DOT/FAA/AM-89/12

Office of Aviation Medicine
Washington, D.C. 20591

The Effects of Wearing Passenger Protective Breathing Equipment On Evacuation Times through Type III and Type IV Emergency Aircraft Exits in Clear Air and Smoke

Phase I -- Evacuations in Clear Air

Phase II -- Evacuations in Smoke

Garnet A. McLean, Ph.D.
E. Arnold Higgins, Ph.D.
Peggy J. Lyne, B.S.
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

and

James H. B. Vant, Ph.D.
Lineacre College
University of Oxford
Oxford, OX1 3JA
Oxfordshire, United Kingdom

November 1989

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-89-12	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE EFFECTS OF WEARING PASSENGER PROTECTIVE BREATHING EQUIPMENT ON EVACUATION TIMES THROUGH TYPE III AND TYPE IV EMERGENCY AIRCRAFT EXITS IN CLEAR AIR AND SMOKE.		5. Report Date November 1989
		6. Performing Organization Code
7. Author(s) G.A.McLean, E.A.Higgins, P.J.Lyne, and J.H.B.Vant		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O.Box 25082 Oklahoma City, OK. 73125		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, SW. Washington, D.C. 20591		14. Sponsoring Agency Code

15. Supplementary Notes

This work was performed under Tasks AM-B-88-PRS-81D and AM-B-89-PRS-81D

16. Abstract

The effects of Passenger Protective Breathing Equipment (PPBE) on the time required for simulated emergency evacuations through Type III and Type IV overwing aircraft exits were studied in two quasi-independent experiments, one in clear air and another in smoke. Two different types of PPBE, the Dupont PELS and the Sabre Industries SABRE, were used in both experiments. Eight groups of 20 subjects participated in each experiment; each group of subjects evacuated with/without PPBE. The order of PPBE presentation condition was counterbalanced to allow analysis of evacuation experience, i.e., learning. The results obtained supported the conclusion that Exit hatch opening size was the most important factor in determining the time required to evacuate through these exits, followed next by the effects of smoke, and finally by the wearing of PPBE. It was further concluded that because the PPBE effects were isolated to the time required to cross the Exit hatch opening, the effects of PPBE were actually dependent on Exit hatch opening size. The effects of smoke were seen to result from the necessity of using tactile information to control egress in the impoverished visual environment afforded subjects. These results were discussed in relation to passenger ergonomics and aircraft design.

17. Key Words Protective Breathing Equipment, Clear Air and Smoke Atmosphere, Exit Hatch Opening.	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	33	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ABSTRACT

ERRATA

This page missing from distributed copy of document.

ACKNOWLEDGMENT

We wish to acknowledge the valuable assistance of several persons who made this study possible. First, we are grateful to Mr. Gordon E. Funkhouser, Mr. Ted Saldivar, Mr. Charles Chittum, and Ms. Robin Reed of the Protection and Survival Laboratory for their hard work and dedication during the preparation and conduct of the study. Excellent photographic documentation of the tests was provided by Messrs. Fenton Winters, David Dyer, and Ellis Young of the Protection and Survival Laboratory, and valuable logistical support during the conduct of the tests was provided by Mr. Mark George and Mr. Joe Young, also of the Protection and Survival Lab. Mr. John McNabb and Mr. John Boath of the Offshore Fire Training Center, Montrose, Scotland, also provided invaluable experience and support. A special thanks is due to Delta Airlines and Ms. Nancy Kilch of Delta, who added realism to the study with her excellent subject orientation and simulated passenger briefings. We also appreciate Mr. Gary Sharp and Ms. Stacy Terrell of the University of Oklahoma Health Sciences Center and Ms. Eleanor Combs of the Aeromedical Clinical Branch, who were present to provide medical support if required. Two other FAA employees, Mr. Lou Brown of the Office of Airworthiness and Mr. Gary Lium of the Northwest-Mountain Region, also require recognition for their assistance during the conduct of the phase I tests. Thanks also to Mr. Art Teffeau and Mr. Steve Lufthultz of E.I. DuPont, Mr. Donald Dawson of I.S.I., and Mr. Claude Lewis of Transport Canada for their enthusiastic support and participation in this study. Finally, we wish to thank Mr. Richard F. Chandler, former supervisor of the Protection and Survival Laboratory, and Dr. Jerry R. Hordinsky, Manager of the Aeromedical Research Division, for their support, encouragement and facilitation of the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THE EFFECTS OF WEARING PASSENGER PROTECTIVE BREATHING EQUIPMENT ON EVACUATION TIMES THROUGH TYPE III AND TYPE IV EMERGENCY AIRCRAFT EXITS IN CLEAR AIR AND SMOKE

INTRODUCTION

It is generally assumed that in aircraft accidents involving fire and smoke "survival is determined largely by the ability of the uninjured passenger to make his way from a seat to an exit within time limits imposed by the thermo-toxic environment (1)." This statement introduces two critical aspects of survival in these accidents: time and the thermo-toxic environment.

Since 1965, the Civil Aeromedical Institute (CAMI) has worked to protect passengers from the potential thermal and toxic smoke hazards resulting from aircraft accidents (2). One approach has been to provide assistance in the development of breathing equipment designed to protect passengers from toxic gases and thermal insult to the head. This type of apparatus is referred to as passenger protective breathing equipment (PPBE).

In addition to providing protection from the thermo-toxic environment, the PPBE should not significantly delay evacuation from the aircraft, since the protective benefits of the PPBE might then be negated. Several studies designed to evaluate effects of PPBE on the time required for evacuation of passengers from airplanes have been reported in the literature. For example, a 1968 study found a 22% to 30% degradation in evacuation rate as a result of using pre-donned PPBE (3). This study, however, compared evacuation rates while wearing PPBE in smoke to those without PPBE in clear air, confounding the effects of smoke and PPBE. A second study published in 1968 reported an 8% increase in the total time required to evacuate an airplane due to PPBE donning alone; the data in the report reveal an approximate increase of 10% in total evacuation time when donning and wearing PPBE (4). Another study found that smoke, but not PPBE, caused significant reductions in emergency evacuation rates, although the design of the study did not control for prior evacuation experience of subjects in the PPBE group (5). To summarize, comparison of the findings in the literature reveals that many of the relevant studies have failed to control critical variables, producing contradictory results.

The purpose of the evaluation reported here was to determine the effect PPBE use would have on evacuation times from an aircraft cabin environment through Type III and Type IV emergency exits in both clear air and simulated smoke. Two independent studies were performed to test the effects of pre-donned PPBE, using subject samples generalizable to the USA population. Phase I examined the effects of two PPBE devices on evacuation times in clear air; Phase II added a simulated smoke-filled environment to the protocol.

PHASE I: EVACUATIONS IN CLEAR AIR

Two types of PPBE were worn by the test subjects: a "PELS" PPBE manufactured by Du Pont and a "Sabre" PPBE manufactured by Sabre Safety Limited. Both devices use compressed oxygen cylinders to provide a breathable atmosphere. The PELS PPBE was completely functional; however, the Sabre devices used in the study lacked the air cylinders and, therefore, had several small holes punched in them to allow breathing of ambient air. The remaining aspects (weight, size, visibility, etc.) were otherwise representative of a functional Sabre PPBE.

SUBJECTS

A total of 160 healthy subjects was divided into eight groups of 20 subjects each. Each group completed two evacuation trials, once with and once without a PPBE. Four groups evacuated through a Type III exit both times and four groups evacuated through a Type IV exit both times; in each case the first evacuation for half of the groups was without a PPBE and with a PPBE for the other half. Consistent with FAA guidelines for evacuation demonstrations, subject assignment to any group was made in a manner which ensured that, while retaining as random an assignment as possible, each group had 35% who were over 50 years in age and at least 40% who were females. Of the subjects over 50 years of age, at least 15% had to be females. Table I displays the subject demographics.

