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ABSTRACT

This study empirically determined the optimizing weight to be applied to the Wrongs Total Score in scoring rubrics of the general form = R - kW, where S is the Score, R the Rights Total, k the weight and W the Wrongs Total, if reliability is to be maximized. As is well known, the traditional formula score rests on a theoretical framework which is of dubious validity. Two instruments, variant approaches to the assessment of mathematical knowledge, were administered to approximately 1,700 entering college freshmen during an orientation period. The method consists of an iterative computer procedure for calculating split-half reliability of the tests as the weights are systematically varied throughout the region of maximization as determined by essentially canonical approaches. The results indicate that in contrast to the negative weight for the a priori formula score, a sizable positive weight maximizes reliability. The implications for rate of work as the single most reliable aspect of test performance seem clear. The validity of much educational testing rests on assumptions of fairness to those tested, achieved through optimization of standardized conditions. The study suggests that factors which alter rate-of-work characteristics of performance may be most detrimental to candidate success. (Author/DEP)

An Optimizing Weight for "Wrong" Scores

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An Optimizing Weight for "Wrongs" Scores*

In scoring a multiple-choice test, the "formula score" or "correction for guessing" is the most widely used alternative to the simple count of the total number of right answers. The formula is

$$F.S. = R - \frac{W}{k-1},$$

where

F.S. = Formula Score
R = Total number right
W = Total number wrong
k = Number of choices per test item

The basic assumption which underlies this formula is that responses fall into two categories: those based on knowledge sufficient to determine a correct answer, and those based on knowledge insufficient to provide any basis for response better than chance responding. The value of R, the total number right, is a combination of the two categories, but the value of W, the total number wrong, reflects only responses based on insufficient information. The size of W is used to "correct" the observed value of R, to estimate the true value of the number of responses based on knowledge, for the chance behaviors are assumed to be randomly spread equally across the k choices per item, so that $\frac{k-1}{k}$ of them will be wrong answers, summing to the observed W score, and $\frac{1}{k}$ of them will be right answers, "buried" in the R score. The ratio of "buried" wrong answers to "observed" wrong answers is thus $\frac{1}{k-1}$.

Thorndike (1971) has discussed this correction, emphasizing its logical flaws and some of its merits. Ebel (1972) has presented research

*The author is indebted to David R. Saxe for the computer operations and for his interest in the problem.

evidence on the superior reliability of tests when they are scored with a formula correction. More recently, Lord (1975) has focussed on examinee behavior under different sets of instructions: formula scoring directions and number-right directions. He states an assumption that under number-right scoring candidates replace "Omit" responses by random marks on the answer sheet. The impact of this random responding is to reduce the sampling error of the formula score when contrasted with the number right score. This point is established by considering not F.S. = R $-\left(\frac{1}{k-1}\right)$ W, but F.S.' = R $+\frac{0}{k}$, where 0 = the number of items unanswered, and R and k are as before. It has long been known that since R, W, and 0 sum to a constant, (T, the total number of items) the two values of the formula scores, F.S. and F.S.', are perfectly correlated.

But the assumption of random responses is not an attractive one. Lord is clearly concerned that the assumption be recognized for its crucial role and that instructions be developed to insure that any omissions under formula scoring are truly items for which candidates have only a chance, random, potential for success. But the theory is not strongly substantiated by our evidence on candidate behavior. Guessing on tests is in the main not random activity.

If the theoretical underpinnings of the formula score are so unattractive, why are we constrained to the weight, $\frac{1}{k-1}$, which it leads to for W? What other weight might we use, and to what purpose? One purpose might clearly be the development of a maximum reliability for the score from a test. In an unpublished study by Fischer and Jackson (1971), the maximization of reliability was taken as the rationale for determining the best weight, x , for the wrongs. Taking Dressel's (1940) formula for the Kuder-Richardson reliability of a formula-scored test, Fischer and Jackson differentiated the equation with respect to the weights for the wrong answers when the right answers are weighted unity. That is, defining a weighted score as

$$W.S. = R + xw$$

where x may take any value, positive or negative, for what value is the reliability of the W.S., the weighted score, a maximum?

Somewhat to their surprise the authors found that the value of x was positive; the sum of the rights and a fraction of the wrongs was the most reliable score. Further, the Rights score alone was more reliable than the conventional formula score in each of four separately--timed subtests, comprising a form of the College Board Scholastic Aptitude Test (SAT), were two verbal and two mathematical sections with x-values of + .295 and + .585 for the mathematical material and + .639 and + .720 for the verbal.

