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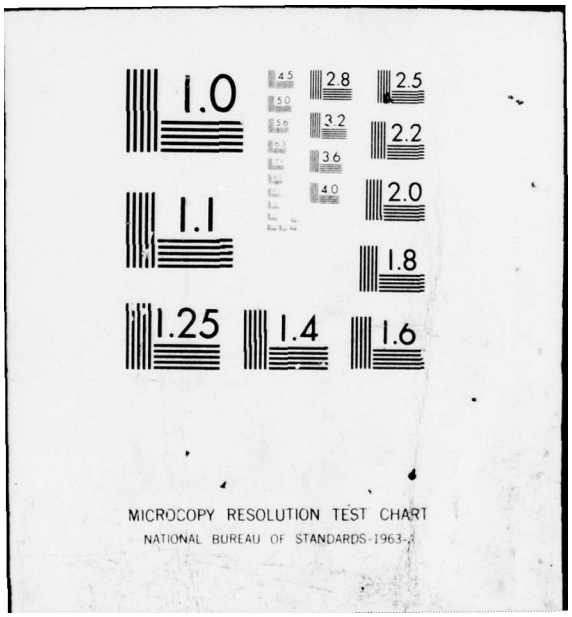
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Final Report:

BIAS-FREE COMPUTERIZED TESTING

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Steven M. Pine

and

David J. Weiss

March 1979

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Steven M. Pine, Principal Investigator

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racial bias	item calibration	factor composition

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Summarized in this report is research from a project designed to investigate the utility of item characteristic curve theory and computerized adaptive testing as means of measuring and reducing ethnic bias and unfairness in ability tests. Included are a summary of the research, conclusions and recommendations, and abstracts of all previous reports. Research in this project comprised a theory development phase and an application phase. During the theory development phase, an item characteristic curve theory model of bias was developed and used in computer simulation studies which inves- →

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tigated the bias reduction and fairness properties of computerized adaptive testing. In addition, a methodology for detecting test item bias was developed and validated. In the application phase the bias detection methodology was applied to six sets of real test data. In addition, the bias-reduction properties of computerized adaptive testing were examined in a live-testing study conducted in a racially mixed high school. The results of this research indicate that (1) item characteristic curve theory provides a viable model for detecting item bias; (2) the incidence of item bias in existing tests is small, but because of its potential adverse effects, ability tests should be carefully examined for possible bias; (3) Black students have different psychological reactions to the conditions of testing than White students; and (4) computerized adaptive testing can improve ability measurement for Black students.

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Final Report:
Bias-Free Computerized Testing

This is the final report of a project which examined item characteristic curve theory and computerized adaptive testing as possible means of measuring and reducing ethnic bias in ability tests. The objectives of this project included the evaluation of bias in existing tests and the exploration of the potential of adaptive testing for improving ability measurement in minority groups. Included in this report are a brief description of the background for this research; the project objectives; and a summary of the research methodology, major findings, and conclusions. Also included are abstracts of the six Technical Reports published and a listing of all other papers completed under this project.