METHODS

Simulated emergency evacuation trials were staged in the CAMI evacuation research facility (ERF) equipped with typical Type III and Type IV overwing exits, using volunteer subjects to simulate passengers. The ERF was configured as a typical narrow-body jet aircraft; floor-to-overhead rack distance was 64 inches, rack width from the wall of the cabin to outer edge was 32 inches (this placed the edge of the overhead rack about 2 inches past the mid-line of the middle seat), top of seat-cushion to overhead-rack distance was 46 inches, and three seats with a 32 inch pitch were located on each side of the aisle. The Type III exit opening was 20 inches by 38 inches with an inside step-up of 19 inches and an outside step-down of 26 inches. The Type IV exit had an opening of 19 inches by 27 inches with an inside step-up of 23 inches and an outside step-down of 31 inches. The exit plugs were removed prior to the beginning of evacuation. The evacuation signal was a loud bell; thereafter, subjects were admonished to hurry by the simulated flight attendant crew. Figures 1 and 2 demonstrate the seats, subject placement, exit position, and camera configuration. A post-evacuation questionnaire was also completed by each subject to provide subjective assessments of their experiences (Fig. 3).

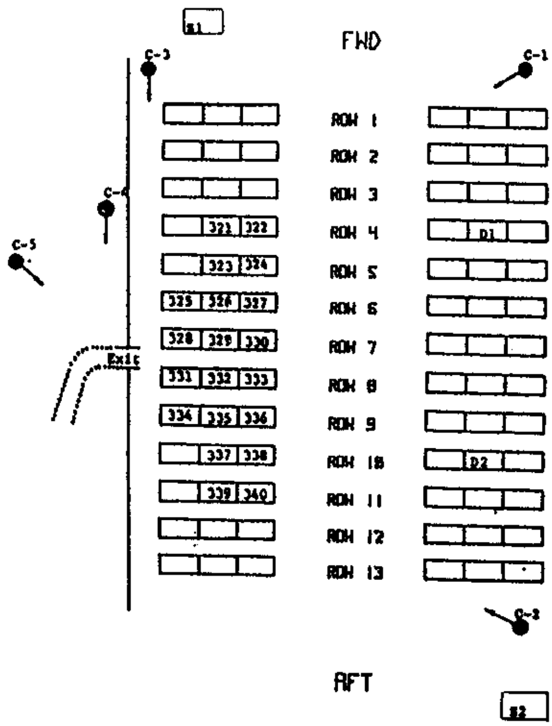
TABLE I

Demographics of Phase I Sample Population
and Reference Populations

		Sample Pop.	Reference Pop.	
Sex:	Male	54 %	60 %	(6)
	Female	46 %	40 %	
Age (yrs):	Mean	38.8	41.5	(7)
	S.D.	13.5	15.6	
	Min/Max	18/60	18.5/65.5	
Height (in):	Mean	67.8	66.6	(7)
	S.D.	3.9	2.7	
	Min/Max	56/78	54/79	
Weight (lb):	Mean	166.0	160	(7)
	S.D.	38.5	32	
	Min/Max	89/289	74/388	
Neck Circumference (in):				
	Mean	14.4	15.1	(8)
	Min/Max	11.5/19	13.7	5th %ile
			16.4	95th %ile
Eyewear:	Total	52.2 %	54.7 %	(10)
	Eyeglasses	42.1 %	47.1 %	
	Contact lens	10.1 %	7.6 %	
Maximum Education:				
Not High School Graduate		2.5 %		
High School Graduate		72.5 %		
College Graduate		15.0 %		
Post-Graduate Studies		10.0 %		
Frequency of Flight History:				
Never flown		10.6 %		
Less than 1 per year		40.6 %		
From 1 to 12 per year		47.5 %		
More than 12 per year		1.3 %		

FIGURE 1

CABIN CONFIGURATION



C = Cameras, S = smoke generators, D = densitometers,

FIGURE 2

RELATIONSHIP OF SEAT ROWS TO EXITS

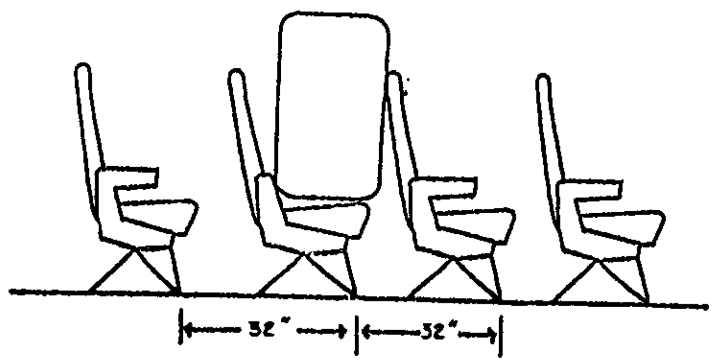


FIGURE 3

POST EVACUATION QUESTIONS

(INSTRUCTIONS): The following questions have to do with your feelings and perceptions. There are no right or wrong answers - just your impressions.

PLEASE CIRCLE THE ANSWER (NUMBER) WHICH BEST DESCRIBES HOW YOU FEEL ABOUT EACH QUESTION.

---

1. How easy was it to put the hood on your head?
2. How clear and useful was the explanation given to you on putting on and using the smoke hood?
3. How easy was it to turn-on or "activate" the hood?
4. How easy was it to breathe while wearing the hood?
5. How easy was it to see while wearing the hood?
6. How comfortable was the smoke hood?
7. How easy was it to exit the plane without the hood?
8. How easy was it to exit the plane with the hood?
9. How easy was it to keep the hood on your head and properly placed?
14. How easy was it to remove the hood after the evacuation?

(THE QUESTIONS ABOVE USED THIS SCALE AFTER EACH ONE)

---------1----------2----------3-----------4------------5-------

VERY EASY   EASY   OK   DIFFICULT   VERY DIFFICULT

10. Rate the weight of the hood.

MUCH TOO LIGHT - TOO LIGHT - OK - TOO HEAVY - MUCH TOO HEAVY

11. Rate the temperature inside the hood at the end of evacuation.

GOOD -- OK -- TOO WARM -- HOT -- VERY HOT

12. Rate the overall size of the hood for your head.

TOO SMALL -- SMALL -- OK -- LARGE -- TOO LARGE

13. Did the hood begin to fog over?

NO - SLIGHTLY - YES, REDUCED VISION - GREATLY REDUCED VISION - YES NO VISION

15. Did you feel trapped or suffocated while wearing the hood?
16. Do you think, in general, that it would be good to have a hood available for passengers to use in a smoke-filled plane?
17. Would you want to use <u>this</u> hood to evacuate from a smoke-filled plane?
18. Do you wear: Eyeglasses?___Contact lenses?___Neither?___

(QUESTIONS 15 - 18 REQUIRED YES/NO ANSWERS)

PHASE I RESULTS

The total evacuation time required for each group was defined as beginning at the time the evacuation alarm sounded and continuing until the last subject cleared the exit; videotapes, inset with digital times, were scored visually to obtain the data. In the results presented below, the evacuation times for both PPBE's have been combined, except where a significant difference was observed due to the type of PPBE worn, or where a direct comparison is being made. The total time required to evacuate each group of 20 subjects may be found in Table II, where the data reflect the PPBE type, order of PPBE presentation condition, and Exit Type. This composite picture of evacuation times is accompanied by additional tables and figures which provide details of the specific effects. Significance levels for these effects were determined by paired t-tests.

TABLE II

Group Evacuation Times (in seconds) by PPBE and Trial Order Within Exit Type in Clear Air

Type III Exit		Type IV Exit	
Trial 1	Trial 2	Trial 1	Trial 2
37 (None)	37 (PELS)	64 (None)	65 (PELS)*
53 (PELS)	38 (None)	73 (PELS)	56 (None)
34 (None)	33 (SABRE)	58 (None)	52 (SABRE)
40 (SABRE)	34 (None)	65 (SABRE)	53 (None)

* Second trial slower than the first.
n = 20 per group.

