

Impact of Combined Respirator, Hood, and Helmet Wear on User Comfort

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ABSTRACT

Subjective estimates of comfort were measured on subjects under simulated work conditions to assess the combined impacts of mask, hood, and helmet wear on comfort. Eight volunteers completed 2-hour test trials involving 4 combinations of mask, hood, and helmet wear. Testing included use of an air-purifying respirator with a butyl rubber hood (M40) or a hooded jacket ensemble (M40 JH) with and without a ballistic protective helmet (PASGT). Volunteers provided subjective responses concerning comfort of the individual protective items as well as complete protective ensembles during and after each test period. Subjective feedback indicated that test participants experienced various amounts of discomfort based on the particular respirator, hood, or helmet combination that was worn. On average, the lowest overall comfort scores were observed for the M40 JH PASGT condition. The M40 condition received the highest overall comfort score. Regardless of the statistical differences among conditions, overall comfort fell between the limited range of “fairly uncomfortable” and “fairly comfortable” rankings. When worn, the helmet was a primary source of user discomfort relative to the other comfort parameters that were assessed. The results of this study provide meaningful data for improving mask, hood, and helmet compatibility as well as individual component designs. Additional work that quantifies user comfort and acceptance on various levels of respiratory and head protection are needed to insure that comfort factors do not constrain user work performance.

Keywords: comfort, respirator, protective hood, helmet

INTRODUCTION

Advancing the design and performance of respiratory protective devices requires attention to multiple disciplines such as material science, threat analysis, filtering technology, and human factors. Usually, objective measures of a respirator's performance determine the effectiveness of the system to protect individuals from chemical and biological hazards. However, objective analysis of any respirator does not take into account subjective impressions that result from wearing the device. Indeed, the interplay of subjective impressions of respirator comfort and physiologic factors may determine whether a worker will actually comply with proper respirator use. In fact, subjective comfort assessment of the characteristics of a mask appears to be the primary factor in determining mask acceptance (Meyer *et al.*, 1997).

Several investigations have indicated that a major problem with the effective use of respirators is user discomfort or subjective strain (Caretti, 1997; Caretti *et al.*, 1995; Johnson *et al.*, 1997; Nielsen *et al.*, 1987; Wilson *et al.*, 1989; Zimmerman *et al.*, 1991). Even so, few studies have focused on subjective evaluations of respirator comfort. Recently, an evaluation was undertaken to obtain subjective estimates

of comfort of negative pressure respirators and respirator components under simulated work conditions (Carette, 2000). The most prominent findings of this study were that a rubber headharness should not be considered as a feasible design for any respirator, that nose cup designs of the tested full-facepiece respirators were not comfortable, and that subjects felt that mask discomfort only slightly impacted their working abilities. At a minimum, these findings identified deficiencies of current respirator designs as far as user comfort is concerned. However, questions concerning the combined effects of other personal protective equipment (PPE) worn with respirators on user comfort and acceptance have not been addressed. Recognizing that the first responder community is the first line of domestic defense for potential weapons of mass destruction (WMD) incidents, the potential for simultaneous wear of respirators, protective suits, and protective headgear is high. For example, for a single WMD incident response, fire personnel may be asked to rescue downed victims, emergency medical personnel to treat contaminated patients, law enforcement personnel to perform tactical operations, and ordnance-disposal personnel to deal with improvised explosive devices. No single type of PPE will provide protection for all of the potential hazards associated with these tasks. Therefore, the purpose of this investigation was to expand upon previous work to gain additional information about respirator comfort and to assess the combined impacts of respirator, hood, and helmet wear on comfort.

MATERIALS AND METHODS

Volunteer subjects

Eight military personnel (7 males and 1 female) volunteered to participate in testing. Subjects were recruited from the U.S. Army's 1st Brigade Combat Team, 1st Infantry Division at Ft. Riley, KS and were healthy and free of coronary risk factors, as determined by completion of a medical history questionnaire. All volunteers reported having previous experience wearing the M40A1 respirator. Subject demographics were as follows (mean $\pm$ SD): age, 24 ± 5 years; weight, 80.3 ± 12.5 Kg; height, 178.9 ± 8.6 cm; years of military service, 5 ± 3 years. Subjects reported to the lab one day prior to commencement of testing to complete a volunteer agreement affidavit, to receive instructions concerning a subjective questionnaire, and to practice specific tasks selected for this study. A written statement of voluntary consent was obtained from each volunteer before testing began. Subjects were instructed to get adequate rest the night before each test day, to eat a light breakfast or lunch, and to drink plenty of fluids excluding caffeine and alcohol before reporting for their scheduled test sessions.