Background

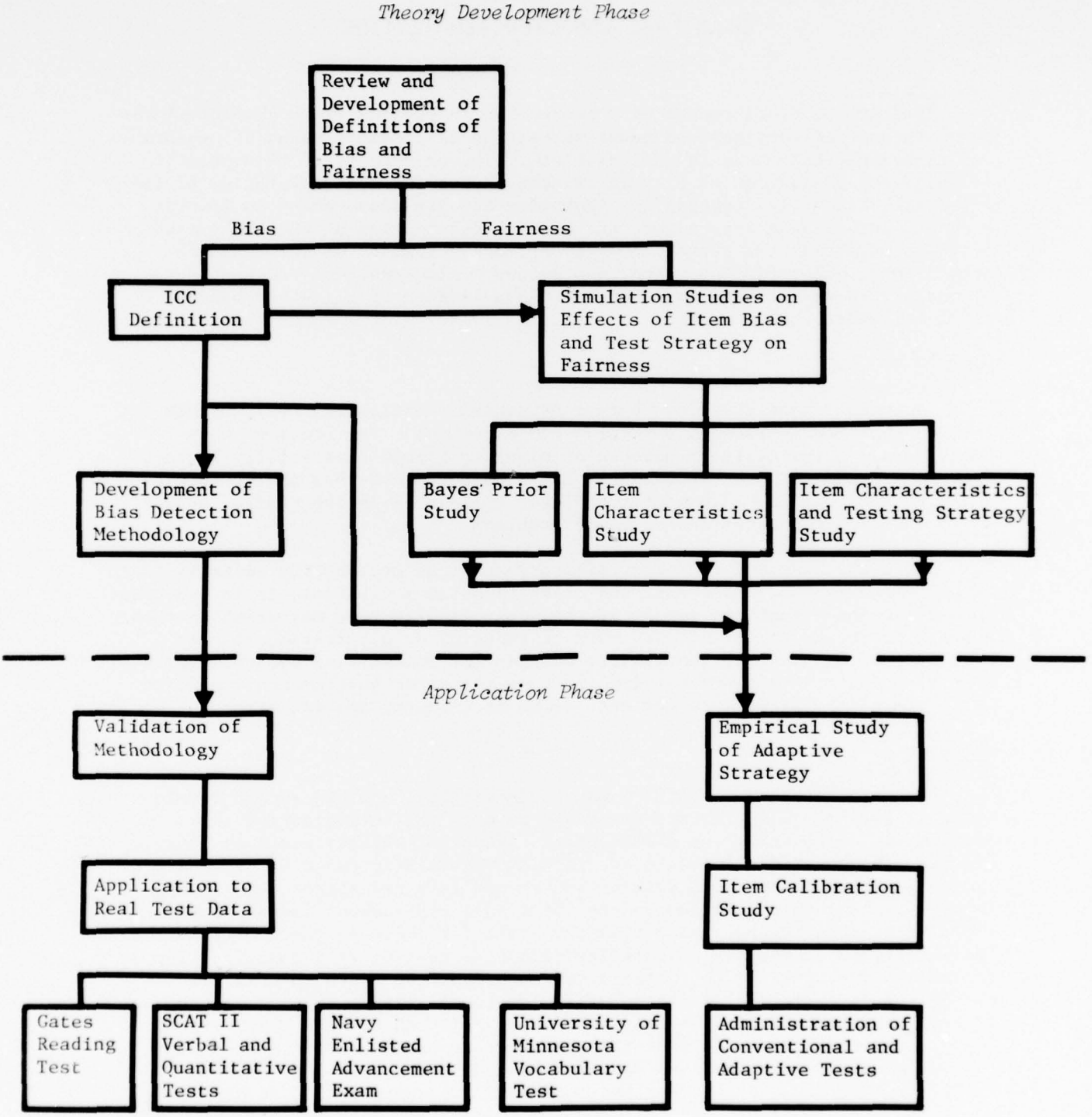
In recent years there has been considerable controversy over the use of ability tests for personnel selection and placement. The focus of this controversy is the claim by members of minority groups that ability tests constructed under current procedures are biased against them and therefore unfair. This has led to a number of legal challenges in the courts, as well as to a search for solutions to these problems.

Since the Navy and the other military services use ability tests in their personnel selection, placement, and classification activities, it is important to examine the extent and impact of the possible bias that may exist in their ability tests and to investigate ways of reducing or eliminating it. In addition, development of generalized methods for identifying and eliminating test bias would have important implications for other governmental agencies which use tests, as well as for test users in industry and education.