When averaged across evacuation trials, mean group exit times through the Type III exit were 35.75 sec without PPBE and 40.75 sec when wearing PPBE. The mean group exit times for the Type IV exit were 57.75 sec and 63.75 sec, respectively. These times signify a 14% (5 sec) increase in time required to exit a Type III exit, and an 11% (6 sec) increase for Type IV, when wearing PPBE. These increases in group evacuation times were statistically significant, ($p < .05$). Figure 4 displays this effect.

TABLE III

PPBE Effects on Group Evacuation Times (in seconds) within Exit Type in Clear Air

Type III Exit			Type IV Exit	
PPBE	No PPBE		PPBE	No PPBE
37	37		65	64
53	38		73	56
33	34		52	58
40	34		65	53
40.75	35.75	Mean	63.75	57.75
4.25	4.25	S.E.	4.25	2.50

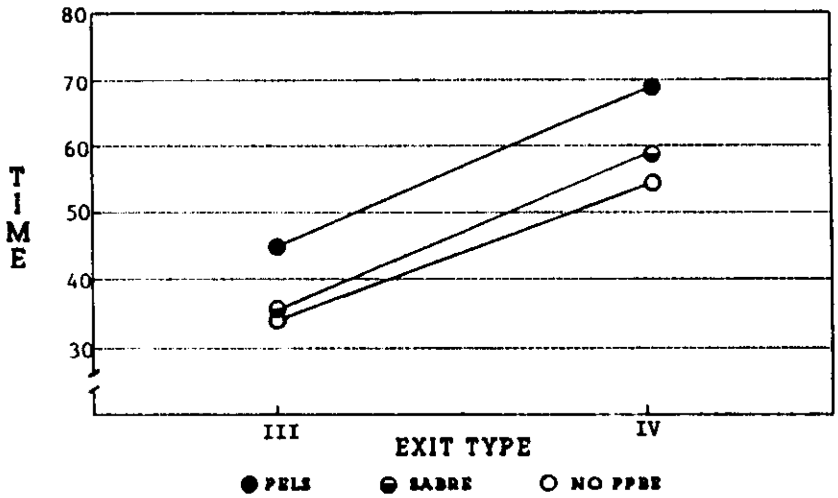
n = 20 per group.

In addition to the mean effects of PPBE displayed in Table III, the relative contribution each type of PPBE produced may be found in Figure 4. As indicated, the PELS PPBE, which increased evacuation times by 25% (11.5 sec) over evacuation times without PPBE, was responsible for almost all of the evacuation delay seen; the SABRE PPBE appeared to have little effect on total evacuation times. Based on responses from the subject questionnaires, this effect was probably caused by the relatively larger size of the PELS PPBE, or possibly because of its visual properties. Note that for the No PPBE condition, the times in Figure 4 represent the evacuation times within PPBE type for the respective trial.

As indicated by the evacuation time means without PPBE, the effect of Exit Type clearly outweighed the effects of wearing PPBE. Returning to Table 3, it can be seen that the mean evacuation time without either PPBE for Exit Type III was 35.75 sec and the mean evacuation time for Exit Type IV was 57.75 sec. This 62% (22 sec) increase ($p < .004$) in total exit time was more than four times as large as the increase produced by wearing PPBE through the Type III exit, indicating that, when using either Type III or Type IV exits, the size of the exit opening was more critical in determining evacuation time than was the wearing of PPBE.

FIGURE 4

PPBE EFFECTS IN CLEAR AIR



To assess more critically the contribution of exit size opening on total evacuation time, the time required for each subject to move through the exit hatch was also analyzed. This "individual hatch crossing time" was defined as beginning at the time the individual reached the exit and continuing until his/her entire body had cleared the exit hatch opening. Table IV displays the individual hatch crossing time means through both exit types, with/without PPBE. There was a small, but statistically significant, ($\underline{p} < .05$), increase in <u>overall</u> mean hatch crossing time when wearing PPBE compared to hatch crossing time without PPBE. This effect resulted from a combination of the 21% (0.3 sec) increase in mean hatch crossing times through the Type III exit and the 14% (0.4 sec) mean increase through the Type IV exit. Upon determining the cumulative effect of these increases in individual hatch crossing times, it can be shown that the entire effect of PPBE on total evacuation times was produced by slower hatch crossing. However, when compared to the 107% (1.5 sec) mean increase in individual hatch crossing times produced only by the smaller Type IV exit, this effect of PPBE on hatch crossing, and thus total evacuation, times is seen to be comparatively small.

TABLE IV

Individual Hatch Crossing Times (in seconds)
in Clear Air

	Type III Exit		Type IV Exit	
	PPBE	No PPBE	PPBE	No PPBE
Mean	1.70	1.40	3.30	2.90
S.E.	0.12	0.08	0.15	0.16
Min/max	0.8/6.2	0.7/5.4	1.4/9.3	1.4/9.3

n = 80 per group.

In addition to the analysis of Exit Type effects, the counter-balanced presentation of PPBE allowed for the identification of evacuation experience, i.e., learning, as a variable critical for evacuation time. When averaged across PPBE presentation condition, prior experience egressing through Type III and Type IV exits was shown to reduce the mean time required to evacuate on the subsequent evacuation by 5.7 sec (16%) and 8.4 sec (15%), respectively. These decreases in evacuation time were significant for both exits, (p < .05), suggesting a general facilitative effect of evacuation experience. This interpretation was confirmed by an extended comparison of total evacuation times within PPBE presentation condition across Exit Types. Subjects wearing PPBE on the initial trial were 20% (9.5 sec) slower than subjects without PPBE, although on the second trial when they were without PPBE their exit times were 7% (3 sec) faster than the subjects who had no PPBE on the first trial (see Figure 5). This represents a total 12.5 sec learning effect due to evacuation experience while wearing PPBE. Similarly, subjects who evacuated without PPBE on the first trial experienced a savings of 11 seconds on the second trial when wearing PPBE, revealing an essentially symmetrical learning function that was independent of initial PPBE condition. The analysis of this effect was then extended to mean individual hatch crossing times, where it became evident that the effect of experience in reducing evacuation times was dependent on learning how to traverse the exit hatch (Figure 6). A comparison of Figures 5 and 6 reveals this relationship.

