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ABSTRACT

A flexilevel test is found to be inferior to a peaked conventional test for measuring examinees in the middle of the ability range, superior for examinees at the extremes. Throughout the entire range of ability, a flexilevel test is much superior to any conventional test that attempts to provide accurate measurement at both extremes. See also ED 042 813. (Author)

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A THEORETICAL STUDY OF THE MEASUREMENT EFFECTIVENESS OF FLEXILEVEL TESTS

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A THEORETICAL STUDY OF THE MEASUREMENT EFFECTIVENESS

OF FLEXILEVEL TESTS

Abstract

A flexilevel test is found to be inferior to a peaked conventional test for measuring examinees in the middle of the ability range, superior for examinees at the extremes. Throughout the entire range of ability, a flexilevel test is much superior to any conventional test that attempts to provide accurate measurement at both extremes.

A THEORETICAL STUDY OF THE MEASUREMENT EFFECTIVENESS OF FLEXILEVEL TESTS*

A conventional test becomes a flexilevel test when modified so that the examinee follows these rules:

1. Answer first a specified test item of median difficulty.
2. After answering an item correctly, attempt next the easiest unanswered item of more-than-median difficulty. After answering an item incorrectly, attempt next the hardest unanswered item of less-than-median difficulty.

A special answer sheet is used so that the examinee will know whether each answer is correct or incorrect. If the conventional test contains N items, the examinee taking the flexilevel test will attempt only $n = (N + 1)/2$ of these. A method for implementing flexilevel testing is described by Lord (1970).

Surprisingly, it appears that number-right scoring is quite effective for flexilevel tests (Lord, 1970), in spite of the fact that different examinees answer different sets of items. A worthwhile refinement, used throughout the research reported here, is to add one-half score point to the number-right score of each examinee who answered his last-attempted item incorrectly.

A crucial question is whether flexilevel testing will be too confusing or too time-consuming for many examinees. Empirical studies are needed to answer this and other questions of practical effectiveness.

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Since a theoretical study can be done more quickly and less expensively than a substantial empirical study, the study reported here was carried out in order to evaluate various flexilevel tests from a theoretical point of view. A further purpose was to try to separate some flexilevel designs that are worth trying out empirically from those that are altogether inferior to other tests.

In order to carry out a theoretical investigation of this type, it is necessary to be able to predict probabilistically how a given examinee will respond to items different from those already administered. Consequently, the present results are derived from item characteristic curve theory (see, for example, Lord, 1968, sections 3-4).

Here we assume the probability P_i that a given examinee will answer item i correctly depends only on his "ability" level, denoted by θ, and on certain item parameters: a ("discriminating power"), b ("difficulty"), and c ("pseudo chance-score level"). These item parameters are assumed to have been already determined, to an adequate approximation, by pretesting.

Conditional Frequency Distribution of Test Score

We can evaluate any given flexilevel test once we can determine $f(x|\theta)$, the conditional frequency distribution of test scores x for examinees at ability level θ. Given some mathematical form for the function $P_i \equiv P_i(\theta) \equiv P(\theta;a_i,b_i,c_i)$, the value of $f(x|\theta)$ can be determined numerically for any specified value of θ by the recursive method outlined below.

Assume the N test items to be arranged in order of difficulty, as measured by the parameter b_i . We will choose N to be an odd number. For present purposes (not for actual test administration) identify the items by the index i , taking on the values $-n + 1$, $-n + 2$, ... , $-1, 0, 1, \ldots , n - 2 , n - 1$, respectively, when the items are arranged in order of difficulty. Thus b_0 is the median item difficulty.

Consider, for example, the sequence of right (R) and wrong (W) answers

R W W R W R R R W R .

Following the rules given for a flexilevel test, we see that the corresponding sequence of items answered is

$$i = 0,+1,-1,-2,+2,-3,+3,+4,+5,-4,+6 \quad .$$

The general rule is that if item i is the v :th item administered and item j is the $(v + 1)$:th, then, for flexilevel tests,

either $j = i + 1$ or $j = i - v$ when $i \geq 0$,

either $j = i - 1$ or $j = i + v$ when $i \leq 0$.