Experimental conditions

Data collection occurred over four consecutive days for each subject. Upon arrival to the lab, subjects were required to drink 300 ml of water to safeguard against becoming inadequately hydrated during testing. Water was also available *ad libitum* to subjects during periods of respirator wear. Volunteers were encouraged to drink during rest periods scheduled at various times throughout each test and at the completion of each trial.

Respirator wear tests were completed over a two-hour period of continuous wear with and without chemical protective hoods and ballistic protective helmets. The experimental conditions selected for this study are presented in Table I. The M40A1 respirator, a full-facepiece air-purifying respirator, was worn for all test conditions. The M40A1 uses a single filter element that can be mounted on either side of the facepiece depending on the dominant handedness of the wearer and has a pass-through drink tube that permits hydration during wear. A butyl rubber hood designed to fit the respirator was used for all trials identified in Table I as "Butyl rubber hood" for the chemical/biological (CB) protective hood type. The second hood type evaluated in this investigation was the integral hood of a waist-length CB protective coat. This hood had a slide fastener front concealed by a flap with hook and loop closure and an extendible elasticized drawcord hem that cinched the hood around the outer edges of the respirator facepiece. The ballistic protective helmet worn with the respirator and hood items was the U.S. Army Personnel Armor System Ground Troops (PASGT) helmet. Each test participant wore his or her own

individually issued PASGT helmet for each helmet condition test of this study. All of the helmets weighed between 1.5 kg and 1.8 kg depending upon size.

Table I. Experimental Conditions

Concept Designator	Mask	CB Protective Hood	Protective Helmet
M40	M40A1	Butyl rubber hood	None
M40 JH	M40A1	CB jacket w/hood	None
M40 PASGT	M40A1	Butyl rubber hood	PASGT
M40 JH PASGT	M40A1	CB jacket w/hood	PASGT

Experimental procedures and test measurements

Prior to the first test period, subjects were briefed on how to answer the questions contained in a 50-item subjective comfort assessment questionnaire. The principal investigator verified the understanding of the wording of each question after a full explanation was given. Subjects also received training for the techniques needed for each of the work tasks selected for this study. Subjects were given as much time as they needed for practicing the methods required for completing each task.

Table II lists the details of the tasks selected for this investigation. The selected tasks represented light to moderate intensity physical workloads. Subjects walked on a treadmill at an intensity of approximately 75% of age-predicted ($220 - \text{age in years}$) (Karvonen *et al.*, 1957) maximal heart rate ($HR_{\max}$). Treadmill speeds and grades were adjusted for each individual to reach this level of intensity. However, treadmill speeds remained at a walking pace at all times. The large assembly task involved construction and dismantling of a metal storage rack (approximately 0.9 m wide by 2.1 m high by 0.6 m deep) that had five shelves. This task required subjects to follow assembly instructions, to lift and position support brackets and shelves, and use hand tools (e.g., screwdrivers and wrenches). The small assembly task involved assembly of an M40A1 respirator, which required subjects to perform the following procedures: 1. Remove the respirator from its packaging; 2. Attach a protective second skin, eyepiece outserts, and quick doff butyl hood to the mask's facepiece; 3. Properly position corrective vision inserts within the mask's eyepieces; 4. Switch the filter canister mount from one side of the respirator to the other side; and 5. Remove the air-purifying canister from its vacuum-sealed container and attach it to the respirator. Subjects completed the large assembly task in pairs, but the small assembly task was done individually.

Table II. Physical Work Tasks Completed by Test Volunteers

Task description	Task duration (min)	Intended work intensity category
Treadmill walk at 75% age predicted $HR_{\max}$	10	Moderate
Large assembly task: assemble/disassemble storage shelving w/5 shelves	20	Moderate
Small assembly task: assembly of an M40A1 respirator	20	Light
Face-to-face communications	20	Light
Rifle firing simulation	20	Light
Mask Fit test	10	Light

The rifle simulation task was accomplished with the use of the BEAMHIT™ Laser Marksmanship Training System (BEAMHIT LLC, Columbia, MD). For this test, participants used the charging handle and trigger of a modified rifle to activate a laser system attached to the end of the firing barrel. Each trigger pull of the rifle emitted a laser pulse that simulated the discharge of a single round of ammunition. For the rifle simulation task subjects fired 10 shots in a prone position at a 1.27 cm diameter center "bulls-eye" of

a target positioned 25 meters away. BEAMHIT™ software recorded each shot's point of impact on the target.

Subjects completed procedures of the Modified Rhyme Test (MRT) for the communications task. Subject pairs were seated opposite each other at a distance of 3 m. The listener was positioned before a computer and monitor that were used for displaying MRT test word choices as well as recording subject responses. Each stimulus word was presented using the carrier phrase "The word is ____." Listeners chose the word that was perceived to be spoken from a list of six response words presented on the computer monitor by clicking on the word with the computer's mouse. A listener then provided a thumbs-up hand signal to the speaker to cue him or her to say the next word. The speaker presented a total of 50 stimulus words for each test. Task conditions were randomly administered to subject pairs.