FIGURE 5

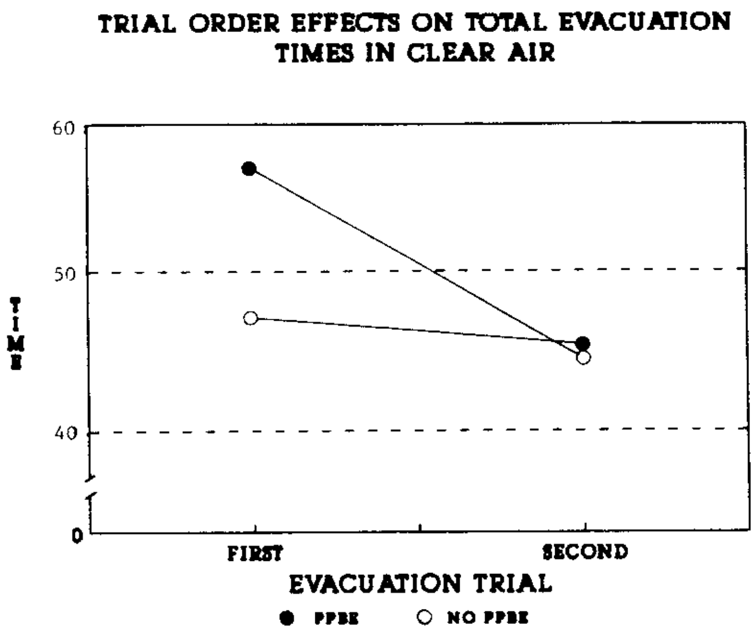
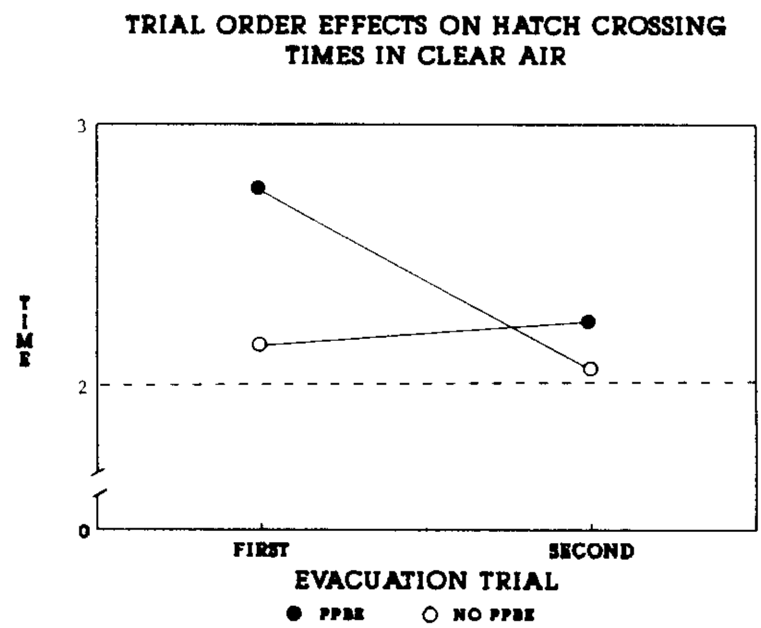


FIGURE 6



In addition to the direct effects of PPBE on evacuation times, each subject also completed a post-evacuation questionnaire, (Figure 3), concerning his/her experience in the study. The range and mean scores from the questionnaires are shown in Table V. With one exception, there were no significant differences between the responses given by the subjects who wore the PELS PPBE and those who wore the Sabre PPBE. However, for question #17 where 11% of all the subjects expressed a lack of desire to use the PPBE, subjects who wore the PELS PPBE (with a larger volume than the Sabre PPBE) reported greater acceptability when exiting through the larger Type III exit, whereas subjects wearing the Sabre PPBE reported greater acceptability when exiting through the smaller Type IV exit, ($p < .05$). The other responses to the questionnaire indicated that 5% of the subjects expressed difficulty donning the PPBE and 9% had difficulty seeing. These responses ranged from 2 to 25% in other studies (3,5) for donning difficulty, and 61% had visual difficulty in another study (3). Similarly, 18% of the subjects in yet another study expressed a lack of desire to use other PPBE, (3). Perhaps as noted here, their desire to use a specific PPBE was a function of the exit opening size and the profile (size) of the PPBE.

Similar comparisons revealed little relationship between education and subject-perceived clarity of instruction for donning and/or activation of the PPBE (recall the SABRE was not functional), and there were no reported problems related to wearing eyeglasses.

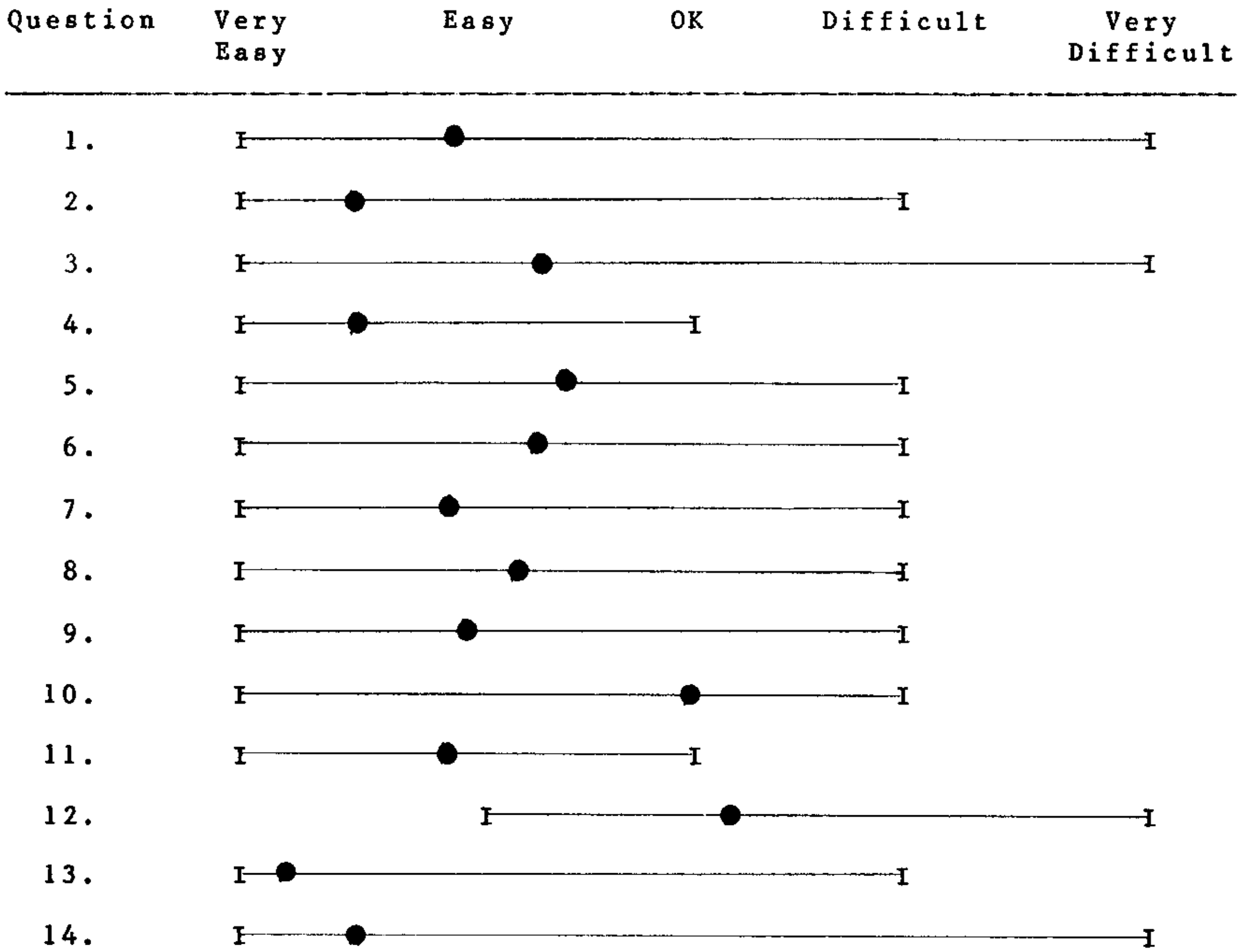
PHASE I DISCUSSION

Phase I evacuations were limited to trials through Type III and IV exits in clear air conditions. The mean total evacuation times increased significantly when the subjects wore both types of PPBE; this increase in the time required to evacuate the ERF was also partially caused by increases in the individual hatch crossing times. Counterbalancing the order of evacuation trials within PPBE type revealed that delays in total evacuation times produced by PPBE could be overcome by prior experience. The most important factor in total evacuation time was the size of the exit hatch, as use of PPBE coupled with the Type III exit produced faster evacuations than those through the Type IV exit without PPBE.

The responses to the post-evacuation questionnaire provided an additional subjective indication that the PPBE functioned as intended, without undue difficulty. With one exception, the type of PPBE worn did not significantly alter the subject responses; however, the particular PPBE design did appear to have an impact on the subjects' general acceptance of PPBE. While this factor could have a crucial impact on passenger use, it seems likely that an actual emergency situation would overcome such bias. For example, the presence of smoke and/or fire should make any PPBE more acceptable, particularly when aircraft passengers must endure such a noxious environment for extended periods.

