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SPEECH INTELLIGIBILITY WHILE WEARING
CIVILIAN FULL-FACEPIECE AIR-PURIFYING RESPIRATORS

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

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14. ABSTRACT
In situations where law enforcement officers are wearing air-purifying respirators (APRs) and communicating either with each other or the public, intelligible speech can be critical. The National Institute for Occupational Safety and Health (NIOSH) requires a 70% speech intelligibility performance rating for commercial chemical, biological, radiological, and nuclear (CBRN) APR certification. As the score is not released, there is no way to know which respirators perform better than others. This effort assessed the speech intelligibility of 12 NIOSH-certified CBRN APRs. Statistically, the Millenium and FR-M40 had significantly higher scores than the FR-7800B. The Millenium also scored significantly higher than the M-TAC. In situations where speech is critical, the Millenium and FR-M40 would be expected to provide higher speech intelligibility than the FR-7800B.

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PREFACE

The work described in this report was authorized under Project No. 9NBNN3. This work was started in October 2008 and completed in June 2009.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

In conducting the research described in this report, the investigators adhered to Army Regulation 70-25, Research and Development--Use of Volunteers as Subjects of Research, dated 25 January 1990, as promulgated by the Office of the Surgeon General, Department of the Army.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Service.

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SPEECH INTELLIGIBILITY WHILE WEARING
CIVILIAN FULL-FACEPIECE AIR-PURIFYING RESPIRATORS

1.   INTRODUCTION

It is critical that law enforcement officers are able to communicate clearly with one another when responding to a chemical, biological, radiological, and nuclear (CBRN) event. These situations include terrorist events and raids on contaminated sites such as methamphetamine laboratories. Head-borne personal protective equipment (PPE), such as respirators, hoods, and helmets, impacts speech intelligibility by interfering with speech transmission and reception. In 2004, the Department of Homeland Security (DHS) adopted the National Institute for Occupational Safety and Health (NIOSH) air-purifying respirator (APR) CBRN standard.[1] DHS requires that equipment purchased with its grants meet NIOSH standards.

The NIOSH CBRN APR communications standard assesses speech intelligibility during mask wear by scores resulting from the Modified Rhyme Test (MRT).[2] The MRT consists of 50 six-word lists of monosyllabic English words, most having three sounds in a consonant-vowel-consonant sequence. The MRT evaluates a listener's ability to comprehend single words and also provides an indication of speech transmission of the selected words. A 70% performance rating is required for a respirator to pass the speech intelligibility test. However, the score is not available to the public. Thus, users have no way of knowing which respirators perform better than others. The goal of this effort was to perform speech communications tests based on the NIOSH standard to assess whether there were any differences in speech intelligibility among certified respirators.

2.   METHODS

When the study began, there were 12 NIOSH-certified CBRN APRs. The respirators were: 3M FR-M40, Avon C50, Peltor-AOSafety M-TAC, Drager CDR 4500, Mine Safety Appliances (MSA) Millenium, Survivair Optifit, MSA Ultra Elite, Scott Health and Safety M120, North 5400, 3M FR-7800B, Scott M110, and Avon FM12.

2.1   Volunteers

Volunteers were recruited from the civilian and military workforce of the U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD. All participants were healthy and free of coronary risk factors as determined by completion of the OSHA respirator medical evaluation questionnaire. Each subject gave written informed consent prior to participation in the study, which had previously received institutional review board approval.

2.2   Test Procedures

All testing was conducted in the Respiratory Protection Technology Branch's Individual Protective Equipment Facility. These trials followed the NIOSH communications certification procedure. Seventy-two volunteers (60 male and 12 female) aged 22 ± 5 years participated. Nine subjects participated in multiple trials. Eight volunteers participated in each trial, serving as either a listener or a speaker. Listener panels consisted of one female and two

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males. Four males and one female participated as speakers for each trial. All volunteers were healthy, native English speakers, who did not have any reading problems. Listeners passed the hearing test outlined in the NIOSH test procedures. Speakers did not have regional accents or any speech defects. All volunteers were trained according to the NIOSH test procedures. Background noise during all trials was set at 60 ± 2 dBA and was measured at the listener's ear level. The MRT was used to assess speech intelligibility. Each speaker read one word list while wearing the mask and one word list without the respirator. Listeners and speakers were familiarized with all words prior to testing. Each respirator was tested on a different test day with a different group of volunteers, though some volunteers participated in more than one trial, depending on their availability. Speakers read the word lists with a speech sound level between 75 and 85 dBA as measured on a sound level meter placed approximately 1 ft in front of the speaker's mouth. The speaker read each word with the carrier sentence, "The word is...." Listeners sat in front of laptop computers with a custom-developed software program used to administer the MRT. Listeners were presented with the six possible word choices. For instance, for the spoken word "bus" the possible answers are "but, bus, bug, bun, buck, buff". They clicked on the word they thought they heard and then clicked a button to move onto the next word. Once all listeners had selected a response, a test administrator cued the speaker to read the next word. This continued until all words on the list were spoken. The speaker and listeners then switched mask conditions, and the speaker read a second list. Each of the five speakers then completed their two word lists. Speech and background sound levels were measured at the beginning, middle, and end of each MRT word list for 30 readings per trial.

2.3   Equipment

Each of these 12 respirators underwent the speech communications certification trials in the same lab where the current effort was conducted. All equipment used was the same with the exception of the sound level meters and corresponded to that listed in the NIOSH standard. In brief, a stereo amplifier, two loudspeakers, and a pink noise generator (Bruel and Kjaer Type 1405, Denmark) were used to transmit pink noise at 60 ± 2 dBA. The noise levels were measured at the position of the listener's ear. The A-weighted fast response setting was used on the sound level meters (Model 322, Center Technology Corporation, Taipei, Taiwan). The meters were calibrated at the start of each test day. Once the meters were calibrated, the room background noise was set.

2.4   Data Analyses

2.4.1   Respirator Trial Analyses

Performance ratings were computed using the method outlined in the NIOSH test procedure. Scores were corrected for words misspoken by the speaker. Per the American National Standards Institute (ANSI) and NIOSH standards, the scores were corrected for chance or guessing made possible by the multiple-choice form of the answer sheet. Scores for each trial were calculated using the following equation:

$$\text{Adjusted Score (\%)} = \left(\frac{\text{\# Correct - \# Correct/5}}{\text{\# Words Spoken Correctly}} \right) \times 100 \qquad (1)$$

The performance rating for each listener was obtained by dividing the average scores during the five mask wear trials (one trial for each speaker) by the average scores from the five no mask trials and converting to a percentage (Equation 2).

$$\text{Performance rating (\%)} = \left(\frac{\text{\% Adjusted Score with respirator}}{\text{\% Adjusted Score without respirator}} \right) \times 100 \qquad (2)$$

These three scores were then averaged to obtain the performance rating of the mask. The respirator passes the NIOSH CBRN APR communications tests if the performance rating is 70% or higher.

A two-way analysis of variance (ANOVA) was performed at the $p = 0.05$ level using SigmaStat v 3.1 (Systat Software, Inc., Chicago, IL) to determine if there were differences in performance ratings among speakers and listeners. To do this, individual performance ratings were calculated for each speaker/listener pair. For each trial, there would be 15 performance ratings, with the average of these representing the overall performance rating of the respirator. The difference between this alternate average and the standard NIOSH method was calculated. A one-way analysis of variance was performed to determine if there were any differences between the methods. A two-way ANOVA at the $p = 0.05$ level was also performed to detect any differences in speaker sound level among speakers and between mask conditions. Average background noise was computed for each trial. Post hoc analyses were performed using either Holm-Sidak or Tukey. The choice was based on which method SigmaStat suggested.

2.4.2   Comparisons Among Trials

A one-way ANOVA was performed to determine if there were any differences in performance ratings among the 12 respirators. A two-way ANOVA was used to assess differences in performance ratings between genders for the listeners and speakers. A one-way ANOVA was performed to identify differences between the speech diaphragm (10 respirators) and the speech horn (2 respirators). Differences in performance ratings between respirators with front-mounted filters (9 respirators) and those with side-mounted filters (3 respirators) were assessed using a one-way ANOVA. An ANOVA was performed to determine if there were differences in performance ratings among the three listener positions.

A Kruskal-Wallis ANOVA on Ranks was performed to determine if there were significant differences in speaker sound levels among test dates. Dunn's method for multiple pairwise comparison was used to show which test dates differed. A second ANOVA on Ranks was performed to determine if there were differences among the mask conditions with the no mask trials treated as a 13th condition. Dunn's method was again used to identify which conditions differed. Linear regression was used to determine whether there was a significant relationship between performance rating and speaker sound level at the $p = 0.05$ level.