Test respirators were sized and fitted by trained U.S. Army civilian personnel for each subject before testing began. Briefly, sizing procedures included checking the positioning of the edge of the facepiece on a subject's forehead, cheeks, and chin, ensuring that an individual's hairline did not fall beneath the peripheral seal, checking the positioning of the respirator's nosecup on the bridge of the nose, and the location of a subject's eyes in relation to the mask's eye lenses. Each participant donned his or her assigned respirator prior to commencement of each test session. All conditions were randomly assigned. A subject's respirator fit was assessed before the start of each trial using the M41 Protection Assessment Test System (TSI, Inc., Shoreview, MN). A fit factor measurement, which is a measure of the respirator leakage during a given period of time, was obtained as volunteers completed the following 10-exercise routine; normal breathing, deep breathing, side-to-side head movement, up and down head movement, talking, sighting a rifle stock, bending at the waist and turning the head side-to-side, reaching for the floor and ceiling, rotation of the jaw, and another normal breathing exercise. Each respirator fit test lasted about 10 minutes. Respirator fit testing was repeated for all instances when an overall fit factor score was less than 1667 after the respirator and helmet (if worn) were removed and then re-donned. A fit factor of 1667 was chosen as the minimal acceptable fit based on guidelines provided by the test sponsor. This level of fit is slightly higher than fit factor requirements for comparable commercial air-purifying respirators (i.e., 1000). Respirator fit was also measured at the end of each two-hour wear trial as one of the test activities. The purpose of the respirator fit test was to insure that respirator harnesses were tightened sufficiently to provide an acceptable seal of the respirator to the face and to prevent subjects from loosening straps to alleviate any discomfort that occurred during testing.

The following objective and subjective parameters were monitored during each test session: room climatic conditions, subject heart rates, and ratings of perceived exertion (RPE), comfort, and thermal sensation. Heart rate was monitored using a Polar Vantage XL® heart rate monitor consisting of transmitter and wristwatch monitor (Polar CIC, Inc., Port Washington, NY). Portable monitors (RSS-214 WibGeT WBGT monitor; Imaging & Sensing Technology, Horseheads, NY) were used to record wet bulb globe temperatures (WBGT) in the separate rooms used in the laboratory for the different work tasks. Subjective RPE, comfort and thermal sensation scores were obtained using specific subjective scales following initial donning of the test respirator and at 10-minute intervals up to the end of each session (Abadie and Carroll, 1993; Borg, 1982; Nielsen *et al.*, 1987). Subjects rated comfort of the following individual respirator components using the breathing apparatus comfort (BAC) scale (Figure 1; Abadie and Carroll, 1993): facepiece, nosecup, headharness, and filter breathing resistance. Likewise, the BAC scale was used for ratings of hood comfort, helmet comfort, and overall comfort of the total respirator, hood, and helmet configuration.

Upon completion of each test session, an estimate of the acceptable duration of wear without significant discomfort was obtained by asking each subject the question "How much longer could you keep this mask on before it became too difficult to wear?" Subjects were also asked to answer the question "If you could change one design feature of the mask to help you perform better, what would that one feature be?" Once answers to these questions were provided, subjects doffed the mask and/or helmet and subjective assessments of respirator, hood, and helmet comfort were obtained through administration of the 50-item subjective comfort assessment questionnaire. Finally, subjects were given an opportunity to provide general comments concerning wear experience for each of the test conditions.

Analysis of variance was used to test for statistical significance of objective and subjective data within and between experimental conditions. Scheffe's *post-hoc* analysis was computed to determine

significant differences between group means if a significant *F* statistic was initially obtained. Relationships between subjective responses and respirator wear conditions were also assessed using Pearson's method of least squares for simple and multiple regression analyses. Statistical computations were performed using SPSS 10.0 for Windows. Statistical significance was accepted at the $p < 0.05$ level.

Breathing Apparatus Comfort Scale (BACS)		Scale of Thermal Sensation	
10	Very, very comfortable	0	Very cold
8	Very comfortable	1	Cold
6	Fairly comfortable	2	Cool
4	Fairly uncomfortable	3	Slightly cool
2	Very uncomfortable	4	Neutral
0	Very, very uncomfortable	5	Slightly warm
		6	Warm
		7	Hot
		8	Very hot

Figure 1. The breathing apparatus comfort scale (BACS) and the scale of thermal sensation.

RESULTS

Independent of experimental condition for the respirator, hood, and helmet combinations, average laboratory WBGT conditions ranged from 19.1 ± 0.6 °C to 20.6 ± 1.1 °C for the four rooms that were utilized to administer the work tasks in this study. Room WBGT values averaged 19.8 ± 1.0 °C (approximately 68°F) for all test sessions.

