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ABSTRACT

The possibility that certain features of items on a reading comprehension test may lead to biased estimates of the reading achievement of particular subgroups of students was investigated. Item response data on the reading comprehension section of a frequently used achievement test were obtained from the Anchor Test Study data files. Eight nonoverlapping subgroups of students were defined by the combinations of three factors: student grade level (fifth or sixth), income level of the neighborhood in which the school was located (low or middle/above), and race of the student (black or white). Estimates of student ability and item parameters were obtained separately for each of the eight subgroups using the three-parameter logistic model. Bias indices were computed based on differences in item characteristic curves for pairs of subgroups. A criterion for labeling an item as biased was developed using the distribution of bias indices for subgroups of the same race that differed only in income level or grade level. Using this criterion, three items were consistently identified as biased in four independent comparisons of subgroups of black and white students. Comparisons of content and format characteristics of items that were identified as biased with those that were not, or between items biased in different directions, did not lead to the identification of any systematic content differences. (Author/MKM)

CENTER FOR THE STUDY OF READING

Technical Report No. 163

AN INVESTIGATION OF ITEM BIAS IN A TEST OF READING COMPREHENSION

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Abstract

The possibility that certain features of items on a reading comprehension test may lead to biased estimates of the reading achievement of particular subgroups of students was investigated. Item response data on the reading comprehension section of a frequently used achievement test were obtained from the Anchor Test Study data files. Eight nonoverlapping subgroups of students were defined by the combinations of three factors: student grade level (fifth or sixth), income level of the neighborhood in which the school was located (low or middle/above), and race of the student (black or white). Estimates of student ability and item parameters were obtained separately for each of the eight subgroups using the three-parameter logistic model. The ability scales were then equated across pairs of subgroups and, in any comparison of a pair of subgroups an item was considered to be biased to the degree that the probability of getting an item right differed from one subgroup to the other when ability was held constant (i.e., the degree to which the item characteristic curves (ICCs) differed). Bias indices were computed based on differences in ICCs for pairs of subgroups. A criterion for labeling an item as biased was developed using the distribution of bias indices for subgroups of the same race that differed only in income level or grade level. Using this criterion, three items were consistently identified as biased in four independent comparisons of subgroups of black and white students. Comparisons of content and format characteristics of items that were identified as biased with those that were not, or between items biased in different directions, did not lead to the identification of any systematic content differences. The study did provide strong support for the viability of the estimation procedure. Some suggestions for improvements in methodology are offered.

An Investigation of Item Bias in a Test of Reading Comprehension

Controversy over mental testing has a history that dates back almost to the introduction of large-scale testing in World War I (Cronbach, 1975). The possibility that tests underestimate the competence of identifiable groups, particularly the poor and members of certain racial and ethnic minorities, has been a recurrent issue in the ebb and flow of controversy. The charge that standardized tests are biased against certain subgroups is a familiar one. The statement that a test is biased has many different meanings, however.

Bias is sometimes claimed as the natural consequence of the fact that tests are culture-dependent. Certainly, performance on a test in English is an unreasonable basis for making claims about the "verbal ability" of a child who speaks and reads only Spanish. Such a claim would not only be "biased"; it would be patently absurd. However, the test may provide a reasonable indication of the child's current competence in English. Thus, it is much more meaningful and potentially fruitful to speak of possible bias in the interpretation and use of test results rather than bias in the test per se.

A common use of tests is to predict some future behavior such as job performance or success in school or college. For the predictive use of tests, the issue of possible bias revolves around the question of whether or not identifiable sub-groups perform better on the job or in college than would be predicted from their test scores (Anastasi, 1976; Cleary, 1968; Linn, 1973; Petersen & Novick, 1976).

Prediction is one of the uses made of achievement tests, but it is by no means the only use. More often achievement tests are used to assess current status, to evaluate programs, and to diagnose problems. For the non-predictive uses of achievement tests, strategies for assessing possible sources of bias have generally focused on the internal characteristics of the test. The goal is to identify non-essential characteristics of test items that result in the misinterpretation of the achievement of certain groups of students. For example, reading is a skill that is incidental to the one that is purported to be measured by a mathematics achievement test. Dependence of the test results on reading ability could lead to a biased indication of the relative competence in mathematics for two groups that differ in reading ability.

If items on a test differ in their dependence on the characteristic that is incidental to the skill being assessed, then the biasing effects of that incidental characteristic would be expected to result in an interaction between the items and the characteristics of the examinees. In other words, the magnitude of group differences in performance would be expected to vary as a function of the extent to which items were dependent on the incidental characteristics. Once identified, the offending items could be revised or replaced in an effort to eliminate their biasing effects.

The idea of searching for item characteristics that interact with group membership in order to reduce possible bias is not new. For example, the stated purpose of the landmark study by Eells, Davis, Havighurst, Herrick, and Tyler (1951) was to "identify (a) those kinds of test problems on which children from high socioeconomic backgrounds show the greatest superiority and (b) those kinds on which children from low socioeconomic backgrounds do relatively well" (p. 6). Interactions between item content and sex were investigated by Coffman (1961), and a number of studies have been conducted to identify types of items that are unusually difficult for members of minority groups (e.g., Angoff & Ford, 1973; Cleary & Hilton, 1968).

One of the limitations of the early studies of item-group interactions is that they relied upon sample-dependent item statistics. There is no sound theoretical basis for expecting a constant difference in the proportion of people in two groups that respond correctly to various items. A second limitation of definitions of item bias that depend on differences in the proportion correct for two groups is that proportion correct is confounded with other item characteristics such as item discriminating power (Hunter, Note 1). The difference in proportion correct for two groups can be expected to vary from item to item solely as a function of differences in the discriminating power of the items. Thus, as stated by Warm (1978), "the use of classical test theory item parameters is inappropriate for, and can lead to erroneous identification of item bias" (p. 128).

Lord (1977a, 1977b), Scheuneman (in press), Wright (1977), and others have suggested that latent trait theory provides a theoretically sounder approach to the problem of identifying items that interact with group membership than can be achieved using item statistics based on classical test theory. Several recent studies (e.g., Harms, 1978; Ironson & Subkoviak, 1979; Rudner, 1977) have compared indices of item bias based on latent trait theory with indices from several earlier approaches. It is clear that the earlier approaches, based on statistics used in classical test theory, are not substitutes for an approach based on latent trait theory.

The primary advantage of an approach based on latent trait theory is that, to the extent that the model holds, the item parameters should be invariant. That is, they should not depend upon the sample of people on which the estimates are based. Thus, except for sampling error, the same estimates would be expected for different groups even though the groups may differ substantially in ability level.

This study has two major purposes, one of which is methodological in nature and the other substantive. Refinements are needed in the techniques used to detect items that lead to biased estimates of the ability of a particular group. The analyses conducted for this study were intended to provide some evaluation of an approach based upon a particular latent trait model and contribute to the development of better methods of using latent trait models to detect items that result in biased ability estimates.

The substantive purpose of this study is to investigate the possibility that certain features of items on a reading comprehension test may lead to biased estimates of the reading achievement level for black students as compared to white students and/or for children attending schools in low-income neighborhoods as compared to those attending schools in middle- or high-income neighborhoods. The identification of items that lead to such estimates would be of particular value if the items so identified could be characterized by some generalizable features that could be used as a guide in constructing and editing reading comprehension tests to minimize bias against particular subgroups of students.

Strategy for Identifying Bias

Birnbaum's (1968) three-parameter logistic model was used to obtain estimates of ability and of the item parameters in all of the analyses reported below. The LOGIST computer program (Wood, Wingersky, & Lord, Note 2) was used to estimate the item parameters and abilities of the students.

According to the three-parameter logistic model, the conditional probability $P_i(\theta)$ that a person randomly chosen from all those with ability θ will answer item i correctly, is

(1) $$P_i(\theta) = c_i + \frac{1 - c_i}{1 + \exp[-1.7a_i(\theta - b_i)]}$$

where a_i, b_i, and c_i are item parameters. Thus, each item is characterized by three parameters: The "item discriminating power," a, the location or "difficulty" of the item, b, and the lower asymptote or probability that persons with extremely low ability will respond correctly to the item, c. The graph of $P_i(\theta)$ as a function of θ is called the item characteristic curve (ICC) for item i. According to the model, the probability of getting the item right is completely determined by θ and the three item parameters. More specifically, members of different groups with equal ability (i.e., equal θ) should have the same probability of getting an item right. In other words, the conditional probabilities, $P_i(\theta)$, and their graphs, should be invariant from one group to another.

We approached identifying items that function differently for members of different subgroups by comparing ICCs that were estimated separately for different subgroups. If the ICCs of some items differ from group to group more than would be expected due to sampling error, then such items may be considered biased: the probability of getting an item right is not equal for persons of the same overall ability who come from different subgroups.

Such bias may be the consequence of multidimensionality. That is, the probability of getting an item right depends on more than one latent trait (i.e., more than one θ) and the groups differ in their distributions of the secondary latent traits (Hunter, Note 1). Multidimensionality may still be considered a form of bias, however, in that it can lead to apparent differences in the primary ability when, in fact, there are no such differences.

Procedures

Data for the analyses reported below were obtained from the Anchor Test Study (Bianchini & Loret, 1974) equating study files. Item response data on the Reading Comprehension section of form F of the Metropolitan Achievement Tests (Durost, Bixler, Wrightstone, Prescott, & Balow, 1970) were obtained for students in grades 5 and 6. Data were available for a total of 15,485 fifth-grade and 14,843 sixth-grade students. At each grade level, slightly over 16% of the students with available data were black and somewhat over 76% were white. All analyses reported below are based on these two groups of students within each grade.

The sample of students was divided into eight subgroups. The subgroups were defined by grade (fifth or sixth), by race (black or white), and by income level of the neighborhood in which the sample school was located (low or middle/high). The analyses were based on all black students for whom the necessary item response data were available. Analyses for white students were based on spaced samples containing roughly the same number of students as were in the black student samples attending low income schools. Listed in Table 1 is the number of students within each subgroup upon which the parameters of the item characteristic curves were estimated. As can be seen, group size was roughly 2000 per subgroup for all but the subgroup of black students attending middle- or high-income schools. The latter was considerably smaller, containing approximately 22% as many students, on the average, as the other three subgroups at each grade level.

Insert Table 1 about here

Under the assumption that the three-parameter logistic model holds for all subgroups, the estimated abilities should be on essentially the same scale regardless of the group used to obtain the estimates. The assumption implies that the different subgroups can differ only by a linear transformation from one subgroup to another. Thus, it is possible to equate the scales by means of linear transformation and then make meaningful comparisons of the ICCs for different subgroups.

The procedure used to find the linear transformation to equate the scales for pairs of subgroups is based upon the property of the model that item difficulties and latent ability estimates of the examinees are expressed on the same scale. (See Lord, 1977b, for discussion of related latent trait theory methods.) In other words, whatever transformation is appropriate for the b's is also appropriate for the θ's and vice versa. Since the b's were estimated for the same items for all subgroups, the distribution of the b's should be the same except for sampling error after the scales are equated.

The specific steps followed to equate the scales of two groups were as follows. First, one group was arbitrarily identified as the "base" group and the other as the "comparison" group. The scale of the base group was left unchanged (i.e., no transformation was made of the θ's or item parameters for the base group). Two constants, A and B, were then found such that the weighted mean and variance of the transformed b's of the comparison group were equal to the weighted mean and variance of the base group. More specifically, if b^*_i is the item difficulty of item i in the comparison group after equating and b_i is the corresponding value prior to equating then

(2) $$b_i^* = A + Bb_i$$

where $\underline{A}$ and $\underline{B}$ are the equating constants selected such that the weighted mean and variance of $\underline{b}^*_i$ in the comparison group are equal to the weighted mean and variance of the original $\underline{b}$'s in the base group. The $\underline{i}^{th}$ weight was the inverse of the larger of the estimated variances of the $\underline{b}_i$ computed from the comparison group and the $\underline{b}_i$ computed from the base group. Thus items for which the difficulty parameter was poorly estimated (i.e., had a large estimated sampling variance) for either of the groups were given relatively less weight in determining the equating constants than were items for which the difficulty parameter was better estimated. Detailed formulas used in estimating the variances and covariances of the errors of estimate for the item parameters and for approximating the standard error of a point on an estimated item characteristic curve are provided in Appendix A and the detailed formulas used to obtain the equating constants (i.e., $\underline{A}$ & $\underline{B}$) are provided in Appendix B.

Once the A and B in Equation 2 were obtained, the comparison group ability estimates and estimates of item discrimination were converted to the base group scale. In particular the transformed θ scale, say θ*, for the comparison group is given by

(3) $$\theta^* = A + B\theta,$$

and the transformed $\underline{a}$'s, say $\underline{a}^*_i$, by

(4) $$a^*_i = a_i/B.$$

No transformation of the $\underline{c}$ parameter estimates is required.

After the estimated abilities and item parameters of a comparison group were transformed to the base group scale, several types of comparisons were made. Item characteristic curves for each group were plotted on the common scale and compared. In order to better evaluate whether observed differences in ICCs were attributable simply to sampling error, the standard errors of the ICCs were estimated and ICCs plus and minus two standard errors of estimate were obtained and plotted for each group.

Indices of Bias

In addition to the comparison of the ICCs and "confidence bands" determined by their standard errors, several indices of item bias were computed. Three of these indices were described by Ironson (Note 3), (see also Ironson & Subkoviak, 1979). They involve areas between the ICCs of a base group and a comparison group. Sums of squared differences between ICCs were also computed. In all, eight bias indices (four weighted and four unweighted) were computed (See Appendix C for details). (Some discussion of the desirability of weighting indices according to the stability of the estimates of the ICCs at various levels of θ will be provided at a later point.) Thus, only the simpler unweighted indices are described here.

The four unweighted bias indices used for the results reported below are as follows.

1. Base High Area: the size of the region between θ = -3 and θ = +3 in which the base group ICC is above the comparison group ICC.

2. Base Low Area: the size of the region between θ = -3 and θ = +3 in which the base group ICC is below the comparison group ICC.

3. Absolute Difference: the sum of 1 and 2.

4. Square Root of the Sum of Squares: the square root of the sum of the squared differences between ICCs in the region of $\theta = -3$ to $\theta = +3$.

An item with a large base high area (index 1) but small or zero base low area (index 2) would be considered to be biased against the comparison group. Such an outcome would indicate that persons in the comparison group have a smaller probability of getting the item right than persons in the base group with equal estimated ability. The direction of the bias would be just the opposite for an item with a large base low area but zero or small base high area. The bias in an item with large base high and large base low areas would depend upon the distribution of ability in the groups of examinees contrasted.

Estimates of item parameters that were obtained separately for the eight subgroups defined by grade level, race, and income level of the school were used to make a total of twelve pairwise comparisons. In each pairwise comparison, the base group and the comparison group differed in only one of the three characteristics used to define the subgroups. Thus, there were four independent comparisons of the different levels of each group characteristic with constant levels of the other two group characteristics. For example, for a fixed grade and income level of school, comparisons were made across racial groups, so that four comparisons were made of black and white students (fifth- or sixth-graders from lower-income or middle/higher-income schools). Similarly, income level comparisons were made for each of four race-by-grade combinations, and grade comparisons were made for each of four race-by-school income combinations. The base group and comparison group in each of the twelve comparisons are listed in Table 2.

Insert Table 2 about here

Results

The item parameter estimates prior to equating of the θ scales are listed in Appendix D for each group. These estimates along with the equating constants reported in Appendix E may be used to compute the ICCs on the scale used in any of the comparisons for any item.

A general indication of the comparability of the ICCs for the 12 pairwise comparisons is provided by the distributions of the square root of the sum of squares bias indices. When an item has very similar ICCs for two groups, the index should be near zero. Distributions of the bias index values for the 45 items are shown for all twelve pair-wise comparisons in Figure 1. The top four distributions provide comparisons of grade 5 with grade 6 holding race and income level constant. The middle four distributions provide income level comparisons holding grade and race constant, and the bottom four distributions show the results of the racial group comparisons with grade and income held constant. The group characteristics that are held constant for a given distribution are identified by the letters and numbers above each histogram. For example, the left-hand histogram in the first row of Figure 1 is the grade comparison for white students attending schools in low-income neighborhoods and is denoted LW. Another example is the M6 over the right-hand histogram n the bottom row of Figure 1. M6 denotes that the racial comparison in the lower right-hand histogram is for sixth-grade students attending schools in middle- or high-income neighborhoods.

Insert Figure 1 about here

An immediate observation that can be made from an inspection of Figure 1 is that there are fewer large values of the bias index for the four comparisons involving only white students than for any of the other comparisons, that is, the comparison of ICCs across grade for white students (the two left-hand distributions in the top row of Figure 1) or across income level for white students (two left-hand distributions in the middle row of Figure 1). Only one of the 180 bias indices is as large as .2 for these four distributions. None is as large as .3.

Items with indices less than .2 have quite similar ICCs. Some indication of the degree of similarity is provided by the plots shown in Figure 2 for two items. The plots in Figure 2 compare the ICCs for fifth-grade white students attending schools in low-income neighborhoods (LW5) with their sixth-grade counterparts (LW6). Item 6 has the second largest index (square root of the sum of squares bias index equals .161) of any of the 45 items. The index for Item 18 is .070, which is closer to the mean of .076 for the 45 items.

Insert Figure 2 about here

The three solid lines show the ICC, the ICC plus two standard errors of estimate, and the ICC minus two standard errors of estimate for LW5 students, and the three dashed lines show the corresponding curves for the LW6 students. The ICCs in Figure 2 are strikingly similar. This provides rather strong support for the claim of invariance. Even the item with the largest sum of squares bias index has ICCs with confidence intervals which overlap substantially throughout most of the range of ability. This evidence of invariance of the parameters over grade level and income level for white students strengthens the case for using ICC comparisons to identify items that result in biased estimates for particular subgroups. The distributions of indices for the four pairwise comparisons of white subsamples also provide a base rate against which the indices for other pairwise comparisons can be evaluated.