A Kruskal-Wallis ANOVA on Ranks was performed to determine if there were significant differences in background sound levels among test dates. Dunn's method for multiple pairwise comparison was used to show which test dates differed. Linear regression was used to determine whether there was a significant relationship between performance rating and background sound level at the $p = 0.05$ level.

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3.   RESULTS

3.1   Overall Respirator Performance Scores

All 12 respirators had performance ratings >70%. The scores shown in Table 1 include the NIOSH score and the alternate average.

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Table 1. Performance ratings by two methods

Mask	NIOSH	Alternate
FR-M40	87.84	88.00
C50	84.10	84.14
M_TAC	79.01	79.11
4500	80.81	80.83
Millenium	90.47	90.45
Optifit	80.89	80.91
Ultra Elite	86.75	86.91
M120	84.82	84.85
5400	84.87	84.95
FR-7800B	78.11	77.95
M110	85.88	85.83
FM12	83.77	83.81

There was not a statistically significant difference between the two methods of computing the averages (p = 0.983).

3.2   Individual Respirator Trials

Scores from the 12 respirator speech intelligibility trials are presented in the order in which they were tested. Respirators were tested in a random order.

3.2.1   Trial on 19 Jul 08: 3M FR-M40

The overall performance rating of the respirator using the NIOSH-specified average was 87.8%, while the alternate average was 88%. There were no significant differences in performance ratings among either speakers or listeners. Performance ratings by speaker and listener are shown in Table 2. The speaker sound levels were neither significantly different between mask and unmasked conditions nor among speakers. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA once (85.1 dBA) during the unmasked trials and once (85.2 dBA) during the masked trials. Speech sound levels are shown in Table 3. Background noise during the trials was 59.9 ± 0.3 dBA.

Table 2. Performance ratings for 3M FR-M40

Role	Subject ID	Mean	Std Dev
Speaker	232	77.4	6.4
	233	93.3	9.5
	234	88.2	6.1
	235	87.3	4.8
	239	93.8	8.1
Listener	237	91.5	8.0
	238	85.2	11.6
	239	87.4	6.0

Table 3. Speaker sound levels for 3M FR-M40

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	232	81.4	2.8	81.7	0.5
	233	80.1	1.2	81.9	2.8
	234	83.6	1.1	82.3	1.4
	235	82.1	2.5	82.7	3.6
	239	84.5	0.8	81.4	1.6

3.2.2   Trial on 26 Jul 08: Avon C50

The overall performance rating of the C50 using the NIOSH-specified and alternate averages was 84.1%. There were no significant differences in performance ratings among speakers. ANOVA on Ranks was used for the listener performance ratings because the data were not normal. No significant differences occurred among listeners. Performance ratings by speaker and listener are shown in Table 4. The speaker sound levels were not significantly different among speakers. However, statistically, the masked trials had a significantly higher speech sound level than the control trials. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA three times during the masked trials. These recorded values were 85.1, 85.7, and 87.5 dBA. Speech sound levels are shown in Table 5. Background noise during the trials was 60.0 ± 0.2 dBA.

Table 4. Performance ratings for Avon C50

Role	Subject ID	Mean	Std Dev
Speaker	240	81.8	7.2
	241	91.8	15.9
	242	87.8	6.4
	243	80.5	8.9
	244	78.8	8.8
Listener		76.8	10.2
		89.4	10.9
		86.2	3.5

Table 5. Speaker sound levels for Avon C50

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	240	84.3	1.3	81.6	1.3
	241	83.4	1.6	78.9	2.9
	242	83.3	1.0	79.5	2.5
	243	83.1	2.2	81.5	2.3
	244	83.4	3.5	82.0	1.1

3.2.3   Trial on 9 Aug 08: Peltor-AOSafety M-TAC

The overall performance rating of the M-TAC using the NIOSH-specified average was 79.0%, while the alternate average was 79.1%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 6. The two-way ANOVA showed no significant differences in speaker sound level among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA three times (85.4, 85.5, and 85.7 dBA) during the unmasked trials and once (85.6 dBA) during the masked trials. Speech sound levels are shown in Table 7. Background noise during the trials was 61.2 ± 0.5 dBA.

Table 6. Performance ratings for Peltor-AOSafety M-TAC

Role	Subject ID	Mean	Std Dev
Speaker	251	74.1	8.5
	256	79.4	4.5
	257	81.3	4.7
	258	74.3	9.0
	259	86.5	9.6
Listener	260	80.0	7.4
	261	82.6	5.8
	262	74.7	9.8

Table 7. Speaker sound levels for Peltor-AOSafety M-TAC

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	251	82.6	2.3	82.8	1.5
	256	82.7	2.1	83.2	2.7
	257	82.0	1.7	82.7	1.5
	258	84.9	0.6	85.2	0.7
	259	83.0	1.7	81.8	1.4

3.2.4   Trial on 16 Aug 08: Drager CDR 4500

The overall performance rating of the CDR 4500 using the NIOSH-specified and alternate averages was 80.8%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 8. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA two times (85.1 and 85.4 dBA) during the unmasked trials. Speech sound levels are shown in Table 9. Background noise during the trials was 60.3 ± 0.2 dBA.

Table 8. Performance ratings for Drager CDR 4500

Role	Subject ID	Mean	Std Dev
Speaker	84	81.4	9.9
	242	77.3	8.4
	243	83.3	7.0
	263	79.7	8.0
	265	82.8	6.9
Listener	264	80.9	6.8
	266	85.9	5.7
	267	75.9	6.5

Table 9. Speaker sound levels for Drager CDR 4500

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	81.4	2.0	79.7	3.0
	242	80.8	2.9	82.1	3.0
	243	79.1	3.6	83.1	3.7
	263	81.5	2.9	82.3	2.8
	265	78.9	3.2	82.4	1.7

3.2.5   Trial on 1 Nov 08: MSA Millenium

The overall performance rating of the Millenium using the NIOSH-specified and alternate averages was 90.5%. The two-way ANOVA showed that there were no significant differences in performance ratings among listeners, but that there were differences among speakers. A Holm-Sidak post-hoc test showed that performance ratings were significantly higher when subject 84 was speaking compared to when subject 290 was the speaker. Performance ratings by speaker and listener are shown in Table 10. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels did not exceed the NIOSH-specified range of 75 to 85 dBA during any of these trials. Speech sound levels are shown in Table 11. Background noise during the trials was 60.1 ± 0.3 dBA.

Table 10. Performance ratings for MSA Millenium

Role	Subject ID	Mean	Std Dev
Speaker	84	99.2	6.8
	98	94.9	2.5
	290	83.2	3.7
	291	86.7	3.1
	292	88.2	5.1
Listener	293	92.6	8.5
	294	90.1	2.6
	295	88.7	9.4

Table 11. Speaker sound levels for MSA Millenium

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	81.6	3.8	80.0	1.1
	98	80.9	3.0	77.9	3.9
	290	80.4	2.8	80.9	1.9
	291	79.5	3.5	81.7	2.6
	292	78.0	1.9	82.2	1.3

3.2.6   Trial on 15 Nov 08: Survivair Optifit

The overall performance rating of the Optifit using the NIOSH-specified and alternate averages was 80.9%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 12. The two-way ANOVA showed no significant differences in speaker sound levels between the no mask and mask conditions. However, there was a significant difference in speaker sound level between speakers and there was a statistically significant interaction between speaker and mask condition. A Tukey Multiple Comparison Procedure showed no differences in speakers for the combined mask and no mask data. However, with speakers 98 and 299, there were significant differences between the mask and no mask conditions. With the no mask condition, there was a significant difference between speakers 98 and 299. No significant differences were detected between speakers for the mask condition. Speech levels did not exceed the NIOSH-specified range of 75 to 85 dBA during any of these trials. Speech sound levels are shown in Table 13. Background noise during the trials was 60.9 ± 0.3 dBA.

Table 12. Performance ratings for Survivair Optifit

Role	Subject ID	Mean	Std Dev
Speaker	84	81.2	9.3
	98	79.8	6.4
	297	69.9	9.3
	298	82.7	2.9
	299	91.0	7.5
Listener	296	79.5	9.6
	300	82.1	13.6
	301	81.2	5.3

Table 13. Speaker sound levels for Survivair Optifit

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	83.0	1.2	82.0	1.7
	98	81.9	2.1	79.3	2.0
	297	79.9	2.1	80.9	1.3
	298	80.6	0.8	82.7	1.2
	299	81.5	1.6	84.2	0.4

3.2.7   Trial on 22 Nov 08: MSA Ultra Elite

The overall performance rating of the Ultra Elite using the NIOSH-specified average was 86.8%, while the alternate average was 86.9%. The two-way ANOVA showed that there were no significant differences in performance ratings among either speakers or listeners. Performance ratings by speaker and listener are shown in Table 14. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA during one (85.9 dBA) no mask trial. Speech sound levels are shown in Table 15. Background noise during the trials was 58.2 ± 0.4 dBA. Background noise fell below the 58 dBA range three (57.5, 57.8, and 57.8 dBA) times during the mask trials and twice (57.8, and 57.8 dBA) during the no mask trials.

