mask FF (6 mins) were calculated. Subjects remained with their S10 respirators on whilst they rested in the shade waiting to be tested (approx 2 hrs 18 mins). In total, subjects wore the S10 respirator for approximately 3 hours.



Figure 1. Equipment used in the determination of operational FF.

Data Manipulation

To calculate operational FF, the first and last 30 seconds of each exercise were discarded leaving 4 minutes of data for each exercise. The ambient particle concentration (C_o) was divided by the concentration of particles inside the S10 respirator due to leakage (C_i) to give an operational FF (C_o/C_i). When the concentration of particles in the mask was equal to zero the operational FF was reported as the ambient particle concentration divided by the lowest level of observed mask leakage (0.3). This was conducted to avoid infinitely large operational FF being reported when the mask concentration was equal to zero².

Calibration

It was noted during the trial that there was a calibration error in one of the PortaCount® instruments. This PortaCount® had no other faults and its response was observed to be linear to that of the other PortaCount®. The fault occurred after a subject (#12) completed the operational FF assessment with his drinking valve closed. This PortaCount® was subsequently only used to measure ambient particle

² Note: FF above $10,000 \pm 10\%$ are above the specification range of the PortaCount® and should be regarded with caution TSI Incorporated, S. P., MN, USA (October, 1996). [PortaCount® Plus Model 8020: Operation and Service Manual.](#)

concentrations since it was less sensitive than the other PortaCount[®], and we were primarily interested in mask leakage. On completion of the trial the PortaCount[®] in question was sent back to the manufacturer for recalibration. The PortaCount's[®] deviation from known standards was recorded by the manufacturer, which was then used to generate a correction term (Calibration Standard = $14.794 + 1.585$ (observed PortaCount[®] result)) for the affected ambient particle concentrations (subjects 13-24, subject 12's operational FF results were excluded).

Statistics

Throughout the analyses various descriptive statistics are presented such as mean (M), standard deviation (SD) and 5th percentile of the log-transformed data. Any reference to "mean FF" refers to the mean log-transformed FF scores.

Mask FF

Mask FF data was transformed by taking the log(FF) of all FF values (Hardis *et al.*, 1983). Subjects 1, 17, 25 and 27 were repeated measurements of subjects 18, 3, 9 and 12, respectively, and subjects 26 and 28 were excluded from the statistical analyses because they failed to complete their final assessment. A 2-way mixed ANOVA was used to compare mask FF before and after the trial and between smokers and non-smokers. A 2(time) x 6(exercise) within-subjects ANOVA was performed on two repeated measurements of log-transformed mask FF for each exercise. The independent variables consisted of time (pre- and post-trial) and exercise (normal breathing, deep breathing, head side-to-side, head up and down, and normal breathing). Statistical differences ($p < 0.05$) were isolated *post hoc* using Newman-Keuls procedure for all cells.

Operational FF

Operational FF data were transformed by taking the log(FF) of all FF values. The overall operational FF was calculated using the following equation ($6 / (1/FF_1 + 1/FF_2 + 1/FF_3 + 1/FF_4 + 1/FF_5 + 1/FF_6)$) where FF_{1-6} represents the different operational exercises. Repeated measurements for subjects 1, 17, 25 and 27 were excluded from the statistical analyses. A 2(smoker) x 6(exercise) mixed ANOVA was used to analyse the transformed operational FF's. Smokers and non-smokers were pooled after the initial mixed ANOVA, and a one-way repeated measures ANOVA was performed on transformed operational FF's for each exercise (x6). Statistical differences ($p < 0.05$) were isolated *post hoc* using Newman-Keuls procedure, for all cells.