Objectives

The purpose of this contract was to investigate how two recent developments in psychological measurement could be used for investigating and eliminating or reducing the differential effects of ability tests on minority groups. These two developments are item characteristic curve (ICC) theory and computerized adaptive testing. ICC theory is a new approach to psychological testing which emerged in the 1960s as a replacement for the traditional test theories that have been the basis for the construction of ability tests for over 50 years. Computerized adaptive testing is the application of on-line computers to the administration of ability tests which adapt themselves to individual differences in levels of ability during the process of test administration. The basic advances in ICC theory and computerized adaptive testing are being made through other research contracts under the support of the Office of Naval Research Personnel and Training Research Programs. The present contract was concerned with whether ICC theory and

Figure 1
Bias-Free Computerized Testing Research Program



computerized adaptive testing could be used to improve ability testing for members of minority groups.

Approach and Major Results

The research activities designed to address this question were organized into a theory development phase and an application phase as shown in Figure 1. The theory development phase, diagrammed in Figure 1 above the dashed line, had as its purpose the definition of the problem in operational terms and the development of a theoretical base to measure the relevant variables. In the application phase, shown below the dashed line in Figure 1, the concepts developed in the theory development phase were tested in a series of empirical studies.

Theory development phase. The first step in the theory development phase was to review the literature on the definitions of terms and existing methodologies with regard to test bias and test fairness (Research Report 76-5). This review led to a distinction between test bias and test fairness which had not been clearly articulated earlier in the literature. Test bias was defined as characteristics of the items constituting the test. Fairness, on the other hand, was defined as a characteristic of the test itself and the use to which it is put. Thus, it was possible that a test composed of unbiased test items could still be used unfairly to discriminate against members of minority groups. The importance of this distinction is that it permitted a division of relevant research into two separable areas--bias and fairness--and a clarification of the issues involved. Once the distinction between bias and fairness is clearly understood by test users, it should be possible in a given situation to define clearly whether it is the test itself that is at fault (bias) or whether it is the use to which the test scores are to be put (fairness) that causes the undesirable results.

In addition, this distinction served to concentrate effort separately on the two types of issues involved. Thus, with regard to test bias, the distinction first led to a definition of test bias phrased in terms of ICC theory. This, in turn, led to a procedure for the detection of bias in test items.

With regard to test fairness, the ICC definition of test bias had implications for a series of computer simulation studies on the effects of item bias and test strategy on test fairness (Research Reports 76-5 and 78-1). These studies varied three major variables: (1) characteristics of a Bayesian adaptive testing strategy (Research Report 78-1), (2) the effects of item characteristics on test fairness (Research Report 76-5), and (3) the interaction of item characteristics and testing strategy (Research Report 78-1). A general conclusion drawn from the simulation studies, based on the models developed in this project, was that computerized adaptive testing could be designed to take into account the bias existing in test items in such a way that the fairness of resultant applications of test scores would be considerably reduced over that from conventional tests. Thus, the simulation studies showed that computerized adaptive testing, in conjunction with the ICC definition of test bias and the methodologies for its detection which were developed in this project, could result in fairer tests.

Application phase. The methodologies developed in the theory development phase were then applied in empirical studies in the application phase. These activities followed the basic distinction between bias and fairness developed in the theory development phase. With regard to item bias, the bias detection methodology developed earlier in the project was validated and was applied to several sets of real test data.

The question in the validation phase was whether or not it was possible to use the methodology developed to detect items which were known to be biased. To investigate this question (Research Report 78-3), a test was purposely constructed which consisted of some biased items; this test was administered to groups of differing racial composition. The data analysis was concerned with determining whether the methods developed in the theory development phase were able to identify as biased those items which were known to be heavily biased. The test was a vocabulary test consisting of 127 items; one-third of the test items were written to be biased in favor of Black students. These items were multiple-choice items in which the correct answer was a definition indigenous to the Black culture that would not be common knowledge to White students; the remainder of the response alternatives were definitions which would be correct in neither culture. Similarly, one-third of the words in the test were biased in favor of White students. These were test items which would be predominately known in the White culture and not in the Black culture. The rest of the words in the test were standard vocabulary items taken from a pool of 600 vocabulary test items used in adaptive testing research at the University of Minnesota.

