Final Report: Adaptive Assessment of Spatial Abilities

Isaac I. Bejar
Educational Testing Service
Princeton, NJ 08541

June 1986

Approved for public release; distribution unlimited. Reproduction in whole or in part is permitted for any purpose of the United States Government.

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-83-C-0761, Contract Authority Identification No. NR 150 531
Final Report: Adaptive Assessment of Spatial Abilities

Isaac I. Bejar

Final

FROM 10/83 TO 3/85
86 June

Spatial ability item response theory
cognitive psychology computerized testing

This report summarizes the results of an 18-month contract entitled Adaptive Assessment of Spatial Ability. The project was focused on the psychometric and technological feasibility of adaptive testing systems of a procedural as opposed to declarative nature. That is, adaptive testing systems where items are generated as needed rather than explicitly retrieved from a database. To investigate the feasibility of such an approach to adaptive testing data was collected from high school students on two types of spatial items, three-dimensional cubes and hidden figure items. The analysis of the three-dimensional cube focused on the fit of the simplest possible item response model capable of modeling response time; the analysis of the hidden figure item focused on the feasibility of generating item from an algorithm in such a way that the psychometric characteristics of the generated items were predictable. The results for the three-dimensional cube...
Items suggested that angular disparity can be used effectively to control the difficulty of true items but this was not the case for false items. That is, true and false items appear to measure different aspects of performance and as a result a multidimensional item response model may be necessary to fully account for performance on even fairly simple spatial items such as three-dimensional cubes. The analysis of the hidden figure items showed that an item generation algorithm can be formulated to produce items of similar psychometric characteristics. The practical and theoretical implication of the results are discussed.
Abstract

This report summarizes the results of an 18-month contract entitled Adaptive Assessment of Spatial Ability. The project was focused on the psychometric and technological feasibility of adaptive testing systems of a procedural as opposed to declarative nature. That is, adaptive testing systems where items are generated as needed rather than explicitly retrieved from a database. To investigate the feasibility of such an approach to adaptive testing data was collected from high school students on two types of spatial items, three-dimensional cubes and hidden figure items. The analysis of the three-dimensional cubes focused on the fit of the simplest possible item response model capable of modeling response time; the analysis of the hidden figure item focused on the feasibility of generating item from an algorithm in such a way that the psychometric characteristics of the generated items were predictable. The results for the three-dimensional cube items suggested that angular disparity can be used effectively to control the difficulty of true items but this was not the case for false items. That is, true and false items appear to measure different aspects of performance and as a result a multidimensional item response model may be necessary to fully account for performance on even fairly simple spatial items such as three-dimensional cubes. The analysis of the hidden figure items showed that an item generation algorithm can be formulated to produce items of similar psychometric characteristics. The practical and theoretical implication of the results are discussed.
Final Report: Adaptive Assessment of Spatial Abilities

Isaac I. Bejar

As the title of this project suggests, the aim of this research is to study the feasibility and requirements of adaptive testing for spatial ability. However, although the content of the research has been spatial abilities, the goal is in fact broader, namely to develop a methodology for what might be called second-generation adaptive testing that will be applicable not only to spatial but to other abilities as well.

First-generation adaptive testing methodology is well known and can be summarized as follows: Given a pool of items calibrated on a common scale, choose the set of items that is maximally informative for a given examinee. This methodology has now reached the point where it is a marketable product, and while there may still exist a need to do research on refinements of the methodology, the basic structure of the paradigm is well set.

A characteristic of first-generation adaptive testing is its declarative nature. That is, each item in the pool must be stored explicitly in a database along with its psychometric parameters with respect to some item response model. A natural elaboration of this approach was investigated in this project. That is, instead of our explicitly enumerating all the items, we investigated the idea of constructing algorithms that generate the items with control of their psychometric characteristics. Rather than calibrating specific items, we calibrated the procedures that generate the items. In short, the elaboration moves from a declarative approach to a procedural one.