Nominal Protection Factor/Acceptable Level of Fit

The Australian Standard (AS/NZS:1716, 1994) requires that the Nominal Protection Factor (NPF) for a full-facepiece negative pressure respirator is 2,000 (3.3 on the log scale). The NPF is calculated from the permitted total inward leakage values derived from criteria specified in the relevant standards (i.e. $NPF = 100 / \text{max total inward leakage}$) (Capon, 1996). Australian Defence Specification NPF for a GSR is more stringent at 10,000 (or 4.0 on the log scale) (DEF(AUST)5686, 2001). The NPF is the level of fit that a respirator must achieve or exceed when tested in the laboratory; it is not necessarily the level of fit achieved in the workplace/battlefield. The NPF is determined in the laboratory using a sodium chloride test from which the mean FF from a range of exercises is calculated (for a detailed explanation see the Australian Standard (AS/NZS 1716:1994). Consequently, the results of the present study cannot be directly related to the NPF. Therefore, in the following results and discussion a minimum acceptable level of mask fit will be referred to as 2,000 or 3.3 on the log scale.

RESULTS AND DISCUSSION

Mask FF

Smokers have previously been identified as recording artificially lower mask FF concomitant with high levels of expired smoke particles (TSI Incorporated October, 1996). Hence, the smokers' initial and final overall mean mask FFs were compared to non-smokers. Smoking was found to significantly affect mask FF ($p=0.009$, Figure 2). Not surprisingly, smokers ($M \pm SD$; 3.65 ± 0.24) were found to have significantly lower initial mask FF than non-smokers (4.19 ± 0.36 ; $p<0.05$). The smokers initial mask FF (3.65 ± 0.24) was also significantly lower than their final mask FF (4.13 ± 0.55 ; $P<0.05$), suggesting that the one-hour control for smokers prior to the trial was not adequate to remove residual smoke particles from their lungs or they did not abstain from smoking 1 hour prior to this trial. Mask FF for non-smokers remained unchanged across the trial (post 4.17 ± 0.36 ; $p>0.05$), indicating that wearing a respirator for 3 hours and completing a moderate bout of exercise (30 mins) had no adverse affect on mask FF.

Interestingly, there was no significant difference between smokers and non-smokers final mask FF. Despite this finding, all smokers except one (subject 10's initial mask FF=3.18 (fail), final mask FF=3.77 (pass), Table I) were still able to achieve an acceptable level of mask fit even though smoking artificially lowered their mask FF's. Overall, all subjects were able to achieve a mask FF (initial or final) greater than the acceptable level of mask fit ($FF>3.3$ or $\log(2000)$), suggesting that all subjects had been issued with appropriately sized respirators (refer to section 2.2).