The results of this study showed that the methodology developed to detect bias correctly identified a portion of the *a priori* biased items for both Black students and White students. The most strongly biased items in this analysis are shown in Table 1. The three most strongly biased items against White students were "shouting," "fry," and "African dominoes"; and those most strongly biased against Black students were "cameo" and "lox." In each case, the definition of bias was based on the fact that White students (or Black students) performed more poorly on these test items than did members of the other group.

Table 1
Biased Items Identified as Biased
by the ICC-Based Procedure

Item	Correct Answer
Items Biased Against Whites	
shouting	in religious sense
fry	to curl one's hair
African dominoes	dice game
Items Biased Against Blacks	
cameo	gem carved in relief
lox	smoked salmon

Given the validation of the bias detection methodology as a result of this live-testing application, the methodology was applied to a number of

other data sets (Research Reports 77-1, 78-3, and 78-5), as summarized in Figure 2. Application of the methodology requires two sets of data on a majority and a minority group. The data are factor analyzed, and if one dominant factor appears for each of the two groups, the process continues. If more than one factor is detected in either group, other methods are required to answer the question. For those data sets in which one factor exists, the procedure continues by splitting the majority group into two subgroups--J1 and J2. ICC item parameterization methods are then used to estimate the difficulty (b) parameter for both of the majority subgroups and for the minority group.

The resulting values are compared by a statistical methodology developed in this research to determine whether or not some of the items in the test are biased. Two outcomes may result from this analysis. Either the items will be found to be biased, or they will not. If no items are found to be biased, then the factors obtained in the two groups are compared; if the factors are comparable, the test items can be said to be unbiased. If the factors are not found to be comparable, this may indicate that there is a constant degree of bias in all the items or that the test measures different dimensions for the two racial groups.

If some items are biased, the question to be raised is whether the items are reliably biased. This is studied by a comparison of the item bias values for each of the majority subgroups versus the minority group, which then leads to a conclusion of either unreliably biased or reliably biased items. If the items are reliably biased, the question of the comparability of factors is investigated by comparing the factors in the two groups. Depending on the outcome of this comparison, it can be concluded that (1) the test measures the same thing for both groups, but with some biased items, or that (2) the test is biased on different dimensions.

This methodology was subsequently applied to seven different tests to determine degrees of bias in those test items. The test included the Gates Reading Test (a test used in elementary and high schools), the Navy Enlisted Advancement Examinations for Boiler Technician and Advanced Machinists Mate, the verbal and quantitative sections of the School and College Aptitude Tests (SCAT II; Research Report 78-5), and ability tests developed for this research at the University of Minnesota (Research Reports 77-1 and 78-3). The results shown in Table 2 indicate that there were very low levels of bias in the majority of the tests, using the methodology developed. The test with the highest degree of bias was the one discussed above, which was explicitly developed to have large numbers of biased items. Each of the remaining tests, with the exception of the Navy Enlisted Advancement Examinations, was found to have two or three biased items. These results imply that there are a small number of biased items on some ability tests, and care should be taken to screen items in ability tests in order to remove items which display subgroup biases.

The results shown in Table 2 indicate that the Navy Enlisted Advancement Examinations were not completely analyzed. These tests were tests of achievement and were found to be highly multidimensional. Consequently, they did not meet the single-factor criterion required by the bias measurement methodology. More research is needed to develop methods for the detection of bias in achievement tests.