Clearly, procedural adaptive testing involves more than psychometrics, since the encoding of items into procedures requires very specific knowledge about the determinants of item performance. It is precisely this requirement that offers some hope of improving the validational status of scores from an adaptive testing procedure. The current approach to adaptive testing improvement in validity is limited to the improvement accruing from more precise measurement. There is hope that the next generation in adaptive testing will improve the validational status of test-score interpretations by continually submitting to testing the theory of item performance embedded in the item-generation algorithm. As a result of that continual challenge, the theory will either be confirmed or revised, and it is very likely that in that process we will learn much about the psychological underpinnings of performance on the test.

The calibration of a procedure consists of item linking those determinants of performance to a psychometric scale. The details of how this is done vary with the item type. In this project, we experimented with a three-dimensional mental rotation item and a hidden-figure item type.
The Psychometrics of Three-dimensional Mental Rotation

An example of this item type is shown in Figure 1. This item type was chosen because there exists a large body of literature (cf., Corballis, 1982) establishing that an angular disparity between the two figures largely determines performance. Moreover, it appears that there are fairly stable and consistent gender differences in performance on mental-rotation tasks (Linn and Petersen, 1985).

The approach taken was to examine the simplest possible psychometric model of an 80-item test based on figures such as those in Figure 1. (There were eight basic items presented at five angles in their true and false version.) The items were presented at angular disparities of 20, 60, 100, 140, and 180 in order to establish the relationship between angular disparity and difficulty. The simplest model that can be fitted to these data makes the following predictions:

- The relationship between difficulty and angular disparity is linear.
- The slope of that relationship is constant at different response times.
- The intercept of the relationship is solely a function of response time.

This model is an extension of the dichotomous item-response model to the case in which the response is response time (see Samejima, 1973). Thus, to score an examinee, we simply note the response time to an item with a certain angular disparity. Together, the angular disparity and response time determine the corresponding difficulty, and they allow us to obtain an ability score for this examinee.

Figure 2 shows the result of a calibration for a typical item based on the responses of nearly 200 high school students. As can be seen, there are some departures from the predictions although, in general, the fit for this item is good. The major deviation from linearity occurred at 100 degrees. Also, beyond 5 seconds, a tendency towards a quadratic relationship between difficulty and angular disparity emerges, a situation which suggests that beyond a certain moment in time different strategies come into play.

The results for the false items are quite different, in that angular disparity does not seem to control performance as it does for the true items. That is, the false items seem to tap the decision aspect of performance, while the true items are tapping the mental rotation aspect. Figure 3 shows the corresponding data.

The results of this study are presented in more detail in The Psychometrics of Mental Rotation (RR-86-19). It is concluded that in
Figure 1

Sample True and False Three-dimensional Rotation Items
Figure 2
Relationship Between Psychometric Difficulty and Angular Disparity
After 3, 4, 5, 6 and 7 Seconds for True Version of Item E1

TRIANGLE = 3 SECONDS
PLUS = 4 SECONDS
STAR = 5 SECONDS
SQUARE = 6 SECONDS
DIAMOND = 7 SECONDS
Figure 3

Relationship Between Psychometric Difficulty and Angular Disparity

After 3, 4, 5, 6 and 7 Seconds for False Version of Item El

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangle</td>
<td>3 seconds</td>
</tr>
<tr>
<td>Plus</td>
<td>4 seconds</td>
</tr>
<tr>
<td>Star</td>
<td>5 seconds</td>
</tr>
<tr>
<td>Square</td>
<td>6 seconds</td>
</tr>
<tr>
<td>Diamond</td>
<td>7 seconds</td>
</tr>
</tbody>
</table>
practical applications, the appropriate psychometric model for this item type is a two-dimensional one. However, in a computerized testing environment, it may be unnecessary to embellish the psychometric model to account for curvilinear relationships between angular disparity and difficulty. Instead, in the tailoring of the test we chose items for an individual in such a way that a response is given within, say, 5 seconds. Such a tailoring strategy may have other benefits as well.