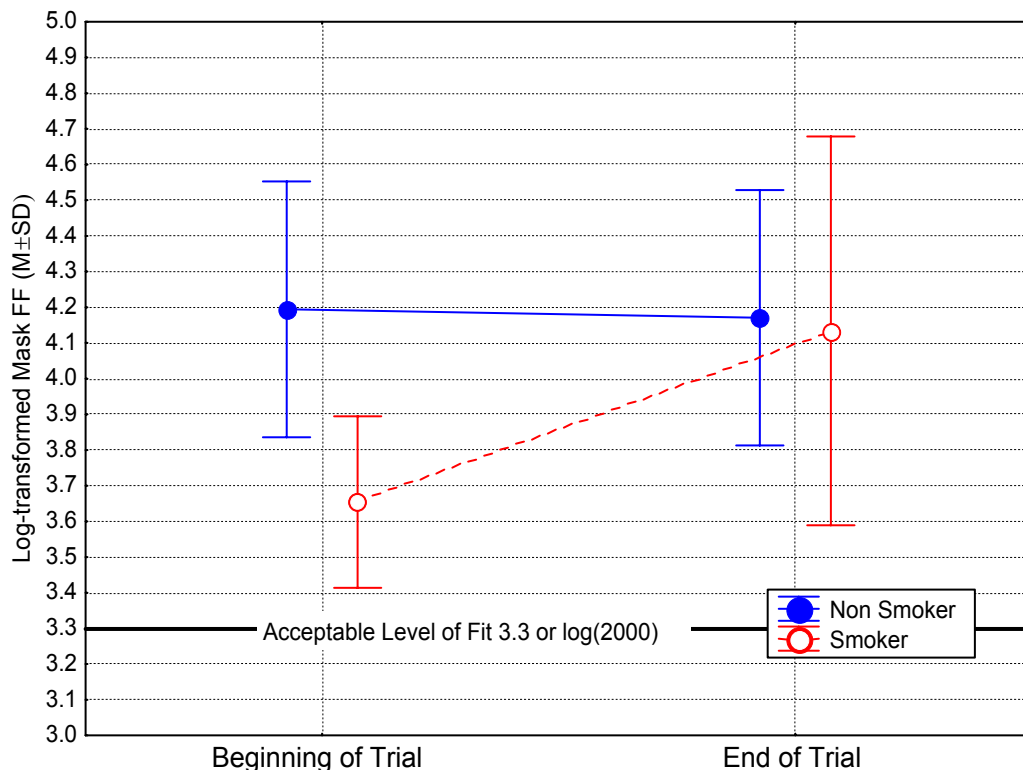


Figure 2. Smokers and non-smokers ($M \pm SD$) Log-transformed mask FF at the beginning and end of trial.

Variability in the initial mask FF measurement was investigated using the data from four subjects involved with the repeated experiment (Section 2.1). No significant difference ($p>0.05$; Power = 54%, $t(4)=3.18$) was observed between the initial mask FF recorded 48 hours apart, (M $\pm$ SD; 0hrs: 3.95 ± 0.32 ; 48 hrs: 4.30 ± 0.25) therefore it appears that mask FF determination is reproducible and reliable on repeated measurements. No comparisons were made for final mask FF measurement, as only two of the repeat subjects were able to complete this task due to time constraints. Similarly no comparisons were made for repeated operational FF measurements due to the small sample size ($n=3$, i.e. subject 12 data invalid (refer section 2.5)).

As smokers were found to have mask FF that differed between the initial to final assessments, data for non-smokers were chosen to analyse any mask FF variations that may be task/exercise specific. Mask FFs for non-smokers were compared at the beginning and end of the trial and for each exercise (Figure 3). There was no significant difference in mask FF between the beginning and end of the trial for each exercise task ($p=0.53$), which is consistent with non-smokers overall mask FF presented in Figure 2. There was, however, a significant effect of exercise ($p<10^{-4}$). Talking resulted in a significantly lower mask FF than any other exercise (all $p<0.05$), yet still remained significantly greater than the acceptable level of mask fit ($FF>3.3$ or $\log(2000)$). The remaining exercises (normal breathing, deep breathing, head side-to-side, head up and down, and normal breathing) were not significantly different from each other (all $p>0.05$).