Returning to Figure 1, it can be seen that the black subsamples provide less evidence of invariance across either grade level or income level. Comparisons involving middle-income black subsamples might be expected to show less invariance because the estimates are all less stable due to the smaller sample sizes. The comparison of black fifth-graders attending schools in low-income neighborhoods (LB5) with black sixth-graders attending schools in low-income neighborhoods (LB6), however, involves sample sizes comparable to the white subgroup comparisons. Yet four of the items have indices of .2 or larger for the LB5 vs. LB6 comparison. A plot of the ICCs and the ICCs plus and minus two standard errors for the item with the largest index in the LB5-LB6 comparison is shown in Figure 3. Item 35 has an index of .256 for the LB5-LB6 comparison. As can be seen in Figure 3, the ICCs show greater divergence for these two groups than was observed for the LW5-LW6 comparisons illustrated in Figure 2. The separation of the ICCs, however, occurs mainly for θ values of 2 or above where there are relatively few examinees in either group. The fact that the ICC, especially for the base group, is poorly estimated for θ values greater than 2.0 is indicated by the divergence of the upper and lower bounds for the ICCs. Considering that Item 35 is the most discrepant of the 45 items in the LB5-LB6 comparison and that the difference occurs only at values of θ greater than 2, one might still argue that the ICCs are generally quite similar for the comparisons of black students at different grade levels.

Insert Figure 3 about here

The comparisons of primary interest in Figure 1 are, of course, those between white and black subgroups of students since it is there that the presence of biased items is most suspected. The last row of Figure 1 shows the distributions of the square root of the sum of squares bias index for the four pairwise comparisons between subgroups of white students and subgroups of black students. Large indices are clearly observed with greater frequency in the four comparisons in the last row of Figure 1 than in the across grade or income level comparisons for white students. Only occasionally are the indices for the racial group comparisons more extreme than they are for the within-race comparisons for black students.

Using a cutoff of .2 to indicate a possibly biased item, one would so identify 13 of the 45 items in the LW5-LB5 comparison and 7 items in each of the other three comparisons between racial groups. The number of items identified as possibly biased obviously depends on the stringency of the criterion employed. But the ICCs corresponding to the largest indices are markedly different.

The agreement among the four independent between-race comparisons regarding the identification of items as possibly biased is far from perfect. On the other hand, the agreement is considerably better than would be expected if items were randomly identified by the four independent comparisons. Using the above criterion, three of the items were identified in all four pairwise comparisons. If an equal number of items had been selected at random in each comparison the probability that an item would be selected all four times is only .00109. Thus, the expected number of items that would be identified four times by a random process is only about .05 (i.e., 45 x .00109). The expected distribution of number of times an item would be selected by a random process in the four independent comparisons is shown in Table 3. Also provided in Table 3 is the corresponding observed distribution. The top three categories (i.e., where an item was identified as biased 2, 3, or 4 times) were collapsed so that the expected frequency was greater than 5 for each category (0, 1, and 2 or more) and a Chi-square statistic with 2 degrees of freedom was computed to test the goodness-of-fit. The resulting Chi-square was 12.13, which is significant at the .01 level. The agreement is clearly better than would be expected on the basis of chance.

Insert Table 3 about here

Table 4 provides additional information about the agreement among the four comparisons in the identification of possibly biased items using a .2 cutoff for the square root of the sum of squares bias indices. The agreement between each pair of independent comparisons is shown in Table 4. Also listed in Table 4 are the phi-coefficients and Chi-square statistics corresponding to the two-by-two contingency tables. With the exception of the low-income grade 5 (L5) vs. the middle-income grade 5 (M5) comparison, the phi coefficients are all significantly different from zero at the .05 level.

Insert Table 4 about here

One final indication of the consistency of the bias indices across independent comparisons of white and black students is provided by the product moment correlations between the square root of the sum of squares bias indices. These correlations are reported in Table 5. With 45 items, a correlation of .3 or greater is significantly different from zero. The correlations involving comparisons that differ only in income level of the groups (e.g., L5 with M5) or only in grade level (e.g., L5 with L6) are all significantly different from zero. Correlations based on comparisons that differ both in income and grade level (e.g., L5 with M6), while positive, are not significant.

Insert Table 5 about here

An attempt was made to improve the bias indices by weighting the differences between the ICCs by the reciprocal of the estimated standard error of the difference between ICCs at each θ value (see Appendix C for computational details). It was reasoned that a weighted index would lead to the appropriate discounting of differences between ICCs in regions of θ where one or both of the ICCs were poorly estimated. However, results for the square root of the weighted sum of squares bias indices were quite similar to those for the unweighted indices using either index: Three items were identified as biased in all four of the independent racial group comparisons. Furthermore, the same three items were so identified with either index. For this reason we have chosen to report results only for the simpler unweighted indices to conserve space. As will be discussed below, however, there are reasons to think that the idea of weighting is a good one and that improved bias indices may be developed using more refined estimating and weighting procedures.

The ICCs for the three items that were identified as possibly biased in all four comparisons using the square root of the sum of squares bias index are shown in Figures 4, 5, and 6. Each of these figures presents four pairs of ICCs plus and minus two standard errors of estimate for a single item. In each figure the solid lines are the ICCs plus and minus two standard errors for the white sample and the dashed lines are the comparable figures for the black sample at the same grade level and income level of neighborhood.

Insert Figures 4, 5, and 6 about here

From an inspection of Figure 4, it is apparent that the four independent comparisons show a great deal of consistency. In each comparison the ICC for the white students is above that of the black students for low and mid-range values of θ. Item 3 is less discriminating (smaller value for a) for white than for black students in each of the comparisons, and therefore the ICCs cross and the one for black students is above the one for white students at high values of θ. Although the direction of bias depends on the value of θ, Item 3 is generally biased against black students in the region where the majority of the black student sample falls (i.e., below a value of θ equal to the mean of the white student sample). If more items with ICCs similar to those of Item 3 were added to the test, the test performance of most black students would appear worse than it currently does in comparison to white students. On the other hand, elimination of Item 3 would tend to improve the relative standing of black students.

Item 25, which is depicted in Figure 5, has large bias indices in all four comparisons. The large bias indices are brought about largely by the very poor discriminating power of Item 25 for black students. Item 25 is a difficult item for all subgroups. It discriminates well among high-ability sixth-grade white students. The discrimination of Item 25 for high-ability black students, however, is problematic. The estimates are poorly determined due to the small number of black students with θ's in the region where Item 25 seems to be most discriminating. This poor estimation of the discriminating power of Item 25 is illustrated by the wide confidence bands for the ICCs for black students in three of the four cases. In the fourth case (Figure 5d), the ICC for black students is essentially flat throughout the -3.0 to +3.0 range of θ. The estimated value of the item discriminating power is so small ($\hat{a} = .01$) that the ICC at $\theta = -3.0$ is essentially equal to the ICC at $\theta = +3.0$.

The results in Figure 6 for Item 31 illustrate a situation that is different from that for either Item 3 or 25. The pairs of ICCs are quite similar for low values of θ but for higher values of θ the curve for black students is above the one for whites in all four of the comparisons. Thus, if anything, Item 31 would be considered biased in favor of black students relative to other items on the test. Inclusion of more items like Item 31 would tend to improve the relative standing of black students on the test.

For comparative purposes, the ICCs for Items 3, 25, and 31 are shown in Figure 7 for the between-grade comparison for white students attending schools in low-income neighborhoods. As can be seen, Items 3 and 31 have confidence intervals that overlap substantially for the two groups throughout the -3.0 to +3.0 range of θ. For Item 25, the confidence intervals generally overlap, but show some divergence around θ equal to 0. As might be expected from an inspection of Figure 7, Item 25 has one of the larger sum of squares bias indices. Indeed, the square root of the sum of squares bias index for Item 25 is .181, which is the largest value for the 45 items in the LW5-LW6 comparison. Although item 25 has a somewhat flatter ICC for the LW5 sample than for the LW6 sample, the difference is not nearly as great as the differences for the white and black samples shown in Figure 5.

Insert Figure 7 about here

The contrasts that are found between groups for the items in Figures 4, 5, and 6 may be summarized by the four bias indices computed for each of the contrasts. In order to facilitate comparisons, the indices for the 45 items were first rank-ordered with a rank of 1 given to the item with the highest value of a particular index for a given contrast. The rank ordering was obtained separately for each index and each contrast. The rank order of the bias indices for the three items in Figures 4, 5, and 6 are listed in Table 6.

Insert Table 6 about here

Item 25 has relatively large base high bias indices in all four of the independent racial group comparisons. Indeed, in three of the four comparisons, Item 25 has the largest or second largest base high bias index. The white sample was used as the base group and the black sample as the comparison group in all four racial group comparisons. Thus, a large value of a base high bias index implies that the ICC for white students tends to be above the ICC for black students. The large base high bias indices for Item 25 accurately reflect the fact (seen in Figure 5) that the ICC for white students is generally above the one for blacks. The relatively smaller, but nonzero, base low bias indices for Item 25 reflect the fact that the ICCs cross in all four comparisons. Item 31, on the other hand, has either the largest or second largest base low bias indices but relatively small base high bias indices in each of the comparisons.

Item 3 has base high and base low bias indices that generally rank among the highest third of the items. Thus, the relatively large overall indices reflect a combination of moderately large base high and base low differences due to the crossover of the ICCs in all four comparisons.

Items 25 and 31 are probably the two most clearly contrasting items in terms of the racial group differences in ICCs. Item 25 was consistently identified as biased against black students while Item 31 was consistently identified as biased in favor of black students. The items are of quite different types. Item 25 asks the meaning of the word "character" as it is used in one of the reading passages on the test. Item 31, on the other hand, asks for the "best title" of a story about a fictional baron presented in another passage.

There are eleven items that ask the meaning of a word as used in a passage and five items that ask the "best title" of a story. The rank order of the base high bias index and the base low bias index is listed in Table 7 for the word meaning and "best title" items for each of the four racial group comparisons (see Appendix F for a complete listing of bias indices for all comparisons). The simple comparison of these two types of items does not reveal a clear tendency for one type to be biased against black students and the other biased in their favor. With the exception of Item 31, the "best title" items have few high ranks on either of the indices. In addition to Item 25, "character," Items 2, "there," 27, "reigning," [illegible], "setting," and 42, "speculate," tend to have fairly high ranks on the base high bias index. Some of the other word meaning items, however, have relatively low ranking base high bias indices and may even rank higher on

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Insert Table 7 about here

---

the base low bias index (e.g., Item 15, "rest"). Thus, generalizations based on such surface-level characteristics of the items do not seem warranted.

Cumulative Effect

Although the analyses have not led to clear generalizations regarding the content or structural characteristics of items that result in bias, there is strong evidence that the ICCs of at least a few items are not constant for groups of white and black students. For some items the ICC for white students tends to fall above the ICC for black students and for others the reverse is true. The overall impact of the difference in ICCs on the total test score depends upon the particular mix of items on the test and the degree to which positively biased items are balanced by negatively biased items. The overall effect on total score was evaluated in two closely related ways. First, test characteristic curves (Lord & Novick, 1968, p. 386) were computed on the equated θ scale separately for white and black students in each of the four racial group comparisons. Secondly, expected observed score frequency distributions were computed separately for white and black groups at selected points on the equated θ scale.

The pairs of test characteristic curves (TCCs) for the four racial group comparisons are shown in Figure 8. A TCC for one group that is above that for another at a particular value of θ implies that the cumulative impact of differences in ICCs yields an overall bias against the members of the group with the lower TCC who are at that θ value. Although the curves show a great deal of similarity, there is a tendency for the TCC for white students to be as high or higher than the one for black students, suggesting a slight cumulative bias against black students.

Insert Figure 8 about here

The difference in TCCs varies as a function of θ. For example, in the LW5-LB5 comparison (section a of Figure 8), the curves are almost identical for low values of θ, say $\theta \leq -1$. At these low values of θ the test does not discriminate very well for either group, but there is no systematic bias. For higher values of θ the TCC for white students is higher than the one for black students. The difference in the TCCs for LW5-LB5 is .021 at $\theta = 0$, .027 at $\theta = 1$, and .027 at $\theta = 2$. Translated into number of items right on the 45-item test, these differences would imply a raw score difference of between .95 and 1.22 points, respectively. Similar comparisons of the pair of TCCs in the other three sections of Figure 7 suggest that up to about one raw score point difference between the scores of white and black students may be attributable to the cumulative impact of group difference in ICCs.

Although one raw score point is only about one-eighth of the group difference in mean scores on the Metropolitan Achievement Tests, even this amount is non-trivial. At some points on the scale, one raw score point would translate into about a tenth of a grade equivalent unit.

The second analysis that was conducted to evaluate the cumulative impact of differences in ICC was the computation of expected raw score fre[illegible] distributions for black students and white students at selected points on the equated θ scale. As would be expected, the results of this analysis are quite consistent with the test characteristic curve results.

They merely provide an alternative way of considering the cumulative effect. Therefore only one pair of expected raw score relative frequency distributions is presented here. Figure 9 shows the expected distributions for fifth-grade white and black students attending schools in low-income neighborhoods. The distributions were computed for $\theta = 0$ using the item characteristic curves separately for each group to estimate the probability that persons from that group with $\theta = 0$ would get each item right. As can be seen, the distributions are very similar except that the LW5 distribution is shifted up approximately one raw score point relative to the LB5 distribution.

Insert Figure 9 about here

An alternative explanation of the results in Figures 8 and 9 is that there is a systematic error in equating the ability scales. That is, if the equating constants, A and B in Equation 2, were changed, the TCC in Figure 8 and the distributions of expected raw scores in Figure 9 could be made to coincide more precisely. The two possible explanations cannot be distinguished. Indeed, the method is not really designed to detect bias that is found consistently in all items. Rather, it can only be expected to identify items that are biased in one direction or the other relative to other items on the test. Thus, an equating procedure that made the TCC* as comparable as possible is probably to be preferred. This alternative approach is currently being investigated.

Discussion and Conclusions

The analyses involving comparisons of students at different grade levels or who attend schools located in neighborhoods with different income levels showed that the ICCs were generally very similar. For example, the ICCs based on a sample of fifth-grade white students attending schools in low-income neighborhoods were almost indistinguishable from those for a sample of their sixth-grade counterparts. The results, showing a high degree of similarity between ICCs for the within-race comparison involving differences in the other two grouping variables, lend credence to the viability of the general approach. A basic assumption of the latent trait model is that the item parameters, and therefore the ICCs, are invariant over different groups of people. Thus, the remarkably good invariance of the ICCs over grade level and income level within racial groups suggests that the model is reasonable for the 45 items on the test that was analyzed.

The degree of invariance in the ICCs was noticeably less for the racial group comparisons than for either the grade level or income comparisons. This suggests that there are some items that function differently for black students than they do for white students. Such items may reasonably be labeled as biased. Whatever the cause of the difference in the ICCs, the effect of including a larger or smaller number of items where the ICC of one group is above that of another is the same. The relative standing of black students would be higher on a test that had fewer items where the ICC for white students was above the one for black students.

Although a few items were consistently identified as biased in each of the four independent comparisons, the consistency of identification at different grade levels and/or different income levels was far from perfect. For example, using the criterion that the square root of the sum of squares bias index was greater than .2, seven items were identified as possibly biased in the comparison of low-income white students in grade 6 with low income black students in grade 6. Of these seven items, 7, 3, and 4 were also identified as possibly biased in the other three racial group comparisons (i.e., LW5-LB5, MW5-MB5, and MW6-MB6, respectively). Only three items were identified as possibly biased in all four comparisons. The modest amount of agreement among the independent comparisons suggests that, at least for the test studied, it is apt to be difficult to identify items that are clearly biased.

Although the ICCs were substantially different for white and black students for a few of the items in one or more of the comparisons, the overall impression is that the ICCs were generally quite similar. Furthermore, the direction of the bias for the few items that showed a consistently large difference was not always against black students. One of the three consistently identified items was, if anything, biased in favor of black students.

Comparisons of the content and format characteristics of items that were identified as biased with those that were not, or between items biased in different directions, did not lead to the identification of any systematic differences. For example, items asking the meaning of a word in context sometimes appeared to be biased in one direction and sometimes in the other. Thus, no generalized principles that would be useful in avoiding items that tend to show bias can be stated for guiding the future construction of tests of reading comprehension. Instead, only a post-hoc analysis procedure that may be useful in eliminating biased items after the items have been administered can be offered.

Analysis of the cumulative impact of the difference in the ICCs suggests that these differences might be used to explain about one point of the gap between raw score means for white and black students. This difference may be an artifact of errors in equating, however. Thus, it seems desirable to explore alternative equating procedures. We are currently investigating a procedure that will solve for the constants used for the linear equating of the ability scales such that the differences between the test characteristic curves are minimized.

There are important advantages in the use of comparisons of ICCs such as those in this study over approaches that simply compare estimated item parameters. It is possible, as was sometimes observed in our analyses, for item parameters to be substantially different, yet for there to be no practical difference in the ICCs. This can occur, for example, where the $\underline{b}$ parameter is estimated to be exceptionally high for one group. To illustrate this, consider the following pairs of hypothetical item parameters for two groups in terms of a common θ scale: group 1, $\underline{a} = 1.8$, $\underline{b} = 3.5$, and $\underline{c} = .2$; group 2, $\underline{a} = .5$, $\underline{b} = 5.0$, and $\underline{c} = .2$. The item difficulties and discriminating powers for the two groups are markedly different. But the difference in the ICCs is never greater than .05 for θ values between −3 and +3. Thus, the suggestion of bias based on a large difference in estimated item difficulty or discriminating power might be misleading. The value of practical concern is the difference in the probability of getting the item right for people of equal ability from different groups. This is, of course, precisely the difference in ICCs.

The use of estimates of the standard errors of the ICCs seems potentially useful. By plotting bands of two standard errors on either side of the ICCs, it became evident that some seemingly large differences in ICC curves were occurring only in regions where one or both of the ICCs being compared were poorly estimated. The advantages of using estimated standard errors, however, were not very apparent in terms of a comparison of the weighted and unweighted bias indices. It may be that better estimation procedures are needed for this purpose.

One problem that may limit the utility of the standard errors as they were estimated in this study is caused by the tendency for the LOGIST estimated abilities of some subjects to diverge. To deal with this problem, the ability estimates were arbitrarily limited to a range of plus and minus 4.0. For some of the groups sizeable numbers of students had ability estimates at the lower extreme. For example, 44 of the MB5 sample students had estimated θ of −4.0. This artificial clustering of subjects at the extreme results in estimated standard errors of the ICC at low ability levels that are too small. That is, the inflated number of examinees at the extreme makes it appear as if there is more information at that ability level than would be the case without the need to fix bounds on θ. In future analyses we plan to deal with this problem by estimating standard errors after deleting examinees with extreme θ values or by using estimated ability distributions.

Despite the limitations noted above and the fact that the results did not lend themselves to making generalizations about features of items that result in biased estimates of achievement for members of a particular subgroup, there are still some noteworthy results from the study. The results provide strong support for the reasonableness of the three-parameter model for data of this kind. The across grade level comparisons revealed strikingly similar item characteristic curves. The procedures used for placing confidence bands around the item characteristic curves yielded reasonable results, which, with refinements such as those suggested above, hold the promise of substantially improving the basis for comparing item parameters and item characteristic curves.