Table 14. Performance ratings for MSA Ultra Elite

Role	Subject ID	Mean	Std Dev
Speaker	84	84.8	3.7
	297	86.3	5.8
	299	89.5	5.1
	302	92.6	6.7
	303	81.3	9.2
Listener	296	90.6	5.0
	304	86.2	1.9
	305	83.9	10.0

Table 15. Speaker sound levels for MSA Ultra Elite

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	80.2	3.7	84.3	1.4
	297	81.7	0.7	81.7	3.6
	299	80.8	0.7	83.9	0.5
	302	82.0	1.5	80.7	0.7
	303	81.0	2.4	81.0	0.7

3.2.8   Trial on 6 Dec 08: Scott M120

The overall performance rating of the M120 using the NIOSH-specified average was 84.8%, while the alternate average was 84.9%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 16. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels did not exceed the NIOSH-specified range of 75 to 85 dBA during any trials. Speech sound levels are shown in Table 17. Background noise during the trials was 59.9 ± 0.2 dBA.

Table 16. Performance ratings for Scott M120

Role	Subject ID	Mean	Std Dev
Speaker	84	82.3	2.7
	98	88.6	6.1
	302	88.9	5.1
	306	80.4	10.4
	307	84.1	2.6
Listener	296	88.0	5.4
	304	81.4	5.5
	309	85.1	7.0

Table 17. Speaker sound levels for Scott M120

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	80.8	3.5	79.3	2.4
	98	79.1	1.3	79.0	2.1
	302	81.7	4.1	82.9	0.9
	306	80.3	2.3	83.8	1.0
	307	80.4	1.3	81.2	1.7

3.2.9   Trial on 31 Jan 09: North 5400

The overall performance rating of the 5400 using the NIOSH-specified average was 84.9%, while the alternate average was 85.0%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 18. The two-way ANOVA showed no significant differences in speaker sound level among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA during one (85.7 dBA) no mask trial. Speech sound levels are shown in Table 19. Background noise during the trials was 59.0 ± 0.2 dBA.

Table 18. Performance ratings for North 5400

Role	Subject ID	Mean	Std Dev
Speaker	84	80.2	9.0
	98	87.1	4.8
	311	88.1	10.8
	312	83.0	8.6
	313	86.3	14.1
Listener	296	90.7	6.5
	315	79.7	9.7
	316	84.4	8.2

Table 19. Speaker sound levels for North 5400

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	81.2	2.0	80.5	3.3
	98	79.0	0.6	82.9	4.0
	311	80.4	2.4	81.3	4.9
	312	81.4	2.3	81.5	0.8
	313	81.6	3.4	82.5	0.3

3.2.10   Trial on 7 Feb 09: 3M FR-7800B

The overall performance rating of the FR-7800B using the NIOSH-specified average was 78.1%, while the alternate average was 78.0%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 20. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA during two (85.3 and 85.6 dBA) mask trials. Speech sound levels are shown in Table 21. Background noise during the trials was 59.8 ± 0.3 dBA.

Table 20. Performance ratings for 3M FR-7800B

Role	Subject ID	Mean	Std Dev
Speaker	84	76.2	14.7
	98	80.8	8.3
	318	86.3	7.5
	319	73.5	5.1
	320	73.0	5.4
Listener	314	82.0	7.4
	317	74.0	7.9
	321	77.9	11.6

Table 21. Speaker sound levels for 3M FR-7800B

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	82.7	2.3	81.1	1.7
	98	79.8	1.0	78.7	1.5
	318	83.9	1.8	79.5	0.3
	319	81.6	1.7	79.0	3.2
	320	79.7	3.6	82.0	1.7

3.2.11   Trial on 7 Mar 09: Scott M110

The overall performance rating of the M110 using the NIOSH-specified average was 85.9%, while the alternate average was 85.8%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers, but that there were differences among the listeners. A Holm-Sidak post-hoc test showed that, statistically, listener 296 had significantly higher scores than listener 326. Performance ratings by speaker and listener are shown in Table 22. The two-way ANOVA showed no significant differences in speaker sound levels among speakers or between no mask and mask conditions. Speech levels exceeded the NIOSH-specified range of 75 to 85 dBA during one (85.2 dBA) mask trial. Speech sound levels are shown in Table 23. Background noise during the trials was 59.4 ± 0.3 dBA.

Table 22. Performance ratings for Scott M110

Role	Subject ID	Mean	Std Dev
Speaker	84	92.0	8.4
	98	90.3	8.6
	327	77.3	9.4
	328	82.7	3.4
	329	86.8	8.3
Listener	296	91.6	8.3
	325	86.0	4.4
	326	79.9	9.4

Table 23. Speaker sound levels for Scott M110

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	81.2	3.7	83.4	2.0
	98	77.7	3.4	77.7	3.4
	327	79.7	2.2	82.8	0.6
	328	78.4	1.7	80.9	3.4
	329	80.6	2.7	81.4	1.8

3.2.12   Trial on 28 Mar 09: Avon FM12

The overall performance rating of the FM12 using the NIOSH-specified and alternate averages was 83.8%. The two-way ANOVA showed that there were no significant differences in performance ratings among speakers or listeners. Performance ratings by speaker and listener are shown in Table 24. The two-way ANOVA showed no significant differences in speaker sound levels among speakers. However, statistically, the speech level during the mask condition was significantly higher than the level during the no mask trials. Speech levels did not exceed the NIOSH-specified range of 75 to 85 dBA during any trials. Speech sound levels are shown in Table 25. Background noise during the trials was 60.1 ± 0.2 dBA.

Table 24. Performance ratings for Avon FM12

Role	Subject ID	Mean	Std Dev
Speaker	84	87.8	7.3
	98	84.8	7.7
	330	85.1	4.6
	332	78.9	3.0
	333	82.6	4.9
Listener	331	80.7	3.1
	335	85.8	5.9
	334	84.9	7.4

Table 25. Speaker sound levels for Avon FM12

Role	Subject ID	Mask		No Mask	
		Mean	Std Dev	Mean	Std Dev
Speaker	84	80.0	3.0	77.9	2.6
	98	81.6	2.0	80.2	3.9
	330	83.5	0.6	80.0	2.2
	332	84.2	1.4	79.9	2.5
	333	82.6	1.6	80.2	2.8

3.3 Comparisons Among Trials

3.3.1 Differences in Performance Ratings by Speaker and Listener Gender

The two-way ANOVA to assess differences in performance ratings by speaker and listener gender showed no differences in performance ratings and no interactions between speaker and listener gender. The scores are shown in Table 26.

Table 26. Performance ratings by gender

Speaker	Listener	Mean	Std Dev
Male	Male	83.1	8.6
Female	Male	85.6	8.1
Male	Female	85.3	8.2
Female	Female	82.4	10.9

3.3.2 Speech Transmission Device Type and Canister Location

There were no statistically significant differences in performance ratings between the speech diaphragm (10 respirators, 84.0 ± 8.7) and horn (2 respirators, 84.0 ± 7.9). There were 9 respirators with side-mounted filter canisters and three with front-mounted canisters. There was not a statistically significant difference in performance ratings between the side (84.3 ± 8.7) and front (82.9 ± 8.2) canister positions.

3.3.3 Listener Position

Listeners were seated in three positions (left, center, and right) in front of the speaker. There were no significant differences in performance ratings among the positions. Listeners in the left position scored 82.2 ± 8.9, in the center 84.2 ± 8.8, and on the right 85.5 ± 7.9.