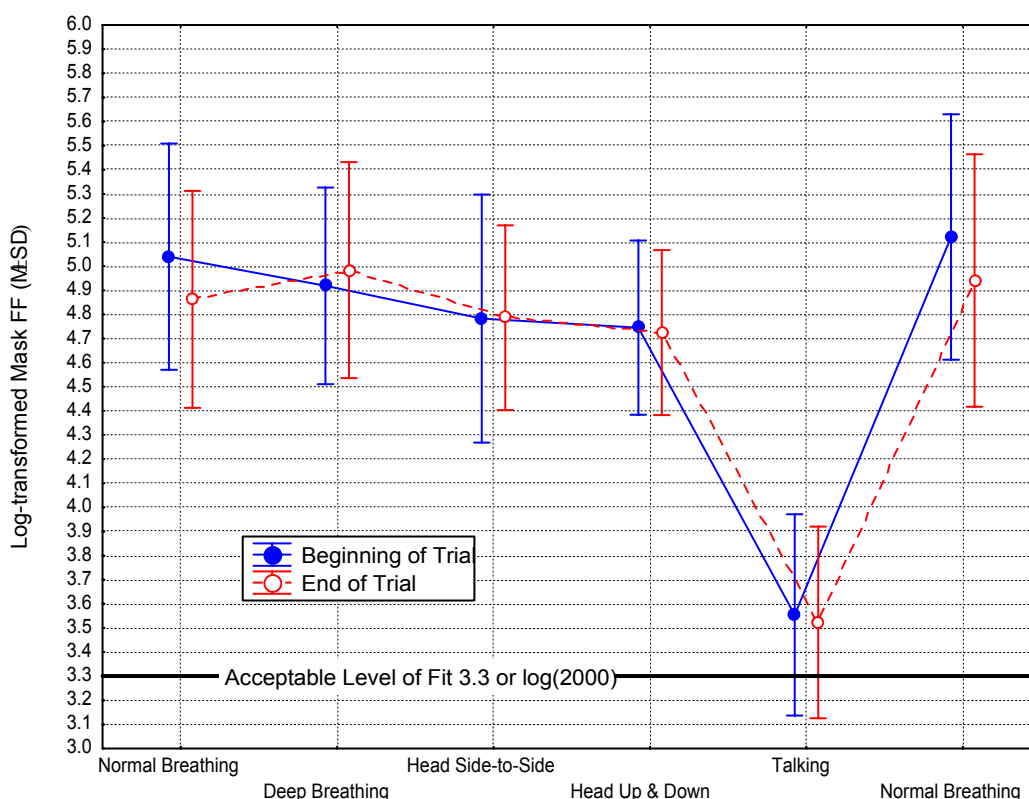


Figure 3. Non-smokers (M $\pm$ SD) Log-transformed mask FF at the beginning and end of trial for all exercise tasks.

In summary, smoking was found to artificially lower mask FF, therefore better control over a subject's prior activity is paramount. Mask FF for non-smokers remained unchanged across the trial, indicating that wearing a respirator for 3 hours and completing a moderate bout of exercise (30 mins) had

no adverse affect on mask FF. Talking resulted in a significantly lower mask FF compared to any other exercise, whereas the remaining exercises (normal breathing, deep breathing, head side-to-side, head up and down, and normal breathing) were equivalent in terms of their influence on mask FF. The repeated measurements experiment (although limited in sample size) demonstrated reliability in mask FF. All subjects (smokers and non-smokers) were able to achieve good levels of mask fit.

Operational FF

Overall Operational FF

Individual and pooled overall operational FF results are presented in Table I. The pooled overall operational FF of 3.64 ± 0.48 ($M \pm SD$) was greater than the required 3.3 ($\log(2000)$). However, despite subjects recording acceptable levels of mask fit during the initial and final mask FF assessments, 7 of the 27 subjects (including repeats) completing the operational FF tasks failed to record an individual overall operational FF greater than 2000 (Table I, individual overall operational FF in bold). The 5th percentile of the overall operational FF including repeats is 2.79, which is equivalent to an operational FF of 620. This score is significantly below the FF of 2000 that we had hoped to achieve. Based on this study an operational FF of 2000 or greater is only achieved by 74% of subjects.

Operational Tasks

It was highlighted previously that initial mask FF for smokers was significantly different from their final mask FF. It was also noted that there was no significant difference in mask FF between smokers and non-smokers at the end of a trial. This suggests that the time between recording the initial and final mask FF was adequate to remove the majority of smoke particles from the smoker's lungs. It is therefore expected that smokers and non-smokers operational FF may differ initially as smokers may not have reached a static equilibrium, in terms of concentration of exhaled smoke particles, when assessments are separated in time. However, due to the large SD for each of the operational FF exercises no significant difference could be established between smokers and non-smokers ($p > 0.05$). Hence, smokers and non-smokers operational FF data were pooled and the results are presented descriptively.