Respirator fit test results

Table III lists both pre-test and post-test fit factors for each experimental condition. No statistical differences in pre-test and post-test respirator fit factors were found within or between any of the mask/hood/helmet conditions. However, fit factors lower than 1667 were recorded for one subject after the M40 PASGT trial. Likewise, fit factors below 1667 were found for two individuals following testing for the M40 JH PASGT condition. These fit factor findings show that respirators were donned with a proper seal at the start of all test trials and that the majority of mask fits were maintained after two hours of testing.

Heart rate responses, perceived exertion and subjective scales

No significant interactions of experimental condition and work task were observed for heart rate, RPE or any of the subjective comfort and thermal sensation parameters. Independent of experimental condition, average heart rate (134.3 ± 15.8) and RPE score (12.3 ± 1.8) were significantly higher during treadmill walking than for all other work tasks. Average subjective RPE scores were also significantly higher for the large assembly task (9.3 ± 2.1) compared to the small assembly (7.9 ± 1.6), rifle simulation (7.9 ± 2.1), and communications (7.3 ± 1.4) tasks, but no differences in heart rate responses were observed between these tasks. These findings suggest that subjects perceived expending more energy for the large assembly task even though physical workload was not statistically different than for all other tasks except walking.

Table III. Mask Fit Factor Scores for Each Experimental Condition before and after 2-Hours of Testing (A Minimum Score of 1667 Was Required for Fit Tests Completed before Comfort Test Trials Commenced)

Concept	Time	Minimum	Maximum	Geometric (n=8)	Mean
M40	Pre	6520	38900	13269	
	Post	7060	14800	10462	
M40 JH	Pre	4370	33700	10574	
	Post	6250	44900	19920	
M40 PASGT	Pre	2580	53100	9506	
	Post	562	40600	9491	
M40 JH PASGT	Pre	1870	44700	7885	
	Post	601	49300	8421	

Subjective comfort ratings for the different respirator and helmet parameters resulted in varying differences between work tasks independent of experimental condition. Even though statistical differences were found between pre-test comfort ratings and the majority of the different tasks for respirator facepiece, nose cup, headharness, hood, and breathing comfort, all average BAC scale values fell between “fairly comfortable” and “fairly uncomfortable” rankings. This was also true for the rankings for helmet comfort and overall comfort.

Since no significant interactions of experimental condition and work task were observed for any of the test parameters, a separate ANOVA was performed to assess the effects of experimental condition on heart rate and subjective responses independent of work task. This analysis showed no significant effect of experimental condition on heart rate responses. Table IV presents average subjective RPE, thermal sensation, and comfort responses for each test condition independent of time. Average subjective ratings of perceived exertion showed that subjects felt that task performance was most strenuous during testing under the M40 JH PASGT conditions, which resulted in an average RPE rating that corresponded to “very light” exertion. However, considering that average RPE scores ranged between “very, very light” and “very light” for all experimental conditions, it appears that subjects did not perceive that any one test configuration had a profound impact on work effort during testing.

Average subjective ratings of thermal sensation of the face ranged from “neutral” to “slightly warm” and were similar for all conditions. Despite various statistical differences between conditions, average thermal sensation scores for the head and whole body also fell within the “neutral” to “slightly warm” range for all conditions. Subjects reported that the head felt warmest for the M40 PASGT condition, whereas whole body thermal sensation scores indicated that subjects were warmest for both conditions involving the hooded CB jacket.

Respirator facepiece comfort responses did not differ between conditions and averaged between scores of “fairly comfortable” and “fairly uncomfortable” on the BAC scale. Nose cup comfort scores differed statistically between M40 and M40 JH PASGT conditions, but corresponded to scores of “fairly comfortable” and “fairly uncomfortable” for all conditions on the BAC scale. Subjects reported that respirator headharness discomfort was most pronounced for both JH hood conditions, which differed significantly from the M40 condition. However, on average, headharness discomfort was rated between “fairly uncomfortable” and “fairly comfortable” for all conditions.

All hood comfort scores averaged above 5.3, indicating that subjects did not perceive any noticeable discomfort due to the type of hood that was worn with the different respirator and helmet combinations. However, hood comfort scores were significantly lower for all JH hood wear trials compared to the M40 respirator condition. The frequency of uncomfortable ratings (i.e., rankings of 4 and

below on the BAC scale) for the hood was highest for the M40 JH (36%) conditions. Helmet comfort score averages corresponded to a “fairly uncomfortable” rating on the BAC scale for both helmet wear conditions.