In the same context, let $P_{ij \cdot v} \equiv P_{ij \cdot v}(\theta)$ denote the probability that item j will be the next item administered after item i .

$$\text{If } i \geq 0 , \quad P_{ij \cdot v} = \begin{cases} P_i(\theta) & \text{if } j = i + 1 , \\ Q_i(\theta) & \text{if } j = i - v , \\ 0 & \text{otherwise.} \end{cases}$$

$$\text{If } i \leq 0 , \quad P_{ij \cdot v} = \begin{cases} P_i(\theta) & \text{if } j = i + v , \\ Q_i(\theta) & \text{if } j = i - 1 , \\ 0 & \text{otherwise.} \end{cases}$$

For examinees at ability level θ , let $p_v(i|\theta)$ denote the probability that item i is the v :th item administered. Clearly,

$$p_{v+1}(j|\theta) = \sum_{i=-n+1}^{n-1} p_v(i|\theta)\, P_{ij.v}(\theta) \quad . \qquad (1)$$

Now, the first item administered ($v = 1$) is always item $i = 0$, so

$$p_1(i|\theta) = \begin{cases} 1 & \text{if } i = 0 , \\ 0 & \text{otherwise} . \end{cases}$$

Starting with this fact and with a knowledge of all the $P_i(\theta)$ (determined from pretest data), equation (1) allows us to compute the values of $p_v(i|\theta)$ for each i , for $v = 2,3,\ldots,n$, and for any specified set of values of θ .

Now we can make use of a readily verified feature of flexilevel tests. Again let j represent the $(v + 1)$:th item to be administered. If $j > 0$, then the number-right score r on the v items already administered is $r = j$; if $j < 0$, then $r = v + j$.

Thus the frequency distribution of the number-right score r for examinees at ability level θ is given by $p_{n+1}(r|\theta)$ for those examinees who answered correctly the n :th (last) item administered, by $p_{n+1}(r-n|\theta)$ for those who answered incorrectly. This frequency distribution can be computed recursively from (1).

As already noted, the actual score assigned on a flexilevel test is $x = r$ if the last item is answered correctly, $x = r + \frac{1}{2}$ if it is answered incorrectly. Consequently the conditional distribution of test scores is

$$f(x|\theta) = \begin{cases} p_{n+1}(x|\theta) & \text{if } x \text{ is an integer,} \\ p_{n+1}(x-n-\frac{1}{2}|\theta) & \text{if } x \text{ is a half-integer.} \end{cases} \quad (2)$$

For any specified test design, this conditional frequency distribution $f(x|\theta)$ can be computed for $x = 0, \frac{1}{2}, 1, 1\frac{1}{2}, \ldots, n$ for various values of θ. Such distributions constitute the totality of possible information relevant to evaluating the effectiveness of x as a measure of ability.

Evaluating a Flexilevel Testing Procedure

If we are to use x as a measure of ability, we would like $\mu_{x|\theta_1}$ (the mean of x when $\theta = \theta_1$) to differ from $\mu_{x|\theta_2}$ whenever $\theta_1 \neq \theta_2$. It seems natural to use the "critical ratio"

$$\frac{\mu_{x|\theta_2} - \mu_{x|\theta_1}}{\sigma_{x|\theta}}$$

to summarize the effectiveness of x for discriminating between ability levels θ_1 and $\theta_2 = \theta_1 + \Delta$, where $\sigma_{x|\theta}$ is the conditional standard deviation of x and Δ represents a small increment in ability (small enough so that $\sigma_{x|\theta} = \sigma_{x|\theta+\Delta}$ approximately).

Actually we will work with the square of this ratio:

$$I_x(\theta) = \frac{k(\mu_{x|\theta+\Delta} - \mu_{x|\theta})^2}{\sigma^2_{x|\theta}}, \quad (3)$$

where k is any convenient constant. Given some small increment Δ, $I_x(\theta)$, as a function of θ, is readily computed from (2) for any specified test design. Since we are only interested in comparisons between designs, the values of k and Δ are of no importance so long as they are the same for all designs compared.

Test Designs Studied

The numerical results reported here are obtained on the assumption that P_i is a normal ogive, possibly modified to accommodate the effects of success due to guessing:

$$P_i = P(\theta;a,b_i,c) = c + (1 - c) \int_{-\infty}^{a(\theta-b_i)} \phi(t)dt \quad , \tag{4}$$

where $\phi(t)$ is the normal density function. The results would presumably be about the same if P_i had been assumed logistic rather than normal ogive.

To keep matters simple, we will only consider tests in which all items have the same discriminating power, a ; also the same pseudo chance level, c . Results are presented here separately for $c = 0$ (no guessing) and $c = .2$. The results are general for any value of $a > 0$, since a can be absorbed into the unit of measurement chosen for the ability scale (as will be noticed for the base line shown in the figures).

In all tests studied, each examinee answers exactly $n = 60$ items. For simplicity, we will consider only tests in which the item difficulties form an arithmetic sequence, so that $b_{i+1} - b_i = d$, say.