Figure 2
Flow Chart for the Analysis of Item Bias

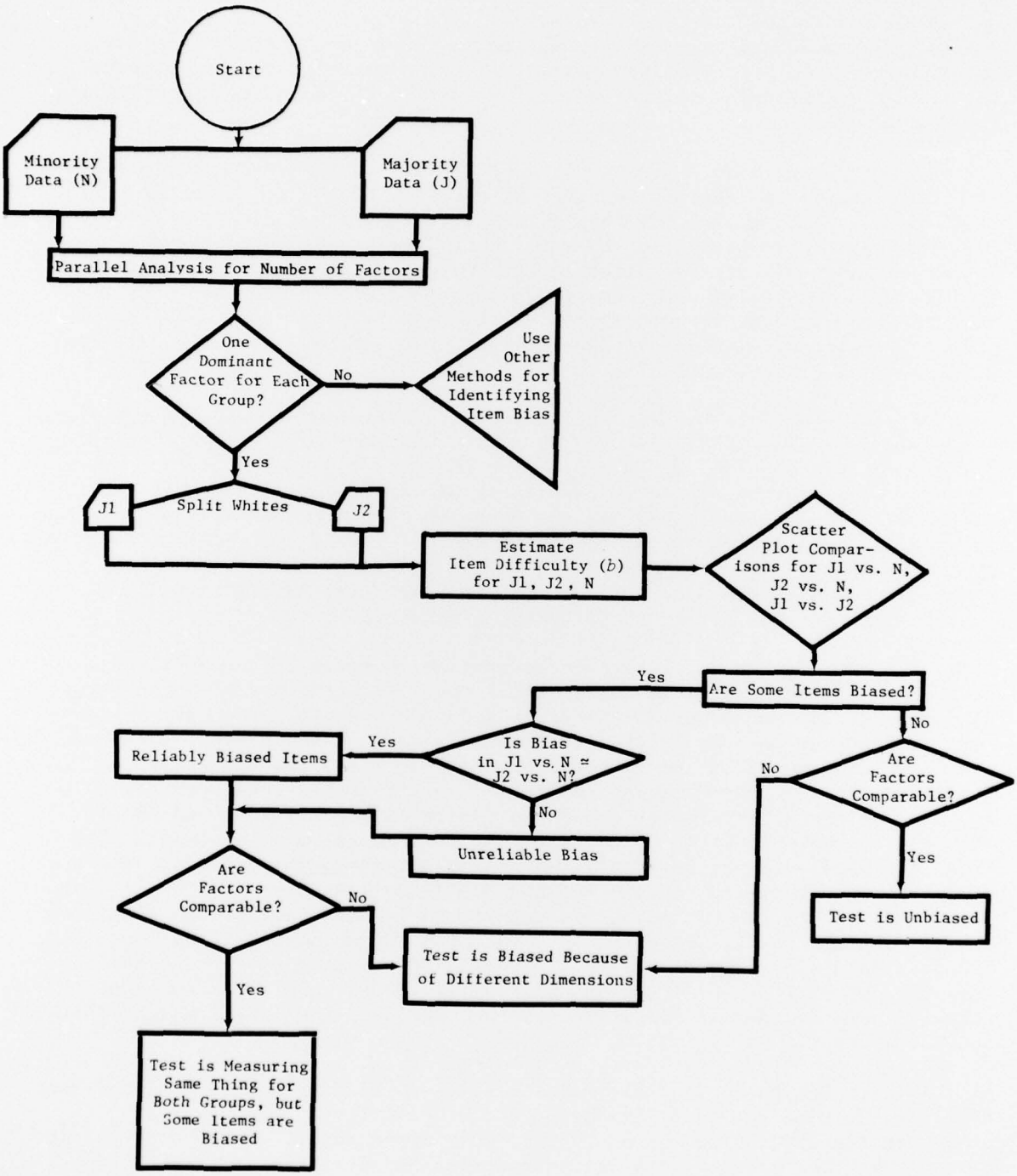


Table 2
Summary of the Extent of Bias Found in Seven Sets of Test Data

Test	Type	Sample Size		Number of Items	
		Minority	Majority	Total	Biased
Gates Reading Test	Reading Test	261	578	50	2
Navy Enlisted Advancement Exam	Boiler Technician	79	498	150	*
Navy Enlisted Advancement Exam	Advanced Machinists Mate	47	656	150	*
SCAT II	Verbal	129	251	45	2
SCAT II	Quantitative	129	251	45	3
U of Minnesota Ability Test	Vocabulary	58	168	75	2
"Biased Test"**	Vocabulary	92	173	127	12

* Bias analysis could not be applied due to multidimensionality of test items.