Hidden Figure Items

Unlike the mental-rotation items, for which the determinants of performance are fairly well known, very little is known about the determinants of performance in hidden-figure items. Therefore, our first task was to discover a psychometrically useful representation of the item. There were two important constraints on that representation. One was that it should provide a description of the item that captures the "psychometric essence" of the items. Ideally, that representation should be psychologically motivated, that is, motivated by previous research on the processes and mental models that account for performance on this type of cognitive task. Unfortunately, for the hidden-figure item, it was not possible to locate the relevant research. In addition, the representation should lend itself to generating items that had the same underlying representation but a different visual realization. For convenience, we call the items generated in this fashion clones. Figure 4 shows a pair of clones.

The chosen representation is a matrix consisting of counts indicating how close the target figure appears at each possible position in the larger pattern and was based on the Hough transform (Mayhew and Frisby, 1984), an artificial intelligence technique used in object recognition. We tested the psychometric validity of this representation by implementing a computer program capable of generating psychometric clones and then by comparing their psychometric characteristics on the basis of responses from high school students.

The item generation algorithm takes the matrix of counts together with a small pattern and tries to create a large pattern that matches the matrix. The generation process is simplified by the fact that patterns only contain horizontal, vertical, and 45 degree lines between nodes. The basic idea is to start with a large pattern including all the possible lines and remove lines until the matching algorithm produces a matrix that equals the input matrix.

The results demonstrated that the clones behaved as such in terms of their difficulty as well as distribution of response times. Figure 5 shows the relationship between the logit for proportion correct and for pairs of clones as well as the corresponding mean response time. Figure 6 shows the cumulative response times for two clones. It can be seen they are very similar, and this was true for the other items as well. The results of this experiment appear in more detail in Analysis and Generation of Hidden Figure Items: A Cognitive Approach to Psychometric Modeling (RR-86-20).
Figure 4
Sample Hidden Figure Items Clones
Figure 5

Relationship Between Accuracy and Latency for Hidden Figure Clones

RELATIONSHIPS BETWEEN DIFFICULTY
FOR CLONES A AND B

RELATIONSHIPS BETWEEN RESPONSE LATENCY
FOR CLONES A AND B
Figure 6

Cumulative Frequency Distribution of Response Times for Two Clones

TIME IN SECONDS

CUMULATIVE FREQUENCY

0.00  0.25  0.50  0.75  1.00
Summary

The choice of item types in this study was not accidental: they were chosen to maximize the chance of a positive demonstration of what we have called "procedural adaptive testing." The essential characteristic of procedural adaptive testing is that, unlike "conventional" adaptive testing, all the items and their associated item parameter estimates need not be stored ahead of time in a database. Instead, through a design incorporating the major determinants of performance on that item, data are collected to determine the relationship between design and psychometric parameters. This simple distinction, however, has important ramifications.

At a practical level, procedural adaptive testing is likely to be more economical since it avoids the need to calibrate a large number of items. This economy may prove advantageous even in paper-and-pencil tests by facilitating the creation of a priori parallel forms and, in general, by better controlling the psychometric characteristics of the items that are placed on the test. (In fact, the item-generation program developed for the hidden-figure item has been used in the development of a Navy pilot test.)

However, the most important implication of procedural adaptive testing may not be its practical value but the constraint that it imposes on the psychometrician. It is no longer sufficient to gather, calibrate, and link items—as if these tasks were not demanding enough. To implement a procedural adaptive test, it is also necessary to have a theory of item performance at a level of specificity that new items can be produced on-line and under computer control. These are not trivial requirements, especially in verbal domains. Thus, in attempting to fulfill this requirement it will be necessary to gather documentation of psychological research related to performance on the item type in question, and if that knowledge is not yet available, go ahead and obtain it. This process will inevitably lead to a better understanding of test scores.