Table IV. Average Subjective Responses for Each Experimental Condition Independent of Work Tasks [Refer to Figure 1 for Thermal Sensation (TS) and Comfort Scales]

Subjective Parameter	Test Condition			
	M40 (N=76)	M40 JH (N=74)	M40 PASGT (N=102)	M40 JH PASGT (N=103)
RPE	7.5 ± 1.9	7.5 ± 2.1	8.2 ± 2.2	9.0 ± 2.6 ^{A,B}
TS face	4.4 ± 0.9	4.8 ± 1.0	4.8 ± 0.9	4.8 ± 1.0
TS head	4.4 ± 1.1	4.7 ± 1.1	4.9 ± 1.1 ^A	4.7 ± 1.0
TS body	3.7 ± 0.9	4.6 ± 1.1 ^A	4.0 ± 1.2 ^B	4.3 ± 1.1 ^A
Facepiece comfort	5.3 ± 1.2	4.7 ± 1.7	5.3 ± 1.2	5.0 ± 1.1
Nosecup comfort	5.9 ± 1.6	5.6 ± 1.7	5.5 ± 1.2	5.1 ± 1.1 ^A
Head-harness comfort	5.6 ± 1.2	4.8 ± 1.5 ^A	5.0 ± 1.6	4.7 ± 1.5 ^A
Breathing comfort	5.5 ± 0.9	5.0 ± 1.1	5.5 ± 1.4	5.0 ± 1.3 ^C
Hood comfort	6.5 ± 1.8	5.4 ± 1.4 ^A	6.2 ± 1.9	5.3 ± 1.6 ^{A,C}
Helmet comfort			4.1 ± 1.9	3.7 ± 2.0
Overall comfort	5.7 ± 1.1	5.1 ± 1.3	5.3 ± 1.5	4.8 ± 1.2 ^A

^A = $P < 0.05$ vs. M40 condition

^B = $P < 0.05$ vs. M40 JH condition

^C = $P < 0.05$ vs. M40 PASGT condition

On average, the lowest overall comfort scores were observed for the M40 JH PASGT condition. The M40 condition received the highest overall comfort score, which was significantly different from the M40 JH PASGT condition. Again, regardless of the statistical differences between conditions, average overall comfort fell between the limited range of “fairly uncomfortable” and “fairly comfortable” rankings.

Relationship between overall comfort and other subjective comfort parameters

Regression analyses performed to quantify the interactions of facepiece, nose cup, headharness, breathing, hood, and helmet comfort with overall comfort scores produced significant correlations dependent upon experimental condition independent of time. Overall comfort scores correlated significantly ($p < 0.01$) with facepiece, nose cup, headharness, breathing, hood, and helmet comfort for all test conditions (Table V). The correlation between hood comfort and overall comfort for the M40 JH PASGT condition was statistically significant at the $p < 0.05$ level. However, this relationship accounted for a very small percentage (6%) of the variability in overall comfort scores.

For the M40 condition, both facepiece comfort and headharness comfort explained the highest percentage (53%) of the variability (R^2) in overall comfort scores. When the CB jacket with hood was substituted for the butyl hood (M40 JH), headharness comfort had the strongest linear relationship with overall subject comfort. Helmet comfort accounted for 72% of the variability of overall comfort for the M40 PASGT condition and 79% of the variability of overall comfort for the M40 JH PASGT condition. Independent of experimental condition, overall comfort correlated most strongly with helmet comfort ($R^2 = 0.74$).

Table V. Correlations of Facepiece, Nosecup, Headharness, Breathing, Hood, and Helmet Comfort with Overall Comfort Scores (All Correlations Were Significant at the $p < 0.01$ Level Unless Otherwise Noted)