Lord, in discussing this result observed that "This does not mean that we should give bonuses for wrong answers. It merely means that that trait of omitting items is a trait that can be quite reliably measured." This trait of omitting items, however, may be the trait of working on test material with a consistent speed. Lord, states in his discussion that his theoretical development will work best for unspeeded tests. But the test studied by Fischer and Jackson was a standard SAT form, moderately speeded. There is a possible difference between omitting an item and not reaching it. In the standard ETS item analysis, an item is considered omitted if there is a response to a later item; it is considered Not Reached if there are no responses to later items. If the preponderance of omitting in Fischer and Jackson's paper was due to a failure to complete the test, to Not Reaching, this would be evidence that the trait which is reliably measured is rate of work, not tendency to omit due to conservatism or caution.

Fischer and Jackson used a generalized internal consistency approach, via Dressel's formula, and determined the maximum reliability by differentiation with respect to the weight for wrongs. The present study extends this work by an empirical determination of the correlation between two half tests on two 50-item mathematics tests. Each half test was scored $R + kW$, (k here is simply the weight in wrongs, exactly equivalent to Fischer and Jackson's x) and the correlation between them computed. This was systematically followed throughout the region $-5.0 < k < 5.0$. The result was the two empirical curves presented in Figure 1 and Figure 2. Each of these curves shows a maximum for a positive weight somewhat less than unity. Tables 1 and 2 provide the data upon which the graphs were based.

This result supports the finding of Fischer and Jackson. The two curves reflect slightly different treatments, however. The curve in Figure 1 was based on a 50-item mathematical test which consisted of data sufficiency items. The curve in Figure 2 is based on a 50-item mathematical test which consisted of "regular math" problems. The data sufficiency items have the form of two statements and a question. The respondent is

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Table 1

Interform Reliability (R) of the Score R + kW

for Selected Values of k : Data Sufficiency Tests

(k)	(R)		(k)	(R)		(k)	(R)	
-0.50000D 01	0.61174D 00	1	-0.16000D 01	0.61562D 00	35	0.18000D 01	0.70270D 00	69
-0.49000D 01	0.61172D 00	2	-0.15000D 01	0.61626D 00	36	0.19000D 01	0.69367D 00	70
-0.48000D 01	0.61171D 00	3	-0.14000D 01	0.61702D 00	37	0.20000D 01	0.68592D 00	71
-0.47000D 01	0.61170D 00	4	-0.13000D 01	0.61790D 00	38	0.21000D 01	0.67925D 00	72
-0.46000D 01	0.61169D 00	5	-0.12000D 01	0.61894D 00	39	0.22000D 01	0.67349D 00	73
-0.45000D 01	0.61169D 00	6	-0.11000D 01	0.62016D 00	40	0.23000D 01	0.66849D 00	74
-0.44000D 01	0.61168D 00	7	-0.10000D 01	0.62160D 00	41	0.24000D 01	0.66414D 00	75
-0.43000D 01	0.61168D 00	8	-0.90000D 00	0.62332D 00	42	0.25000D 01	0.66033D 00	76
-0.42000D 01	0.61168D 00	9	-0.80000D 00	0.62536D 00	43	0.26000D 01	0.65698D 00	77
-0.41000D 01	0.61169D 00	10	-0.70000D 00	0.62762D 00	44	0.27000D 01	0.65402D 00	78
-0.40000D 01	0.61169D 00	11	-0.60000D 00	0.63078D 00	45	0.28000D 01	0.65140D 00	79
-0.39000D 01	0.61170D 00	12	-0.50000D 00	0.63437D 00	46	0.29000D 01	0.64905D 00	80
-0.38000D 01	0.61172D 00	13	-0.40000D 00	0.63875D 00	47	0.30000D 01	0.64696D 00	81
-0.37000D 01	0.61174D 00	14	-0.30000D 00	0.64411D 00	48	0.31000D 01	0.64507D 00	82
-0.36000D 01	0.61176D 00	15	-0.20000D 00	0.65070D 00	49	0.32000D 01	0.64337D 00	83
-0.35000D 01	0.61179D 00	16	-0.10000D 00	0.65883D 00	50	0.33000D 01	0.64182D 00	84
-0.34000D 01	0.61182D 00	17	0.0	0.66886D 00	51	0.34000D 01	0.64042D 00	85
-0.33000D 01	0.61187D 00	18	0.10000D 00	0.68121D 00	52	0.35000D 01	0.63914D 00	86
-0.32000D 01	0.61192D 00	19	0.20000D 00	0.69628D 00	53	0.36000D 01	0.63797D 00	87
-0.31000D 01	0.61198D 00	20	0.30000D 00	0.71431D 00	54	0.37000D 01	0.63690D 00	88
-0.30000D 01	0.61205D 00	21	0.40000D 00	0.73521D 00	55	0.38000D 01	0.63591D 00	89
-0.29000D 01	0.61214D 00	22	0.50000D 00	0.75814D 00	56	0.39000D 01	0.63500D 00	90
-0.28000D 01	0.61223D 00	23	0.60000D 00	0.78119D 00	57	0.40000D 01	0.63416D 00	91
-0.27000D 01	0.61235D 00	24	0.70000D 00	0.80135D 00	58	0.41000D 01	0.63338D 00	92
-0.26000D 01	0.61248D 00	25	0.80000D 00	0.81515D 00	59	0.42000D 01	0.63266D 00	93
-0.25000D 01	0.61263D 00	26	0.90000D 00	0.82016D 00	60	0.43000D 01	0.63198D 00	94
-0.24000D 01	0.61280D 00	27	0.10000D 01	0.81608D 00	61	0.44000D 01	0.63136D 00	95
-0.23000D 01	0.61301D 00	28	0.11000D 01	0.80460D 00	62	0.45000D 01	0.63077D 00	96
-0.22000D 01	0.61324D 00	29	0.12000D 01	0.78921D 00	63	0.46000D 01	0.63022D 00	97
-0.21000D 01	0.61351D 00	30	0.13000D 01	0.77199D 00	64	0.47000D 01	0.62970D 00	98
-0.20000D 01	0.61381D 00	31	0.14000D 01	0.75503D 00	65	0.48000D 01	0.62922D 00	99
-0.19000D 01	0.61417D 00	32	0.15000D 01	0.73935D 00	66	0.49000D 01	0.62876D 00	100
-0.18000D 01	0.61458D 00	33	0.16000D 01	0.72539D 00	67	0.50000D 01	0.62833D 00	101
-0.17000D 01	0.61506D 00	34	0.17000D 01	0.71321D 00	68			