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Appendices

A. Procedure for approximating the standard error of a point on an estimated item characteristic curve.

B. Procedure for estimating equating constants.

C. Procedures for estimating item bias indices.

D. Item parameter estimates and standard errors for each subgroup prior to scale equating.

E. Estimates of equating constants.

F. Bias indices for each pairwise comparison.

Appendix A

Procedure for Approximating the Standard Error of a Point on an Estimated Item Characteristic Curve

A.1 Motivation and Notation

A plausible measure of the extent to which an item has different characteristics for different groups is

$$(1) \qquad \int_a^b [P(x) - P^*(x)]^2 dx \; .$$

Here $P(x)$ is the estimated ICC evaluated ability x for one group and $P^*(x)$ for the other group.

The comments that follow are equally applicable to measures of the form

$$\int_a^b |P(x) - P^*(x)| \, dx$$

$$\sum_{i=1}^{n} (P(x_i) - P^*(x_i))^2$$

$$\sum_{i=1}^{n} |P(x_i) - P^*(x_i)| \; .$$

A problem with (1) is that it will be strongly influenced by the least reliable parts of data. More specifically, if the statistics $P(x)$ and $P^*(x)$ have large sampling errors, then the difference between these independent statistics will tend to be large too. Consequently, the least-well-estimated values of $P(x)$ and $P^*(x)$ are expected to make a relatively large contribution to (1), and a confounding between item unfairness and estimation error is likely.

One way to improve upon (1) is to consider introducing weights $w(x)$ that would control the contribution at ability level x to the measure and give a formula of the form

$$\int_a^b (P(x) - P^*(x))^2 \, w(x) \, dx \; .$$

The goal is to give relatively large weight to those values of x such that $P(x) - P^*(x)$ is well estimated and small weight to values of x such that the difference is poorly estimated. In particular we consider

$$\int_a^b \left[\frac{P(x) - P^*(x)}{\sigma(x)}\right]^2 dx \; ,$$

where $\sigma(x)$ is an approximation of the standard error of the difference $P(x) - P^*(x)$. To use (2), an approximation of $\sigma(x)$ is needed.

Since $P(x)$ and $P^*(x)$ are estimated from different groups (and therefore independent statistics),

$$\sigma^2(x) = \text{Variance}\,[P(x) - P^*(x)]$$

$$= \text{Variance}\,[P(x)] + \text{Variance}\,[P^*(x)] \; .$$

Therefore, it will be sufficient to develop an approximation for $Var[P(x)]$ and $Var[P^*(x)]$ separately.

To do this, a more explicit notation is needed. Let $P(a, b, c; x)$ be the general three-parameter curve evaluated at x, i.e.,

$$P(a, b, c; x) = c + (1-c)\{1 + \exp - [a(x-b)]\}^{-1} \; .$$

We restrict attention to a particular item, say the first, and let $\dot{a}$, $\dot{b}$, $\dot{c}$ denote the "true" parameter values. Let $\hat{a}$, $\hat{b}$, $\hat{c}$ denote their maximum likelihood estimates (MLE's), and $\hat{P}$ be the MLE $P(\hat{a}, \hat{b}, \hat{c}, x)$. Using Taylor's formula, we obtain the linear approximation

$$(3) \qquad \hat{P} \doteq P(\dot{a}, \dot{b}, \dot{c}; x) + (\hat{a}-\dot{a})\, P_1(\dot{a}, \dot{b}, \dot{c}; x) + (\hat{b}-\dot{b})\, P_2(\dot{a}, \dot{b}, \dot{c}; x) + (\hat{c}-\dot{c})\, P_3(\dot{a}, \dot{b}, \dot{c}; x) ,$$

where $P_1 = \frac{\partial}{\partial a} P(a, b, c; x)$ and P_2, P_3 are the other partial derivatives. In the sequel we use this approximation to extimate $\sigma(x)$.

A.2 Rationale for an Approximation of the Standard Error of $\hat{P}$

At this time the theory for item parameter estimation is not sufficiently well developed to precisely specify the conditions under which the maximum likelihood estimates are consistent and asymptotically normal. In this applied paper we shall assume that these yet-to-be-specified conditions have been met and that the parameter estimates obtained from LOGIST are approximately normal with covariance matrix given by the inverse of an information matrix (Kendal & Stuart, 1967). In this case $\hat{a}-\dot{a}$, $\hat{b}-\dot{b}$, $\hat{c}-\dot{c}$ will be approximately multivariate normal with zero expectation and with a covariance matrix obtainable by inverting the information matrix. All of the other terms on the righthand side of (3) are constants. Thus $\hat{P}$ is approximately equal to a linear function of multivariate normal random variables and therefore normal.

To approximate the constants on the right of (3), we first note that $P(\dot{a}, \dot{b}, \dot{c}; x)$ makes no contribution to the variance of $\hat{P}$ and can be ignored. To estimate the partial derivatives, we replace the parameter values by their estimates and approximate

$$P_1(\dot{a}, \dot{b}, \dot{c}; x) \text{ by } P_1(\hat{a}, \hat{b}, \hat{c}; x) ,$$

$$P_2(\dot{a}, \dot{b}, \dot{c}; x) \text{ by } P_2(\hat{a}, \hat{b}, \hat{c}; x) ,$$

$$P_3(\dot{a}, \dot{b}, \dot{c}; x) \text{ by } P_3(\hat{a}, \hat{b}, \hat{c}; x) .$$

To approximate the covariance matrix for $\hat{a}-\dot{a}$, $\hat{b}-\dot{b}$, $\hat{c}-\dot{c}$, we consider a 3 x 3 matrix $\underline{I} = (\underline{I}_{ij})$ which will be shown to be an approximation of an information matrix. The typical entry, say $\underline{I}_{12}$, in this matrix is computed as follows. Let θ_j be the ability of the $\underline{j}^{\underline{th}}$ examinee and $\hat{\theta}_j$ be its maximum likelihood estimate. $\underline{I}_{12}$ is given by the formula

(4)
$$-I_{12} = \sum_j P \frac{\partial^2}{\partial a\, \partial b} \log P(\hat{a}, \hat{b}, \hat{c}; \theta_j) + \sum_j Q \frac{\partial^2}{\partial a\, \partial b} \log [1 - P(\hat{a}, \hat{b}, \hat{c}; \theta_j)]$$

where $\underline{P} = \underline{P}(\hat{\underline{a}}, \hat{\underline{b}}, \hat{\underline{c}}; \theta_j)$ and $\underline{Q} = 1 - \underline{P}$.

The rationale for this formula is obtained by regarding each answer sheet or vector of item responses as the outcome of a two-stage experiment. In the first stage an ability θ is sampled. In the second stage the vector of item responses is generated as the outcome of sequence of Bernoulli trials. Thus, the probability that the $\underline{j}^{\underline{th}}$ examinee answers item $\underline{i}$ correctly is $\underline{P}(\dot{\underline{a}}_i, \dot{\underline{b}}_i, \dot{\underline{c}}_i; \theta_j)$. (This experiment differs from the usual conceptualization of latent trait data only in that abilities θ_j are regarded as random variables rather than parameters.)

Relative to this experiment, the information matrix for the item parameters will consist of zeros except for 3 x 3 matrices along the diagonal. There will be one such 3 x 3 matrix for each item. Since the inverse of such a matrix will by another "block diagonal" matrix consisting of the inverses of the original 3 x 3 matrices along the diagonal, we can restrict attention to a single item and return to the problem of approximating the typical term. Relative to the two-stage experiment, the typical information matrix term in the first block (i.e., for item one) is

$$(5) \qquad - \mathcal{E} \frac{\partial^2}{\partial a \partial b} \log \prod_{j=1}^{N} P(\dot{a}, \dot{b}, \dot{c}; \theta_j)^{u_{1j}} Q(\dot{a}, \dot{b}, \dot{c}; \theta_j)^{1-u_{1j}} ,$$

where u_{1j} is the item score random variable for the first item and jth examinee, where N is the number of examinees, and $Q = 1 - P$. The symbol "$\mathcal{E}$" denotes expectation, in this case with respect to both item scores and abilities.

The expression (5) can be rewritten as a sum of two terms:

$$- \mathcal{E} \frac{\partial^2}{\partial a \partial b} \sum_{j=1}^{N} u_{1j} \log P(\dot{a}, \dot{b}, \dot{c}; \theta_j)$$

$$- \mathcal{E} \frac{\partial^2}{\partial a \partial b} \sum_{j=1}^{N} (1-u_{1j}) \log Q(\dot{a}, \dot{b}, \dot{c}; \theta_j) .$$

Computing the expectation of the first term gives

$$-N \int_{-\infty}^{\infty} P(\dot{a}, \dot{b}, \dot{c}; \theta) \frac{\partial^2}{\partial a \partial b} \log P(a, b, c; \theta) \, dF(\theta) ,$$

where F is the (unknown) ability distribution function for the N identically distributed θ_j's. If F is approximated by the distribution which takes a step of size $1/N$ at each θ_j (i.e., by the sample cumulative distribution of the (unobserved) abilities), then we obtain

$$- \sum_{j=1}^{N} P(\dot{a}, \dot{b}, \dot{c}; \theta_j) \frac{\partial^2}{\partial a \partial b} \log P(\dot{a}, \dot{b}, \dot{c}; \theta_j) .$$

Finally, the approximation (4) is obtained by replacing $\dot{\underline{a}}$, $\dot{\underline{b}}$, $\dot{\underline{c}}$ by $\hat{\underline{a}}$, $\hat{\underline{b}}$, $\hat{\underline{c}}$ and θ_j by its maximum likelihood estimate $\hat{\theta}_j$.

A.3 Computational Details

The actual computation of the covariance matrix conformed to the procedure just outlined, except for some minor exceptions. In computing terms in the information matrix by (4), examinees who omitted the item of interest or for whom LOGIST failed to converge were ignored.

The covariance matrix was approximated by inverting the information matrix. The approximation of the variance of $\hat{\underline{P}}$ was obtained from (3), the covariance matrix, and the usual formula for the variance of a sum of correlated variables.

Appendix B

Procedure for Estimating Equating Constants

Let b_{i1} be the LOGIST estimate of the difficulty parameter for item i in the base group and b_{i2} be the corresponding value in the comparison group. Let b^*_{i2} be the item difficulty of item i in the comparison group after equating. The b^*_{i2} are obtained by a linear transformation of the b_{i2}. Specifically,

$$b_{i2} = A + Bb_{i2} ,$$

where A and B are the equating constants. The value of A and of B was computed such that the weighted mean and variance of the b^*_{i2} was equal to the weighted mean and variance of the b_{i1}.

The weight for item i, w_i, was obtained as follows. Let V_{i1} and V_{i2} be the estimated sampling variances of b_{i1} and b_{i2} respectively (see Appendix A for procedures used to estimate the variances). The weight for item i is:

$$w_i = \begin{cases} V_{i1}^{-1} & \text{if} \quad V_{i1} \geq V_{i2} \\ V_{i2}^{-1} & \text{if} \quad V_{i1} \geq V_{i2} \end{cases}$$

The w_i were used to compute the weighted mean of the b_{i1} ($\bar{b}_1$) and the b_{i2} ($\bar{b}_2$). Similarily weighted standard deviations of the b's were computed in each group (S_1 and S_2). The equating constants were then computed from

$$B = S_1/S_2 ,$$

and

$$A = \bar{b}_1 - B\bar{b}_2 .$$

Appendix C

Procedures for Estimating Item Bias Indices

The comparison group scale was first equated to the base group scale by a linear transformation (see Appendix B). Weights for the weighted bias indices were based on an estimate of the standard error of the difference between the ICCs for the comparison and base groups. Areas and weighted areas between ICCs as well as weighted and unweighted sum-of-squares differences were computed between $\theta = -3$ and $\theta = 3$.

The areas were approximated by dividing the distance between $\theta = -3$ and $\theta = 3$ into 600 equal intervals. The distance between the ICCs at the middle of each interval was multiplied by the length of the interval to approximate the area between the ICCs for that interval. Areas were then summed either before or after weighting for the appropriate indices, i.e., base high, base low, and absolute indices. The sum-of-squares indices were computed in a similar fashion except that the distance between the ICCs at the center of each interval was first squared. The specific equations and computational procedures are given below.

Let

$$\theta_o = -3.0$$

and

$$\theta_j = \theta_{j-1} + .01 \text{ for } j = 1,2, \ldots 600 .$$

The midpoint of the *j*th interval is

$$\bar{\theta}_j = \theta_j - .005 .$$

Let $\underline{P}_{j1}$ be the height o.. the ICC for the item in question when evaluated at $\bar{\theta}_j$ using the estimated item parameters for the base group and let $\underline{P}_{j2}$ be the corresponding value for the comparison group. Finally, let $\underline{V}_{pj1}$ and $\underline{V}_{pj2}$ be the estimated variances of the ICCs at $\bar{\theta}_j$ for the base group and comparison group respectively (see Appendix A).

The four bias indices that were used in the results reported in the text were:

I_1 = base high area,

I_2 = base low area,

I_3 = absolute difference, and

I_4 = square root of sum of squares.

Four weighted bias indices were also computed for each item. These were:

W_1 = weighted base high area,

W_2 = weighted base low area,

W_3 = weighted absolute difference, and

W_4 = square root of weighted sum of squares.

Detailed results are not reported for the weighted indices since they did not prove to have clear advantages over the simpler unweighted indices for the data analyzed for this report. The bias indices were obtained as shown below. All summations are for $\underline{j}$ = 1 to 600.

$$I_1 = (.01) \sum \delta_j D_j ,$$

$$I_2 = (.01) \sum (1-\delta_j) D_j ,$$

$$I_3 = I_1 + I_2$$

$$I_4 = \left[(.01) \sum D_j^2\right]^{1/2},$$

$$W_1 = (.01) \sum S_{Dj}^{-1} \delta_j D_j ,$$

$$W_2 = (.01) \sum S_{Dj}^{-1} (1-\delta_j) D_j ,$$

$$W_3 = W_1 + W_2 , \text{ and}$$

$$W_4 = \left[(.01) \sum S_{Dj}^{-1} D_j^2\right]^{1/2},$$

where $D_j = P_{j1} - P_{j2}$,

$$\delta_j = \begin{cases} 1 \text{ if } P_{j1} > P_{j2} , \\ 0 \text{ if } P_{j1} > P_{j2} , \end{cases}$$

and $S_{Dj}^2 = V_{pj1} + V_{pj2}$.

Appendix D

Item Parameter Estimates and Standard Errors for Each Subgroup Prior to Scale Equating

LB5

	a	Standard Error	b	Standard Error	c	Standard Error
1	0.652	0.060	-0.626	0.122	0.220	0.032
2	0.862	0.071	-0.130	0.076	0.220	0.025
3	1.002	0.201	1.915	0.136	0.220	0.016
4	1.989	0.490	1.977	0.092	0.220	0.011
5	0.495	0.077	1.136	0.141	0.220	0.030
6	0.989	0.079	-0.032	0.066	0.220	0.023
7	[illegible]	0.077	-0.025	0.069	0.220	0.023
8	1.202	0.122	0.875	0.056	0.220	0.017
9	0.267	0.088	1.875	0.355	0.220	0.070
10	0.955	0.088	0.471	0.066	0.220	0.021
11	0.951	0.098	0.786	0.068	0.220	0.020
12	1.989	0.499	1.991	0.094	0.220	0.011
13	0.546	0.079	1.095	0.125	0.220	0.028
14	1.409	0.115	0.285	0.047	0.220	0.019
15	1.989	0.133	-0.224	0.032	0.122	0.016
16	0.895	0.078	0.186	0.071	0.220	[illegible]
17	1.989	0.375	1.688	0.065	0.261	0.012
18	1.989	0.510	2.039	0.100	0.195	0.010
19	1.989	0.155	0.498	0.032	0.146	0.013
20	1.919	0.235	[illegible]	0.046	0.239	0.013
21	0.874	0.088	0.640	0.073	0.220	0.022
22	1.578	0.317	1.840	0.089	0.220	0.012
23	1.591	0.173	0.965	0.049	0.248	0.015
24	0.676	0.096	[illegible]	0.110	0.190	[illegible]
25	0.185	0.186	5.635	2.910	0.220	0.102
26	1.389	0.154	1.135	0.054	0.190	0.015
27	0.750	0.279	2.681	0.445	0.228	0.018
28	0.951	0.071	-0.021	0.059	0.136	0.020
29	1.989	0.293	1.408	0.052	0.240	0.013
30	1.989	0.715	2.200	0.148	0.248	0.011
31	1.989	0.587	2.046	0.111	0.255	0.012
32	1.632	0.252	1.462	0.063	0.244	0.014
33	1.342	0.154	1.138	0.058	0.190	0.015
34	1.989	0.513	2.009	0.098	0.194	0.011
35	0.560	0.366	3.679	1.353	0.220	0.022
36	1.758	0.576	2.099	0.142	0.268	0.013
37	1.624	0.266	1.514	0.068	0.220	0.013
38	1.525	0.455	2.041	0.144	0.253	0.013
39	0.638	0.108	1.499	0.141	0.200	0.026
40	1.989	2.583	2.817	0.840	0.258	0.012
41	1.989	0.856	2.238	0.183	0.256	0.012
42	0.729	0.169	1.952	0.204	0.220	0.022
43	0.010	99.000	226.886	99.000	0.266	0.264
44	0.917	0.114	0.835	0.083	0.220	0.022
45	1.744	0.258	1.329	0.062	0.190	0.013