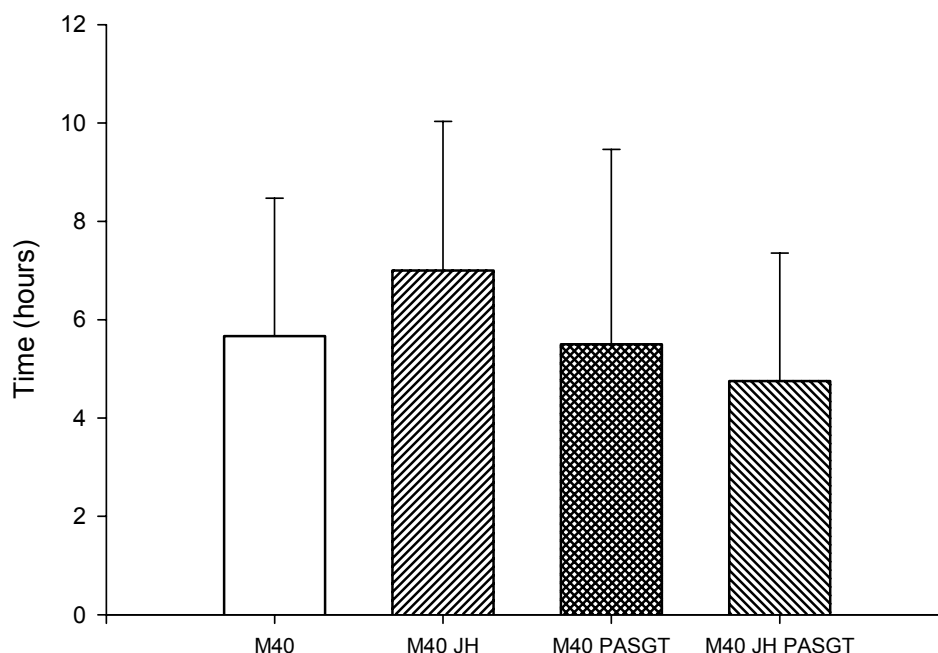
Condition	Facepiece	Nosecup	Head-harness	Breathing	Hood	Helmet
M40	0.53	0.16	0.53	0.49	0.30	
M40 JH	0.67	0.27	0.76	0.71	0.18	
M40 PASGT	0.58	0.22	0.62	0.59	0.62	0.72
M40 JH PASGT	0.67	0.38	0.42	0.62	0.06 ^A	0.79
All Conditions	0.59	0.25	0.59	0.61	0.31	0.74

R^2 = coefficient of determination

^A Correlation significant at the 0.05 level (2-tailed)

Estimated wear duration and recommended design changes

The amount of additional time that subjects projected to be acceptable for wearing each respirator, hood, and helmet combination without significant discomfort was statistically similar for all respirator conditions. On average, the shortest acceptable additional wear time was reported for the M40 JH PASGT helmet wear condition (4.8 ± 2.6 hours) and the longest acceptable duration of wear was projected for the M40 JH condition (7.0 ± 3.0 hours) (Figure 2).

**Figure 2. Average ($\pm$ SD) additional wear times projected to be acceptable for each test condition.**

The most frequent answers provided to the questions concerning recommended design changes of the respirator, hood, and helmet to help alleviate discomfort and enhance performance are presented in Table VI. These results show that facepiece material design was identified as the main area of mask

design improvement for two of the four experimental conditions. Recommended design changes specific to the protective hoods worn in testing were categorized as improvements in hood material and reduction of hood bulkiness. Suggestions for hood material improvements were specific to the butyl rubber hood conditions and subject comments concerning the hood frequently implied that the hood should be made of a “breathable” material to permit heat dissipation. Suggestions to reduce the bulkiness of the hood were specific to the hooded CB jacket conditions. Specifically, the majority of subjects indicated that the hood of the jacket tended to bunch up in the area of the neck. The most frequent recommendations for improved helmet designs were reduced weight and bulk for both PASGT wear trials.

Table IV. Main Mask, Hood, and Helmet Design Changes Recommended by Test Volunteers

Condition	Mask Changes	Hood Changes	Helmet Changes
M40	Facepiece material (50%) ^A	Material (50%)	
M40 JH	Drink tube (66.7%)	Bulk (66.7%)	
M40 PASGT	Headharness (25%)	Material (50%)	Weight/bulk (62.5%)
M40 JH PASGT	Facepiece material (37.5%)	Bulk (50%)	Weight/bulk (50%)

^A Percentage represents response frequency.

Post-test subjective questionnaire responses

Results from the 50-item post-test questionnaire were analyzed as frequency responses to each questionnaire item independent of time. Findings for only select questionnaire items will be addressed. Responses to questions quantifying the amount of difficulty that subjects experienced with keeping the respirator or helmet in place during testing indicated that subjects had no problems with the stability of either item. Independent of respirator or helmet condition, subjects generally indicated that a respirator was less stable than a helmet.

Four post-test questionnaire items were worded to assess the thermal impact of the respirator facepiece. Specifically, subjects were asked to rate facial sweating and moisture in the facepiece as well as the thermal conditions of the facepiece. For the question “Was your face sweating inside the mask?” the greatest percentage of responses was “slightly” or “moderately” for all conditions. When asked to rate the amount of moisture that accumulated in the respirator facepiece from sweating, most subjects perceived that facial sweating caused the respirator to be “slightly wet” or “wet.” Responses to the question concerning the thermal conditions inside the respirator facepiece indicated that subjects’ faces felt no worse than “warm” for all experimental conditions with the exception of the M40 JH PASGT condition which resulted in a rating of “hot” from 13% of respondents. The same percentage of respondents indicated that the thermal conditions of the facepiece were “poor” for the M40 PASGT condition.