3.3.4 Speech Sound Levels Among Test Dates

An ANOVA could not be run because the equal variance test failed. A Kruskal-Wallis ANOVA on Ranks showed significant differences in speaker sound levels among test dates. Dunn's method for multiple pairwise comparison was used to show which test dates differed. The speech sound levels for mask and no mask conditions were higher for the MTAC (median 83.4) than for the Millenium (80.7), M120 (81.0), and FR-M7800B (80.6). A second Kruskal-Wallis ANOVA on ranks was performed on the mask condition. The mask condition included the 12 masks with the no mask condition treated as a separate, but combined, mask condition. Dunn's Method showed that the C50 speech levels (median 83.4) were higher than the M110 (79.8) and the Millenium (79.3). The M-TAC (83.4) was also louder than the M110. There was no significant relationship between performance rating and speaker sound level (p = 0.321), although there was a very slight decrease in performance rating as sound level increased, as shown in Figure 1.
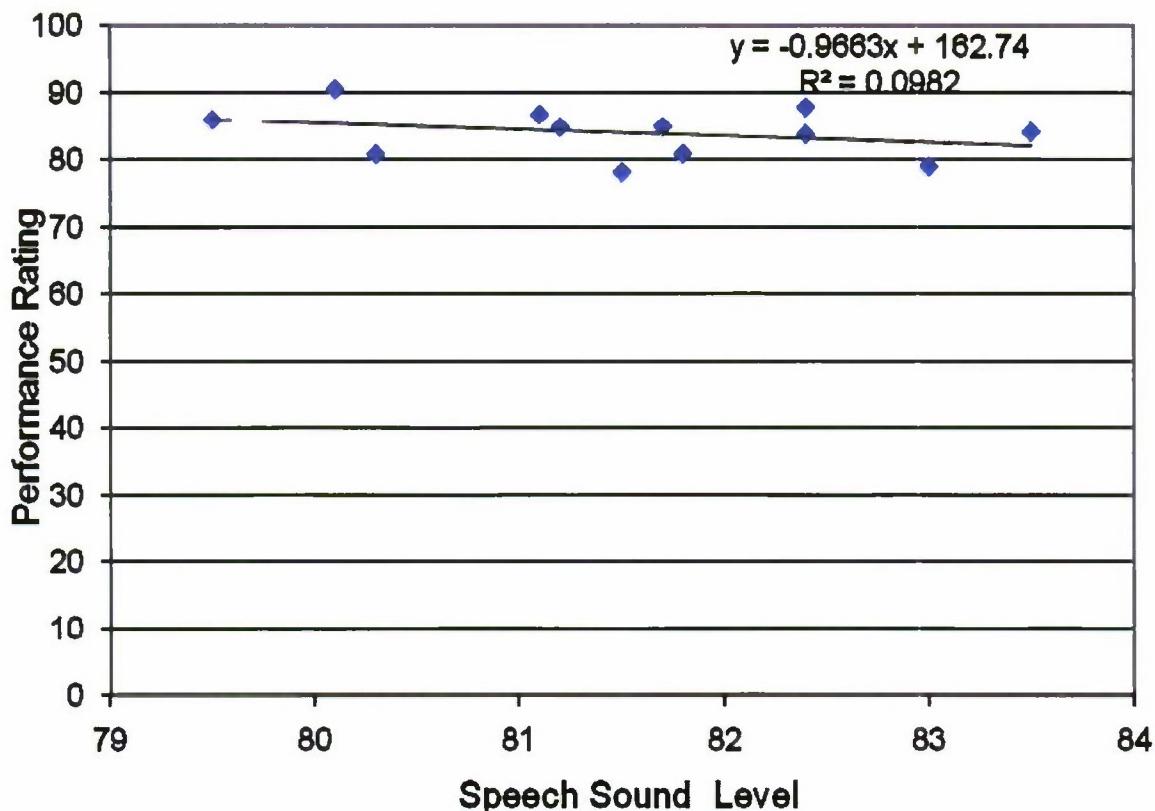
Figure 1. Performance rating as a function of speaker sound level

3.3.5   Background Sound Levels

A Kruskal-Wallis ANOVA on Ranks showed significant differences in background sound levels among test dates. Dunn's method for multiple pairwise comparison was used to show which test dates differed. The background noise during the M-TAC trial was significantly louder than all trials except for the Optifit and 4500. The Optifit had significantly louder background noise than all trials except for the 4500. The 4500 background noise was significantly louder than the ultra, 5400, M110, 7800, and M120. Background noise during the Millenium, FM12, C50, and FRM40 trials was louder than that of the ultra, 5400, and M110. The background noise during the M120 trial was louder than that during either the Ultra or 5400, while the noise during the 7800 was louder than that during the Ultra.

A plot of the performance rating versus background noise showed a slight decline in performance rating with an increase in background noise, as shown in Figure 2. However, the relationship was not statistically significant (p = 0.113).
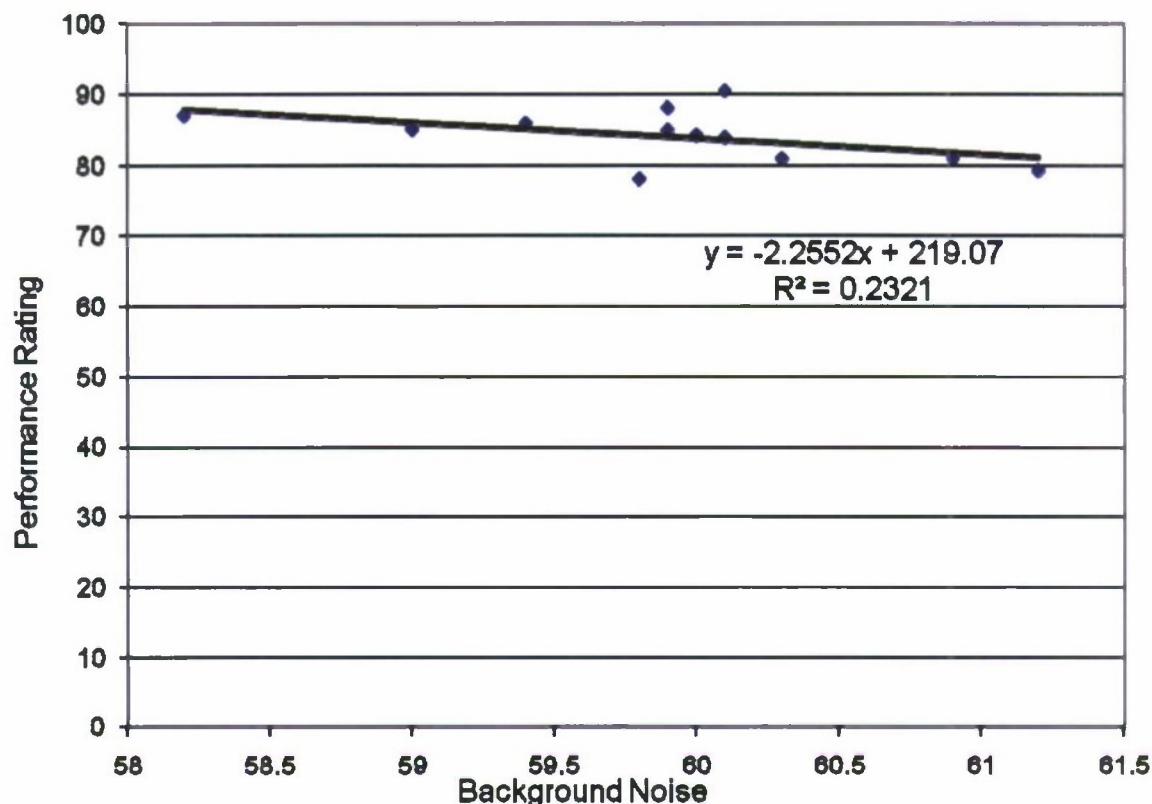
Figure 2. Performance rating as a function of background noise level

3.3.6 Respirator

There were significant differences in performance ratings by respirator. Statistically, the Millenium and FR-M40 had significantly higher scores than the FR-7800B. The Millenium also scored significantly higher than the M-TAC.

4. DISCUSSION

Each of the 12 respirators tested scored above the NIOSH-required 70% passing score. This was expected because each respirator had already received NIOSH CBRN certification. The trials were conducted by two experienced test administrators with trained subjects. Even so, the difficulty in consistently administering the trials as well as the subjectivity of the MRT is evident in the results. While every effort was made to ensure consistency in the test administration, there were several instances of speakers exceeding the 85 dBA limit for the test. This occurred because subjects were encouraged to maintain their speech levels in the upper part of the 75 to 85 dBA range to be consistent across speakers and trials. The result was that occasionally a speaker exceeded the range. During the Ultra Elite trial, background noise fell below the required range five times.

There were only small differences between the performance ratings calculated using the NIOSH and alternate methods. Statistically, the differences were not significantly different. The alternate average was calculated to compare performance among speakers. This was not possible with the NIOSH average. Although the two methods are very similar calculations, the statistical difference was assessed to ensure that no biases were introduced into the analyses.

On several occasions, there were statistically significant differences in either speaker or listener performance ratings. For instance, the M110 and FM12 both had one listener around 80% and one around 91%, with the third scoring in the middle. This is a large difference in performance. Similarly, some speakers scored higher than others. For the Millenium trials, listeners scored 99% when subject 84 was speaking, but only 83% when subject 290 was speaking. This highlights the subjectivity of the test and underscores the need for multiple listeners and speakers. The National Fire Protection Agency has a requirement that the standard deviation of the scores cannot exceed 10. Such a requirement may prove useful for eliminating some of the large score differences seen here.

Some of the mechanics of the test standard were investigated to see how these might impact the performance scores. Because the respirator had the speech device on the front of the respirator and sometimes an additional one on the right side, the impact of listener position was investigated. While listeners on the right scored slightly higher than those in the center and on the left, the difference was not significant. The NIOSH standard requires one female speaker and one female listener. The impact of gender was investigated. There were no significant differences in PR by either speaker or listener gender.