** This was the validation test discussed above.

The second part of the application phase of this project was a live-testing study which compared strategies of computerized adaptive testing designed to reduce test bias with conventional tests typically used to measure verbal ability (Research Report 79-2). In addition to studying the specially designed bias-reduction properties of adaptive testing, a variable found in a related project was studied to determine its effect on test performance. This variable was the effect of immediate knowledge of results on the ability test performance of Black and White high school students. Additional dependent variables in this study were the reactions of the students to the test-taking conditions. The results of this study showed that Black students reacted differently than White students to the conditions of testing, specifically to the provision of immediate knowledge of results and the mode of test administration. The Black students were also more motivated by the adaptive tests than by the conventional tests. The ability data showed that the bias-reduced tests eliminated mean racial differences in ability estimates when these tests were administered without knowledge of results. Thus, it is relevant to consider, not only the items themselves in terms of their bias, but the conditions and strategies of test administration as well, in an attempt to reduce the adverse effects of ability tests on the scores and performance of members of minority groups.

Conclusions

This was the first research project in which item characteristic curve theory and computerized adaptive testing were investigated as means of improving ability tests for minorities. Based on the findings of this project, it appears that item characteristic curve theory and computerized adaptive testing, used either singly or jointly, are viable means of accomplishing this objective.

Seven tests, including the Navy Enlisted Advancement Examination, were examined for bias using a methodology based on ICC theory developed in this

project. On the average, about 4% of the test items examined were found to be biased. Although this is a relatively small amount of bias, it could lead to a relatively large number of individuals being discriminated against in a large-scale testing program. Therefore, methods such as the one developed in this project should be used regularly during the earlier stages of test development to screen out biased items.

The potential of adaptive testing for reducing bias and test unfairness was explored by using computer simulations of one adaptive testing procedure, as well as by the administration of actual computerized adaptive tests in a public high school. The general conclusion drawn from the simulation studies was that adaptive tests, because of their ability to tailor item administration to the individual being tested, have the potential to be more reliable and fair for members of minority groups than conventional tests. This general finding was further explored in the live-testing, as opposed to simulated-testing, phase of this project.

The live-testing phase, conducted in a racially mixed public high school, compared several adaptive and several paper-and-pencil tests of verbal ability. In addition, the effect of immediate knowledge of results was also examined. The results of this study supported earlier research in showing that Black students had different psychological reactions than White students to the conditions of testing, specifically to the provision of immediate knowledge of results and the mode of test administration (computerized versus paper-and-pencil). The data also showed that under certain conditions, the bias-reduced tests eliminated mean racial group differences in ability estimates.

In addition, evidence was found in this research program to support the idea that computerized adaptive testing can improve ability measurement for Black students in several ways. Finally, the overall results, both for Black and White students, added to the growing body of evidence which indicates the general superiority of computerized adaptive testing over conventional paper-and-pencil testing in the measurement of abilities.

ABSTRACTS OF RESEARCH REPORTS

Research Report 76-5

Effects of Item Characteristics on Test Fairness

Steven M. Pine and David J. Weiss

December 1976

This report examines how selection fairness is influenced by the item characteristics of a selection instrument in terms of its distribution of item difficulties, level of item discrimination, and degree of item bias. Computer simulation was used in the administration of conventional ability tests to a hypothetical target population consisting of a minority and a majority subgroup. Fairness was evaluated by three indices which reflect the degree of differential validity, errors in prediction (Cleary's model), and proportion of applicants exceeding a selection cutoff (Thorndike's model). Major findings were that (1) tests with a uniform distribution of difficulties had fairness properties generally superior to tests having a peaked distribution of item difficulties; (2) subgroup validity differences can be expected to occur when test items are biased against one of the subgroups; (3) when differential prediction is used, the Thorndike model reflects varying degrees of unfairness due to item bias and other test characteristics, while the Cleary and validity models do not; (4) differential prediction provides fairer selection than the use of majority prediction only, regardless of the internal characteristics of the test, although substantial degrees of unfairness still exist under certain test item configurations. It was concluded that the internal characteristics of a selection instrument will affect the fairness of test scores in specific applications and that further research is needed to delineate which testing strategies and/or item characteristics are optimal in reducing unfairness.