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Table 2

Interform Reliability (R) of the Score R + kW

for Selected Values of k : Math Achievement Test

(k)	(R)		(k)	(R)		(k)	(R)	
-0.500000 D 01	0.724940 D 00	1	-0.160000 D 01	0.738140 D 00	35	0.180000 D 01	0.804600 D 00	69
-0.490000 D 01	0.724990 D 00	2	-0.150000 D 01	0.739720 D 00	36	0.190000 D 01	0.799100 D 00	70
-0.480000 D 01	0.725050 D 00	3	-0.140000 D 01	0.741500 D 00	37	0.200000 D 01	0.794050 D 00	71
-0.470000 D 01	0.725110 D 00	4	-0.130000 D 01	0.743520 D 00	38	0.210000 D 01	0.789440 D 00	72
-0.460000 D 01	0.725180 D 00	5	-0.120000 D 01	0.745820 D 00	39	0.220000 D 01	0.785250 D 00	73
-0.450000 D 01	0.725260 D 00	6	-0.110000 D 01	0.748440 D 00	40	0.230000 D 01	0.781430 D 00	74
-0.440000 D 01	0.725340 D 00	7	-0.100000 D 01	0.751420 D 00	41	0.240000 D 01	0.777960 D 00	75
-0.430000 D 01	0.725430 D 00	8	-0.900000 D 00	0.754820 D 00	42	0.250000 D 01	0.774800 D 00	76
-0.420000 D 01	0.725530 D 00	9	-0.800000 D 00	0.758710 D 00	43	0.260000 D 01	0.771920 D 00	77
-0.410000 D 01	0.725640 D 00	10	-0.700000 D 00	0.763150 D 00	44	0.270000 D 01	0.769300 D 00	78
-0.400000 D 01	0.725760 D 00	11	-0.600000 D 00	0.768200 D 00	45	0.280000 D 01	0.766900 D 00	79
-0.390000 D 01	0.725890 D 00	12	-0.500000 D 00	0.773930 D 00	46	0.290000 D 01	0.764710 D 00	80
-0.380000 D 01	0.726030 D 00	13	-0.400000 D 00	0.780420 D 00	47	0.300000 D 01	0.762700 D 00	81
-0.370000 D 01	0.726190 D 00	14	-0.300000 D 00	0.787690 D 00	48	0.310000 D 01	0.760850 D 00	82
-0.360000 D 01	0.726360 D 00	15	-0.200000 D 00	0.795750 D 00	49	0.320000 D 01	0.759160 D 00	83
-0.350000 D 01	0.726550 D 00	16	-0.100000 D 00	0.804550 D 00	50	0.330000 D 01	0.757590 D 00	84
-0.340000 D 01	0.726760 D 00	17	0.0	0.813970 D 00	51	0.340000 D 01	0.756150 D 00	85
-0.330000 D 01	0.726990 D 00	18	0.100000 D 00	0.823760 D 00	52	0.350000 D 01	0.754820 D 00	86
-0.320000 D 01	0.727240 D 00	19	0.200000 D 00	0.833560 D 00	53	0.360000 D 01	0.753580 D 00	87
-0.310000 D 01	0.727520 D 00	20	0.300000 D 00	0.842680 D 00	54	0.370000 D 01	0.752430 D 00	88
-0.300000 D 01	0.727820 D 00	21	0.400000 D 00	0.851170 D 00	55	0.380000 D 01	0.751360 D 00	89
-0.290000 D 01	0.728160 D 00	22	0.500000 D 00	0.857850 D 00	56	0.390000 D 01	0.750370 D 00	90
-0.280000 D 01	0.728530 D 00	23	0.600000 D 00	0.862440 D 00	57	0.400000 D 01	0.749440 D 00	91
-0.270000 D 01	0.728940 D 00	24	0.700000 D 00	0.864650 D 00	58	0.410000 D 01	0.748570 D 00	92
-0.260000 D 01	0.729400 D 00	25	0.800000 D 00	0.864420 D 00	59	0.420000 D 01	0.747760 D 00	93
-0.250000 D 01	0.729900 D 00	26	0.900000 D 00	0.861950 D 00	60	0.430000 D 01	0.747000 D 00	94
-0.240000 D 01	0.730470 D 00	27	0.100000 D 01	0.857620 D 00	61	0.440000 D 01	0.746290 D 00	95
-0.230000 D 01	0.731090 D 00	28	0.110000 D 01	0.851900 D 00	62	0.450000 D 01	0.745610 D 00	96
-0.220000 D 01	0.731790 D 00	29	0.120000 D 01	0.845270 D 00	63	0.460000 D 01	0.744980 D 00	97
-0.210000 D 01	0.732570 D 00	30	0.130000 D 01	0.838170 D 00	64	0.470000 D 01	0.744390 D 00	98
-0.200000 D 01	0.733440 D 00	31	0.140000 D 01	0.830930 D 00	65	0.480000 D 01	0.743820 D 00	99
-0.190000 D 01	0.734420 D 00	32	0.150000 D 01	0.823820 D 00	66	0.490000 D 01	0.743290 D 00	100
-0.180000 D 01	0.735510 D 00	33	0.160000 D 01	0.817000 D 00	67	0.500000 D 01	0.742790 D 00	101
-0.170000 D 01	0.736750 D 00	34	0.170000 D 01	0.810570 D 00	68			