TABLE V

Post-Evacuation Questionnaire Range and Mean Scores for Phase I (see Figure 3)



	YES	NO
15. FELT SUFFOCATED	10.6 %	89.4 %
16. PPBE A GOOD IDEA	96.0 %	4.0 %
17. WOULD USE: PELS (III)	94.9 %	5.1 %
(IV)	82.5 %	17.5 %
SABRE (III)	86.5 %	13.5 %
(IV)	92.5 %	7.5 %

I———I Range ● Mean

Together, these findings imply that the use of PPBE in aircraft emergencies could delay evacuation times, although this effect could be greatly reduced by prior training or actual evacuation experience. In addition, it is possible that these evacuation trials using PPBE in clear air might not have adequately simulated an actual emergency situation in smoke and/or fire, where the negative effects seen here on evacuation times might be overcome by other aspects of PPBE. For example, the protection afforded the eyes should enhance the ability to see the aisle and exit openings in a smoky environment, leading to a relatively positive net benefit of PPBE on evacuation times in the intended situation.

PHASE I SUMMARY

In summary, PPBE use resulted in significantly longer evacuation times through both Type III and Type IV exits, although exit size was shown to be a more critical factor than use of PPBE. Subject responses to PPBE were generally positive, with the smaller PPBE preferred for the smaller Type IV exit and the larger PPBE deemed more favorable for the larger Type III exit. Evaluating the delay produced by PPBE revealed a need to provide a more detailed assessment of PPBE in a smoke-filled aircraft simulator; Phase II of this study was intended to provide this information.

PHASE II: EVACUATIONS IN SMOKE

The same two types of PPBE tested in Phase I, the Dupont "PELS" and the Sabre Industries "SABRE", were used again in Phase II. Recall that both devices provide compressed air to breathe, but in this study the Sabre devices had the air cylinders removed and holes punched in them to make them reusable. The PELS devices were new and fully functional. Addition of white, non-toxic simulated smoke to the protocol was the only systematic change.

SUBJECTS

A total of 160 healthy subjects were divided into eight groups of 20 subjects each. Each group evacuated the ERF twice, once with and once without a PPBE. Four groups evacuated through a Type III exit both times and four groups evacuated through a Type IV both times; in each case the first evacuation for half of the groups was without PPBE and with PPBE for the other half. Assignment of subjects to each group was again made in the manner consistent with FAA guidelines for evacuation demonstrations, which provided all the groups with at least 40% females (15% of which were over 50 years of age) and 35% who over 50 years of age. Subject demographics are displayed in Table VI.

TABLE VI

Demographics of Phase II Sample Population
and Reference Populations

		Sample Pop.	Reference Pop.	
Sex:	Male	52 %	60 %	(6)
	Female	48 %	40 %	
Age (yrs):	Mean	34.2	41.5	(7)
	S.D.	13.2	15.6	
	Min/Max	18/63	18.5/65.5	
Height (in):	Mean	68.6	66.6	(7)
	S.D.	3.6	2.7	
	Min/Max	61/77	54/79	
Weight (lb):	Mean	169.4	160	(7)
	S.D.	37.3	32	
	Min/Max	98/306	74/388	
Neck Circumference (in):				
	Mean	14.2	15.1	(8)
	Min/Max	11.2/18.7	13.7	5th %ile
			16.4	95th %ile
Eyewear:	Total	57.5 %	54.7 %	(10)
	Eyeglasses	45.6 %	47.1 %	
	Contact lens	11.9 %	7.6 %	
Maximum Education:				
Not High School Graduate		1.9 %		
High School Graduate		74.4 %		
College Graduate		18.1 %		
Post-Graduate Studies		5.6 %		
Frequency of Flight History:				
Never flown		10.0 %		
Less than 1 per year		43.8 %		
From 1 to 12 per year		43.8 %		
More than 12 per year		2.4 %		

METHODS

Simulated emergency evacuation trials were staged in the CAMI evacuation research facility (ERF) equipped with typical Type III and Type IV overwing exits, using volunteer subjects to simulate passengers. The ERF was configured as a typical narrow-body jet aircraft, identical to the configuration in Phase I. Similarly, the Type III and Type IV exit openings were the same as used in Phase I. Again, the exit plugs were removed prior to the start of the evacuation. Simulated smoke produced by a Concept Spirit Smoke Generator was introduced into the ERF at a concentration sufficient to produce an optical density of 0.5/foot, which reduced light transmission to approximately 30% of control values at standing eye level. The evacuation signal was a loud bell; thereafter subjects were admonished to hurry by shouts from the simulated flight attendant crew. Figures 1 and 2 show the seat arrangement, subject seating exit position, smoke generator locations, densitometer locations, and camera locations.

PHASE II RESULTS

Recall that the total evacuation time required for each group was defined as beginning at the time the evacuation alarm sounded and continuing until the last subject cleared the exit. In the results presented below, the evacuation times for both PPBE's have again been combined, except where a direct comparison between PPBE types is being made. The total time required to evacuate each group of 20 subjects may be found in Table VII, where the data reflect the PPBE type, trial order of PPBE presentation condition, and Exit Type. This composite presentation of evacuation times is also accompanied by the complementary tables and figures, which detail specific effects. Significance levels for these effects were determined by paired t-tests.

When averaged across evacuation trials, mean group evacuation times through the Type III exit were 48.25 sec without PPBE and 53.25 sec when wearing PPBE. The mean group evacuation times for the Type IV exit were 67.00 sec without PPBE and 77.25 sec when wearing PPBE. When compared to the evacuation times from the Phase I evacuations in clear air, these times represent a 24% (12 sec) mean increase in total evacuation time due to the addition of smoke. These times also indicate a relatively stable effect of PPBE on evacuation time, given the statistically insignificant 10.4% (5 sec) increase in the time required to exit a Type III exit when using PPBE and the larger 15.3% (10.25 sec) increase for the Type IV exit when wearing the PPBE in smoke, ($\underline{p} < .03$). Table VII provides the mean PPBE times by group, while Figure 7 shows the relative contribution each type of PPBE produced; note that the PELS PPBE times were again significantly longer than the SABRE ($\underline{p} < .001$) or <u>No PPBE</u> ($\underline{p} < .009$) times, whereas the SABRE and <u>No PPBE</u> times were nearly equal ($\underline{p} < .76$). As suggested for Phase I, this difference probably reflects the large size of the PELS PPBE.

The proportional increase in exit time beyond that produced by the combination of smoke and the SABRE PPBE was likely produced by an enhancement of this effect, as indicated by responses to the subject questionnaires which are discussed below.