Conclusions

Psychologists, from psychometric and cognitive perspectives, have been interested in spatial ability for some time. Psychometricians should clearly be credited with the discovery and initial study of "spatial abilities." But it is equally clear that cognitive psychologists deserve credit for the understanding we have today about the nature of those abilities. Having a better understanding, however, does not mean that we are more certain about how to measure spatial abilities. Just and Carpenter (1985), for example, concluded that "item and test difficulty may be major determinants of what strategies and processes will be evoked in a task." By suggesting that item and test difficulty are causes, rather than the result of those strategies and processes, they seem to suggest that psychometric and psychological models are concerned with different phenomena. The alternative view is that not only are both models attempting to explain different manifestations of the same phenomena, but in addition the parameters of the psychometric model ought to be explainable by the psychological theory.
Adopting this view creates the potential for measurement instruments that are both theoretically and psychometrically sound. Although this project focused from the start on the development of more advanced adaptive tests, it seems that even if this had not been the case the conclusion about the need for adaptive testing would have been inescapable. If, as Just and Carpenter suggest, different strategies are invoked by items of a certain difficulty level, then it appears that a valuable contribution of adaptive testing is its preventing the use of different strategies by controlling the difficulty of items presented to the examinee. The three-dimensional rotation data collected as part of this project suggest that different strategies may emerge if an examinee has not made a decision after five seconds. In an adaptive test it would be relatively simple to select items in such a way that the response would be given within, say, five seconds. This motivation for tailoring does not negate the valuable information that may lie in the ability to choose different strategies. Rather, through better control of what a given test measures, we are likely to improve the precision and validity of test outcomes. Indeed, we may be able to detect with more certainty the presence of alternative strategies by being able to identify respondents that depart from an expected pattern of performance.

Other Reports


Samejima, F. (December, 1983). A general model for the homogeneous case of the continuous response. (ONR/RR-83-3), University of Tennessee.
Personnel Analysis Division, 
AF/MPXA
5C360, The Pentagon 
Washington, DC 20330

Air Force Human Resources Lab 
AFHRL/MPD
Brooks AFB, TX 78235

Dr. Earl A. Alluisi 
HQ, AFHRL (AFSC) 
Brooks AFB, TX 78235

Dr. Erling B. Andersen 
Department of Statistics 
Studiestraede 6 
1455 Copenhagen 
DENMARK

Dr. Phipps Arabie 
University of Illinois 
Department of Psychology 
603 E. Daniel St. 
Champaign, IL 61820

Technical Director, ARI 
5001 Eisenhower Avenue 
Alexandria, VA 22333

Dr. Eva L. Baker 
UCLA Center for the Study of Evaluation 
145 Moore Hall 
University of California 
Los Angeles, CA 90024

Dr. Isaac Bejar 
Educational Testing Service 
Princeton, NJ 08450

Dr. Menucha Birenbaum 
School of Education 
Tel Aviv University 
Tel Aviv, Ramat Aviv 69978 
ISRAEL

Dr. Arthur S. Blaiwes 
Code N711 
Naval Training Systems Center 
Orlando, FL 32813

Dr. Bruce Bloxom 
Administrative Sciences 
Code 54B1 
Navy Postgraduate School 
Monterey, CA 93943-5100

Dr. R. Darrell Bock 
University of Chicago 
NORC 
6030 South Ellis 
Chicago, IL 60637

Cdt. Arnold Bohrer 
Sectie Psychologisch Onderzoek 
Rekruterings-En Selectiecentrum 
Kwartier Koningen Astrid 
Bruijnstraat 
1120 Brussels, BELGIUM

Dr. Robert Breaux 
Code N-095R 
Naval Training Systems Center 
Orlando, FL 32813

Dr. Robert Brennan 
American College Testing Programs 
P. O. ox 168 
Iowa City, IA 52243

Dr. Patricia A. Butler 
OERI 
555 New Jersey Ave., NW 
Washington, DC 20208

Mr. James W. Carey 
Commandant (G-PTE) 
U.S. Coast Guard 
2100 Second Street, S.W. 
Washington, DC 20593