The effects of speech device type and filter canister location were also investigated. No differences in either were detected. However, only 2 of the 12 respirators had speech horns, and only 3 of the 12 had front-mounted canisters, so there weren't equal numbers of respirators in each group. Any effects may have been masked.

Speech sound levels were investigated to see if there were any differences among test dates or among respirator conditions. On the day the M-TAC was tested, the speech sound levels for the mask and no mask conditions combined (83.4 dBA) were significantly louder than the trials for the Millenium (80.7), M120 (81.0), and FR-M7800B (80.6). Out of the 30 speech readings for that day, the M-TAC trial date had four readings (85.4, 85.5, 85.7, and 85.6) that exceeded 85 dBA. Neither the Millenium nor the M120 test dates had any readings over 85 dBA. However, the FR-M7800B had two readings (85.3 and 85.6) that exceeded the speech sound level range. The M-TAC PR score (79%) was similar to that of the FR-M7800B (78%), but was less than that of the Millenium (90.5%) and M120 (84.5%).

The analysis of the sound levels for each mask and the combined no mask scores showed that the speech level (83.4 dBA) when the C50 was worn was higher than the levels when the M110 (79.8 dBA) and Millenium (79.3 dBA) were worn. The M-TAC (83.4) was also louder than the M110. The C50 performance rating (84.1%) was similar to that of the M110 (85.9%), higher than that of the M-TAC (79%), and lower than that of the Millenium (90.5%). No clear pattern emerged between PR and speech sound level. So, a linear regression was performed on performance rating and speech sound level to assess the relationship between these two parameters. While there was a slight decrease in performance rating as speech sound level increased, the R^2 was only 0.098, and the relationship was not statistically

significant (p = 0.321). Therefore, over the small speech sound level range used, performance rating was not impacted by speech sound level.

Similar analyses were performed on the background noise level. Background noise during the M-TAC trials (61.2 ± 0.5 dBA) was significantly louder than all trials except the Optifit (60.9 ± 0.3 dBA) and CDR 4500 (60.3 ± 0.2 dBA). Because of the differences in background noise, the relationship between performance rating and background nose was determined. This was not a significant relationship (p = 0.113). So, over the small range of 58.2 dBA to 61.2 dBA, there was no significant impact of background noise on performance.

The Millenium (90.5% PR) and the FR-M40 (87.8%) scored significantly higher than the FR-7800B (78.1%). The Millenium also scored higher than the M-TAC (79.0%). No other differences were detected. It was speculated that the respirators could be classified based on their MRT scores. However, there was very little difference in speech intelligibility among most of the respirators. The Millenium and FR-M40, however, would be expected to provide better speech intelligibility than the FR-7800B, and the Millenium would also likely perform better than the M-TAC.

A major drawback of the MRT procedure is the time and cost required to conduct the test. In addition, the test participants must be attentive and motivated. Five speakers and three listeners are required to complete the test. Test speakers must speak without an accent and are required to maintain a sound output level between 75 and 85 dB when not wearing a mask and then duplicate the same vocal effort with a mask on. As the mask alters the sound level, there is no way to assess whether the words are being spoken with the same intensity. Speakers may also over-enunciate words while wearing the mask, further altering the sound signal. While scores are averaged across speakers, it is possible that one very bad speaker could cause a respirator that should have passed to result in a failed test. Because this is a subjective test, results cannot be reproduced exactly. An automated speech intelligibility system is being developed through a Defense Threat Reduction Agency Small Business Innovation Research effort. The information from this study will help to validate the performance of that system. It is hoped that the new system will provide consistent, repeatable results because of the decreased subjectivity of the test.

A follow-on study is planned that will attempt to relate MRT scores to operational performance. The information from this study will be useful for developing performance requirements for the Office of Law Enforcement Standards. Garinther et al.[3] investigated the impact of speech intelligibility on performance of military tasks. They considered simple and complex tasks. Speech intelligibility was altered through the use of an electronic clipping circuit. The MRT was used to assess speech intelligibility. For a relatively simple gunnery task, a tank commander told the gunner which of four targets to shoot and which type of ammunition to use. For this task, there was an exponential relationship between targets hit and speech intelligibility. Speech intelligibility as low as 75% resulted in 90% of targets being hit. The more complex task involved a company commander directing a tank commander who then communicated with a gunner and driver. The tank had to proceed to and report in at three checkpoints along a 3 km route. Certain enemy vehicles along the route were engaged, while others were not. At each checkpoint, either the tank commander or the driver had to provide a four-item report to the company commander. For this task, there was a linear decline in successful mission performance with decreasing speech intelligibility. A 100% MRT score was required for a 90% successful mission completion rate. A 90% MRT resulted in an 80% mission performance, while 80 and 70% MRTs resulted in 66 and 57% successfully completed missions, respectively.

For relatively simple tasks, speech intelligibility is not a major factor in performance. However, for complex tasks, degraded speech intelligibility can severely impair mission performance and may put lives at stake. These results have direct application to law enforcement activities. Assessing the impact of speech intelligibility on law enforcement tasks is a critical next step.

5.   CONCLUSIONS

Speech intelligibility trials of 12 CBRN APR were tested according to NIOSH standard procedures. Statistically, the MSA Millenium (90% performance rating) and the 3M FR-M40 (88%) scored significantly higher than the 3M FR-7800B (78%). The Millenium also scored higher than the Peltor-AOSafety M-TAC (79.1%). Thus, in situations where speech is critical, the Millenium and FR-M40 would be expected to provide higher speech intelligibility than the FR-7800B. While the MRT may assess the overall speech intelligibility of a respirator and can show large performance differences, it is probably not sensitive enough to easily discriminate among respirators due to the high subjectivity and variability of the test. A more objective method is needed to accurately assess speech intelligibility. Also, further work is needed to relate the speech intelligibility to successful performance of law enforcement tasks.