BEST WEIGHTED WRONGS DETERMINATION

Figure 1

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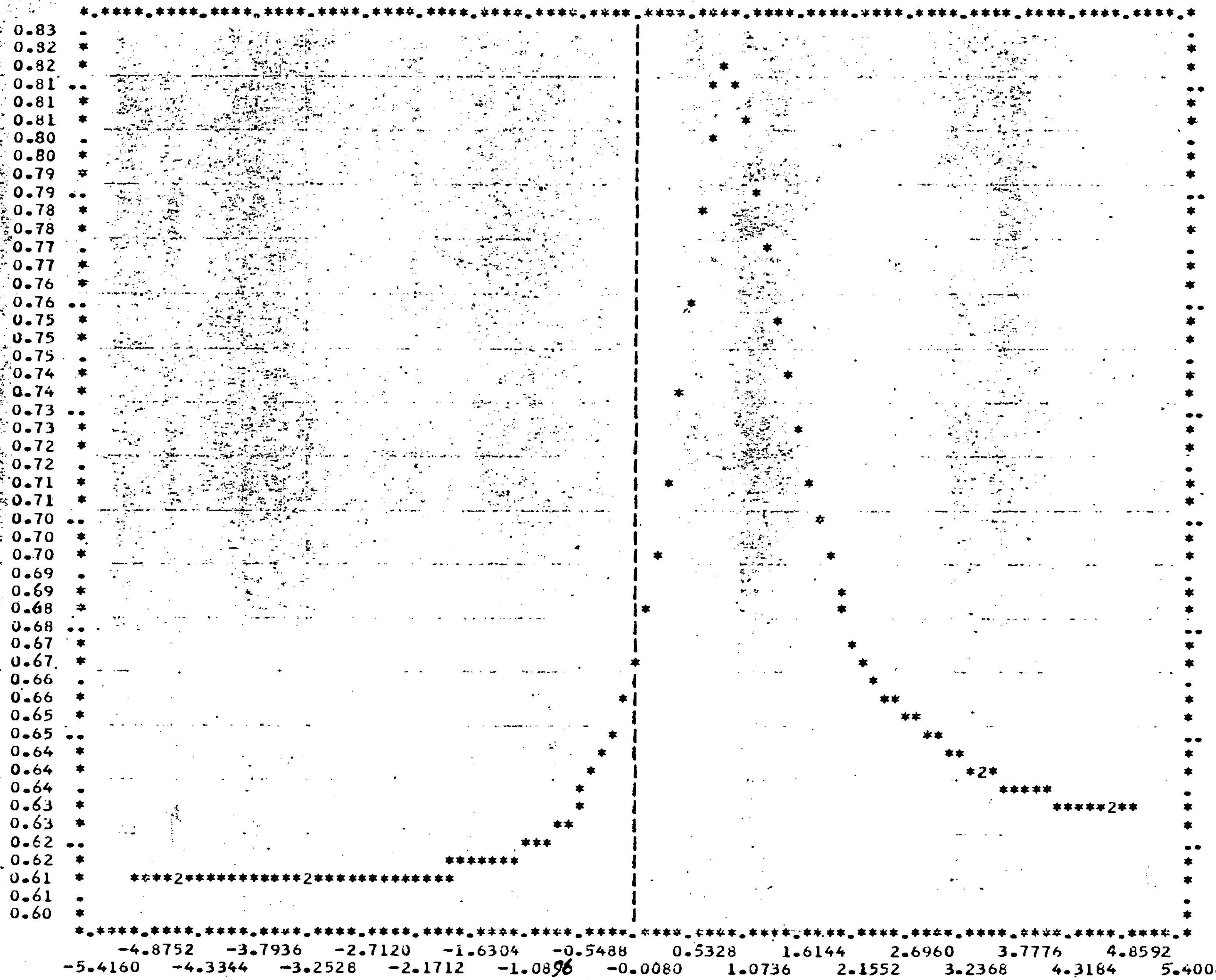