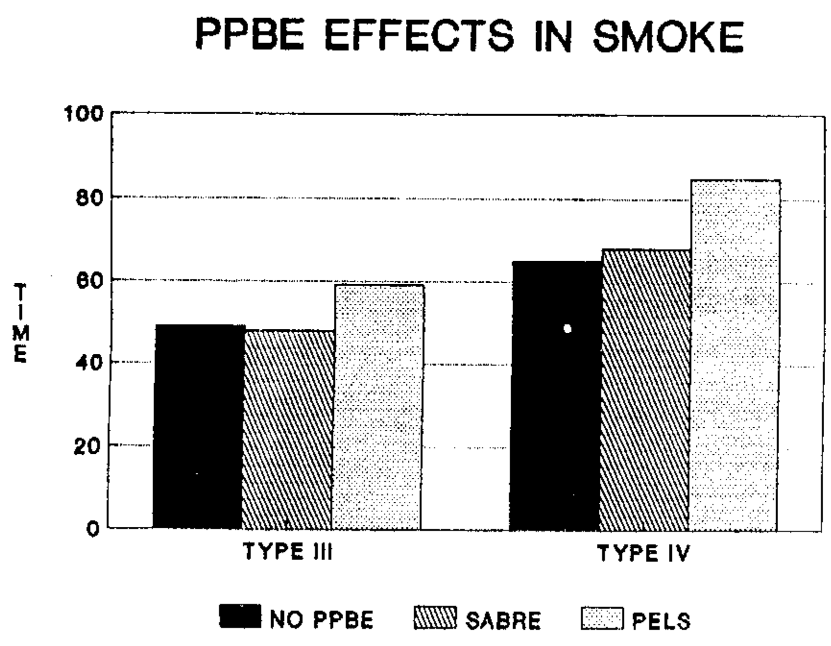
TABLE VII

Group Evacuation Times (in seconds) by PPBE and Trial Order within Exit Type

Type III Exit		Type IV Exit	
Trial 1	Trial 2	Trial 1	Trial 2
50 (None)	59 (PELS)	71 (None)	85 (PELS)
59 (PELS)	49 (None)	86 (PELS)	69 (None)
52 (None)	47 (SABRE)*	73 (None)	74 (SABRE)
48 (SABRE)	42 (None)	64 (SABRE)	55 (None)

* Second trial with PPBE faster than the first without.
n = 20 per group.

FIGURE 7



In addition to the exit time increases produced by the smoke, the effect of Exit Type again was clear. In Table VIII, it can be seen that the mean evacuation time without either PPBE for Exit Type III was 48.25 sec and the mean evacuation time for Exit Type IV was 67.00 sec. This 39% (18.75 sec) increase ($p < .007$) in exit time caused only by the smaller exit opening again shows that exit size is the most critical variable when comparing egress through Type III and Type IV exits, even while wearing PPBE in smoke.

TABLE VIII

PPBE Effects on Group Evacuation Times (in seconds) within Exit Type in Smoke

Type III Exit			Type IV Exit	
PPBE	No PPBE		PPBE	No PPBE
59	50		85	71
59	49		86	69
47	52		74	73
48	42		64	55
53.25	48.25	Mean	77.25	67.00
3.33	2.17	S.E.	5.19	4.08

n = 20 per group.

As in Phase I, the time required for each subject to move through the hatch was also analyzed. This "individual hatch crossing time" was again defined as beginning at the time the individual reached the exit hatch and continuing until his/her entire body had cleared the opening. Table IX provides the mean hatch crossing times through the Type III and Type IV exits in smoke. There was a statistically significant difference in mean hatch crossing times when wearing a PPBE compared to hatch crossing times without a PPBE for both types of exit hatch. This effect resulted from an 18% (0.3 sec) mean increase in individual hatch crossing times through the Type III exit ($p < .02$), and a 27% (0.7 sec) increase in hatch crossing times through the Type IV exit ($p < .001$), when wearing the PPBE. As was shown for Phase I, the cumulative effect of these mean increases in individual hatch crossing time was responsible for the entire effect of PPBE on total evacuation time for both exit types.

Again, however, the use of individual hatch crossing times to examine more completely the relative effects of PPBE and Exit Type on total evacuation time shows that Exit Type had the greatest impact on evacuation time, rather than the wearing of PPBE. The mean individual hatch crossing time egressing through Exit Type IV without PPBE was 53% (.9 sec) longer than that through Exit Type III without PPBE, and also 30% (0.6 sec) longer than egressing through the Type III exit hatch when wearing PPBE. Both effects were highly significant ($p <.001$), indicating, that compared to exit size, PPBE accounted for a relatively small portion of the total delay through the Type III exit, although the PPBE produced a relatively larger effect for the Type IV exit in smoke. As shown in the following section on learning effects, the effects of PPBE in producing increases in total evacuation time can once again be traced directly to increases in individual hatch crossing times, which are controlled by exit opening size.

TABLE IX

Individual Hatch Crossing Times (in seconds) in Smoke

	Type III Exit		Type IV Exit	
	PPBE	No PPBE	PPBE	No PPBE
Mean	2.00	1.70	3.30	2.60
S.E.	0.09	0.08	0.16	0.12
Min/max	0.9/5.0	0.9/4.3	1.0/7.0	1.1/5.9

n = 80 per group.

The counterbalanced presentation of PPBE within Exit Type which allowed for an evaluation of the effects of evacuation experience in clear air was analyzed for evacuations in smoke. Averaging across PPBE presentation condition resulted in an exit time savings of 6% (3.0 sec) through a Type III and 2% (1.75 sec) through the Type IV exit on the second trial. These decreases in evacuation times were statistically insignificant for both exits. However, when comparing learning effects within PPBE type across Exit Types, it may be seen that, contrary to the effects seen in clear air, there was a marked difference in the learning effects produced with and without PPBE. Subjects who wore the PPBE in their first evacuation trial had a mean savings of 16% (10.5 sec) in evacuation time for the second trial without PPBE, whereas subjects who evacuated without PPBE on the first trial were 8% (4.75 sec) slower on the second trial with PPBE. This asymmetrical learning function suggests an altogether different evacuation experience for naive subjects with/without PPBE in smoke (Fig. 8); this effect, in a replication of the Phase I findings, was shown to be controlled by individual hatch crossing times (Fig. 9). Given the large control of exit opening size on individual hatch crossing times, it becomes clear that much of the PPBE effects are, in fact, due to difficulties in exit hatch egress caused by the small exit opening size. A comparison of Figures 8 and 9 confirms this relationship.

In addition to the direct effects of PPBE on evacuation times in smoke, each subject completed the post-evacuation questionnaire as first administered in Phase I, (Figure 3). The response range and mean scores from the questionnaires are given in Table X. Generally, there was little difference between the responses given in smoke conditions and the responses given in Phase I; observed differences were related to increased evacuation difficulty both with and without PPBE. This increase in perceived difficulty was probably caused by the smoke, as reflected in item 5 (reported visual difficulty), as well as in items 7 and 8, which reported increases in general evacuation difficulty. Also, in item 17 the use of the SABRE PPBE was deemed more acceptable for both exit types; recall that in clear air the PELS was preferred when exiting the larger Type III exit. Given the stability of the responses in general, these specific changes in subject reports reveal that the smoke produced a general reduction in evacuation effectiveness which had little to do with the particular PPBE worn.

PHASE II DISCUSSION

Phase II evacuation trials were identical to those in Phase I except for the addition of simulated smoke. In order of importance for evacuation delays, reduced exit hatch size was replicated as the factor producing the largest increase in total evacuation time, followed next by the effect of simulated smoke. As in clear air, the mean total exit times also increased significantly when the subjects wore PPBE, particularly the Dupont PELS. Increases in