LITERATURE CITED

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APPENDIX

RAW DATA

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
7/19/08	FR-M40	232	237	49	0	49	49	100.0	FALSE
7/19/08	FR-M40	233	237	46	3	45.4	49	92.7	FALSE
7/19/08	FR-M40	234	237	47	3	46.4	50	92.8	FALSE
7/19/08	FR-M40	235	237	46	4	45.2	50	90.4	FALSE
7/19/08	FR-M40	236	237	46	4	45.2	50	90.4	FALSE
7/19/08	FR-M40	232	237	41	9	39.2	50	78.4	TRUE
7/19/08	FR-M40	233	237	46	3	45.4	49	92.7	TRUE
7/19/08	FR-M40	234	237	45	5	44	50	88.0	TRUE
7/19/08	FR-M40	235	237	43	7	41.6	50	83.2	TRUE
7/19/08	FR-M40	236	237	43	7	41.6	50	83.2	TRUE
7/19/08	FR-M40	232	238	48	1	47.8	49	97.6	FALSE
7/19/08	FR-M40	233	238	48	1	47.8	49	97.6	FALSE
7/19/08	FR-M40	234	238	49	1	48.8	50	97.6	FALSE
7/19/08	FR-M40	235	238	48	2	47.6	50	95.2	FALSE
7/19/08	FR-M40	236	238	46	4	45.2	50	90.4	FALSE
7/19/08	FR-M40	232	238	37	13	34.4	50	68.8	TRUE
7/19/08	FR-M40	233	238	41	8	39.4	49	80.4	TRUE
7/19/08	FR-M40	234	238	42	8	40.4	50	80.8	TRUE
7/19/08	FR-M40	235	238	43	7	41.6	50	83.2	TRUE
7/19/08	FR-M40	236	238	47	3	46.4	50	92.8	TRUE
7/19/08	FR-M40	232	239	49	0	49	49	100.0	FALSE
7/19/08	FR-M40	233	239	48	1	47.8	49	97.6	FALSE
7/19/08	FR-M40	234	239	47	3	46.4	50	92.8	FALSE
7/19/08	FR-M40	235	239	48	2	47.6	50	95.2	FALSE
7/19/08	FR-M40	236	239	46	4	45.2	50	90.4	FALSE
7/19/08	FR-M40	232	239	43	7	41.6	50	83.2	TRUE
7/19/08	FR-M40	233	239	47	2	46.6	49	95.1	TRUE
7/19/08	FR-M40	234	239	42	8	40.4	50	80.8	TRUE
7/19/08	FR-M40	235	239	41	9	39.2	50	78.4	TRUE
7/19/08	FR-M40	236	239	41	9	39.2	50	78.4	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
7/26/08	C50	240	245	47	2	46.6	49	95.1	FALSE
7/26/08	C50	241	245	49	1	48.8	50	97.6	FALSE
7/26/08	C50	242	245	49	1	48.8	50	97.6	FALSE
7/26/08	C50	243	245	45	3	44.4	48	92.5	FALSE
7/26/08	C50	244	245	45	5	44	50	88.0	FALSE
7/26/08	C50	240	245	42	8	40.4	50	80.8	TRUE
7/26/08	C50	241	245	45	5	44	50	88.0	TRUE
7/26/08	C50	242	245	44	6	42.8	50	85.6	TRUE
7/26/08	C50	243	245	42	8	40.4	50	80.8	TRUE
7/26/08	C50	244	245	38	12	35.6	50	71.2	TRUE
7/26/08	C50	240	246	41	8	39.4	49	80.4	FALSE
7/26/08	C50	241	246	47	3	46.4	50	92.8	FALSE
7/26/08	C50	242	246	43	7	41.6	50	83.2	FALSE
7/26/08	C50	243	246	43	5	42	48	87.5	FALSE
7/26/08	C50	244	246	44	6	42.8	50	85.6	FALSE
7/26/08	C50	240	246	33	17	29.6	50	59.2	TRUE
7/26/08	C50	241	246	38	12	35.6	50	71.2	TRUE
7/26/08	C50	242	246	41	9	39.2	50	78.4	TRUE
7/26/08	C50	243	246	34	16	30.8	50	61.6	TRUE
7/26/08	C50	244	246	33	17	29.6	50	59.2	TRUE
7/26/08	C50	240	247	45	4	44.2	49	90.2	FALSE
7/26/08	C50	241	247	44	6	42.8	50	85.6	FALSE
7/26/08	C50	242	247	46	4	45.2	50	90.4	FALSE
7/26/08	C50	243	247	42	6	40.8	48	85.0	FALSE
7/26/08	C50	244	247	45	5	44	50	88.0	FALSE
7/26/08	C50	240	247	41	9	39.2	50	78.4	TRUE
7/26/08	C50	241	247	47	3	46.4	50	92.8	TRUE
7/26/08	C50	242	247	39	11	36.8	50	73.6	TRUE
7/26/08	C50	243	247	38	12	35.6	50	71.2	TRUE
7/26/08	C50	244	247	40	10	38	50	76.0	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
8/9/08	M_TAC	251	260	48	2	47.6	50	95.2	FALSE
8/9/08	M_TAC	252	260	46	3	45.4	49	92.7	FALSE
8/9/08	M_TAC	257	260	43	6	41.8	49	85.3	FALSE
8/9/08	M_TAC	258	260	44	6	42.8	50	85.6	FALSE
8/9/08	M_TAC	259	260	46	4	45.2	50	90.4	FALSE
8/9/08	M_TAC	251	260	37	12	34.6	49	70.6	TRUE
8/9/08	M_TAC	252	260	37	13	34.4	50	68.8	TRUE
8/9/08	M_TAC	257	260	36	14	33.2	50	66.4	TRUE
8/9/08	M_TAC	258	260	36	12	33.6	48	70.0	TRUE
8/9/08	M_TAC	259	260	43	7	41.6	50	83.2	TRUE
8/9/08	M_TAC	251	261	44	6	42.8	50	85.6	FALSE
8/9/08	M_TAC	252	261	47	2	46.6	49	95.1	FALSE
8/9/08	M_TAC	257	261	46	3	45.4	49	92.7	FALSE
8/9/08	M_TAC	258	261	45	5	44	50	88.0	FALSE
8/9/08	M_TAC	259	261	46	4	45.2	50	90.4	FALSE
8/9/08	M_TAC	251	261	37	12	34.6	49	70.6	TRUE
8/9/08	M_TAC	252	261	41	9	39.2	50	78.4	TRUE
8/9/08	M_TAC	257	261	39	11	36.8	50	73.6	TRUE
8/9/08	M_TAC	258	261	35	13	32.4	48	67.5	TRUE
8/9/08	M_TAC	259	261	43	7	41.6	50	83.2	TRUE
8/9/08	M_TAC	251	262	47	3	46.4	50	92.8	FALSE
8/9/08	M_TAC	252	262	45	4	44.2	49	90.2	FALSE
8/9/08	M_TAC	257	262	44	5	43	49	87.8	FALSE
8/9/08	M_TAC	258	262	48	2	47.6	50	95.2	FALSE
8/9/08	M_TAC	259	262	49	1	48.8	50	97.6	FALSE
8/9/08	M_TAC	251	262	33	16	29.8	49	60.8	TRUE
8/9/08	M_TAC	252	262	39	11	36.8	50	73.6	TRUE
8/9/08	M_TAC	257	262	40	10	38	50	76.0	TRUE
8/9/08	M_TAC	258	262	33	15	30	49	61.2	TRUE
8/9/08	M_TAC	259	262	39	11	36.8	50	73.6	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
8/16/08	4500	84	264	46	4	45.2	50	90.4	FALSE
8/16/08	4500	242	264	46	4	45.2	50	90.4	FALSE
8/16/08	4500	243	264	43	7	41.6	50	83.2	FALSE
8/16/08	4500	263	264	46	4	45.2	50	90.4	FALSE
8/16/08	4500	265	264	46	4	45.2	50	90.4	FALSE
8/16/08	4500	84	264	40	10	38	50	76.0	TRUE
8/16/08	4500	242	264	37	13	34.4	50	68.8	TRUE
8/16/08	4500	243	264	35	14	32.2	49	65.7	TRUE
8/16/08	4500	263	264	38	10	36	48	75.0	TRUE
8/16/08	4500	265	264	39	11	36.8	50	73.6	TRUE
8/16/08	4500	84	266	47	3	46.4	50	92.8	FALSE
8/16/08	4500	242	266	47	3	46.4	50	92.8	FALSE
8/16/08	4500	243	266	47	3	46.4	50	92.8	FALSE
8/16/08	4500	263	266	48	2	47.6	50	95.2	FALSE
8/16/08	4500	265	266	48	2	47.6	50	95.2	FALSE
8/16/08	4500	84	266	43	7	41.6	50	83.2	TRUE
8/16/08	4500	242	266	42	8	40.4	50	80.8	TRUE
8/16/08	4500	243	266	37	12	34.6	49	70.6	TRUE
8/16/08	4500	263	266	41	7	39.6	48	82.5	TRUE
8/16/08	4500	265	266	44	6	42.8	50	85.6	TRUE
8/16/08	4500	84	267	49	1	48.8	50	97.6	FALSE
8/16/08	4500	242	267	48	2	47.6	50	95.2	FALSE
8/16/08	4500	243	267	46	4	45.2	50	90.4	FALSE
8/16/08	4500	263	267	48	2	47.6	50	95.2	FALSE
8/16/08	4500	265	267	48	2	47.6	50	95.2	FALSE
8/16/08	4500	84	267	37	13	34.4	50	68.8	TRUE
8/16/08	4500	242	267	37	13	34.4	50	68.8	TRUE
8/16/08	4500	243	267	39	10	37	49	75.5	TRUE
8/16/08	4500	263	267	35	13	32.4	48	67.5	TRUE
8/16/08	4500	265	267	41	9	39.2	50	78.4	TRUE