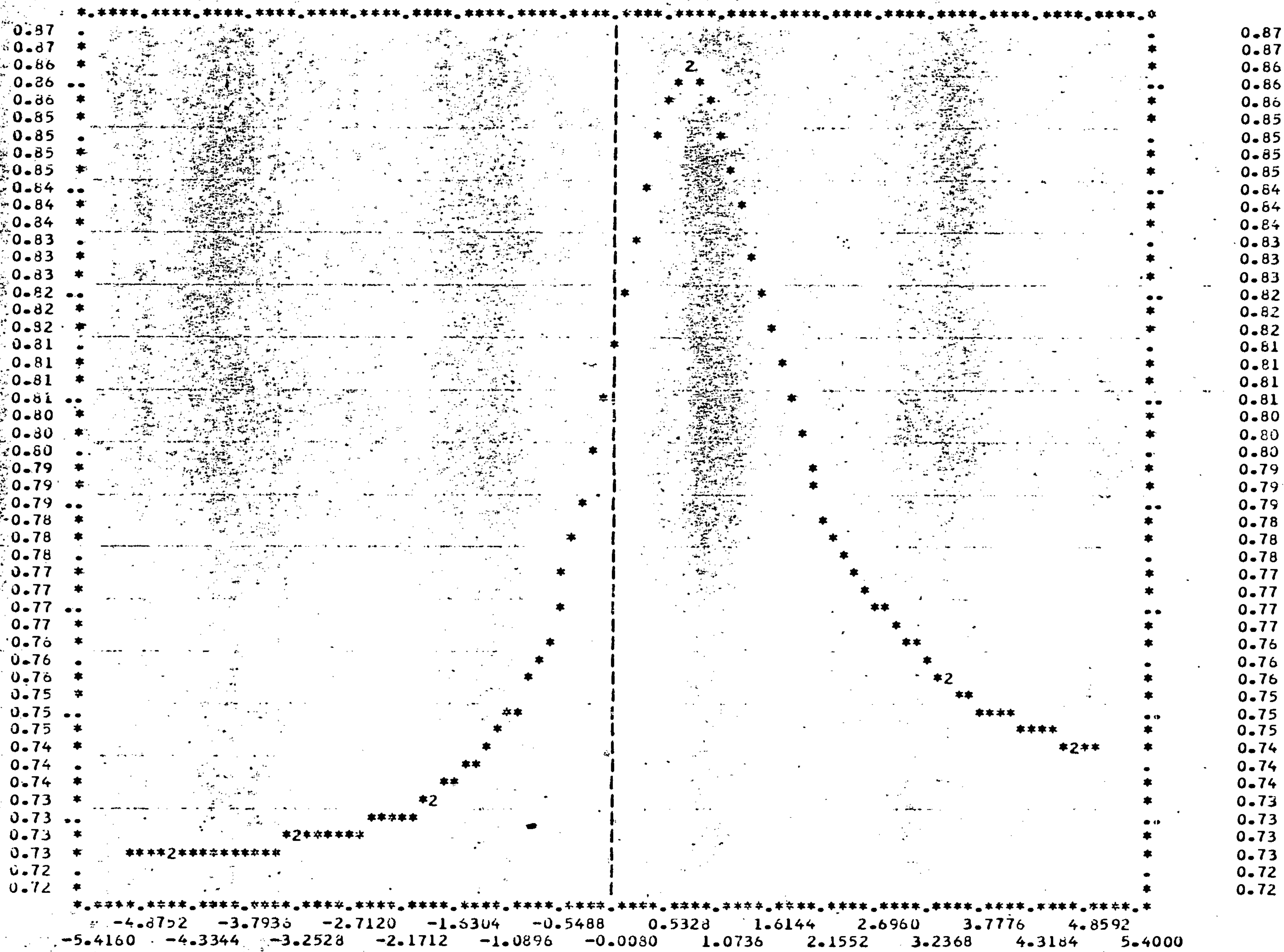
DATA SUFFICIENCY PARALLEL FORMS RELIABILITY: WRONGS WT. (X AXIS) VS. RELIABILITY (Y AXIS)