Subjects pooled log-transformed mean operational FF for each exercise are presented in Figure 4. The walk and command exercise recorded the lowest mean operational FF compared to all other exercises. The stair climb, and lift and carry exercises tended to record greater operational FF than all other exercises. Operational FF for all exercises (except walk and command) exceeded the acceptable level of mask fit (> 3.3 or $\log(2000)$).

The poor FF for walk and command is similar to that reported earlier for talking during the mask FF assessment. Both the operational and mask FF exercises involving speech, recorded statistically lower FF. This may be a consequence of facial deformation during speech resulting in a poor face seal with the S10 respirator. It may also be a function of the inward leakage through the outlet valve due to speech-induced vibration. Alternatively, the speech process may result in the generation of particles that are counted by the PortaCount[®], thereby artificially lowering the recorded FF. van der Gijp *et al.* (2001) found that *"...breathing vigorously did not result in the production of particles and hence in an artificially lower protection factor. Speaking however did, the generation of particles could however be avoided by "playbacking" the text..."*. "Playbacking" means talking without making a sound (i.e. lip-synching). The manufacturers of the PortaCount[®] do not report that there is a significant production of particles during speech that is detected by the PortaCount[®]. Fairchild and Stampfer (1987) have reported that particles are exhaled in each breath, even in air containing no particles, which can result in artificially lower FF (Fairchild and Stampfer, 1987).

The potential contribution of body-generated particles to the particle count may account for the poor mean walk and command operational FF failing the acceptable level of mask fit (3.3 or $\log(2000)$). Removing the walk and command task from the overall operational FF for individuals (Table I) results in only one of the seven subjects (whom previously failed) meeting the acceptable level of mask fit (Subject

25, repeat for subject 9). Irrespective, the potential contribution of body-generated particles requires the focus of a separate study and therefore will not be discussed in any further detail.

Table I. Summary Statistics for Initial, Operational and Final Mask FF Assessments

Subject	Size	Smoker	Mask FF		Overall Operational FF
			Initial	Final	
1	2	N	4.00	4.59	3.90
2	2	Y	3.74	5.05	3.94
3	2	N	4.21	4.38	3.73
4	2	Y	3.73	4.34	4.25
5	2	N	4.56	4.45	4.31
6	2	N	4.21	4.60	4.51
7	2	N	4.73	4.44	4.07
8	2	N	4.89	4.66	4.06
9	2	N	3.48	4.00	3.64
10	2	Y	3.18	3.77	3.81
11	2	Y	3.83	4.20	3.90
12	2	N	4.10	4.23	n/a
13	2	N	4.35	4.15	4.18
14	2	N	4.61	4.54	3.99
15	2	Y	3.79	3.99	3.22
16	2	N	4.01	3.84	2.91
17(R3)	2	N	3.89	3.68	3.35
18 (R1)	2	N	3.88	4.21	3.85
19	2	N	3.88	3.91	3.78
20	2	N	3.97	3.81	3.08
21	2	N	4.05	3.63	3.55
22	4	N	4.12	3.78	3.18
23	2	Y	3.66	3.46	3.04
24	3	N	3.95	3.71	2.79
25 (R9)	2	N	3.94	n/a	2.76
26	2	Y	3.93	n/a	3.35
27(R12)	2	N	4.13	n/a	3.63
28	3	N	3.96	n/a	3.48
M					3.64
SD					0.48
5th Percentile					2.79

Note: R-subject repeated experiment.