LWS

	a	Standard Error	b	Standard Error	c	Standard Error
1	[illegible]	0.060	-1.634	0.210	0.225	0.061
2	0.895	0.065	-1.440	0.139	0.225	0.046
3	0.452	0.073	0.668	0.186	0.225	0.047
4	1.291	0.143	1.017	0.052	0.225	0.017
5	0.703	0.065	-0.229	0.116	0.225	0.036
6	0.969	0.073	-0.833	0.091	0.225	0.035
7	1.265	0.093	-1.078	0.075	0.225	0.033
8	1.327	0.097	-0.289	0.057	0.225	0.025
9	0.533	0.068	0.300	0.154	0.225	0.041
10	0.990	0.076	-0.401	0.079	0.225	0.030
11	1.356	0.104	-0.172	0.057	0.255	0.025
12	1.354	0.201	1.434	0.068	0.242	0.015
13	0.827	0.069	0.210	0.122	0.225	0.036
14	1.855	0.139	-0.720	0.049	0.225	0.026
15	1.553	0.114	-0.882	0.059	0.225	0.029
16	1.115	0.081	-0.806	0.078	0.225	0.032
17	0.759	0.091	0.796	0.086	0.225	0.027
18	2.300	0.193	0.936	0.034	0.200	0.013
19	2.000	0.143	-0.396	0.039	0.200	0.022
20	1.969	0.166	0.203	0.040	0.302	0.019
21	1.210	0.087	-0.276	0.059	0.200	0.025
22	0.828	0.092	0.675	0.078	0.225	0.026
23	1.030	0.084	-0.033	0.070	0.225	0.027
24	1.009	0.084	0.192	0.065	0.200	0.025
25	0.433	0.117	2.062	0.258	0.225	0.039
26	1.256	0.093	0.279	0.045	0.142	0.019
27	1.405	0.183	1.192	0.056	0.269	0.016
28	1.151	0.085	-0.495	0.070	0.225	0.029
29	1.584	0.128	0.323	0.043	0.225	0.019
30	1.818	0.243	1.264	0.048	0.264	0.014
31	1.040	0.192	1.624	0.106	0.270	0.018
32	1.471	0.147	0.764	0.047	0.248	0.018
33	1.868	0.145	0.295	0.036	0.200	0.017
34	2.000	0.174	0.836	0.032	0.151	0.013
35	2.000	0.368	1.672	0.068	0.225	0.012
36	0.642	0.125	1.626	0.144	0.225	0.027
37	2.000	0.168	0.493	0.035	0.201	0.016
38	2.000	0.212	0.838	0.039	0.274	0.016
39	1.425	0.122	0.321	0.050	0.225	0.020
40	2.000	0.263	1.272	0.044	0.225	0.013
41	2.000	0.325	1.483	0.055	0.225	0.013
42	0.555	0.103	1.328	0.144	0.225	0.034
43	2.000	0.353	1.565	0.062	0.225	0.013
44	1.212	0.101	-0.109	0.065	0.225	0.026
45	1.854	0.189	0.796	0.040	0.209	0.016

MWS

	$\hat{a}$	Standard Error	$\hat{b}$	Standard Error	$\hat{c}$	Standard Error
1	0.641	0.063	-2.133	0.283	0.240	0.087
2	0.727	0.067	-2.121	0.231	0.240	0.075
3	0.362	0.068	-0.256	0.442	0.240	0.088
4	1.520	0.154	0.850	0.041	0.230	0.016
5	0.839	0.069	-0.544	0.106	0.240	0.037
6	0.802	0.066	-1.692	0.164	0.240	0.056
7	1.025	0.082	-1.778	0.125	0.240	0.048
8	1.001	0.075	-1.009	0.098	0.240	0.038
9	0.663	0.064	-0.492	0.145	0.240	0.044
10	0.929	0.071	-1.064	0.109	0.240	0.040
11	1.018	0.076	-0.902	0.094	0.240	0.036
12	1.687	0.180	0.940	0.039	0.240	0.015
13	0.475	0.065	-0.219	0.241	0.240	0.058
14	1.611	0.129	-1.372	0.071	0.240	0.035
15	1.310	0.100	-1.434	0.086	0.240	0.039
16	0.788	0.065	-1.530	0.157	0.240	0.053
17	0.581	0.071	0.137	0.150	0.240	0.042
18	1.790	0.155	0.613	0.035	0.230	0.016
19	1.882	0.150	-1.111	0.057	0.240	0.031
20	1.435	0.105	-0.400	0.058	0.259	0.027
21	1.187	0.086	-0.731	0.075	0.240	0.032
22	0.867	0.081	0.122	0.085	0.240	0.030
23	1.021	0.078	-0.476	0.083	0.240	0.032
24	1.189	0.092	-0.074	0.062	0.240	0.026
25	0.877	0.145	1.379	0.094	0.240	0.021
26	1.238	0.086	-0.179	0.055	0.181	0.024
27	0.987	0.106	0.666	0.064	0.240	0.023
28	1.157	0.085	-1.034	0.086	0.240	0.036
29	1.431	0.105	-0.167	0.053	0.240	0.024
30	1.256	0.147	0.928	0.052	0.260	0.019
31	0.587	0.107	1.255	0.125	0.240	0.033
32	1.387	0.120	0.339	0.050	0.260	0.021
33	1.456	0.107	-0.112	0.051	0.230	0.024
34	2.000	0.169	0.656	0.031	0.192	0.015
35	2.000	0.295	1.379	0.051	0.240	0.013
36	0.721	0.121	1.259	0.103	0.240	0.027
37	2.000	0.150	0.005	0.038	0.230	0.020
38	1.431	0.125	0.327	0.050	0.260	0.022
39	1.356	0.107	-0.174	0.061	0.260	0.026
40	1.886	0.190	0.788	0.036	0.240	0.016
41	2.000	0.225	0.932	0.036	0.240	0.015
42	0.443	0.097	1.110	0.195	0.240	0.049
43	2.000	0.254	1.112	0.060	0.240	0.015
44	1.401	0.110	-0.450	0.064	0.240	0.028
45	1.273	0.121	0.425	0.056	0.230	0.022

MBS

	$\hat{a}$	Standard Error	$\hat{b}$	Standard Error	$\hat{c}$	Standard Error
1	0.630	0.122	-1.006	0.310	0.215	0.080
2	1.225	0.185	-0.512	0.124	0.215	0.051
3	0.671	0.187	1.166	0.217	0.215	0.050
4	1.835	0.573	1.559	0.125	0.215	0.024
5	0.785	0.150	0.194	0.172	0.215	0.054
6	0.885	0.145	-0.578	0.175	0.215	0.059
7	1.562	0.234	-0.437	0.100	0.215	0.048
8	1.229	0.201	0.036	0.113	0.215	0.045
9	0.476	0.142	0.767	0.307	0.215	0.072
10	1.078	0.181	0.055	0.127	0.215	0.048
11	1.290	0.215	0.128	0.108	0.215	0.044
12	1.437	0.482	1.682	0.166	0.215	0.027
13	0.523	0.138	0.547	0.273	0.215	0.068
14	1.698	0.257	-0.370	0.092	0.215	0.046
15	2.000	0.293	-0.427	0.077	0.180	0.042
16	0.738	0.130	-0.539	0.211	0.215	0.063
17	0.642	0.208	1.452	0.260	0.220	0.050
18	1.738	0.519	1.493	0.122	0.215	0.026
19	1.965	0.308	-0.010	0.074	0.180	0.037
20	0.968	0.200	0.645	0.138	0.215	0.044
21	1.129	0.181	0.088	0.114	0.180	0.044
22	1.106	0.259	1.069	0.132	0.200	0.036
23	1.628	0.288	0.364	0.087	0.215	0.037
24	1.039	0.229	0.861	0.134	0.215	0.041
25	0.276	0.269	3.591	1.793	0.215	0.112
26	1.693	0.320	0.630	0.086	0.215	0.034
27	2.000	0.755	1.696	0.141	0.252	0.025
28	1.495	0.246*	-0.001	0.099	0.215	0.044
29	2.000	0.390	0.658	0.080	0.220	0.031
30	1.741	0.643	1.613	0.148	0.281	0.028
31	1.693	0.717	1.833	0.181	0.259	0.027
32	1.042	0.258	1.032	0.151	0.220	0.040
33	1.867	0.386	0.739	0.090	0.215	0.032
34	1.725	0.542	1.536	0.127	0.191	0.026
35	0.042	0.758	33.069	343.715	0.215	1.297
36	0.913	0.453	2.123	0.376	0.245	0.037
37	2.000	0.450	0.861	0.092	0.215	0.031
38	0.794	0.270	1.554	0.248	0.215	0.044
39	1.600	0.351	0.725	0.111	0.245	0.037
40	2.000	0.925	1.890	0.173	0.252	0.026
41	1.493	0.712	1.986	0.239	0.215	0.027
42	1.078	0.392	1.614	0.219	0.220	0.036
43	2.000	1.088	2.084	0.219	0.215	0.025
44	1.353	0.236	0.398	0.136	0.215	0.046
45	1.436	0.407	1.274	0.131	0.180	0.031

LB6

	a	Standard Error	b	Standard Error	c	Standard Error
1	0.686	0.063	-0.729	0.130	0.235	0.037
2	0.883	0.073	-0.536	0.090	0.235	0.031
3	0.777	0.141	1.714	0.133	0.235	0.021
4	1.839	0.376	1.843	0.082	0.235	0.012
5	0.580	0.080	0.844	0.124	0.235	0.032
6	1.140	0.090	-0.284	0.066	0.235	0.027
7	1.222	0.094	-0.444	0.064	0.235	0.027
8	1.776	0.157	0.506	0.040	0.220	0.017
9	0.407	0.083	1.331	0.203	0.235	0.043
10	0.950	0.083	0.018	0.075	0.235	0.027
11	1.013	0.098	0.482	0.068	0.235	0.023
12	1.512	0.307	1.894	0.099	0.220	0.012
13	0.612	0.079	0.735	0.117	0.235	0.031
14	1.518	0.121	-0.010	0.049	0.235	0.022
15	1.262	0.097	-0.457	0.062	0.235	0.027
16	0.873	0.075	-0.214	0.085	0.235	0.029
17	1.645	0.236	1.402	0.059	0.250	0.014
18	2.000	0.342	1.654	0.061	0.220	0.012
19	2.000	0.141	0.090	0.032	0.124	0.015
20	1.703	0.178	0.870	0.045	0.243	0.016
21	1.036	0.100	0.473	0.066	0.235	0.023
22	1.769	0.244	1.364	0.054	0.235	0.014
23	1.241	0.119	0.566	0.056	0.235	0.021
24	0.854	0.099	0.869	0.080	0.220	0.024
25	0.312	0.166	3.766	1.068	0.235	0.049
26	1.070	0.093	0.555	0.055	0.145	0.019
27	1.752	0.420	1.966	0.102	0.262	0.012
28	1.046	0.088	-0.079	0.071	0.235	0.027
29	1.988	0.221	0.943	0.042	0.243	0.015
30	1.839	0.368	1.803	0.079	0.235	0.012
31	1.236	0.264	1.906	0.121	0.251	0.015
32	1.132	0.157	1.296	0.074	0.235	0.018
33	1.383	0.157	0.956	0.056	0.235	0.017
34	2.000	0.351	1.801	0.067	0.145	0.010
35	2.000	0.611	2.184	0.126	0.235	0.012
36	2.000	0.473	1.939	0.089	0.235	0.012
37	1.481	0.171	1.117	0.053	0.175	0.015
38	1.427	0.232	1.510	0.075	0.235	0.015
39	2.000	0.275	1.127	0.051	0.285	0.015
40	1.996	0.724	2.296	0.156	0.246	0.012
41	2.000	0.560	2.022	0.109	0.247	0.013
42	0.775	0.188	2.005	0.196	0.235	0.022
43	2.000	1.157	2.690	0.287	0.257	0.012
44	0.824	0.079	0.343	0.079	0.138	0.025
45	1.220	0.175	1.349	0.075	0.178	0.017

LWo

	$\hat{a}$	Standard Error	$\hat{b}$	Standard Error	$\hat{c}$	Standard Error
1	0.747	0.068	-1.810	0.199	0.230	0.067
2	0.775	0.071	-1.936	0.200	0.230	0.069
3	0.402	0.076	0.403	0.293	0.230	0.068
4	1.458	0.133	0.573	0.045	0.230	0.019
5	0.706	0.068	-0.359	0.132	0.230	0.043
6	0.910	0.075	-1.598	0.138	0.230	0.053
7	1.035	0.084	-1.626	0.121	0.230	0.050
8	1.108	0.084	-0.758	0.084	0.230	0.036
9	0.726	0.070	-0.261	0.124	0.230	0.041
10	0.922	0.073	-1.004	0.112	0.230	0.043
11	1.141	0.086	-0.672	0.080	0.230	0.035
12	0.799	0.109	0.956	0.084	0.230	0.027
13	0.671	0.071	-0.052	0.132	0.230	0.041
14	1.941	0.161	-1.056	0.056	0.230	0.032
15	1.591	0.127	-1.151	0.069	0.230	0.036
16	0.907	0.073	-1.284	0.125	0.230	0.048
17	0.754	0.080	0.208	0.104	0.230	0.034
18	1.733	0.153	0.578	0.039	0.230	0.017
19	2.000	0.160	-0.903	0.050	0.219	0.029
20	1.348	0.100	-0.308	0.060	0.230	0.027
21	1.702	0.090	-0.663	0.075	0.230	0.033
22	0.740	0.081	0.272	0.106	0.230	0.035
23	1.013	0.081	-0.431	0.085	0.230	0.034
24	1.154	0.094	-0.018	0.066	0.230	0.027
25	0.836	0.130	1.230	0.089	0.235	0.024
26	1.104	0.087	-0.135	0.069	0.210	0.029
27	2.000	0.199	0.688	0.038	0.290	0.017
28	1.265	0.095	-0.796	0.075	0.230	0.035
29	1.430	0.110	-0.107	0.055	0.235	0.026
30	2.000	0.219	0.808	0.039	0.306	0.017
31	0.587	0.110	1.302	0.132	0.230	0.035
32	1.398	0.128	0.419	0.052	0.260	0.022
33	1.482	0.112	-0.020	0.050	0.210	0.023
34	1.776	0.139	0.539	0.034	0.148	0.015
35	2.000	0.238	1.075	0.038	0.230	0.014
36	0.836	0.111	0.895	0.082	0.230	0.027
37	2.000	0.156	0.174	0.038	0.218	0.019
38	1.723	0.150	0.446	0.042	0.235	0.019
39	1.458	0.118	-0.066	0.057	0.260	0.026
40	1.698	0.191	0.989	0.041	0.210	0.016
41	2.000	0.250	1.061	0.040	0.248	0.015
42	0.650	0.094	0.744	0.118	0.230	0.036
43	2.000	0.271	1.197	0.042	0.230	0.014
44	1.849	0.156	-0.212	0.051	0.291	0.026
45	1.493	0.138	0.448	0.049	0.230	0.021

MB6

	$\hat{a}$	Standard Error	$\hat{b}$	Standard Error	$\hat{c}$	Standard Error
1	1.081	0.171	-1.011	0.183	0.230	0.078
2	1.015	0.162	-0.869	0.187	0.230	0.076
3	0.818	0.197	0.713	0.178	0.230	0.056
4	0.874	0.187	1.088	0.135	0.092	0.036
5	0.943	0.186	0.284	0.159	0.230	0.057
6	0.838	0.142	-1.096	0.246	0.230	0.087
7	1.156	0.181	-0.932	0.167	0.230	0.073
8	2.000	0.325	-0.115	0.079	0.210	0.043
9	0.782	0.176	0.453	0.193	0.230	0.062
10	1.018	0.164	-0.702	0.180	0.230	0.073
11	0.936	0.167	-0.169	0.177	0.230	0.066
12	1.259	0.409	1.489	0.157	0.230	0.033
13	0.539	0.145	0.295	0.332	0.230	0.089
14	1.188	0.186	-0.842	0.160	0.230	0.071
15	0.856	0.145	-1.158	0.245	0.230	0.087
16	0.945	0.154	-0.763	0.197	0.230	0.076
17	1.116	0.240	0.718	0.127	0.230	0.045
18	1.477	0.253	0.802	0.081	0.108	0.028
19	2.000	0.321	-0.565	0.094	0.210	0.053
20	1.671	0.280	0.188	0.089	0.230	0.042
21	1.364	0.229	-0.025	0.114	0.230	0.051
22	1.664	0.310	0.577	0.089	0.230	0.037
23	1.076	0.191	0.027	0.145	0.230	0.057
24	1.303	0.232	0.272	0.113	0.230	0.046
25	0.010	0.032	95.172	81.489	0.230	0.467
26	1.266	0.224	0.302	0.112	0.210	0.046
27	1.309	0.354	1.216	0.124	0.230	0.035
28	1.256	0.201	-0.574	0.145	0.230	0.065
29	1.750	0.310	0.418	0.086	0.230	0.039
30	1.300	0.381	1.332	0.135	0.230	0.034
31	0.802	0.306	1.644	0.257	0.230	0.046
32	1.392	0.372	0.980	0.125	0.320	0.040
33	2.000	0.361	0.457	0.079	0.230	0.036
34	1.475	0.366	1.346	0.108	0.127	0.026
35	1.126	0.412	1.637	0.200	0.230	0.035
36	1.074	0.375	1.539	0.188	0.230	0.038
37	2.000	0.370	0.463	0.082	0.230	0.038
38	1.134	0.279	0.930	0.134	0.230	0.044
39	2.000	0.374	0.490	0.082	0.230	0.038
40	2.000	0.549	1.290	0.093	0.203	0.029
41	2.000	0.710	1.510	0.117	0.230	0.029
42	0.373	0.216	1.707	0.559	0.230	0.118
43	2.000	0.880	1.744	0.158	0.230	0.028
44	1.292	0.293	0.292	0.128	0.230	0.051
45	1.055	0.283	1.060	0.147	0.210	0.045

MW6

	$\hat{a}$	Standard Error	$\hat{b}$	Standard Error	$\hat{c}$	Standard Error
1	0.599	0.070	-2.512	0.432	0.245	0.141
2	0.686	0.078	-2.683	0.392	0.245	0.141
3	0.294	0.076	-0.445	0.882	0.245	0.151
4	1.132	0.110	0.492	0.057	0.240	0.023
5	0.730	0.065	-0.878	0.153	0.245	0.052
6	0.683	0.071	-2.269	0.304	0.245	0.104
7	0.694	0.082	-2.850	0.433	0.245	0.161
8	0.764	0.068	-1.674	0.191	0.245	0.068
9	0.615	0.063	-0.845	0.200	0.245	0.060
10	0.673	0.065	-1.757	0.240	0.245	0.079
11	0.807	0.069	-1.461	0.163	0.245	0.059
12	1.010	0.109	0.676	0.066	0.245	0.024
13	0.363	0.068	-0.733	0.571	0.245	0.116
14	1.135	0.099	-1.932	0.132	0.245	0.058
15	1.124	0.099	-1.971	0.135	0.245	0.059
16	0.620	0.066	-2.142	0.332	0.245	0.107
17	0.449	0.065	-0.518	0.332	0.245	0.079
18	1.184	0.103	0.256	0.060	0.245	0.025
19	2.000	0.188	-1.528	0.068	0.245	0.040
20	1.199	0.090	-0.877	0.082	0.245	0.038
21	1.051	0.082	-1.204	0.106	0.245	0.045
22	0.626	0.070	-0.156	0.159	0.245	0.047
23	0.877	0.071	-1.097	0.128	0.245	0.049
24	1.104	0.085	-0.450	0.079	0.245	0.034
25	1.177	0.145	1.038	0.059	0.259	0.019
26	1.125	0.085	-0.598	0.081	0.245	0.035
27	1.239	0.108	0.247	0.059	0.260	0.025
28	0.979	0.081	-1.637	0.137	0.245	0.056
29	1.126	0.086	-0.637	0.082	0.245	0.036
30	1.222	0.114	0.482	0.055	0.245	0.022
31	0.375	0.102	1.525	0.260	0.245	0.063
32	1.357	0.110	0.041	0.057	0.259	0.025
33	1.320	0.098	-0.523	0.068	0.245	0.032
34	1.668	0.127	0.358	0.037	0.175	0.018
35	1.175	0.156	1.213	0.063	0.240	0.018
36	0.601	0.092	0.833	0.132	0.245	0.039
37	1.421	0.108	-0.211	0.057	0.240	0.027
38	1.114	0.093	-0.087	0.073	0.245	0.030
39	1.246	0.095	-0.619	0.075	0.245	0.035
40	1.165	0.120	0.662	0.058	0.240	0.023
41	1.817	0.188	0.813	0.039	0.260	0.017
42	0.596	0.084	0.474	0.150	0.245	0.044
43	2.000	0.211	0.910	0.036	0.245	0.016
44	1.432	0.112	-0.664	0.069	0.245	0.034
45	1.305	0.113	0.160	0.060	0.245	0.026