BEST WEIGHTED WRONGS DETERMINATION

Figure 2

MATH PARALLEL FORMS RELIABILITY: WRONGS WT. (X AXIS) VS. RELIABILITY (Y AXIS)



to indicate whether or not there is sufficient information in the statements to answer the question. An example would be as follows:

If x is a whole number, is it a two-digit number?

(1) x^2 is a three-digit number.

(2) 10x is a three-digit number.

(A) if statement (1) ALONE is sufficient but statement (2) alone is not sufficient to answer the question asked,

(B) if statement (2) ALONE is sufficient but statement (1) alone is not sufficient to answer the question asked,

(C) if both statements (1) and (2) TOGETHER are sufficient to answer the question asked, but NEITHER statement ALONE is sufficient,

(D) If EACH statement is sufficient by itself to answer the question asked,

(E) if statements (1) and (2) TOGETHER are NOT sufficient to answer the question asked and additional data specific to the problem are needed.

This difference in the item format was accompanied by differences in test content. The data sufficiency material was parallel in content to the College Board SAT, which used about 30% items of this type at that time. The regular math test was parallel to the College Board basic-level achievement test in mathematics. This test has a more advanced content than the Scholastic Aptitude Test.

A third difference between the two tests (in addition to format and content) concerns the development of the half-tests. The data sufficiency test was developed as two separately timed subtests of 25 items each. These were the two half-tests correlated in the current study. The mathematics achievement test was administered with a single time limit and divided into two half tests consisting of all the odd items and all the even items.

The role of these different factors on the somewhat different outcomes for the two tests is difficult to determine. The maximum value for the data sufficiency test was approximately + 0.90 as a weight for the wrongs. The maximum value for the regular math test was + 0.70. These empirical values contrast with the values of + 0.295 and + 0.585 observed for SAT mathematics subtests in the Fischer and Jackson study.

Table 3 presents the means, standard deviations and intercorrelations for the four half-tests considered in the study. The pattern of intercorrelation is consistent across the two tests. The interhalf reliability of the data sufficiency Rights score was .67 , versus the value of .81 for the math achievement. Similarly the wrongs score for the math achievement test was more reliable, .73 versus .62. The cross-score correlations, $R_1 - W_2$ and $R_2 - W_1$, were - .46 and - .45 for the data sufficiency test and - .34 and - .35 for the math achievement; with similarly lower cross-score correlations for the intratest comparisons ($R_1 - W_1$, $R_2 - W_2$) for the math achievement test.