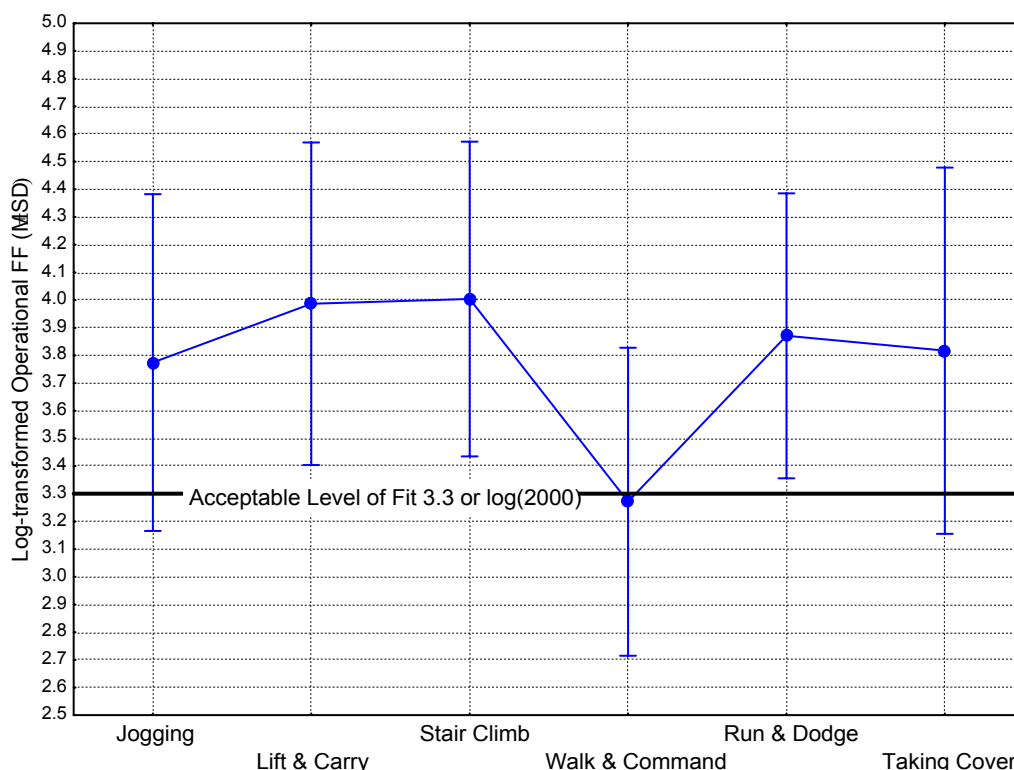


Figure 4. Pooled Log-transformed operational FF ($M \pm SD$) for each exercise.

In summary, no difference was observed between smokers and non-smokers operational FF. Walk and command had the lowest mean operational FF, followed by jogging and taking cover, then run and dodge, with lift and carry and stair climb exercises producing the highest mean operational FF. That is, (with the exception of walk and command), tasks that result in greater facial and head movements, higher breathing and heart rates (in order of severity) tend to have the most negative influence on operational FF. Similar to mask FF findings, all subjects (smokers and non-smokers) were able to achieve good levels of mask fit during the operational exercises except for walk and command.

Individual Observations

Whilst the majority of subjects achieved good levels of mask fit, some areas of the S10 respirator were identified as having the potential for improvement. Firstly, two subjects (22 & 24, Table I) had problems with the mask slipping and tended to record lower operational FF. The sole female (subject 22, Table I) had her hair tied in a bun, which made the central location of the harness difficult. As a consequence the harness position was higher and increased the potential for the mask to move (slip). The second subject (subject 24, Table I) sweated profusely, contributing to mask slippage. Consequently, improvements in the S10 respirator could be made by improving sweat removal (Johnson *et al.*, 1997; Carretti and Gardner, 1999) and offering a more versatile mask harness design/configuration. A third subject (subject 13, Table I) who had his harness incorrectly fitted (skewed to the side) did not have any problems with mask slippage and recorded high mask (4.35 initial, 4.15 final) and operational (4.18) FF.

Subject 25 whom repeated the experiment (also subject 9, Table I) failed to achieve a FF of greater than 3.3 with no obvious cause. Subjects 10, 15, 17 & 20 were all noted to work harder during some period of the trial. Whilst subjects 22 & 24 appeared to exercise notably harder than the other

subjects throughout the whole trial, however this was not quantified. Similar to subject 25, no reason was evident for subject 23 failing to achieve an overall operational FF of 3.3 or greater. The results of the individual subjects (excluding 23 & 25) who failed to achieve an overall operational FF of 3.3 is consistent with the previous statement that greater facial and head movements, higher breathing and heart rates (in order of severity) tend to have the most negative influence on operational FF.