Research Report 77-1

Applications of Item Characteristic Curve Theory to the Problem of Test Bias

Steven M. Pine

In David J. Weiss (Ed.), *Applications of Computerized Adaptive Testing*

March 1977

It is argued that a major problem in current efforts to develop less biased tests is an over-reliance on classical test theory. Item characteristic curve (ICC) theory, which is based on individual rather than group-oriented measurement, is offered as a more appropriate measurement model. A definition of test bias based on ICC theory is presented. Using this definition, several empirical tests for bias are presented and demonstrated with real test data. Additional applications of ICC theory to the problem of test bias are also discussed.

Research Report 78-1

A Comparison of the Fairness of Adaptive and Conventional Testing Strategies

Steven M. Pine and David J. Weiss

August 1978

This report examines how selection fairness is influenced by the characteristics of a selection instrument in terms of its distribution of item difficulties, level of item discrimination, degree of item bias, and testing strategy. Computer simulation was used in the administration of either a

conventional or a Bayesian adaptive ability test to a hypothetical target population consisting of a minority and a majority subgroup. Fairness was evaluated by three indices which reflect the degree of differential validity, errors in prediction (Cleary's model), and proportion of applicants exceeding a selection cutoff (Thorndike's model). Major findings were (1) when used in conjunction with either the Bayesian adaptive or the conventional test, differential prediction increased fairness and facilitated the interpretation of the fairness indices; (2) the Bayesian adaptive tests were consistently fairer than the conventional tests for all item pools above the a=.7 discrimination level for tests of more than 30 items; (3) the differential prediction version of the Bayesian adaptive test produced almost perfectly fair performance on all fairness indices at high discrimination levels; and (4) the placement of subgroup prior distribution in the Bayesian adaptive testing procedure can affect test fairness.

Research Report 78-3

A Comparison of Levels and Dimensions of Performance in Black and White Groups on Tests of Vocabulary, Mathematics, and Spatial Ability

Austin T. Church, Steven M. Pine, and David J. Weiss

October 1978

The nature and extent of ability test performance differences between Black and White high school students on vocabulary, mathematics, and spatial ability tests were examined. Mean differences on total test scores were found for all three tests, with Whites averaging higher than Blacks. In the vocabulary test, however, this effect could not be interpreted independently of sex and parents' educational level. Parents' educational levels were significantly related to performance on the vocabulary and spatial tests; in the vocabulary test parental education interacted with the race and sex variables. Separate factor analyses were performed for the Black and White groups to determine the number and nature of dimensions underlying performance for each group. While the number of factors needed to account for the common item variance in each test was the same for Blacks and Whites, items defining each factor and the correlations of factors across the three tests indicated that the nature of the factors was different for the two groups. For the vocabulary test, degree of item bias was evaluated in terms of the difference in item difficulties for Blacks and Whites as indexed by the difficulty (b) parameter of item characteristic curve (ICC) theory. Comparison of the ICC item parameters for the Blacks and the Whites showed differences in both difficulties and discriminations. By comparing the index of item bias with the vocabulary factor structures in both groups, a "bias" factor defined by "Black-type" words was identified in the White group. Analysis of racial group differences in relationships among subtest scores and factor scores showed that Whites had more common variance among subtests than Blacks, with the largest differences occurring where the vocabulary test was involved. It was concluded that when the factor structures underlying ability tests differ sufficiently for two or more racial groups, the meaning of mean group performance differences becomes less clear. Investigation of the fairness of psychometric tests should include examination of possible bias at both item and factor levels.