While omits were not distinguished from Not Reached in the present study, the general trait of omissiveness can be gauged somewhat by considering the numbers of items not responded to in each of the four half-tests studied. The values can be derived from Table 3 as follows:

Table 3

Means, Standard Deviations and Intercorrelations for the Half-Test Scores

Data Sufficiency

	R_1	W_1	R_2	W_2
R_1	1.00	-0.75	0.67	-0.46
W_1	-0.75	1.00	-0.45	0.62
R_2	0.67	-0.45	1.00	-0.79
W_2	-0.46	0.62	-0.79	1.00
Mean	12.15	11.02	12.26	11.24
S.D.	3.82	3.57	3.50	3.36

Math Achievement

	R_1	W_1	R_2	W_2
R_1	1.00	-0.48	0.81	-0.34
W_1	-0.48	1.00	-0.35	0.73
R_2	0.81	-0.35	1.00	-0.51
W_2	-0.34	0.73	-0.51	1.00
Mean	12.51	6.70	12.97	6.60
S.D.	4.43	3.75	4.57	3.67

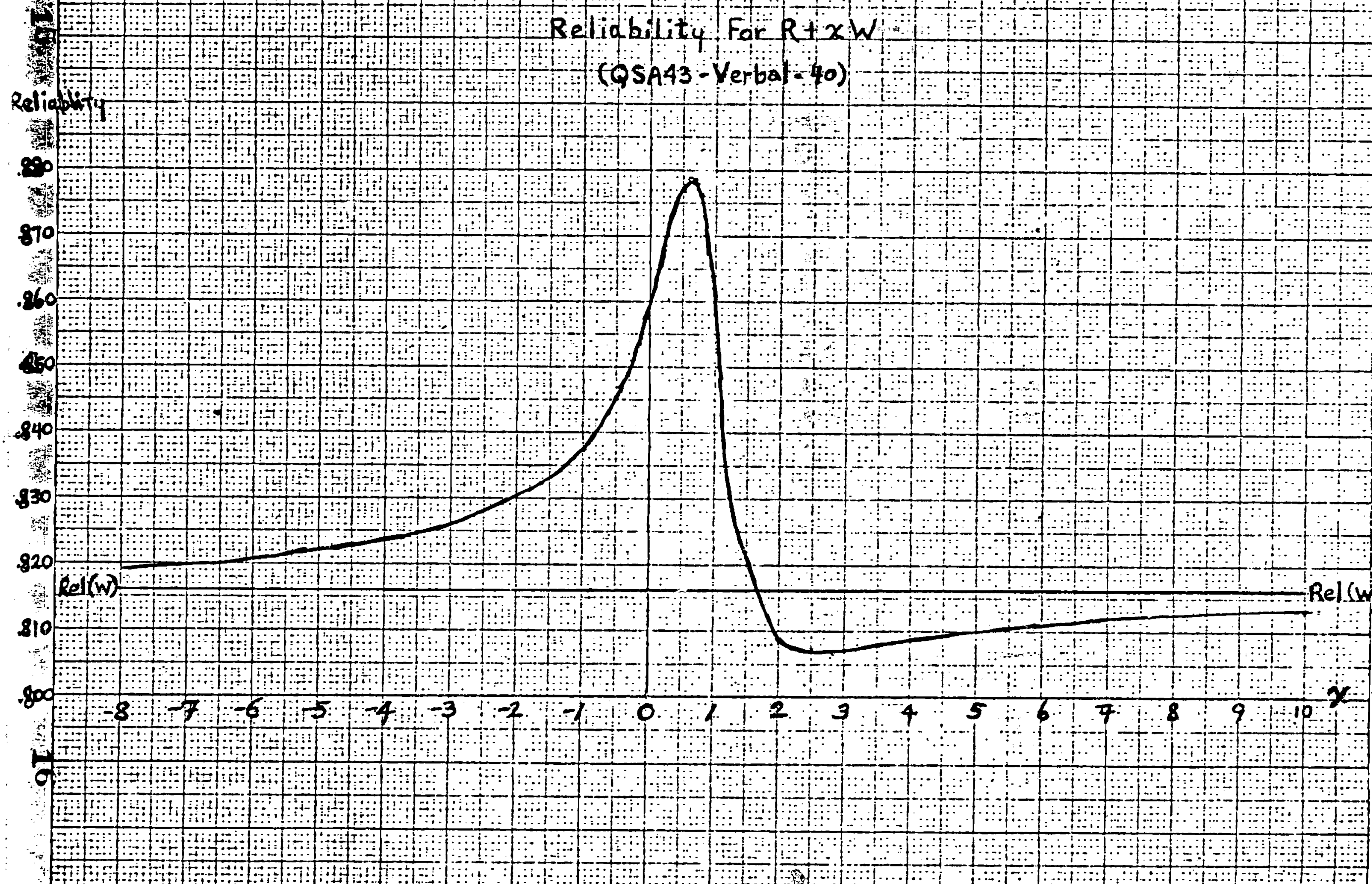
Average Number of Items Not Responded To