Appendix E

Estimation of Equating Constants

Base Group	Comparison Group	B Slope	A Intercept
LW5	LB5	1.01091	-0.92508
LW5	MW5	0.88857	0.45232
LB5	MB5	1.05854	0.47350
MW5	MB5	1.13246	-1.00965
LW6	LB6	0.95032	-0.97707
LW6	MW6	0.79275	0.36811
LB6	MB6	1.03924	0.57221
MW6	MB6	1.22931	-1.03913
LW5	LW6	1.00590	0.38167
LB5	LB6	0.97725	0.34253
MW5	MW6	0.88891	0.32543
MB5	MB6	0.98476	0.36079

$$b_j^* = A + Bb_j$$

Appendix F

Bias Indices for Each Pairwise Comparison

(W 3 - L B)

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.05566	0.00000	0.05566	0.00080
2	0.27477	0.00000	0.27477	0.02182
3	0.48908	0.12220	0.61127	0.07524
4	0.12740	0.05926	0.18666	0.01014
5	0.35695	0.02611	0.38305	0.03512
6	0.00006	0.08392	0.08398	0.00220
7	0.14926	0.02844	0.17770	0.00920
8	0.20669	0.00000	0.20669	0.01473
9	0.39708	0.14544	0.54252	0.06540
10	0.00435	0.02654	0.03089	0.00032
11	0.15288	0.02013	0.17301	0.00808
12	0.08415	0.24688	0.33103	0.03608
13	0.04874	0.05887	0.10760	0.00217
14	0.09793	0.02049	0.11842	0.00572
15	0.13646	0.15544	0.29190	0.02806
16	0.10530	0.03157	0.13686	0.00469
17	0.14643	0.26369	0.41012	0.04221
18	0.18094	0.00000	0.18094	0.01526
19	0.11947	0.00000	0.11947	0.00567
20	0.27885	0.00000	0.27885	0.01868
21	0.09366	0.14590	0.23955	0.01220
22	0.31457	0.07750	0.39206	0.04048
23	0.08596	0.09264	0.17859	0.00818
24	0.26895	0.04660	0.31555	0.02632
25	0.33323	0.09895	0.43218	0.05622
26	0.00000	0.20183	0.20183	0.00842
27	0.51161	0.00000	0.51161	0.08522
28	0.03754	0.18710	0.22463	0.01783
29	0.11153	0.02920	0.14072	0.00872
30	0.09947	0.00270	0.10216	0.00240
31	0.08199	0.33869	0.42068	0.06280
32	0.00794	0.15226	0.16021	0.01096
33	0.05765	0.08103	0.13867	0.00607
34	0.17391	0.12147	0.29538	0.02490
35	0.50792	0.10076	0.60867	0.17887
36	0.05918	0.43460	0.49378	0.08167
37	0.08953	0.06720	0.15673	0.00656
38	0.26067	0.00000	0.26067	0.02817
39	0.36829	0.10771	0.47600	0.05912
40	0.43952	0.10129	0.54080	0.11589
41	0.00000	0.24846	0.24846	0.01451
42	0.05753	0.16493	0.22246	0.01274
43	0.97340	0.19580	1.16918	0.58095
44	0.09769	0.06066	0.15835	0.00578
45	0.03647	0.26858	0.30505	0.04042

L W S - M W S

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.07886	0.01023	0.08908	0.00267
2	0.00000	0.02153	0.02153	0.00012
3	0.00000	0.33308	0.33308	0.02059
4	0.14760	0.01832	0.16592	0.01183
5	0.14816	0.04851	0.19666	0.00919
6	0.00006	0.18722	0.18727	0.01073
7	0.00800	0.07[illegible]65	0.07864	0.00230
8	0.00661	0.16396	0.17056	0.00968
9	0.02466	0.26225	0.28691	0.02097
10	0.00000	0.10883	0.10883	0.00280
11	0.01280	0.10392	0.11672	0.00553
12	0.03466	0.12724	0.16190	0.01052
13	0.06460	0.08741	0.15200	0.00434
14	0.00000	0.06979	0.06979	0.00175
15	0.03525	0.02125	0.05649	0.00097
16	0.03613	0.13239	0.16851	0.00810
17	0.00242	0.23073	0.23315	0.01245
18	0.02295	0.09459	0.11753	0.00311
19	0.00000	0.20976	0.20976	0.01437
20	0.09112	0.03295	0.12406	0.00424
21	0.01190	0.06190	0.07379	0.00181
22	0.00000	0.13105	0.13105	0.00484
23	0.02852	0.02595	0.05448	0.00072
24	0.09158	0.07000	0.16157	0.00674
25	0.19246	0.20515	0.39760	0.04252
26	0.00000	0.11479	0.11479	0.00308
27	0.07259	0.07118	0.14377	0.00479
28	0.01620	0.03317	0.04936	0.00059
29	0.00000	0.06421	0.06421	0.00092
30	0.05706	0.03365	0.09071	0.00255
31	0.10426	0.09347	0.19772	0.00929
32	0.00000	0.05173	0.05173	0.00055
33	0.04132	0.09544	0.13676	0.00414
34	0.11695	0.11275	0.22970	0.01497
35	0.00496	0.06939	0.07435	0.00104
36	0.03146	0.07552	0.10698	0.00335
37	0.00000	0.12807	0.12807	0.00371
38	0.04232	0.05787	0.10019	0.00318
39	0.00000	0.13334	0.13334	0.00383
40	0.00000	0.15431	0.15431	0.00706
41	0.00000	0.21989	0.21989	0.01769
42	0.04012	0.07130	0.11141	0.00236
43	0.00000	0.16153	0.16153	0.00791
44	0.10775	0.02886	0.13660	0.00707
45	0.0575[illegible]	0.11106	0.16856	0.00589

L B S - M B S

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.05910	0.01127	0.07037	0.00106
2	0.12658	0.06615	0.19273	0.00815
3	0.02305	0.25137	0.27441	0.02044
4	0.12754	0.00000	0.12754	0.00804
5	0.07515	0.29277	0.36792	0.03404
6	0.02468	0.09054	0.11522	0.00341
7	0.14488	0.10218	0.24706	0.01400
8	0.00375	0.26766	0.27141	0.02557
9	0.16492	0.18164	0.34656	0.02562
10	0.06910	0.00338	0.07247	0.00139
11	0.03901	0.14960	0.18861	0.01003
12	0.18995	0.00658	0.19653	0.02407
13	0.01561	0.05008	0.06569	0.00087
14	0.00990	0.15271	0.16262	0.01104
15	0.15143	0.11142	0.26285	0.02130
16	0.01992	0.21884	0.23876	0.01507
17	0.34053	0.12421	0.46474	0.07278
18	0.02548	0.12581	0.15129	0.00426
19	0.00172	0.15049	0.15220	0.00604
20	0.16977	0.14174	0.31151	0.02514
21	0.16361	0.06965	0.23326	0.01037
22	0.05755	0.17188	0.22943	0.01697
23	0.09010	0.04133	0.13142	0.00385
24	0.07607	0.10475	0.18081	0.00795
25	0.07555	0.03572	0.11126	0.00254
26	0.00330	0.09940	0.10270	0.00218
27	0.06449	0.21853	0.28301	0.03712
28	0.24457	0.09500	0.33957	0.03545
29	0.05827	0.15383	0.21210	0.01602
30	0.00975	0.20437	0.21411	0.00855
31	0.22704	0.01287	0.23991	0.03575
32	0.19338	0.03990	0.23328	0.01584
33	0.07230	0.07987	0.15217	0.00560
34	0.08108	0.00659	0.08767	0.00440
35	0.14276	0.17410	0.31686	0.02490
36	0.34208	0.00337	0.34546	0.06506
37	0.02117	0.09687	0.11804	0.00584
38	0.22244	0.06712	0.28955	0.02120
39	0.07507	0.35034	0.42541	0.05497
40	0.02073	0.18986	0.21059	0.02958
41	0.39717	0.00000	0.39717	0.04394
42	0.23391	0.00190	0.23581	0.01653
43	0.30295	0.23412	0.53707	0.09743
44	0.09873	0.02555	0.12428	0.00356
45	0.42755	0.00000	0.42755	0.07444

M W 5 - M B 5

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.08497	0.00099	0.08596	0.00169
2	0.31471	0.02292	0.33762	0.05087
3	0.48730	0.04990	0.53719	0.06612
4	0.04264	0.05782	0.10045	0.00244
5	0.01902	0.12318	0.14219	0.00574
6	0.06000	0.00000	0.06000	0.00097
7	0.22094	0.01476	0.23569	0.02579
8	0.08469	0.00809	0.09276	0.00306
9	0.36827	0.03280	0.40107	0.03669
10	0.13493	0.00000	0.13493	0.00534
11	0.09226	0.01530	0.10755	0.00375
12	0.09757	0.03757	0.13513	0.00375
13	0.00350	0.04230	0.04580	0.00046
14	0.01337	0.01445	0.02783	0.00034
15	0.10876	0.07040	0.17915	0.01141
16	0.06082	0.03295	0.09376	0.00186
17	0.40620	0.00000	0.40620	0.03108
18	0.10725	0.00000	0.10725	0.00331
19	0.18746	0.00000	0.18746	0.01171
20	0.23600	0.02092	0.25691	0.01957
21	0.04308	0.04432	0.08738	0.00236
22	0.19689	0.00911	0.20599	0.01079
23	0.09510	0.13076	0.22586	0.01204
24	0.11913	0.01472	0.13385	0.00479
25	0.49042	0.20814	0.69856	0.14226
26	0.00000	0.18740	0.18740	0.00913
27	0.21489	0.06704	0.28193	0.02586
28	0.08316	0.02004	0.10318	0.00354
29	0.06065	0.08015	0.14079	0.00525
30	0.00000	0.15690	0.15690	0.00632
31	0.17645	0.28633	0.46278	0.05641
32	0.09372	0.10220	0.19591	0.00910
33	0.04407	0.04850	0.09256	0.00213
34	0.08812	0.02471	0.11283	0.00524
35	1.08299	0.14120	1.22418	0.64073
36	0.09269	0.00296	0.09565	0.00266
37	0.03431	0.02023	0.05454	0.00082
38	0.45765	0.01198	0.46964	0.06784
39	0.04086	0.01010	0.05096	0.00069
40	0.23860	0.02917	0.26777	0.03166
41	0.33312	0.00000	0.33312	0.03803
42	0.29580	0.28134	0.57714	0.06461
43	0.28796	0.00000	0.28796	0.02465
44	0.05940	0.07661	0.13600	0.00510
45	0.17755	0.00000	0.17755	0.00793

L W 6 - L B 6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.09098	0.00000	0.09098	0.00213
2	0.25530	0.00230	0.25759	0.02572
3	0.38277	0.15515	0.53792	0.05544
4	0.15181	0.01497	0.16677	0.01361
5	0.14074	0.01635	0.15709	0.00565
6	0.23056	0.01183	0.24238	0.02367
7	0.15021	0.01061	0.16081	0.01123
8	0.26339	0.04202	0.30540	0.03373
9	0.42732	0.07541	0.50273	0.05559
10	0.03059	0.01368	0.04427	0.00053
11	0.10868	0.00339	0.11207	0.00420
12	0.18142	0.21451	0.39592	0.03540
13	0.00000	0.17502	0.17502	0.00670
14	0.06612	0.02152	0.08764	0.00304
15	0.00150	0.20270	0.20419	0.01911
16	0.06400	0.00000	0.06400	0.00128
17	0.22599	0.17155	0.39753	0.03826
18	0.07335	0.02424	0.09759	0.00251
19	0.21039	0.00053	0.21091	0.01870
20	0.10882	0.02624	0.13505	0.00779
21	0.10022	0.00711	0.10733	0.00385
22	0.24832	0.21909	0.46741	0.04934
23	0.05133	0.07291	0.12423	0.00377
24	0.03690	0.10884	0.14573	0.00587
25	0.49330	0.14933	0.64263	0.12330
26	0.07733	0.15697	0.23431	0.01415
27	0.25342	0.00000	0.25342	0.01828
28	0.00116	0.20106	0.20222	0.01526
29	0.06348	0.06542	0.12889	0.00550
30	0.22355	0.00700	0.23054	0.01494
31	0.07559	0.40036	0.47595	0.07124
32	0.03874	0.07953	0.11827	0.00434
33	0.00000	0.11118	0.11118	0.00327
34	0.18015	0.00086	0.18100	0.01726
35	0.01296	0.01572	0.02868	0.00023
36	0.19482	0.21278	0.40760	0.04362
37	0.09895	0.03606	0.13500	0.00461
38	0.03120	0.02233	0.05353	0.00091
39	0.09558	0.05406	0.14964	0.00814
40	0.11739	0.09780	0.21519	0.01352
41	0.00345	0.08499	0.08844	0.00441
42	0.15873	0.02014	0.17887	0.00776
43	0.25132	0.07922	0.33053	0.04229
44	0.20052	0.13552	0.33604	0.02879
45	0.10444	0.04262	0.14706	0.00579

L W 6 - M W 6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.09425	0.00000	0.09425	0.00260
2	0.07309	0.00687	0.07995	0.00265
3	0.00000	0.27560	0.27560	0.01413
4	0.12294	0.01781	0.14075	0.00725
5	0.06350	0.08982	0.15332	0.00473
6	0.10110	0.00061	0.10170	0.00313
7	0.00488	0.17471	0.17958	0.01430
8	0.00373	0.17914	0.18286	0.01139
9	0.00000	0.07310	0.07310	0.00107
10	0.01685	0.05505	0.07190	0.00153
11	0.00524	0.12446	0.12970	0.00562
12	0.08038	0.15060	0.23098	0.01371
13	0.09604	0.23585	0.33189	0.02259
14	0.02427	0.13104	0.15530	0.00983
15	0.00931	0.06794	0.07723	0.00239
16	0.03337	0.07078	0.10414	0.00313
17	0.03516	0.26208	0.29723	0.02037
18	0.02276	0.08172	0.10447	0.00244
19	0.03147	0.04113	0.07259	0.00198
20	0.00069	0.05595	0.05664	0.00097
21	0.03506	0.01387	0.04893	0.00086
22	0.00000	0.06669	0.06669	0.00086
23	0.00000	0.09227	0.09227	0.00212
24	0.02801	0.05072	0.07873	0.00147
25	0.08245	0.17632	0.25877	0.01737
26	0.01752	0.09615	0.11367	0.00302
27	0.07615	0.05811	0.13426	0.00475
28	0.00000	0.13266	0.13266	0.00571
29	0.00000	0.05088	0.05088	0.00069
30	0.19576	0.00711	0.20286	0.00986
31	0.10974	0.08250	0.19224	0.00802
32	0.03660	0.04588	0.08247	0.00196
33	0.00000	0.12379	0.12379	0.00353
34	0.06301	0.06464	0.12764	0.00489
35	0.18879	0.04015	0.22894	0.02106
36	0.07398	0.04880	0.12277	0.00304
37	0.02394	0.07395	0.09789	0.00225
38	0.00735	0.15266	0.16000	0.00936
39	0.03699	0.03606	0.07304	0.00129
40	0.00430	0.19721	0.20151	0.01013
41	0.00000	0.08442	0.08442	0.00203
42	0.01800	0.05713	0.07513	0.00139
43	0.00000	0.14337	0.14337	0.00735
44	0.16963	0.00000	0.16963	0.00773
45	0.02023	0.03596	0.05619	0.00076

I B S - M B S

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.24235	0.07057	0.31292	0.02448
2	0.16493	0.00115	0.16608	0.00828
3	0.00339	0.24824	0.25162	0.01862
4	0.52711	0.04643	0.57353	0.06635
5	0.20344	0.11392	0.31735	0.01952
6	0.03569	0.22598	0.26167	0.01981
7	0.05320	0.00222	0.05542	0.00109
8	0.03106	0.03850	0.06956	0.00129
9	0.21895	0.21478	0.43373	0.03832
10	0.00233	0.12073	0.12306	0.00450
11	0.01326	0.06313	0.07639	0.00170
12	0.13247	0.04738	0.17985	0.01236
13	0.10632	0.02188	0.12821	0.00438
14	0.00900	0.21864	0.22763	0.02151
15	0.07448	0.18127	0.25575	0.01651
16	0.02200	0.01367	0.03567	0.00026
17	0.09610	0.08989	0.18599	0.00854
18	0.37434	0.07945	0.45379	0.04386
19	0.00000	0.35020	0.35020	0.03319
20	0.03029	0.05720	0.08749	0.00238
21	0.11120	0.03527	0.14646	0.00537
22	0.01048	0.13617	0.14665	0.00991
23	0.06543	0.02481	0.09023	0.00222
24	0.08066	0.11243	0.19308	0.00927
25	0.19036	0.22280	0.41315	0.03811
26	0.15032	0.12057	0.27088	0.01739
27	0.11256	0.07206	0.18462	0.00719
28	0.07731	0.02091	0.09821	0.00249
29	0.09820	0.00000	0.09821	0.00301
30	0.13533	0.02466	0.15999	0.01218
31	0.24237	0.00736	0.24972	0.02777
32	0.08161	0.24406	0.32567	0.02269
33	0.12433	0.03221	0.15651	0.00804
34	0.21072	0.00234	0.21306	0.01805
35	0.09805	0.08655	0.18460	0.01445
36	0.17960	0.06127	0.24086	0.02803
37	0.00000	0.27364	0.27364	0.01459
38	0.06972	0.04343	0.11314	0.00389
39	0.19155	0.00097	0.19252	0.00978
40	0.16610	0.22812	0.39422	0.04332
41	0.16876	0.00000	0.16876	0.00723
42	0.10774	0.28217	0.38991	0.03129
43	0.11055	0.15851	0.26905	0.02452
44	0.23307	0.12622	0.35928	0.03381
45	0.19200	0.10598	0.29797	0.02129