FIGURE 8

TRIAL ORDER EFFECTS ON TOTAL EVACUATION TIMES IN SMOKE

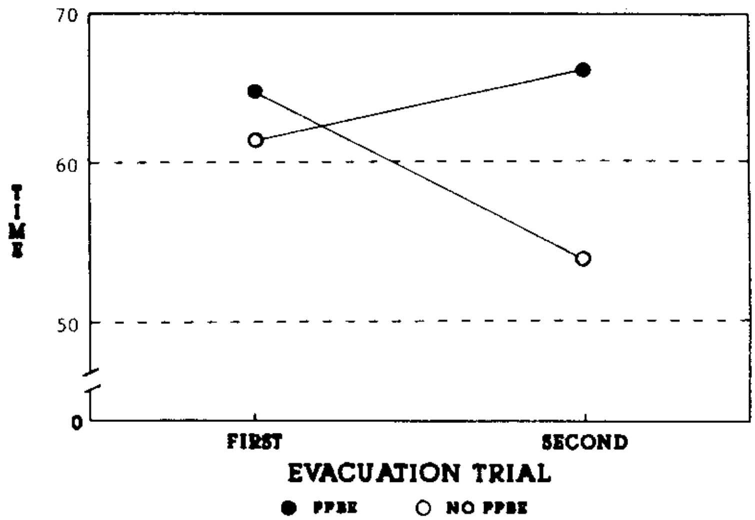
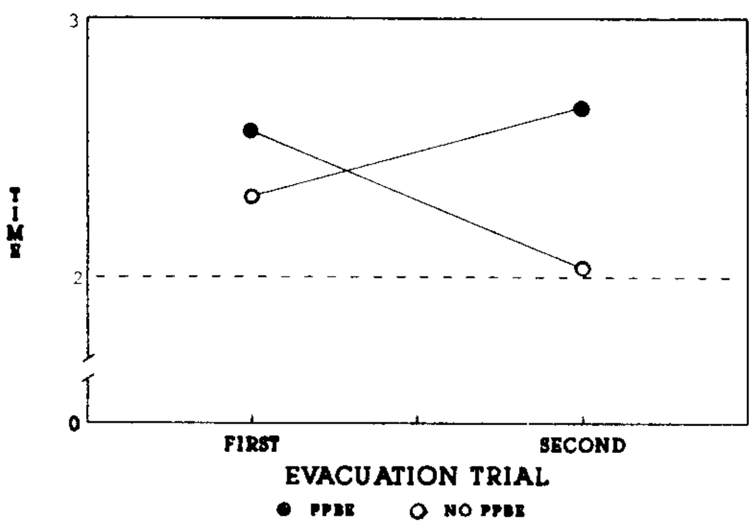


FIGURE 9

TRIAL ORDER EFFECTS ON HATCH CROSSING TIMES IN SMOKE



individual hatch crossing times were shown to be responsible for these PPBE effects, confirming that the wearing of PPBE produced ergonomic difficulties. Interestingly, however, the contribution of PPBE to evacuation times in smoke was relatively unchanged compared to PPBE effects on evacuation times in clear air, indicating that the useful/harmful effects of PPBE were generally independent of the environmental situation, and more related to the size of the exit opening.

As in clear air, counterbalancing the order of evacuation trials within PPBE presentation condition revealed that these delays in total evacuation time could be overcome by prior evacuation experience crossing the exit hatch while wearing PPBE in a smoky environment, although initial evacuations in smoke without PPBE produced no such savings on subsequent trials. This asymmetrical learning function suggests that subjects were forced to use different evacuation strategies in smoke compared to clear air, a situation apparently dependent on the limited availability of visual cues. Perhaps this need to rely on other, primarily tactile, cues for feedback about their spatial locations relative to the exit hatch produced a greater awareness when they were wearing PPBE, especially since the larger PELS PPBE contributed the largest percentage to both the evacuation delays and savings.

The responses to the post-evacuation questionnaire provided additional evidence for this interpretation. In addition to smoke-related increases in the reported difficulty of exiting the ERF, subjects also reported greater difficulty wearing the PPBE in smoke. Also, the preference for the PELS PPBE when evacuating through the Type III exit in clear air was not replicated in smoke, further suggesting that even with the larger exit opening, getting out of the ERF was more difficult. Thus, although subjects found evacuations in smoke to be very demanding when wearing PPBE, especially the PELS, the added attention to tactile cues demanded by wearing either PPBE apparently produced implicit learning that did not occur for evacuations without PPBE. As such, it appears that PPBE use could enhance subsequent evacuation rates in a smoke-filled cabin environment if practice evacuations while wearing PPBE were generally available.

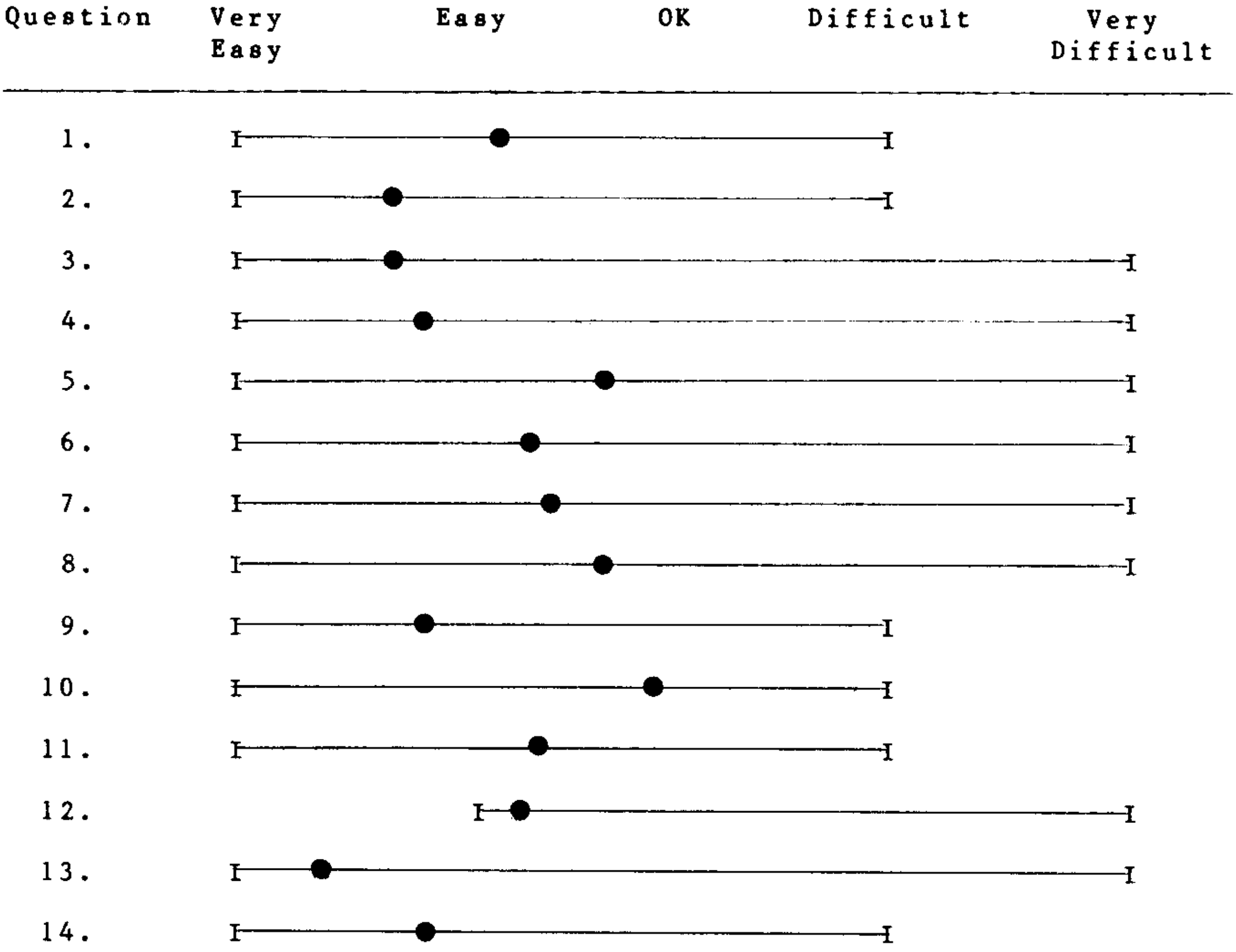
Together, these findings confirm and extend the results found for evacuations in clear air. However, the addition of smoke to the evacuation scenario produced additional detrimental effects on evacuation times, including interactions with exit hatch size and PPBE use which confirm the serious consequences that smoke produces on human performance functions in such situations.