Dr. James Carlson 
American College Testing Program 
P.O. Box 168 
Iowa City, IA 52243

Dr. John B. Carroll 
409 Elliott Rd. 
Chapel Hill, NC 27514
Dr. Gerhard Fischer  
Liebiggasse 5/3  
A 1010 Vienna  
AUSTRIA

Prof. Donald Fitzgerald  
University of New England  
Department of Psychology  
Armidale, New South Wales 2351  
AUSTRALIA

Mr. Paul Foley  
Navy Personnel R&D Center  
San Diego, CA 92152-6800

Dr. Carl H. Frederiksen  
McGill University  
3700 McTavish Street  
Montreal, Quebec H3A 1Y2  
CANADA

Dr. Robert D. Gibbons  
University of Illinois-Chicago  
P.O. Box 6998  
Chicago, IL 60680

Dr. Janice Gifford  
University of Massachusetts  
School of Education  
Amherst, MA 01003

Dr. Robert Glaser  
Learning Research & Development Center  
University of Pittsburgh  
3939 O'Hara Street  
Pittsburgh, PA 15260

Dr. Bert Green  
Johns Hopkins University  
Department of Psychology  
Charles & 34th Street  
Baltimore, MD 21218

Dr. Ronald K. Hambleton  
Prof. of Education & Psychology  
University of Massachusetts at Amherst  
Hills House  
Amherst, MA 01003

Ms. Rebecca Hetter  
Navy Personnel R&D Center  
Code 62  
San Diego, CA 92152-6800

Dr. Paul W. Holland  
Educational Testing Service  
Rosedale Road  
Princeton, NJ 08541

Prof. Lutz F. Hornke  
Institut fur Psychologie  
RWTH Aachen  
Jaegerstrasse 17/19  
D-5100 Aachen  
WEST GERMANY

Dr. Paul Horst  
677 G Street, #184  
Chula Vista, CA 90010

Mr. Dick Hoshaw  
OP-135  
Arlington Annex  
Room 2834  
Washington, DC 20350

Dr. Lloyd Humphreys  
University of Illinois  
Department of Psychology  
603 East Daniel Street  
Champaign, IL 61820

Dr. Steven Hunka  
Department of Education  
University of Alberta  
Edmonton, Alberta  
CANADA

Dr. Huynh Huynh  
College of Education  
Univ. of South Carolina  
Columbia, SC 29208

Dr. Robert Jannarone  
Department of Psychology  
University of South Carolina  
Columbia, SC 29208

Dr. Douglas A. Jones  
P.O. Box 6640  
Lawrenceville  
NJ 08648
Educational Testing Service/Bejar

Dr. G. Gage Kingsbury
Portland Public Schools
Research and Evaluation Department
501 North Dixon Street
P. O. Box 3107
Portland, OR 97209-3107

Dr. William Koch
University of Texas-Austin
Measurement and Evaluation Center
Austin, TX 78703

Dr. Leonard Kroeker
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Michael Levine
Educational Psychology
210 Education Bldg.
University of Illinois
Champaign, IL 61801

Dr. Charles Lewis
Faculteit Sociale Wetenschappen
Rijksuniversiteit Groningen
Oude Boteringestraat 23
9712GC Groningen
The NETHERLANDS

Dr. Robert Linn
College of Education
University of Illinois
Urbana, IL 61801

Dr. Robert Lockman
Center for Naval Analysis
4401 Ford Avenue
P.O. Box 16268
Alexandria, VA 22302-0268

Dr. Frederic M. Lord
Educational Testing Service
Princeton, NJ 08541

Dr. James Lumsden
Department of Psychology
University of Western Australia
Nedlands W.A. 6009
AUSTRALIA

Dr. William L. Maloy
Chief of Naval Education and Training
Naval Air Station
Pensacola, FL 32508