9W6-MB6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.07244	0.08599	0.15842	0.00767
2	0.24754	0.00144	0.24898	0.02890
3	0.38849	0.24792	0.63640	0.08003
4	0.34124	0.01255	0.35379	0.02909
5	0.16257	0.00000	0.16257	0.00697
6	0.00000	0.04552	0.04552	0.00063
7	0.24935	0.00708	0.25642	0.03627
8	0.41975	0.07601	0.49576	0.09151
9	0.28163	0.00000	0.28163	0.01736
10	0.01033	0.13810	0.14842	0.00555
11	0.18257	0.00000	0.18257	0.00824
12	0.14186	0.00000	0.14186	0.00432
13	0.09064	0.06268	0.15331	0.00495
14	0.01436	0.06293	0.07728	0.00277
15	0.04903	0.15885	0.23786	0.02650
16	0.07757	0.04150	0.11905	0.00484
17	0.40773	0.16289	0.57062	0.06845
18	0.27091	0.09937	0.37028	0.03674
19	0.00551	0.10992	0.11543	0.00886
20	0.09233	0.00988	0.10221	0.00365
21	0.12426	0.00013	0.12438	0.00536
22	0.20607	0.30562	0.51169	0.05220
23	0.09579	0.00000	0.09579	0.00243
24	0.00299	0.15800	0.16100	0.00905
25	1.11280	0.24987	1.36264	0.57430
26	0.03958	0.00720	0.04678	0.00071
27	0.25575	0.00000	0.25575	0.01505
28	0.00154	0.06090	0.06244	0.00132
29	0.14144	0.02311	0.16453	0.00859
30	0.13898	0.00000	0.13898	0.00507
31	0.17279	0.25937	0.43216	0.04074
32	0.06606	0.16848	0.23453	0.01249
33	0.09791	0.02672	0.12462	0.00460
34	0.38261	0.00000	0.38261	0.03749
35	0.01663	0.16831	0.18494	0.01155
36	0.20641	0.09042	0.29683	0.01677
37	0.01292	0.18383	0.19675	0.01618
38	0.18843	0.00000	0.18843	0.01009
39	0.18768	0.01365	0.20132	0.01506
40	0.15912	0.11068	0.26980	0.01448
41	0.11710	0.00000	0.11710	0.00288
42	0.37177	0.12886	0.50063	0.05794
43	0.20757	0.00000	0.20757	0.03517
44	0.07800	0.04996	0.12796	0.00442
45	0.20708	0.01925	0.22633	0.01416

L W 5 - L W 6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.09760	0.01558	0.11318	0.00436
2	0.00031	0.08440	0.08470	0.00249
3	0.06605	0.04015	0.10620	0.00234
4	0.00222	0.06582	0.06805	0.00168
5	0.16764	0.00000	0.16764	0.00650
6	0.00000	0.29447	0.29447	0.02591
7	0.01386	0.14465	0.15851	0.00955
8	0.02027	0.10328	0.12355	0.00462
9	0.05610	0.18760	0.24370	0.01301
10	0.00006	0.18183	0.18189	0.00978
11	0.03378	0.05624	0.09001	0.00245
12	0.09370	0.15601	0.24970	0.01661
13	0.07315	0.00121	0.07436	0.00142
14	0.02308	0.00442	0.02749	0.00040
15	0.07213	0.00173	0.07386	0.00259
16	0.03279	0.11096	0.14374	0.00584
17	0.00000	0.16882	0.16882	0.00625
18	0.02898	0.12728	0.15625	0.00492
19	0.00000	0.15163	0.15163	0.00886
20	0.16673	0.03676	0.20349	0.01034
21	0.00003	0.08937	0.08939	0.00241
22	0.02677	0.06879	0.09555	0.00179
23	0.00127	0.03099	0.03226	0.00028
24	0.07447	0.03747	0.11193	0.00357
25	0.14345	0.20186	0.34530	0.03282
26	0.01351	0.26226	0.27577	0.01973
27	0.00354	0.17332	0.17687	0.00970
28	0.05106	0.00603	0.05709	0.00128
29	0.00763	0.07895	0.08658	0.00220
30	0.00000	0.22715	0.22715	0.00981
31	0.16896	0.07782	0.24677	0.01644
32	0.02476	0.04053	0.06528	0.00083
33	0.07364	0.05426	0.12790	0.00443
34	0.08485	0.00044	0.08528	0.00381
35	0.00000	0.18302	0.18302	0.01553
36	0.01099	0.20540	0.21638	0.01770
37	0.03410	0.04207	0.07616	0.00147
38	0.14458	0.00000	0.14458	0.00469
39	0.00000	0.12018	0.12018	0.00355
40	0.14477	0.00000	0.14477	0.00616
41	0.00000	0.12842	0.12842	0.00321
42	0.00826	0.11859	0.12685	0.00542
43	0.01122	0.01833	0.02955	0.00018
44	0.11549	0.11138	0.22687	0.01498
45	0.05099	0.10280	0.15378	0.00483

1 8 5 - 1 8 6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.13984	0.00003	0.13987	0.00517
2	0.00000	0.08165	0.08165	0.00133
3	0.05202	0.11257	0.16459	0.00549
4	0.10303	0.05838	0.16141	0.00836
5	0.05113	0.04115	0.09228	0.00194
6	0.05798	0.02830	0.08627	0.00207
7	0.02356	0.11934	0.14291	0.00580
8	0.07543	0.10060	0.17603	0.00913
9	0.15415	0.08558	0.23972	0.01140
10	0.00000	0.13515	0.13515	0.00384
11	0.00905	0.04136	0.05041	0.00051
12	0.13814	0.00566	0.14380	0.01423
13	0.01018	0.06063	0.07081	0.00151
14	0.02054	0.03325	0.05379	0.00071
15	0.11013	0.33250	0.44262	0.04915
16	0.00000	0.08718	0.08718	0.00160
17	0.07253	0.00580	0.07832	0.00152
18	0.00000	0.18638	0.18638	0.00675
19	0.05860	0.04078	0.09937	0.00242
20	0.00804	0.04439	0.05242	0.00078
21	0.10231	0.02487	0.12717	0.00476
22	0.00000	0.19007	0.19007	0.01079
23	0.04987	0.05274	0.10261	0.00266
24	0.00000	0.20402	0.20402	0.01163
25	0.08232	0.04175	0.12407	0.00322
26	0.09500	0.12557	0.22056	0.01240
27	0.04023	0.25365	0.29388	0.03665
28	0.06714	0.14643	0.21356	0.01350
29	0.00000	0.11867	0.11867	0.00704
30	0.04757	0.05354	0.10110	0.00265
31	0.12292	0.03220	0.15512	0.01287
32	0.15064	0.01670	0.16734	0.01095
33	0.04897	0.12896	0.17793	0.00675
34	0.32276	0.00000	0.32276	0.01904
35	0.05985	0.23979	0.29964	0.06556
36	0.27429	0.00000	0.27429	0.01639
37	0.15298	0.01591	0.16888	0.00661
38	0.09559	0.11609	0.21167	0.01036
39	0.10612	0.40169	0.50780	0.06263
40	0.05029	0.10817	0.15846	0.01254
41	0.10917	0.00000	0.10917	0.00325
42	0.17991	0.02217	0.20208	0.01167
43	0.11382	0.12692	0.24074	0.03047
44	0.18301	0.00583	0.18884	0.01157
45	0.30486	0.00000	0.30486	0.03809

M W 5 - M W 6

	Base-High Area	Base Low Area	Absolute Difference	Root Sum of Square
1	0.10295	0.00004	0.10299	0.00370
2	0.01955	0.00924	0.02879	0.00030
3	0.09621	0.00632	0.10253	0.00237
4	0.00748	0.11290	0.12037	0.00427
5	0.05533	0.00186	0.05719	0.00088
6	0.01447	0.01125	0.02572	0.00017
7	0.01094	0.22123	0.23216	0.02562
8	0.01247	0.11946	0.13192	0.00589
9	0.03384	0.00334	0.03718	0.00037
10	0.02595	0.13257	0.15852	0.00786
11	0.01493	0.07013	0.08505	0.00219
12	0.07603	0.11208	0.18811	0.00890
13	0.03178	0.09954	0.13132	0.00378
14	0.04195	0.05765	0.09958	0.00316
15	0.00943	0.01055	0.01997	0.00012
16	0.03148	0.04287	0.07434	0.00147
17	0.00363	0.19968	0.20331	0.00978
18	0.03628	0.13652	0.17280	0.00772
19	0.05769	0.00884	0.06652	0.00269
20	0.01658	0.01964	0.03622	0.00043
21	0.00000	0.02196	0.02196	0.00014
22	0.09177	0.06426	0.15602	0.00471
23	0.00000	0.14060	0.14060	0.00575
24	0.00242	0.01730	0.01972	0.00010
25	0.03076	0.17501	0.20577	0.01304
26	0.00000	0.20062	0.20062	0.01060
27	0.01430	0.16992	0.18422	0.01023
28	0.00036	0.07875	0.07910	0.00229
29	0.00826	0.07775	0.08601	0.00252
30	0.03887	0.10926	0.14812	0.00600
31	0.17878	0.07512	0.25389	0.01649
32	0.03335	0.01215	0.04550	0.00061
33	0.00000	0.06376	0.06376	0.00098
34	0.05244	0.00168	0.05413	0.00073
35	0.08072	0.07044	0.15115	0.00768
36	0.00000	0.16239	0.16239	0.00563
37	0.10406	0.03333	0.13739	0.00705
38	0.02984	0.03994	0.06977	0.00136
39	0.02945	0.02549	0.05494	0.00074
40	0.12785	0.03474	0.16258	0.01010
41	0.06410	0.05712	0.12121	0.00398
42	0.07746	0.23871	0.31617	0.02471
43	0.01951	0.02323	0.04274	0.00053
44	0.12885	0.00273	0.13158	0.00836
45	0.02442	0.04297	0.06739	0.00099

M B 5 - M B 6

	Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Square
1	0.28523	0.09715	0.38238	0.03685
2	0.04918	0.07063	0.11980	0.00326
3	0.01355	0.11393	0.12748	0.00515
4	0.44782	0.05264	0.50045	0.04955
5	0.29420	0.00192	0.29612	0.02661
6	0.00000	0.13842	0.13842	0.00517
7	0.02906	0.15711	0.18616	0.01106
8	0.22281	0.04058	0.26339	0.02568
9	0.19388	0.14271	0.33659	0.02230
10	0.00000	0.34006	0.34006	0.03210
11	0.10485	0.10238	0.20723	0.00884
12	0.08606	0.05876	0.14481	0.00532
13	0.02930	0.00569	0.03499	0.00030
14	0.04132	0.15541	0.19672	0.01174
15	0.09179	0.47525	0.56704	0.09759
16	0.11285	0.05126	0.16410	0.00624
17	0.06214	0.29585	0.35799	0.04235
18	0.32775	0.15207	0.47981	0.04789
19	0.00000	0.23694	0.23694	0.01932
20	0.06836	0.19055	0.25892	0.01913
21	0.10857	0.07213	0.18069	0.00951
22	0.00972	0.22923	0.23894	0.01669
23	0.09686	0.13162	0.22847	0.01158
24	0.00000	0.22906	0.22906	0.01657
25	0.22952	0.21005	0.43957	0.04419
26	0.07660	0.03799	0.11459	0.00395
27	0.08646	0.10019	0.18665	0.00944
28	0.00209	0.20293	0.20501	0.014[illegible]
29	0.08169	0.03040	0.11208	0.00448
30	0.26564	0.00000	0.26564	0.01320
31	0.21505	0.07467	0.28972	0.02652
32	0.06617	0.26205	0.32821	0.02510
33	0.03723	0.03782	0.07504	0.00165
34	0.41039	0.00000	0.41039	0.03053
35	0.15046	0.66482	0.81528	0.28938
36	0.06457	0.11416	0.17872	0.00920
37	0.00000	0.09166	0.09166	0.00193
38	0.01168	0.23089	0.24257	0.02220
39	0.15840	0.01040	0.16880	0.00946
40	0.18446	0.14473	0.32919	0.02375
41	0.00216	0.16511	0.16728	0.01076
42	0.23116	0.38514	0.61629	0.07952
43	0.00000	0.07935	0.07935	0.00110
44	0.15893	0.01672	0.17565	0.01123
45	0.11051	0.15349	0.26400	0.01348

Table 1

Number of Students Within Each Subgroup

Used to Estimate Parameters of

Item Characteristic Curves

Income	Blacks	Whites
Grade 5		
Low	2024	2109
Middle or High	463	2111
Grade 6		
Low	1907	2028
Middle or High	444	2137

Table 2

Base Group and Comparison Group

in Each of the Twelve Pairwise Comparisons

Base Group		Comparison Group	
Grade Level Comparisons			
LW5:	Low income, white, grade 5	LW6:	Low income, white, grade 6
LB5:	Low income, black, grade 5	LB6:	Low income, black, grade 6
MW5:	Middle income, white, grade 5	MW6:	Middle income, white, grade 5
MB5:	Middle income, black, grade 5	MB6:	Middle income, black, grade 5
Income Comparisons			
LW5:	Low income, white, grade 5	MW5:	Middle income, white, grade 5
LB5:	Low income, black, grade 5	MB5:	Middle income, black, grade 5
LW6:	Low income, white, grade 6	MW6:	Middle income, white, grade 6
LB6:	Low income, black, grade 6	MB6:	Middle income, black, grade 6
Racial Comparisons			
LW5:	Low income, white, grade 5	LB5:	Low income, black, grade 5
MW5:	Middle income, white, grade 5	MB5:	Middle income, black, grade 5
LW6:	Low income, white, grade 6	LB6:	Low income, black, grade 6
MW6:	Middle income, white, grade 6	MB6:	Middle income, black, grade 6

Table 3

Expected and Observed Distributions of the Number of Times an Item is Identified as Biased Based on a Root of the Sum of Squares Bias Index Greater than or Equal to .2

Number of Times Identified	Expected Frequency[a]	Observed Frequency
4	.05	3
3	.92	1
2	6.29	6
1	18.48	7
0	19.27	28

[a]Expected frequency based on assumption that 13, 7, 7, and 7 items are randomly identified as biased in the four independent replications (i.e., LW5-LB5, LW6-LB6, MW5-MB5, and MW6-MB6).

Table 4

Agreement in the identification of Items

as Biased Based on the Square Root of the Sum of Squares

Greater than .2 for the Pairs of Racial Group Comparisons

Comparison			U	B	Phi	Chi-Square
L5	L6	B	6	7	.67	20.38
		U	32	0		
L5	M5	B	9	4	.27	3.23
		U	29	3		
L5	M6	B	8	5	.40	7.31
		U	30	2		
L6	M5	B	4	3	.32	4.69
		U	34	4		
L6	M6	B	3	4	.49	10.89
		U	35	3		
M5	M6	B	3	4	.49	10.89
		U	35	3		

Note: U = unbiased, B = biased

Table 5

Correlations between the Square Root of the Sum-of-Squares Bias Indices for Pairs of Independent Racial Group Comparisons

Comparison[a]	L5	L6	M5	M6
L5	-			
L6	.39	-		
M5	.47	.14	-	
M6	.21	.64	.36	-

[a]The comparisons are between racial groups within income and grade level. L5 = low income, grade 5; L6 = low income, grade 6; M5 = middle income, grade 5; and M6 = middle income, grade 6.

Table 6

Rank Order of Bias Indices for the Three Items Identified as Possibly Biased in All Four Comparisons

Item	Comparison	Index			
		Base-High Area	Base-Low Area	Absolute Difference	Root Sum of Squares
3	L5	3	15	2	6
	L6	3	10	2	4
	M5	3	15	4	4
	M6	4	4	2	3
25	L5	9	20	9	10
	L6	1	11	1	1
	M5	2	3	2	2
	M6	1	3	1	1
31	L5	33	2	10	8
	L6	30	1	4	2
	M5	18	1	6	6
	M6	20	2	7	7

Table 7

Rank Order of Base-High and Base-Low Area Bias Indices

for the Four Racial Group Comparisons

Involving Word Meaning and Best Title Items

Item Number	Word	Base-High Area				Base-Low Area			
		L5	L6	M5	M6	L5	L6	M5	M6
				Word Meaning					
2	there	12	5	8	12	41.5	40	24.0	33
6	rings	43	9	34	45	22.0	35	41.5	23
15	rest	21	42	21	36	11.0	5	12.0	5
17	setting	20	10	5	3	4.0	8	41.5	9
19	run	23	12	16	42	41.5	42	41.5	14
23	tribute	31	35	24	29	21.0	20	7.0	40
25	character	9	1	2	1	20.0	11	3.0	3
27	reigning	2	6	14	10	41.5	44	13.0	40
29	assumed	24	37	33	24	31.0	21	10.0	26
39	true	7	27	39	18	17.0	22	33.0	28
42	speculate	1	17	9	6	10.0	30	2.0	12
				Best Title					
5		8	20	41	21	34.0	31	8.0	40
11		18	23	27	19	36.0	39	28.0	40
18		16	31	22	9	41.5	27	41.5	15
24		13	37	20	43	29.0	14	30.0	10
31		33	30	18	20	2.0	1	1.0	2

Figure Captions

Figure 1. Distributions of the square root of the sum of squares bias indices for the twelve pairwise comparisons.

Figure 2. Item characteristic curves and confidence intervals for fifth- and sixth-grade white students attending schools in low-income neighborhoods (Items 6 and 18).

Figure 3. Item characteristic curves and confidence intervals for fifth- and sixth-grade black students attending schools in low-income neighborhoods (Item 35).

Figure 4. Item characteristic curves and confidence intervals for four independent racial group comparisons (Item 3).