Data Sufficiency Half-Test 1	1.82
Data Sufficiency Half-Test 2	1.50
Math Achievement Half-Test 1	5.79
Math Achievement Half-Test 2	5.42

Clearly, the mathematics achievement test was characterized by a greater tendency to omit. Whether this was due to its greater speededness or to a true lack of knowledge of the material on the part of the subjects cannot be determined from this data. Either is plausible, since it is a characteristic of data sufficiency items that they are processed more rapidly by subjects. Referring to the Fischer and Jackson weights for mathematics tests, which were .295 and .585 , the higher weight was achieved by the section which had a sizable set of data sufficiency items (18 of its 35-item total) and a slightly more generous time allotment, .77 seconds per item versus .72 seconds per item. This suggests that the weight approaches unity as the test is unspeeded. However, the general parity of the number correct on the various half-tests, versus the differences in number wrong, suggests that there may be a greater tendency to give a response to the data sufficiency items, to guess at an answer, than to respond to the mathematics achievement items. This implies a more complex cause for the differences in weight than simply rate of work.

It is interesting to contrast the curves in Figures 1 and 2 with one provided by Fischer and Jackson, presented as Figure 3. In the present study, using empirically determinal curve, there is no suggestion of the minimum point for reliability which is clear in the Fischer and Jackson development. Whether this point would occur outside of the range observed

Figure 3


Reliability For R+xW
(QSA43 - Verbal - 40)
Reliability
.880
.870
.860
.850
.840
.830
.820
.810
.800
Rel(W)
Rel(W)
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
x

is not clear since no theoretical analysis of the intercorrelations of the tests in this study was undertaken.

Findings of a maximized reliability through a positive weight would seem to indicate that the most reliable aspect of a test performance is the total number of marks which are made. This hardly seems a worthwhile characteristic to focus on, since it would have little implication for validity. However, it is possible that further study of omissiveness would lead to an understanding of the reliability of the two forms of omissiveness: Omits and Not Reached. The best current data on this reliability is available from a study by Flaugher, Melton and Myers (1966), which shows the correlation between a mathematical section of the Scholastic Aptitude Test and each of four other, parallel sections introduced experimentally. The results are summarized in Table 4.

Table 4

Parallel Form Reliability for Four Scores:
Rights, Wrongs, Omits and Not Reached*

	Correlations with Master Form			
Parallel Forms	Rights-Rights	Wrongs-Wrongs	Omits-Omits	Not Reached-Not Reached
1	.790	.700	.628	.452
2	.785	.713	.536	.485
3	.776	.720	.648	.464
4	.770	.710	.576	.446

*From Flaugher, Melton and Myers (1966)

This data suggests that the Not Reached score is not as reliable as the Omits score. While this cannot be generalized too broadly, it bears on the meaning of the positive weight for the maximally reliable composite score. To the extent that the number of omits on parallel forms reflects a reliable tendency not to know a certain proportion of the answers, it is surprising that this would be a more reliable characteristic of an individual than rate-of-work would be. Even with major efforts at content and difficulty parallelism, most parallel forms vary a good deal, so that one would not readily predict that individuals would find comparable numbers of items they would decide not to attempt. Further research seems indicated to clarify the degree to which the Omit response is determined by rate of work.

This paper has confirmed the determination by Fischer and Jackson of a positive weight for the wrongs as a reliability maximizing score. The parallel-forms technique in the present study varied somewhat from the internal-consistency approach which they used. The implications of this weight, as Lord suggests, are that the trait of omissiveness is a reliable one. The source of this reliability and the implications for work on test speededness could be meaningful future areas for research.

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