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Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
11/1/08	Millenium	84	293	44	6	42.8	50	85.6	FALSE
11/1/08	Millenium	98	293	47	3	46.4	50	92.8	FALSE
11/1/08	Millenium	290	293	43	7	41.6	50	83.2	FALSE
11/1/08	Millenium	291	293	47	1	46.8	48	97.5	FALSE
11/1/08	Millenium	292	293	45	4	44.2	49	90.2	FALSE
11/1/08	Millenium	84	293	46	4	45.2	50	90.4	TRUE
11/1/08	Millenium	98	293	45	5	44	50	88.0	TRUE
11/1/08	Millenium	290	293	37	12	34.6	49	70.6	TRUE
11/1/08	Millenium	291	293	43	7	41.6	50	83.2	TRUE
11/1/08	Millenium	292	293	43	7	41.6	50	83.2	TRUE
11/1/08	Millenium	84	294	46	4	45.2	50	90.4	FALSE
11/1/08	Millenium	98	294	48	2	47.6	50	95.2	FALSE
11/1/08	Millenium	290	294	45	5	44	50	88.0	FALSE
11/1/08	Millenium	291	294	47	1	46.8	48	97.5	FALSE
11/1/08	Millenium	292	294	47	2	46.6	49	95.1	FALSE
11/1/08	Millenium	84	294	43	7	41.6	50	83.2	TRUE
11/1/08	Millenium	98	294	45	5	44	50	88.0	TRUE
11/1/08	Millenium	290	294	39	10	37	49	75.5	TRUE
11/1/08	Millenium	291	294	45	5	44	50	88.0	TRUE
11/1/08	Millenium	292	294	44	6	42.8	50	85.6	TRUE
11/1/08	Millenium	84	295	45	5	44	50	88.0	FALSE
11/1/08	Millenium	98	295	48	2	47.6	50	95.2	FALSE
11/1/08	Millenium	290	295	43	7	41.6	50	83.2	FALSE
11/1/08	Millenium	291	295	44	4	43.2	48	90.0	FALSE
11/1/08	Millenium	292	295	47	2	46.6	49	95.1	FALSE
11/1/08	Millenium	84	295	45	5	44	50	88.0	TRUE
11/1/08	Millenium	98	295	47	3	46.4	50	92.8	TRUE
11/1/08	Millenium	290	295	35	14	32.2	49	65.7	TRUE
11/1/08	Millenium	291	295	40	10	38	50	76.0	TRUE
11/1/08	Millenium	292	295	41	9	39.2	50	78.4	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
11/15/08	Optifit	84	296	49	1	48.8	50	97.6	FALSE
11/15/08	Optifit	98	296	50	0	50	50	100.0	FALSE
11/15/08	Optifit	297	296	48	2	47.6	50	95.2	FALSE
11/15/08	Optifit	298	296	45	4	44.2	49	90.2	FALSE
11/15/08	Optifit	299	296	49	1	48.8	50	97.6	FALSE
11/15/08	Optifit	84	296	37	13	34.4	50	68.8	TRUE
11/15/08	Optifit	98	296	42	8	40.4	50	80.8	TRUE
11/15/08	Optifit	297	296	36	14	33.2	50	66.4	TRUE
11/15/08	Optifit	298	296	39	10	37	49	75.5	TRUE
11/15/08	Optifit	299	296	46	4	45.2	50	90.4	TRUE
11/15/08	Optifit	84	300	47	3	46.4	50	92.8	FALSE
11/15/08	Optifit	98	300	50	0	50	50	100.0	FALSE
11/15/08	Optifit	297	300	49	1	48.8	50	97.6	FALSE
11/15/08	Optifit	298	300	47	2	46.6	49	95.1	FALSE
11/15/08	Optifit	299	300	50	0	50	50	100.0	FALSE
11/15/08	Optifit	84	300	42	8	40.4	50	80.8	TRUE
11/15/08	Optifit	98	300	44	6	42.8	50	85.6	TRUE
11/15/08	Optifit	297	300	33	17	29.6	50	59.2	TRUE
11/15/08	Optifit	298	300	39	10	37	49	75.5	TRUE
11/15/08	Optifit	299	300	49	1	48.8	50	97.6	TRUE
11/15/08	Optifit	84	301	44	6	42.8	50	85.6	FALSE
11/15/08	Optifit	98	301	49	1	48.8	50	97.6	FALSE
11/15/08	Optifit	297	301	47	3	46.4	50	92.8	FALSE
11/15/08	Optifit	298	301	48	1	47.8	49	97.6	FALSE
11/15/08	Optifit	299	301	49	1	48.8	50	97.6	FALSE
11/15/08	Optifit	84	301	39	11	36.8	50	73.6	TRUE
11/15/08	Optifit	98	301	38	12	35.6	50	71.2	TRUE
11/15/08	Optifit	297	301	39	11	36.8	50	73.6	TRUE
11/15/08	Optifit	298	301	42	7	40.6	49	82.9	TRUE
11/15/08	Optifit	299	301	42	8	40.4	50	80.8	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
11/22/08	Ultra Elite	84	296	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	297	296	47	3	46.4	50	92.8	FALSE
11/22/08	Ultra Elite	299	296	48	2	47.6	50	95.2	FALSE
11/22/08	Ultra Elite	302	296	45	3	44.4	48	92.5	FALSE
11/22/08	Ultra Elite	303	296	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	84	296	45	5	44	50	88.0	TRUE
11/22/08	Ultra Elite	297	296	43	6	41.8	49	85.3	TRUE
11/22/08	Ultra Elite	299	296	45	4	44.2	49	90.2	TRUE
11/22/08	Ultra Elite	302	296	45	5	44	50	88.0	TRUE
11/22/08	Ultra Elite	303	296	43	7	41.6	50	83.2	TRUE
11/22/08	Ultra Elite	84	304	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	297	304	47	3	46.4	50	92.8	FALSE
11/22/08	Ultra Elite	299	304	48	2	47.6	50	95.2	FALSE
11/22/08	Ultra Elite	302	304	46	2	45.6	48	95.0	FALSE
11/22/08	Ultra Elite	303	304	46	4	45.2	50	90.4	FALSE
11/22/08	Ultra Elite	84	304	44	6	42.8	50	85.6	TRUE
11/22/08	Ultra Elite	297	304	41	8	39.4	49	80.4	TRUE
11/22/08	Ultra Elite	299	304	41	8	39.4	49	80.4	TRUE
11/22/08	Ultra Elite	302	304	42	8	40.4	50	80.8	TRUE
11/22/08	Ultra Elite	303	304	42	8	40.4	50	80.8	TRUE
11/22/08	Ultra Elite	84	305	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	297	305	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	299	305	47	3	46.4	50	92.8	FALSE
11/22/08	Ultra Elite	302	305	45	3	44.4	48	92.5	FALSE
11/22/08	Ultra Elite	303	305	50	0	50	50	100.0	FALSE
11/22/08	Ultra Elite	84	305	42	8	40.4	50	80.8	TRUE
11/22/08	Ultra Elite	297	305	41	8	39.4	49	80.4	TRUE
11/22/08	Ultra Elite	299	305	42	7	40.6	49	82.9	TRUE
11/22/08	Ultra Elite	302	305	46	4	45.2	50	90.4	TRUE
11/22/08	Ultra Elite	303	305	38	12	35.6	50	71.2	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
12/6/08	M120	84	296	50	0	50	50	100.0	FALSE
12/6/08	M120	98	296	50	0	50	50	100.0	FALSE
12/6/08	M120	302	296	46	4	45.2	50	90.4	FALSE
12/6/08	M120	306	296	48	2	47.6	50	95.2	FALSE
12/6/08	M120	307	296	48	2	47.6	50	95.2	FALSE
12/6/08	M120	84	296	43	7	41.6	50	83.2	TRUE
12/6/08	M120	98	296	45	5	44	50	88.0	TRUE
12/6/08	M120	302	296	44	6	42.8	50	85.6	TRUE
12/6/08	M120	306	296	43	5	42	48	87.5	TRUE
12/6/08	M120	307	296	41	9	39.2	50	78.4	TRUE
12/6/08	M120	84	304	47	3	46.4	50	92.8	FALSE
12/6/08	M120	98	304	49	1	48.8	50	97.6	FALSE
12/6/08	M120	302	304	49	1	48.8	50	97.6	FALSE
12/6/08	M120	306	304	49	1	48.8	50	97.6	FALSE
12/6/08	M120	307	304	49	1	48.8	50	97.6	FALSE
12/6/08	M120	84	304	41	9	39.2	50	78.4	TRUE
12/6/08	M120	98	304	42	8	40.4	50	80.8	TRUE
12/6/08	M120	302	304	43	7	41.6	50	83.2	TRUE
12/6/08	M120	306	304	36	12	33.6	48	70.0	TRUE
12/6/08	M120	307	304	42	8	40.4	50	80.8	TRUE
12/6/08	M120	84	309	47	3	46.4	50	92.8	FALSE
12/6/08	M120	98	309	48	2	47.6	50	95.2	FALSE
12/6/08	M120	302	309	46	4	45.2	50	90.4	FALSE
12/6/08	M120	306	309	46	4	45.2	50	90.4	FALSE
12/6/08	M120	307	309	47	3	46.4	50	92.8	FALSE
12/6/08	M120	84	309	39	11	36.8	50	73.6	TRUE
12/6/08	M120	98	309	46	4	45.2	50	90.4	TRUE
12/6/08	M120	302	309	41	9	39.2	50	78.4	TRUE
12/6/08	M120	306	309	36	12	33.6	48	70.0	TRUE
12/6/08	M120	307	309	42	8	40.4	50	80.8	TRUE