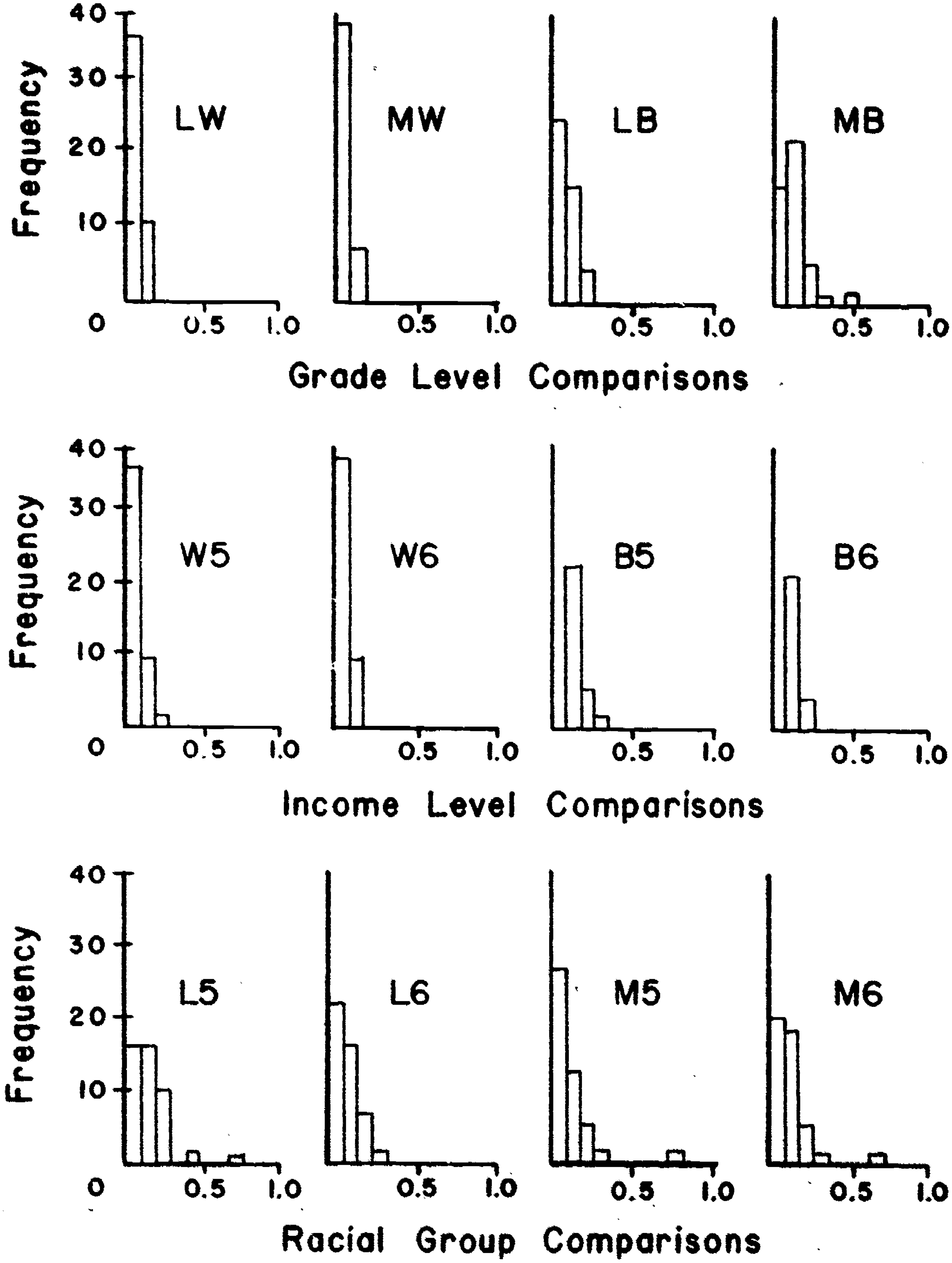
Figure 5. Item characteristic curves and confidence intervals for four independent racial group comparisons (Item 25).

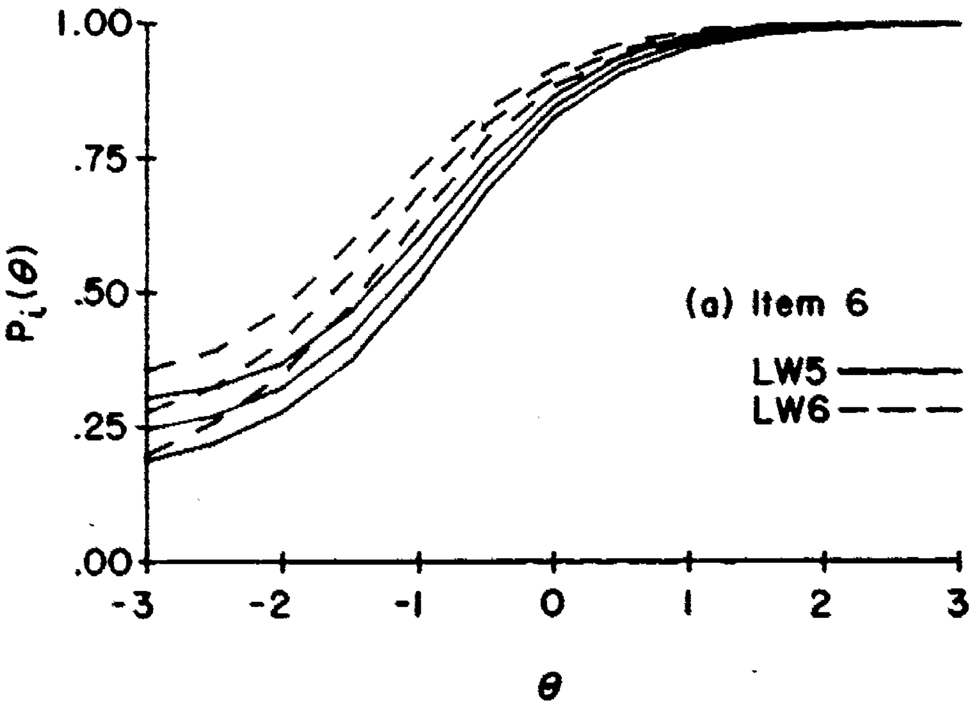
Figure 6. Item characteristic curves and confidence intervals for four independent racial group comparisons (Item 31).

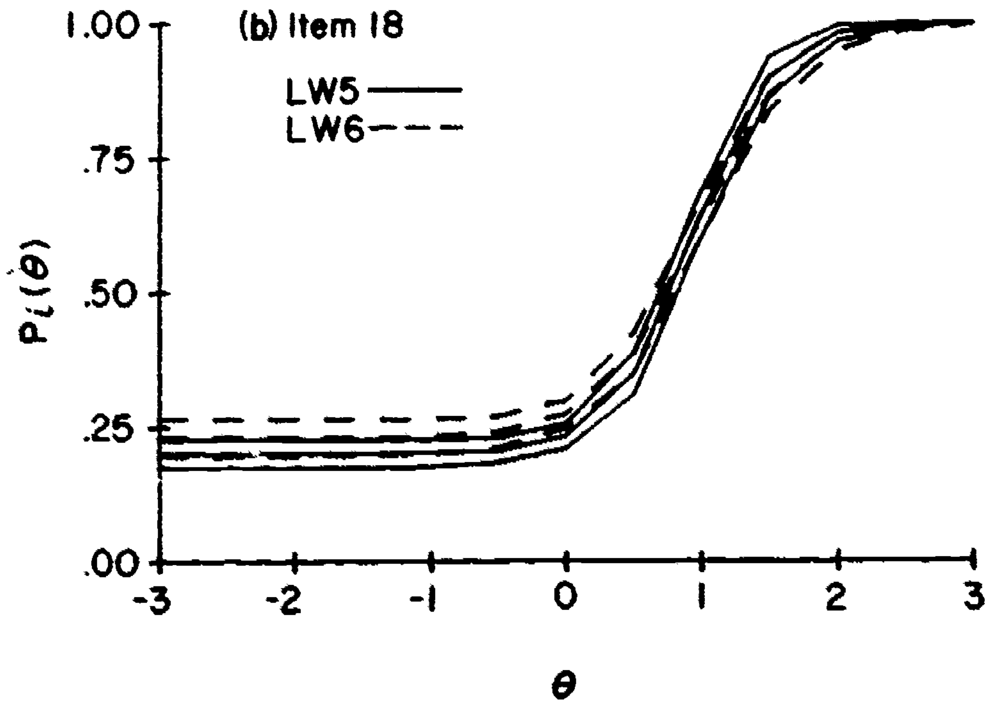
Figure 7. Item characteristic curves and confidence intervals for fifth- and sixth-grade white students attending schools in low-income neighborhoods (Items 3, 25, and 31).

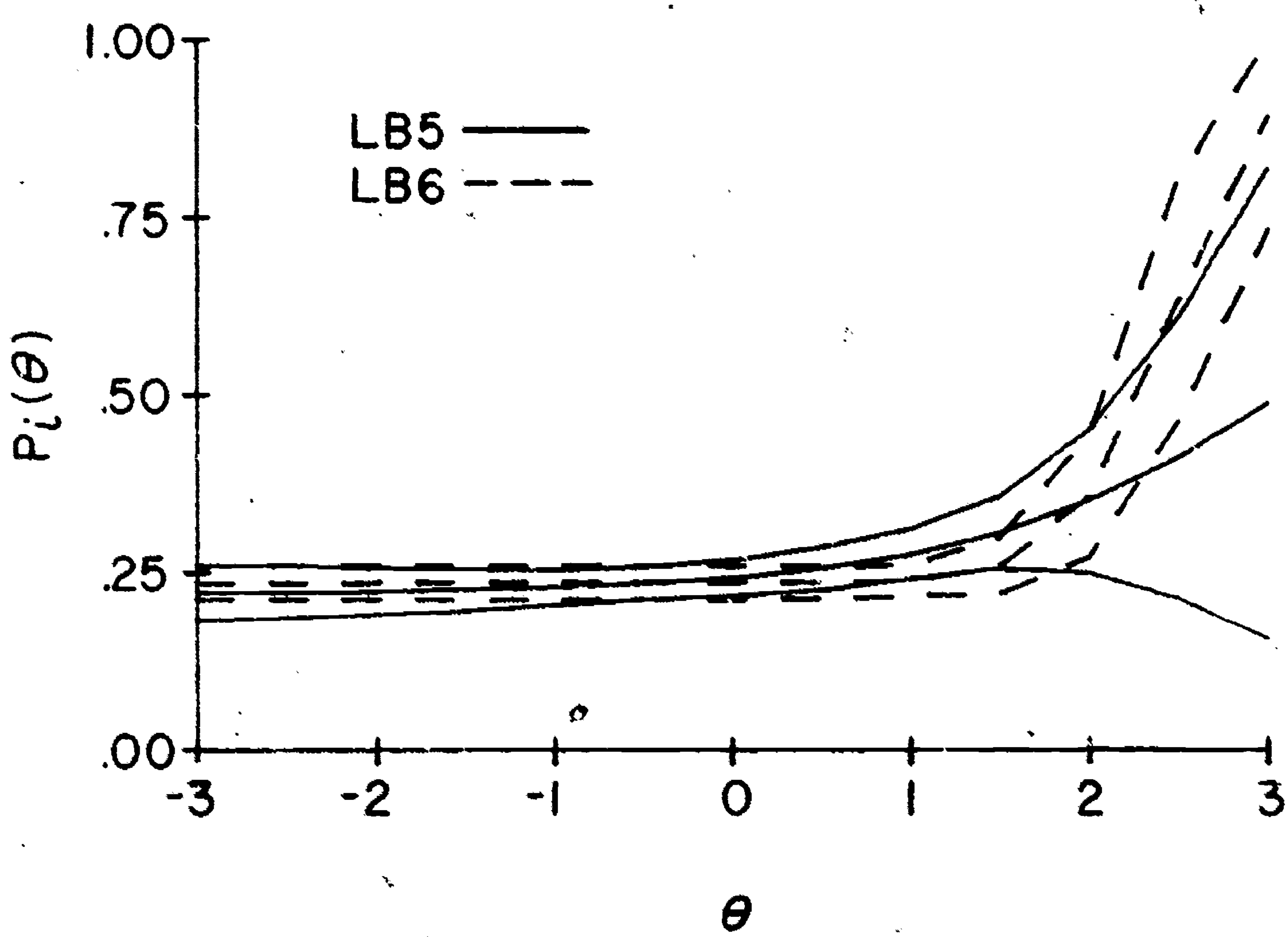
Figure 8. Test characteristic curves for four independent racial group comparisons.

Figure 9. Expected raw score distributions for LW5 and LB5 students with $\theta = 0$.

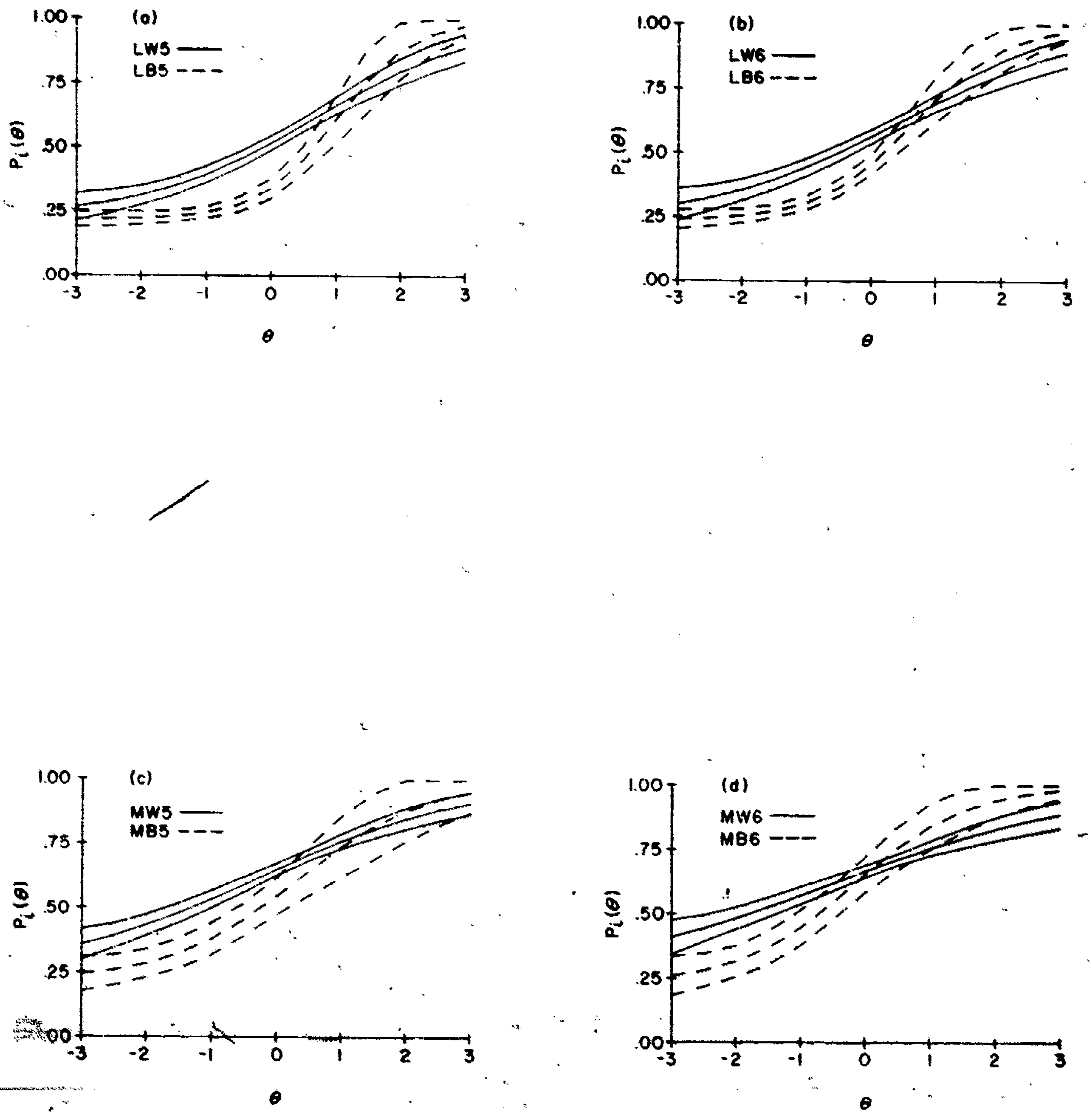

Frequency
40
30
20
10
0
0.5
1.0
LW
MW
LB
MB
Grade Level Comparisons
W5
W6
B5
B6
Income Level Comparisons
L5
L6
M5
M6
Racial Group Comparisons