In addition to rating thermal conditions of the respirator, subjects were asked to rate perceptions of the thermal status of the different hoods worn in combination with the PASGT helmet. As was observed for a respirator, the majority of responses were “slightly” or “moderately” for all conditions when subjects were asked about sweating inside of the hood. Responses for the two no-helmet conditions showed that 83% of respondents rated head sweating as “slightly” for the M40 JH condition compared to a 40% “slightly” sweating frequency response for the M40 condition. The level of acceptance of the thermal conditions of the hood varied by experimental condition. Without a helmet, all subjects rated the thermal conditions of the hooded CB jacket as “acceptable” or better, whereas only 60% of subjects rated the thermal conditions of the butyl hood as “acceptable” without a helmet. The thermal conditions of the hooded jacket also received favorable ratings (i.e., “acceptable” or better) from 88% of respondents for the M40 JH PASGT condition compared to 63% for the M40 PASGT condition.

Responses to the question concerning the level of neck discomfort due to the weight and bulk of the respirator, hood, and/or helmet indicated that the least amount of discomfort was experienced for both no-helmet conditions. The M40 JH PASGT condition appeared to cause substantial neck discomfort based on a frequency response of 76% for ratings of a “somewhat high” to “high” level of neck discomfort

for this condition. When asked to rate how heavy and bulky the respirator, hood, and helmet felt, subject responses spanned the entire range from “very light” to “very heavy.” Even without a helmet, 40% of M40 respondents and 67% of M40 JH respondents rated the weight and bulk of the respirator and hood as being “slightly heavy.” However, no “heavy” or “very heavy” ratings were reported for these no-helmet conditions. About one quarter of respondents rated the M40 PASGT condition as “heavy” or “very heavy” and 38% of them rated the weight and bulk of the M40 JH PASGT the same.

The final three items of the post-test subjective questionnaire asked subjects to identify the primary reasons they would or would not want to wear each respirator configuration and to rate how comfortable they felt based on the different constraints of the respirator, hood, and helmet condition that they wore during each test session. All respondents indicated that the only plausible reason for wearing the different test configurations would be for protection. When asked to select a main reason that they would not want to wear the different test configurations, subject responses varied by experimental condition. The primary reason identified for the M40 condition was the impact on breathing caused by the respirator. For the JH condition, subjects gave equal weighting to factors concerning the restrictions on movement caused by the hooded CB jacket and the breathing impacts of the respirator. The main reason selected for not wanting to wear either the M40 PASGT or M40 JH PASGT conditions was that each configuration was considered to restrict head movement.

The overall ratings of comfort based on the various constraints for each respirator, hood, and helmet condition are presented in Figure 3. Approximately 38% of the subjects felt that the M40 PASGT condition was either “very uncomfortable” or “uncomfortable” and nearly 63% of them rated the M40 JH PASGT condition the same. The highest percentages of “acceptable” ratings were observed for the M40 (60%) and M40 JH (67%) conditions.

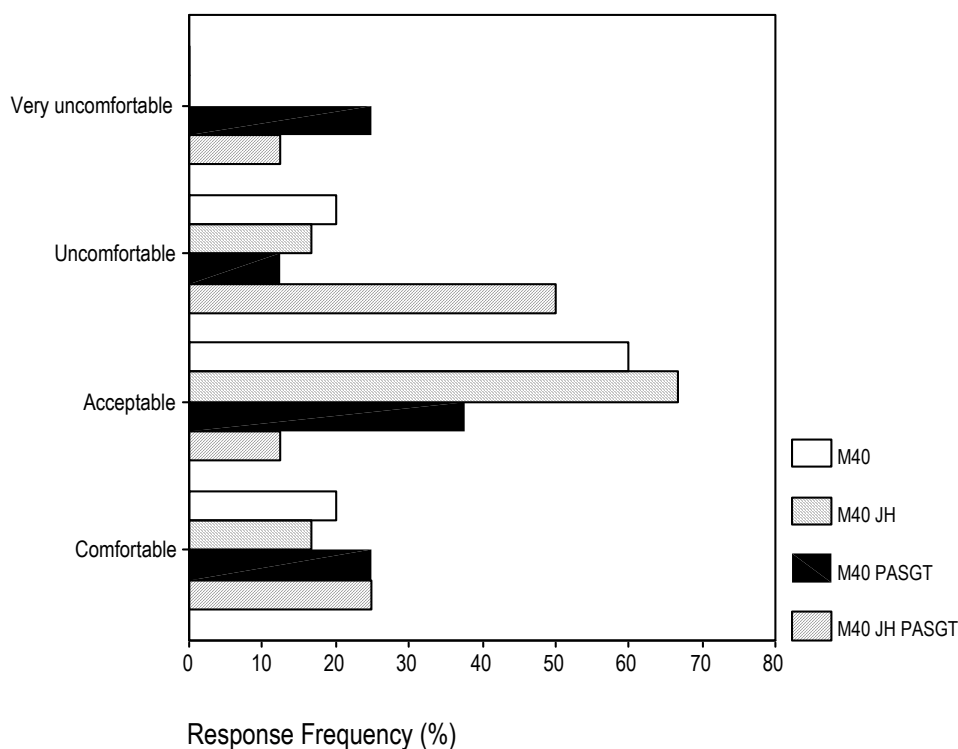


Figure 3. Frequency responses of overall comfort ratings based on the various constraints of each experimental condition.