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Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
1/31/09	5400	84	296	45	5	44	50	88.0	FALSE
1/31/09	5400	98	296	50	0	50	50	100.0	FALSE
1/31/09	5400	311	296	45	5	44	50	88.0	FALSE
1/31/09	5400	312	296	48	1	47.8	49	97.6	FALSE
1/31/09	5400	313	296	44	6	42.8	50	85.6	FALSE
1/31/09	5400	84	296	39	11	36.8	50	73.6	TRUE
1/31/09	5400	98	296	44	6	42.8	50	85.6	TRUE
1/31/09	5400	311	296	45	5	44	50	88.0	TRUE
1/31/09	5400	312	296	46	4	45.2	50	90.4	TRUE
1/31/09	5400	313	296	41	9	39.2	50	78.4	TRUE
1/31/09	5400	84	315	45	5	44	50	88.0	FALSE
1/31/09	5400	98	315	48	2	47.6	50	95.2	FALSE
1/31/09	5400	311	315	43	7	41.6	50	83.2	FALSE
1/31/09	5400	312	315	48	1	47.8	49	97.6	FALSE
1/31/09	5400	313	315	42	8	40.4	50	80.8	FALSE
1/31/09	5400	84	315	34	16	30.8	50	61.6	TRUE
1/31/09	5400	98	315	45	5	44	50	88.0	TRUE
1/31/09	5400	311	315	38	12	35.6	50	71.2	TRUE
1/31/09	5400	312	315	41	9	39.2	50	78.4	TRUE
1/31/09	5400	313	315	32	18	28.4	50	56.8	TRUE
1/31/09	5400	84	316	47	3	46.4	50	92.8	FALSE
1/31/09	5400	98	316	50	0	50	50	100.0	FALSE
1/31/09	5400	311	316	46	4	45.2	50	90.4	FALSE
1/31/09	5400	312	316	49	0	49	49	100.0	FALSE
1/31/09	5400	313	316	42	8	40.4	50	80.8	FALSE
1/31/09	5400	84	316	42	8	40.4	50	80.8	TRUE
1/31/09	5400	98	316	43	7	41.6	50	83.2	TRUE
1/31/09	5400	311	316	38	12	35.6	50	71.2	TRUE
1/31/09	5400	312	316	40	10	38	50	76.0	TRUE
1/31/09	5400	313	316	41	9	39.2	50	78.4	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
2/7/09	FR-7800B	84	314	48	2	47.6	50	95.2	FALSE
2/7/09	FR-7800B	98	314	50	0	50	50	100.0	FALSE
2/7/09	FR-7800B	318	314	48	2	47.6	50	95.2	FALSE
2/7/09	FR-7800B	319	314	41	6	39.8	47	84.7	FALSE
2/7/09	FR-7800B	320	314	40	9	38.2	49	78.0	FALSE
2/7/09	FR-7800B	84	314	45	5	44	50	88.0	TRUE
2/7/09	FR-7800B	98	314	44	6	42.8	50	85.6	TRUE
2/7/09	FR-7800B	318	314	40	10	38	50	76.0	TRUE
2/7/09	FR-7800B	319	314	32	15	29	47	61.7	TRUE
2/7/09	FR-7800B	320	314	34	16	30.8	50	61.6	TRUE
2/7/09	FR-7800B	84	317	47	3	46.4	50	92.8	FALSE
2/7/09	FR-7800B	98	317	50	0	50	50	100.0	FALSE
2/7/09	FR-7800B	318	317	47	3	46.4	50	92.8	FALSE
2/7/09	FR-7800B	319	317	41	6	39.8	47	84.7	FALSE
2/7/09	FR-7800B	320	317	42	7	40.6	49	82.9	FALSE
2/7/09	FR-7800B	84	317	33	17	29.6	50	59.2	TRUE
2/7/09	FR-7800B	98	317	38	12	35.6	50	71.2	TRUE
2/7/09	FR-7800B	318	317	41	9	39.2	50	78.4	TRUE
2/7/09	FR-7800B	319	317	34	13	31.4	47	66.8	TRUE
2/7/09	FR-7800B	320	317	33	17	29.6	50	59.2	TRUE
2/7/09	FR-7800B	84	321	48	2	47.6	50	95.2	FALSE
2/7/09	FR-7800B	98	321	50	0	50	50	100.0	FALSE
2/7/09	FR-7800B	318	321	45	5	44	50	88.0	FALSE
2/7/09	FR-7800B	319	321	43	4	42.2	47	89.8	FALSE
2/7/09	FR-7800B	320	321	42	7	40.6	49	82.9	FALSE
2/7/09	FR-7800B	84	321	37	13	34.4	50	68.8	TRUE
2/7/09	FR-7800B	98	321	44	6	42.8	50	85.6	TRUE
2/7/09	FR-7800B	318	321	43	7	41.6	50	83.2	TRUE
2/7/09	FR-7800B	319	321	32	15	29	47	61.7	TRUE
2/7/09	FR-7800B	320	321	32	18	28.4	50	56.8	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
3/7/09	M110	84	296	48	2	47.6	50	95.2	FALSE
3/7/09	M110	98	296	49	1	48.8	50	97.6	FALSE
3/7/09	M110	327	296	48	2	47.6	50	95.2	FALSE
3/7/09	M110	328	296	46	4	45.2	50	90.4	FALSE
3/7/09	M110	329	296	48	2	47.6	50	95.2	FALSE
3/7/09	M110	84	296	48	2	47.6	50	95.2	TRUE
3/7/09	M110	98	296	48	2	47.6	50	95.2	TRUE
3/7/09	M110	327	296	39	9	37.2	48	77.5	TRUE
3/7/09	M110	328	296	40	10	38	50	76.0	TRUE
3/7/09	M110	329	296	46	4	45.2	50	90.4	TRUE
3/7/09	M110	84	325	50	0	50	50	100.0	FALSE
3/7/09	M110	98	325	50	0	50	50	100.0	FALSE
3/7/09	M110	327	325	48	2	47.6	50	95.2	FALSE
3/7/09	M110	328	325	42	8	40.4	50	80.8	FALSE
3/7/09	M110	329	325	47	3	46.4	50	92.8	FALSE
3/7/09	M110	84	325	47	3	46.4	50	92.8	TRUE
3/7/09	M110	98	325	42	8	40.4	50	80.8	TRUE
3/7/09	M110	327	325	40	8	38.4	48	80.0	TRUE
3/7/09	M110	328	325	37	13	34.4	50	68.8	TRUE
3/7/09	M110	329	325	42	8	40.4	50	80.8	TRUE
3/7/09	M110	84	326	50	0	50	50	100.0	FALSE
3/7/09	M110	98	326	49	1	48.8	50	97.6	FALSE
3/7/09	M110	327	326	49	1	48.8	50	97.6	FALSE
3/7/09	M110	328	326	46	4	45.2	50	90.4	FALSE
3/7/09	M110	329	326	50	0	50	50	100.0	FALSE
3/7/09	M110	84	326	43	7	41.6	50	83.2	TRUE
3/7/09	M110	98	326	46	4	45.2	50	90.4	TRUE
3/7/09	M110	327	326	34	14	31.2	48	65.0	TRUE
3/7/09	M110	328	326	38	12	35.6	50	71.2	TRUE
3/7/09	M110	329	326	41	9	39.2	50	78.4	TRUE

Date	Mask	S_#	L_#	# Right	# Wrong	Score	# Spoken Correct	% Score	Mask Worn?
3/28/09	FM12	84	331	49	1	48.8	50	97.6	FALSE
3/28/09	FM12	98	331	50	0	50	50	100.0	FALSE
3/28/09	FM12	330	331	47	3	46.4	50	92.8	FALSE
3/28/09	FM12	332	331	45	5	44	50	88.0	FALSE
3/28/09	FM12	333	331	46	3	45.4	49	92.7	FALSE
3/28/09	FM12	84	331	41	9	39.2	50	78.4	TRUE
3/28/09	FM12	98	331	40	10	38	50	76.0	TRUE
3/28/09	FM12	330	331	41	9	39.2	50	78.4	TRUE
3/28/09	FM12	332	331	38	12	35.6	50	71.2	TRUE
3/28/09	FM12	333	331	40	10	38	50	76.0	TRUE
3/28/09	FM12	84	334	48	2	47.6	50	95.2	FALSE
3/28/09	FM12	98	334	50	0	50	50	100.0	FALSE
3/28/09	FM12	330	334	50	0	50	50	100.0	FALSE
3/28/09	FM12	332	334	49	1	48.8	50	97.6	FALSE
3/28/09	FM12	333	334	48	1	47.8	49	97.6	FALSE
3/28/09	FM12	84	334	46	4	45.2	50	90.4	TRUE
3/28/09	FM12	98	334	46	4	45.2	50	90.4	TRUE
3/28/09	FM12	330	334	42	8	40.4	50	80.8	TRUE
3/28/09	FM12	332	334	41	9	39.2	50	78.4	TRUE
3/28/09	FM12	333	334	40	10	38	50	76.0	TRUE
3/28/09	FM12	84	335	50	0	50	50	100.0	FALSE
3/28/09	FM12	98	335	50	0	50	50	100.0	FALSE
3/28/09	FM12	330	335	48	2	47.6	50	95.2	FALSE
3/28/09	FM12	332	335	49	1	48.8	50	97.6	FALSE
3/28/09	FM12	333	335	48	1	47.8	49	97.6	FALSE
3/28/09	FM12	84	335	45	5	44	50	88.0	TRUE
3/28/09	FM12	98	335	45	5	44	50	88.0	TRUE
3/28/09	FM12	330	335	44	6	42.8	50	85.6	TRUE
3/28/09	FM12	332	335	39	11	36.8	50	73.6	TRUE
3/28/09	FM12	333	335	44	6	42.8	50	85.6	TRUE

APPENDIX 44