PHASE II SUMMARY

In summary, PPBE use resulted in significantly longer evacuation times through both Type III and Type IV exits, although exit size was again shown to be more critical than use of PPBE. The addition

TABLE X

Post-Evacuation Questionnaire Range and Mean Scores for Phase II (see Figure 3)



		YES	NO
15. FELT SUFFOCATED		16.9 %	83.1 %
16. PPBE A GOOD IDEA		96.9 %	3.1 %
17. WOULD USE: PELS	(III)	87.5 %	12.5 %
	(IV)	82.5 %	17.5 %
SABRE	(III)	92.5 %	7.5 %
	(IV)	95.0 %	5.0 %

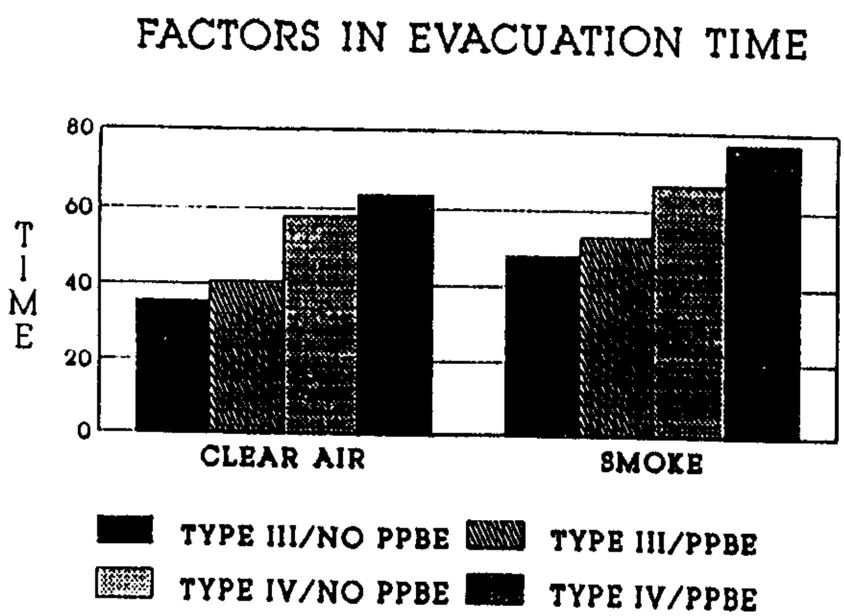
I———I Range ● Mean

of smoke appeared to alter the cabin environment to produce a more hazardous and demanding evacuation experience, where use of PPBE was shown to produce essentially the same delay on evacuation times as in clear air, but enhance subsequent evacuations after the experience. Subject responses to PPBE were again generally positive.

GENERAL DISCUSSION

Significant evacuation delays when egressing through Type III and Type IV emergency aircraft exits have been shown to result from reduced exit hatch opening size, a smoke-filled cabin environment and the wearing of PPBE, in that order, although the effects of exit hatch size and PPBE were manifest in both clear air and smoke. Figure 10 displays the relative contributions of these factors.

FIGURE 10



However, the most significant finding is that the effects of PPBE were directly controlled by exit hatch opening size. This effect was particularly apparent when comparing evacuations through the relatively small Type III and Type IV emergency exits, although the generalization of this effect implies that evacuation through any small opening will be impeded by PPBE (or any other appliance which enlarges an individual's personal "ergonomic space"). Conversely, any action, such as increasing the emergency exit hatch opening size, which reduces the physical environmental restrictions associated with emergency evacuation will counteract this enlargement of personal ergonomic space.

The other factor shown to be significant was the increase in evacuation time caused by the reduction in available environmental information produced by smoke. This effect was prominent in the increased evacuation times in smoke, as well as the failure of subjects to improve their evacuation times in smoke after having a prior evacuation experience. One might presume initially that this effect would be more pronounced as individuals moved from their seats toward the exit openings; however, this effect was again shown to interact more with exit hatch opening size in producing increased total evacuation times. This increase in evacuation time apparently occurred because in clear air subjects were able to use visual cues in maximizing the behavioral functions required for egress, whereas the smoke eliminated these cues to create a paucity of visual information by which to guide evacuation performance. This situation effectively produced 20 "newly-blind" subjects, each with a resultant need for reliance on tactile cues, a condition for which sighted persons are basically unprepared. Whereas the time inherent in queueing for the exit hatch may have masked these effects on ambulatory functions, the inability of subjects to accurately discern the exit opening and the local environmental restrictions (seats, other subjects, etc.) produced a bottleneck condition which impeded emergency egress.

This condition was exacerbated by the increase in individual ergonomic space caused by the wearing of PPBE, as evidenced by the longer evacuation times. However, this increase in personal space probably accounted for the asymmetrical learning function seen for evacuations in smoke, because subjects who initially evacuated while wearing PPBE were forced to become more aware of themselves, leading to better evacuation performance on the second trial when they were not wearing PPBE. Conversely, subjects who had not worn PPBE during the first evacuation trial in smoke were unaware of the increase in personal space produced by the PPBE, and were, therefore, unprepared for the ergonomic allowances they would have to make when wearing PPBE on the second evacuation trial. Thus, the inextricably-linked effects of small exit hatch opening size and PPBE-produced increase in personal ergonomic space which were first shown in clear air, were made much more salient in smoke by the need for reliance on those sensory cues that these two factors most clearly disturbed.

CONCLUSION

The conclusions to be drawn from this study are as relevant to aircraft design as they are to PPBE. Whether using PPBE or not, it is clear that large exit hatch openings are necessary for effective emergency egress, although the use of PPBE makes this design factor essentially mandatory. In addition, a clear area surrounding the exit opening should be required. PPBE use itself was shown to have no detrimental effects on egress beyond those related to delays in exit hatch crossing, indicating that if PPBE donning time poses no further problems, then PPBE should have a positive net benefit on evacuation times through the larger emergency exits being incorporated into modern aircraft. A recent study (11) investigating the effects of PPBE concluded that "donning time lacks the significance that many attribute to it" when PPBE were readily available to, and under the control of, passengers; in that study a more orderly evacuation was also observed in smoke when subjects were wearing PPBE. Given the combination of those findings with the data reported here, it appears that in a properly designed aircraft cabin environment, PPBE could provide the emergency protection intended, without undue hazard caused by ergonomic factors.

REFERENCES

1. Snow, CC, JJ Carroll, and MA Allgood: Survival in Emergency Escape from Passenger Aircraft, FAA Office of Aviation Medicine Report FAA-AM-70-16, 1970.

2. Higgins, EA: Summary Report of the History and Events Pertinent to the Civil Aeromedical Institute's Evaluation of Providing Smoke/Fume Protective Breathing Equipment for Airline Passenger Use, FAA Office of Aviation Medicine Report FAA-AM-87-5, 1987.

3. Aerospace Industries Association of America: Lighting and Exit Awareness, AIA Report No. AIA-CPD-3, 1968.

4. Wullenwaber, GE: Smoke Hood Evaluation Program, Flight Standards Technical Division, FAA, Special Project Report No. 01271, 1968.

5. McFadden, EB and RC Smith: Protective Smoke Hood Studies, FAA Office of Aviation Medicine Report FAA-AM-70-20, 1970.

6. Personal Communications: Piedmont Airlines Adults for 1986.

7. Annon. The Second Health and Nutrition Examination Survey, 1976-1980. DWHS Pub. No. (PHS) 81-1317, Series 1, No. 15, 1981.

8. Snow, CC and RG Snyder: Anthropometry of Air Traffic Control Trainees, FAA Office of Aviation Medicine Report FAA-AM-65-26, 1965.

9. Kemsley, WFF: Women's Measurements and Sizes, Cheltenham Press, Cheltenham, UK, 1957.

10. Statistics Office, American Optometric Association, USA Population for 1985.

11. Vant, JHB: Smokehoods Donned Quickly - The Impact of Donning Smokehoods on Evacuation Times, AGARD-CCP-467, 1989.

12. Marrison, C, H Muir and AF Taylor: Passenger Evacuation: A Literature Review, Cranfield Institute of Technology, College of Aeronautics Report, July 1987.

*U.S.GPO:1991-561-116/40002