DISCUSSION

Under the experimental conditions of this study, subjective feedback indicates that test participants experienced various amounts of discomfort based on which combination of respirator, hood, and helmet was worn. Specific inquiries concerning the M40A1 respirator indicated that the average facepiece, nosecup, headharness, and breathing comfort scores were between “fairly comfortable” and “fairly uncomfortable” for all combinations of hood and helmet wear.

The major differences among the experimental conditions of this investigation were the different hood types worn for testing. On average, hood comfort ratings for each condition were between “fairly comfortable” and “fairly uncomfortable,” indicating that subjects did not perceive any substantial discomfort due to the type of hood that was worn in combination with the respirator and helmet conditions. However, average hood comfort scores dropped about one comfort scale value for the hooded CB jacket trial compared to the butyl hood condition for both the no-helmet and PASGT helmet conditions. In addition, a higher frequency of uncomfortable ratings (i.e., rankings of 4 and below on the comfort scale) for the hood was observed for both hooded jacket conditions compared to the butyl hood trials. These findings suggest that the jacket with the integral hood was more uncomfortable than the butyl hood. Post-test questionnaire responses indicated that the CB jacket hood was considered to be bulkier and caused a higher degree of neck discomfort for the M40 JH PASGT condition compared to the butyl hood trials. Likewise, subjects identified reducing the bulkiness of the hood as the main design upgrade of the hooded CB Jacket. Nevertheless, the higher amount of discomfort of the CB hooded jacket did not result in average overall comfort ratings that differed significantly from those reported for the no-helmet and PASGT butyl hood conditions and correlations of hood comfort with overall user comfort were marginal.

Complaints on the use of helmets are common, especially for inexperienced users who must adjust to the increased head-helmet mass. However, quantitative data on use and acceptance are lacking for both military and industrial users. In this study, helmet comfort ratings were lower than all other individual mask and hood variables within each helmet wear trial (Table IV). On average, helmet comfort was rated as “fairly uncomfortable” regardless of the hood condition. Subject responses indicated that discomfort associated with the helmet was associated with its weight and bulk and overall comfort scores were strongly correlated with helmet comfort ratings. These findings indicate that the helmet was a primary source of user discomfort relative to the other comfort parameters that were assessed. While the helmet used in this investigation was a military ballistic protective helmet, the range of tested helmet weights did not exceed helmet weights of commercially available firefighter helmets or military-style tactical law enforcement helmets. Therefore, it seems likely that the level of helmet discomfort found in this study would be representative of helmet discomfort that may be experienced by first responders when some combination of respirator and helmet use is required.

In addition to attempting to quantify the combined effects of respirator, hood, and helmet wear on user comfort, another goal of this effort was to expand upon previous respirator comfort work in order to gain more information about respirator comfort (Caretto, 2000). Differences between this earlier work and the present study, including shorter respirator wear periods and the absence of respirator hoods and protective helmets, limits a direct comparison of the efforts. However, individual respirator component comfort scores for the standard M40A1 condition of the first study and the M40A1 condition of this investigation were almost identical. Likewise, overall comfort of the M40A1 was rated the same in each instance. These findings suggest that comfort associated with the standard configuration of the M40A1 was fairly consistent across the different military subject populations that participated in each experiment. Since this respirator system was rated as being “fairly comfortable” in two separate investigations, it appears that subjective discomfort of the respirator may not be as great a concern as once thought. However, the results obtained in a controlled laboratory environment may not always be extrapolated to a real-world situation where work conditions and respirator user experience may be quite variable. Thus, additional testing of respirators like the M40A1 under real world conditions should be performed to gain a better understanding of subjective respirator comfort.

CONCLUSIONS

From the data collected in this study, user comfort was shown to vary only a small degree among different conditions of combined respirator, hood, and helmet wear. A higher degree of subjective discomfort was observed during wear of a CB hooded jacket compared to a butyl rubber hood due to the bulkiness of the hooded jacket. The helmet was a primary source of user discomfort relative to the other comfort parameters that were assessed when added to the protective ensemble configurations. Even so, subjective ratings of overall user comfort did not suggest that a high degree of discomfort was experienced for any of the conditions that were tested. The results of this study provide data that may be used for improving mask, hood, and helmet compatibility as well as individual component designs. Additional work that quantifies user comfort and acceptance on various levels of respiratory and head protection are needed to insure that comfort factors do not constrain user work performance.

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