Research Report 78-5

An Item Bias Investigation of a Standardized Aptitude Test

John T. Martin, Steven M. Pine, and David J. Weiss

December 1978

Verbal and quantitative data from a standardized aptitude test (SCAT, Series II, Level 2) were analyzed separately for Native American and White high school students. Item correlation matrices were factor analyzed for each group, separately for each ability. Coefficients of congruence comparing factor structures between groups were high for the first verbal factor and the first and second quantitative factors, implying that ability factor structures were similar for the two groups. The first factors were of sufficient size to allow parameterization of the items by item characteristic curve (ICC) methods. Item difficulty (b) parameters derived for the two groups were compared by regressing difficulty parameters for the Native American group on the difficulty parameters for the White group, and values of elliptic-D were computed for each item and group. Results led to the conclusion that there were no reliably biased items in the verbal subtest, while there were two reliably biased items in the quantitative subtest--one item biased against the Native American group and one item biased against the White group. Internal consistency reliabilities were higher for the Native American group in both tests, and the scores of the Native American students were better predictors of high school rank than were scores for the White students; but these results were significant ($p<.05$) only for the quantitative subtest. Results indicated that different approaches to the identification of bias led to different conclusions. Thus, additional research is needed to determine which indices of item and test bias yield the most meaningful approach to the analysis of bias in ability tests.

Research Report 79-2

Effects of Computerized Adaptive Testing on Black and White Students

Steven M. Pine, Austin T. Church, Kathleen A. Gialluca, and David J. Weiss

March 1979

Bias-reduced and non-bias-reduced conventional paper-and-pencil and computerized adaptive tests of word knowledge were administered to Black and White high school students to study differential effects on ability estimates and psychological reactions. Independent variables examined were bias reduction, the presence or absence of knowledge of results after each item, mode of administration (paper-and-pencil or computerized adaptive), order of administration, and race. Dependent variables were three test performance variables (the ability estimates derived from both conventional paper-and-pencil and computerized adaptive tests, the variance of those estimates, and the number of omitted responses) and four psychological reaction variables (reaction to knowledge of results, nervousness, motivation, and guessing). Bias-reduced tests were specially constructed from items which had previously been shown to be less biased towards Black students in terms of an item bias index derived from item characteristic curve (ICC) theory. The bias-reduced tests eliminated mean racial differences between Black and White students under certain test conditions, but the effect interacted with other conditions of test administration, e.g., whether or not knowledge of results was provided. Since the bias-reduced tests provided less precise measurement than the non-bias-reduced tests, it was concluded that more traditional item statistics, such as item discriminations, should be considered along with an index of item bias in test construction. Computerized adaptive tests were generally shown

to be more motivating than the conventional paper-and-pencil tests. Black students, in particular, seemed to be less tolerant of the conventional paper-and-pencil tests, especially when taken after the adaptive tests. This was reflected in levels of reported motivation, number of omitted responses, and reported amounts of guessing. Differential psychological reactions for Black and White students were found for other conditions of test administration as well; however, the computer-administered adaptive tests appeared to reduce these differences in comparison to the conventional paper-and-pencil tests. These data imply the need for further study of the effects of test administration conditions on members of minority groups to determine those administration conditions which maximize ability estimates either directly or through their effects on the psychological environment of testing.

Other Project Reports

Pine, S.M. Differential effects of prior distributions in Bayesian adaptive testing. Paper presented at the spring meeting of the Psychometric Society, Murry Hill, NJ, April 1976.

Pine, S.M. Applying item characteristic curve theory to detect bias. Paper presented at the 18th annual meeting of the Military Testing Association, Gulf Shores, AL, October 1976.

Pine, S.M. Reducing test bias with computerized adaptive testing. Paper presented at the Third International Symposium on Educational Testing, University of Leyden, Leyden, The Netherlands, June 1977.

Pine, S.M. Racial differences in a computerized adaptive test. Paper presented at the 19th annual meeting of the Military Testing Association, San Antonio, TX, October 1977.

Pine, S.M., and Wattawa, S. CONTRAST: A computer program for evaluating item bias. Educational and Psychological Measurement, 1978, 38, 147-151.

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