Dr. Gary Marco
Stop 31-E
Educational Testing Service
Princeton, NJ 08451

Dr. Clessen Martin
Army Research Institute
5001 Eisenhower Blvd.
Alexandria, VA 22333

Dr. James McBride
Psychological Corporation
c/o Harcourt, Brace, Jovanovich Inc.
1250 West 6th Street
San Diego, CA 92101

Dr. Clarence McCormick
HQ, MEPCOM
MEPCT-P
2500 Green Bay Road
North Chicago, IL 60064

Mr. Robert McKinley
University of Toledo
Department of Educational Psychology
Toledo, OH 43606

Dr. Barbara Means
Human Resources Research Organization
1100 South Washington
Alexandria, VA 22314

Dr. Robert Mislevy
Educational Testing Service
Princeton, NJ 08541

Headquarters, Marine Corps
Code MPI-20
Washington, DC 20380

Dr. W. Alan Nicewander
Department of Psychology
Oklahoma City, OK 73069
Dr. William E. Nordbrock  
FMC-ADCO Box 25  
APO, NY 09710  

Dr. Melvin R. Novick  
356 Lindquist Center  
for Measurement  
University of Iowa  
Iowa City, IA 52242  

Director, Manpower and Personnel Laboratory,  
NPRDC (Code 06)  
San Diego, CA 92152-6800  

Library, NPRDC  
Code P201L  
San Diego, CA 92152-6800  

Commanding Officer,  
Naval Research Laboratory  
Code 2627  
Washington, DC 20390  

Dr. James Olson  
WICAT, Inc.  
1875 South State Street  
Orem, UT 84057  

Office of Naval Research,  
Code 1142PT  
800 N. Quincy Street  
Arlington, VA 22217-5000  
(6 Copies)  

Special Assistant for Marine Corps Matters,  
ONR Code OOMC  
800 N. Quincy St.  
Arlington, VA 22217-5000  

Dr. Judith Orasanu  
Army Research Institute  
5001 Eisenhower Avenue  
Alexandria, VA 22333  

Wayne M. Patience  
American Council on Education  
GED Testing Service, Suite 20  
One Dupont Circle, NW  
Washington, DC 20036  

Dr. James Paulson  
Department of Psychology  
Portland State University  
P.O. Box 751  
Portland, OR 97207  

Dr. Roger Pennell  
Air Force Human Resources Laboratory  
Lowry AFB, CO 80230  

Dr. Mark D. Reckase  
ACT  
P. O. Box 168  
Iowa City, IA 52243  

Dr. Malcolm Ree  
AFHRL/MP  
Brooks AFB, TX 78235  

Dr. Carl Ross  
CNET-PDCD  
Building 90  
Great Lakes NTC, IL 60088  

Dr. J. Ryan  
Department of Education  
University of South Carolina  
Columbia, SC 29208  

Dr. Fumiko Samejima  
Department of Psychology  
University of Tennessee  
Knoxville, TN 37916  

Mr. Drew Sands  
NPRDC Code 62  
San Diego, CA 92152-6800  

Dr. Robert Sasmor  
HQDA DAMA-ARL  
Pentagon, Room 3E516  
Washington, DC 20310-0631  
USA  

Dr. Mary Schratz  
Navy Personnel R&D Center  
San Diego, CA 92152-6800  

Dr. W. Steve Sellman  
OASD(MR&L)  
2B269 The Pentagon  
Washington, DC 20301
Mr. Brad Symson  
Navy Personnel R&D Center  
San Diego, CA 92152-6800

Dr. Kikumi Tatsuoka  
CERL  
252 Engineering Research Laboratory  
Urbana, IL 61801

Dr. Maurice Tatsuoka  
220 Education Bldg  
1310 S. Sixth St.  
Champaign, IL 61820

Dr. David Thissen  
Department of Psychology  
University of Kansas  
Lawrence, KS 66044