CONCLUSIONS

Subjects wearing the S10 respirator performed a range of exercises considered to be representative of operational tasks commonly encountered by the CBRR Squadron. All subjects were able to achieve a mask FF (initial or final) above 2000. However, only 74% of subjects including those who repeated the experiment were able to achieve an operational FF above 2000. Based on the present study we can be confident that 95% of a sample is able to achieve a FF of greater than 620 which is significantly lower than the expected level of 2000. It must be remembered that we are not trying to define the maximum possible fit of the S10 respirator but an indication of fit under its current use and handling in the field by soldiers. It is therefore important to be aware that FF achieved under operational conditions are unlikely to replicate those achieved during standard mask fit tests.

ACKNOWLEDGMENTS

DSTO would like to thank the volunteers from the CBRR Squadron for their invaluable help in this study. In particular we would like to thank Maj C. Madden and WO J. Cochbain for their help in the coordination of this study.

REFERENCES

- AS/NZS:1716 (1994). AS/NZS 1716:1994.: Respiratory Protective Devices. Homebush, NSW, Australia, Standards Australia.
- Bancroft, B., M. P. Clayton, et al. (1999). "Workplace Fit of Full Face Mask Respirators - A New Approach." Journal of the International Society for Respiratory Protection **17**(2): 24-54.
- Capon, A. (1996). "Protection Factors - Who Do They Protect." Journal of the International Society for Respiratory Protection **14**(3): 19-25.
- Carretti, D. M. and P. D. Gardner (1999). "Respirator fit factor performance while sweating." American Industrial Hygiene Association Journal **60**(1): 84-8.
- DEF(AUST)5686 (2001). DEF(AUST)5686.: Operational Requirements and Evaluation criteria for General Service Masks in the Timeframe 1985-2005, Army Standardisation.
- Fairchild, C. I. and J. F. Stampfer (1987). "Particle Concentration in Exhaled Breath." American Industrial Hygiene Association Journal **48**(11): 948-9.
- Hardis, K. E., C. A. Cadena, et al. (1983). "Correlation of quantitative results from testing respirator fit." American Industrial Hygiene Association Journal **44**(2): 78-87.

Johnson, A. T., W. H. Scott, et al. (1997). "Sweat rate inside a full-facepiece respirator." American Industrial Hygiene Association Journal **58**(12): 881-4.

Myers, W. R., M. J. r. Peach, et al. (1984). "Workplace protection factor measurements on powered air purifying respirators at a secondary lead smelter: results and discussion." American Industrial Hygiene Association Journal **45**(10): 681-8.

Richardson, G. S. and C. Bee (2001). Measurement of Respirator Performance on the Battlefield using a Man Mountable Evaluation Tool. Seventh International Symposium on Protection Against Chemical and Biological Warfare Agents, Stockholm, Sweden.

Spear, T. M., J. DuMond, et al. (2000). "An effective protection factor study of respirators used by primary lead smelter workers." Applied Occupational and Environmental Hygiene **15**(2): 235-243.

Tannahil, S. N., R. J. Willey, et al. (1990). "Workplace protection factors of HSE approved negative pressure full-facepiece dust respirators during asbestos stripping: preliminary findings." Annals of Occupational Hygiene **34**(6): 547-52.

TSI Incorporated, S. P., MN, USA (October 1996). PortaCount® Plus Model 8020: Operation and Service Manual.

van der Gijp, S., J. Hoefs, et al. (2001). Gas Mask Protection Level in the Field. Seventh International Symposium on Protection Against Chemical and Biological Warfare Agents, Stockholm, Sweden.