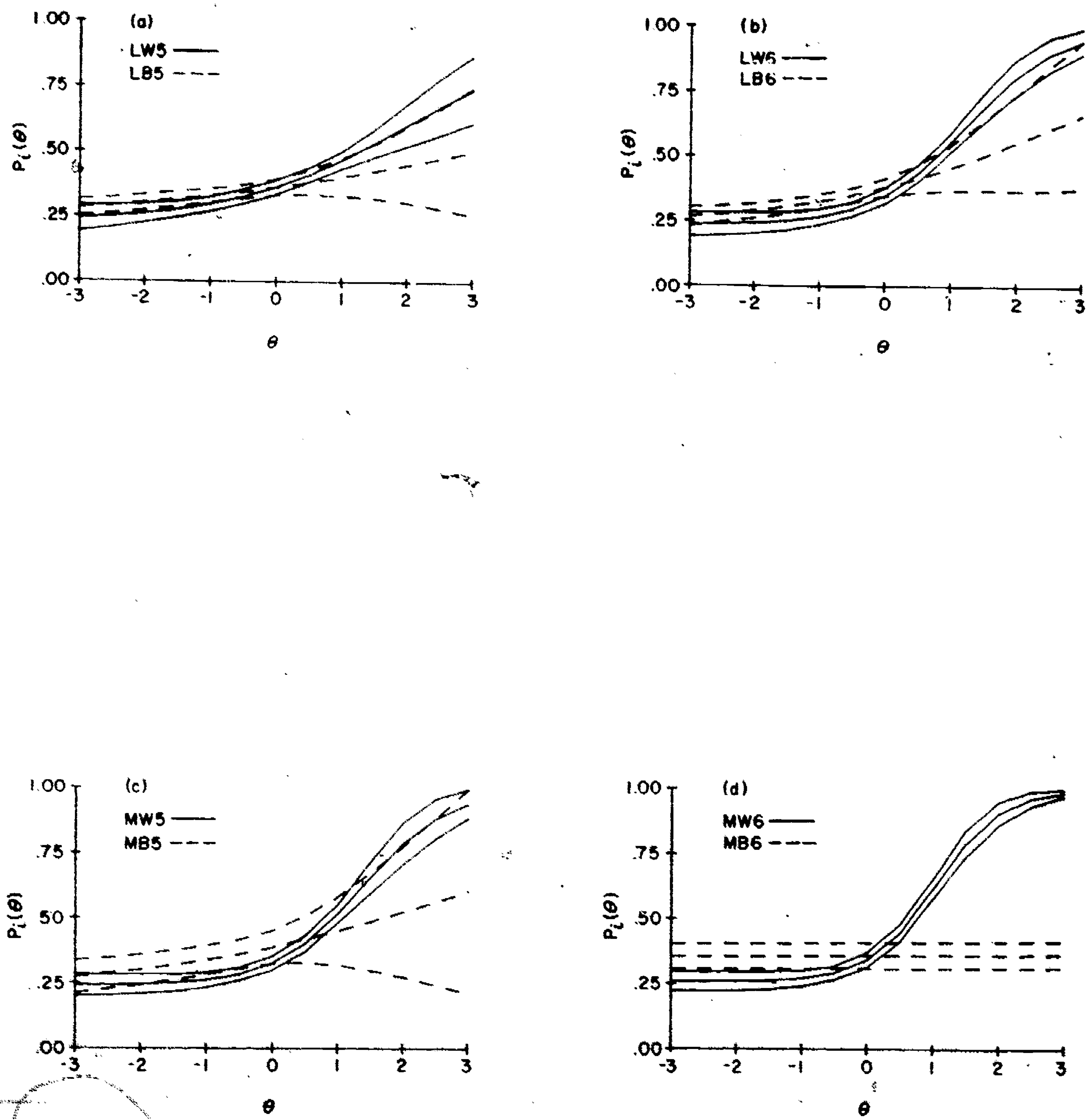

1.00
.75
.50
.25
.00
$P_i(\theta)$
(a) Item 6
LW5
LW6
-3
-2
-1
0
1
2
3
θ

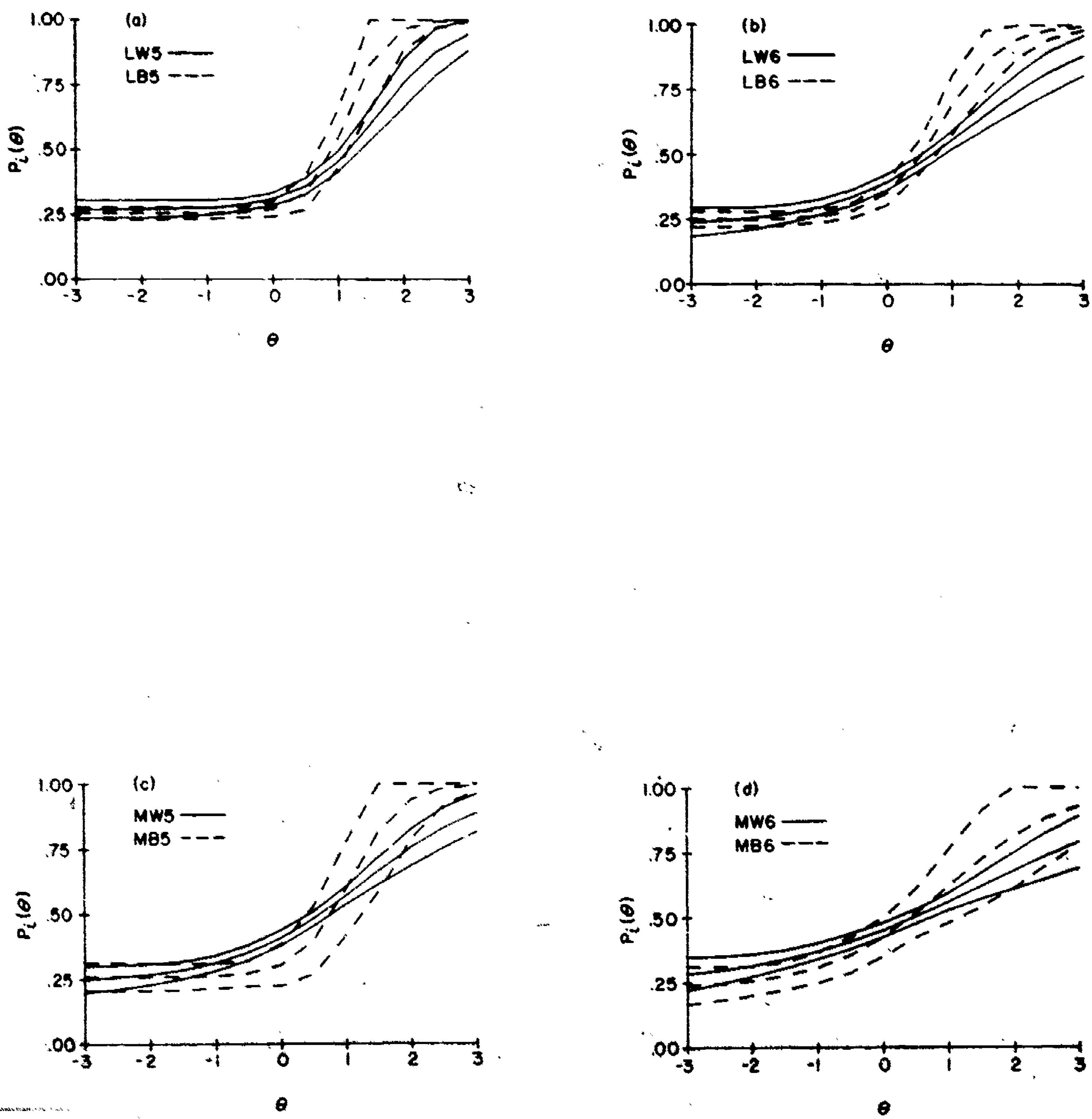

1.00
.75
.50
.25
.00
$P_i(\theta)$
(b) Item 18
LW5
LW6
-3
-2
-1
0
1
2
3
θ

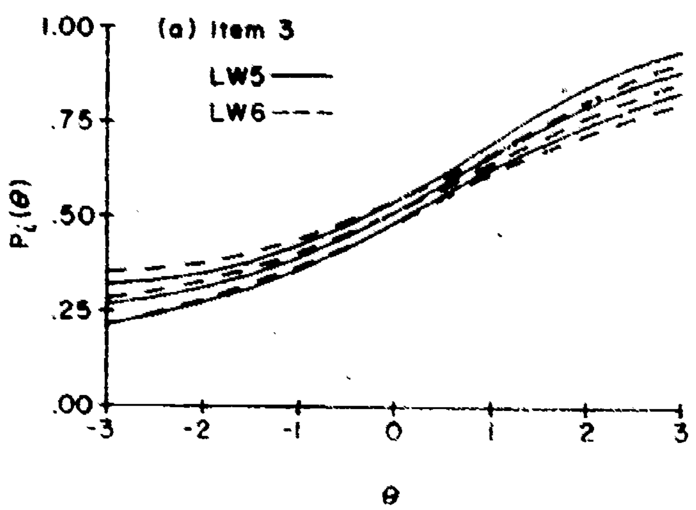


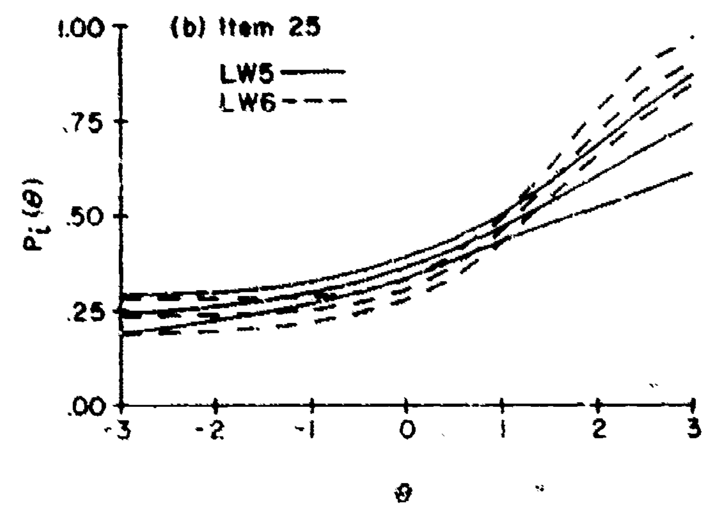
1.00
.75
.50
.25
.00
LB5
LB6
$P_i(\theta)$
-3
-2
-1
0
1
2
3
θ

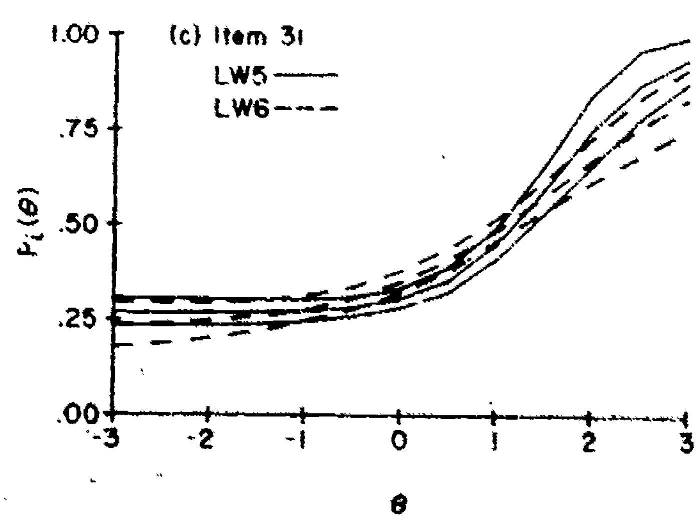

(a)
LW5
LB5
(b)
LW6
LB6
(c)
MW5
MB5
(d)
MW6
MB6
Pi(θ)
θ
1.00
.75
.50
.25
.00
-3
-2
-1
0
1
2
3

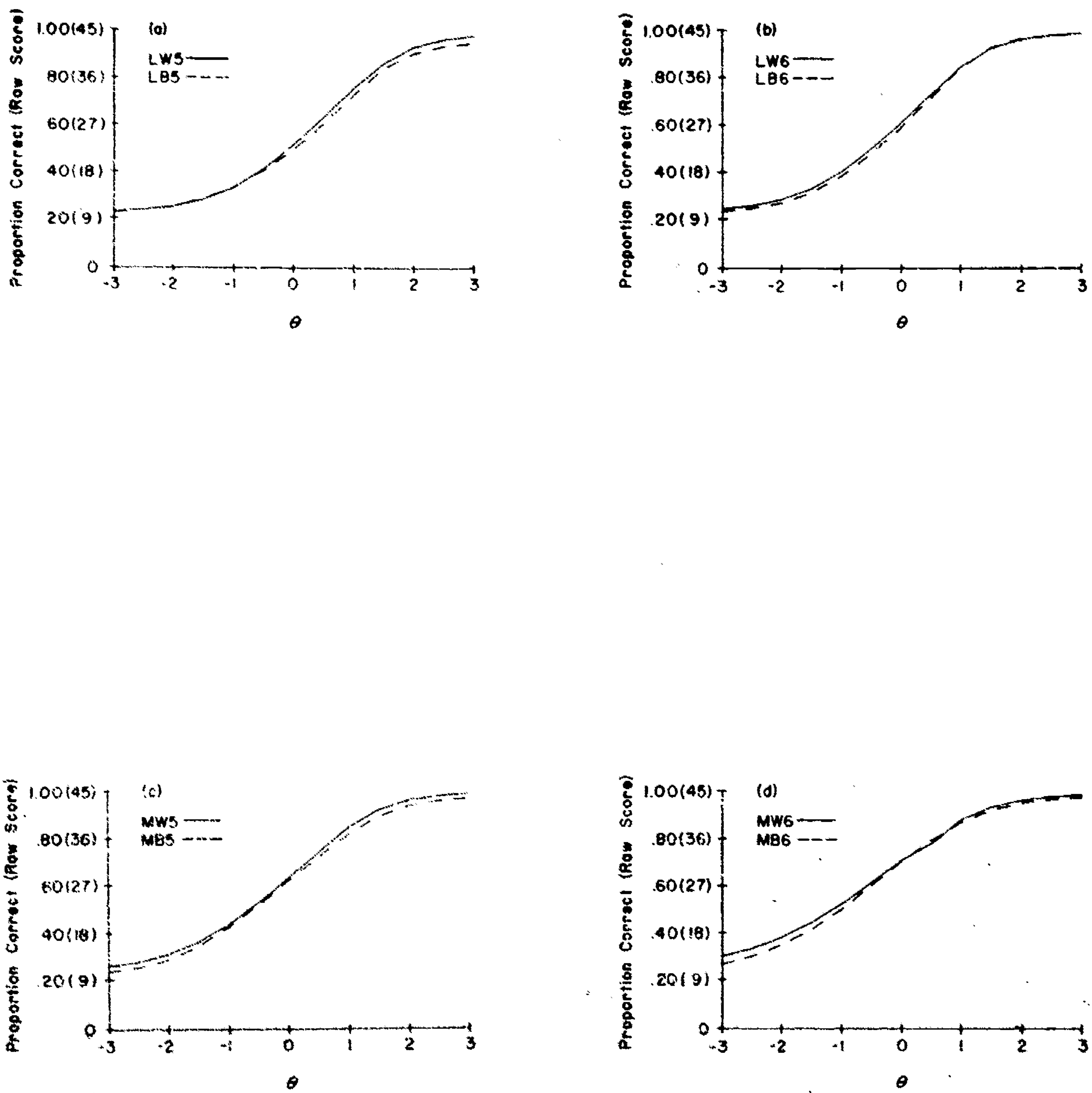

(a)
LW5
LB5
(b)
LW6
LB6
(c)
MW5
MB5
(d)
MW6
MB6
$P_i(\theta)$
θ
1.00
.75
.50
.25
.00
-3
-2
-1
0
1
2
3

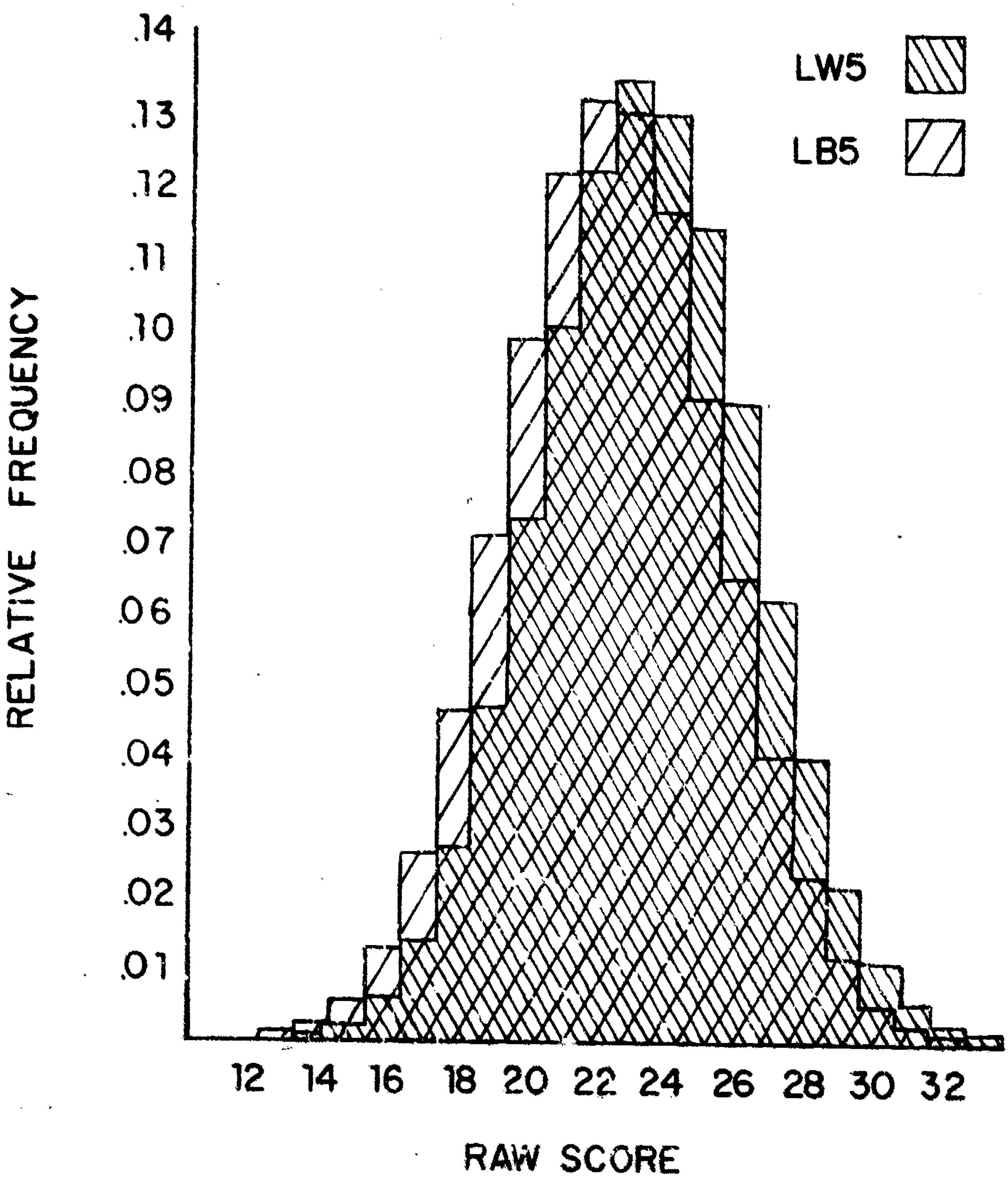

(a)
LW5
LB5
(b)
LW6
LB6
(c)
MW5
MB5
(d)
MW6
MB6
$P_i(\theta)$
1.00
.75
.50
.25
.00
-3
-2
-1
0
1
2
3
θ


1.00
.75
.50
.25
.00
(a) Item 3
LW5
LW6
$P_i(\theta)$
-3
-2
-1
0
1
2
3
θ


1.00
.75
.50
.25
.00
(b) Item 25
LW5
LW6
$P_i(\theta)$
-3
-2
-1
0
1
2
3
θ


1.00
.75
.50
.25
.00
(c) Item 31
LW5
LW6
$P_i(\theta)$
-3
-2
-1
0
1
2
3
θ


(a)
LW5
LB5
(b)
LW6
LB6
(c)
MW5
MB5
(d)
MW6
MB6
Proportion Correct (Raw Score)
1.00(45)
.80(36)
.60(27)
.40(18)
.20(9)
0
-3
-2
-1
0
1
2
3
θ



.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
RELATIVE FREQUENCY
LW5
LB5
12
14
16
18
20
22
24
26
28
30
32
RAW SCORE

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