Mr. Gary Thomasson  
University of Illinois  
Educational Psychology  
Champaign, IL 61820

Dr. Robert Tsutakawa  
University of Missouri  
Department of Statistics  
222 Math. Sciences Bldg.  
Columbia, MO 65211

Dr. Ledyard Tucker  
University of Illinois  
Department of Psychology  
603 E. Daniel Street  
Champaign, IL 61820

Dr. Vern W. Urry  
Personnel R&D Center  
Office of Personnel Management  
1900 E. Street, NW  
Washington, DC 20415

Dr. David Vale  
Assessment Systems Corp.  
2233 University Avenue  
Suite 310  
St. Paul, MN 55114

Dr. Frank Vicino  
Navy Personnel R&D Center  
San Diego, CA 92152-6800

Dr. Kazuo Shigemasu  
7-9-24 Kugenuma-Kaiga  
Fujusawa 251  
JAPAN

Dr. William Sims  
Center for Naval Analysis  
4401 Ford Avenue  
P.O. Box 16268  
Alexandria, VA 22302-0268

Dr. H. Wallace Sinaiko  
Manpower Research  
and Advisory Services  
Smithsonian Institution  
801 North Pitt Street  
Alexandria, VA 22314

Dr. Richard Sorensen  
Navy Personnel R&D Center  
San Diego, CA 92152-6800

Dr. Paul Speckman  
University of Missouri  
Department of Statistics  
Columbia, MO 65201

Dr. Martha Stocking  
Educational Testing Service  
Princeton, NJ 08541

Dr. Peter Stoloff  
Center for Naval Analysis  
200 North Beauregard Street  
Alexandria, VA 22311

Dr. William Stout  
University of Illinois  
Department of Mathematics  
Urbana, IL 61801

Maj. Bill Strickland  
AF/MFXOA  
4E168 Pentagon  
Washington, DC 20330

Dr. Hariharan Swaminathan  
Laboratory of Psychometric and Evaluation Research  
School of Education  
University of Massachusetts  
Amherst, MA 01003
Dr. Howard Wainer  
Division of Psychological Studies  
Educational Testing Service  
Princeton, NJ 08541

Dr. Ming-Mei Wang  
Lindquist Center for Measurement  
University of Iowa  
Iowa City, IA 52242

Dr. Thomas A. Warm  
Coast Guard Institute  
P. O. Substation 18  
Oklahoma City, OK 73169

Dr. Brian Waters  
Program Manager  
Manpower Analysis Program  
HumRRO  
1100 S. Washington St.  
Alexandria, VA 22314

Dr. David J. Weiss  
N660 Elliott Hall  
University of Minnesota  
75 E. River Road  
Minneapolis, MN 55455

Dr. Ronald A. Weitzman  
NPS, Code 54Wz  
Monterey, CA 92152-6800

Major John Welsh  
AFHRL/MOAN  
Brooks AFB, TX 78223

Dr. Rand R. Wilcox  
University of Southern California  
Department of Psychology  
Los Angeles, CA 90007

German Military Representative  
ATTN: Wolfgang Wildegrube  
Streitkraefteamt  
D-5300 Bonn 2  
4000 Brandywine Street, NW  
Washington, DC 20016

Dr. Bruce Williams  
Department of Educational Psychology  
University of Illinois  
Urbana, IL 61801

Dr. Hilda Wing  
Army Research Institute  
5001 Eisenhower Ave.  
Alexandria, VA 22333

Dr. Martin F. Wiskoff  
Navy Personnel R & D Center  
San Diego, CA 92152-6800

Mr. John H. Wolfe  
Navy Personnel R&D Center  
San Diego, CA 92152-6800

Dr. George Wong  
Biostatistics Laboratory  
Memorial Sloan-Kettering Cancer Center  
1275 York Avenue  
New York, NY 10021

Dr. Wendy Yen  
CTB/McGraw Hill  
Del Monte Research Park  
Monterey, CA 93940
END

1 - 81

DTIC