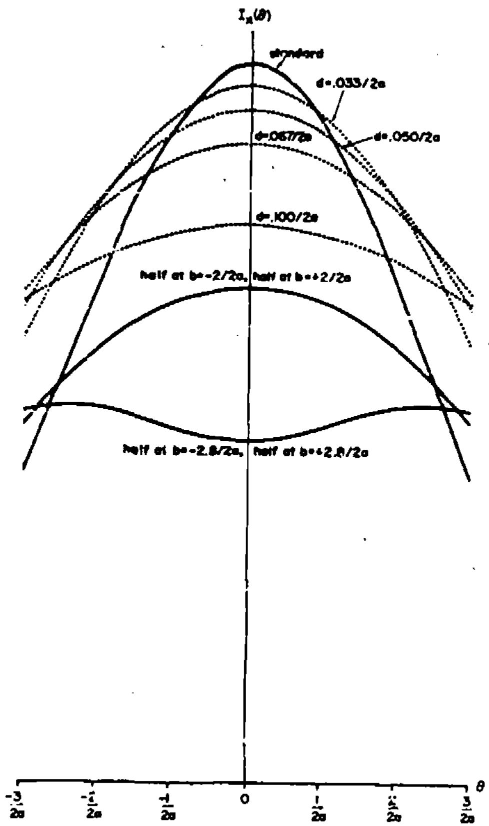
Results for Tests with No Guessing

Figure 1 compares the effectiveness of four 60-item ($n = 60$, $N = 119$) flexilevel tests with each other and with three bench mark tests. The scale chosen for θ in the figures is such that for typical achievement and aptitude tests the standard deviation of θ in typical high school and college groups will be very roughly $\sigma_\theta = 1/2a$ (a more detailed explanation is given in Lord, 1969).

The "standard test" is a conventional 60-item test composed entirely of items of difficulty $b = 0$, scored by counting the number of right answers. There is no guessing, so $c = 0$. The values of a and c are the same for bench mark and flexilevel tests. For fixed a and c , no test composed of dichotomously scored items with characteristic curves (4) can have a higher value of $I_x(\theta)$ at any θ than the standard test has at $\theta = b_0$ (see Birnbaum, 1968).

As would be expected, the figure shows that the standard test is best for discriminating among examinees at ability levels near $\theta = 0$. If good discrimination is important at $\theta = \pm 2/2a$ or $\theta = \pm 3/2a$, then a flexilevel test such as the one with $d = .033/2a$ or $d = .050/2a$ is better. The larger d is, the poorer the measurement at $\theta = b_0$, but the better the measurement at extreme values of θ .

Suppose the best possible measurement is required at $\theta = \pm 2$, with $a = 0.5$. It might be thought that an effective conventional 60-item test for this limited purpose would consist of 30 items at $b = +2$ and 30 items at $b = -2$. The curve for this last test is shown in Figure 1.



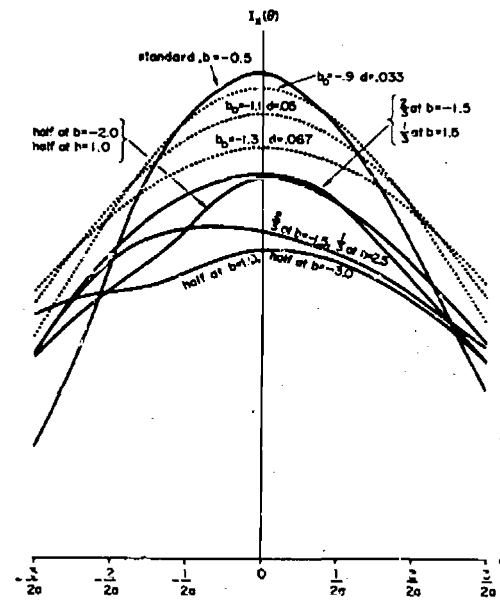


Figure 1 (left). Relative efficiency of four 60-item flexilevel tests with $b_0 = 0$ (curves with d's) and three bench mark tests. $c = 0$.

Figure 2 (right). Relative efficiency of three 60-item flexilevel tests (curves with d's) and five bench mark tests. $c = 0.2$. (Numerical labels on curves are for $a = 0.5$.)

The fact is that with $a = 0.5$, no unpeaked test (i.e., no test with items at more than one difficulty level) can simultaneously measure as well at both $\theta = +2$ and $\theta = -2$ as does the standard test (which has all items peaked at $b = 0$).

The situation is different if the best possible measurement is required at $\theta = \pm 3$, with $a = 0.5$. Using dichotomously scored items, the best 60-item conventional test for this purpose consists of 30 items at $b = -2.8$ and 30 items at $b = +2.8$, approximately. The curve for this test is shown in Figure 1.

For fixed θ, the number-right score x on a standard test has a binomial distribution. Thus, the expected score is

$$\mu_{x|\theta} = nP$$

and the variance of the scores is

$$\sigma^2_{x|\theta} = nPQ \quad ,$$

where $P \equiv P(\theta)$ is given by (4). It is apparent from (3) that $I_x(\theta)$ for a standard test is proportional to n, the test length.

We now see that when $a = 0.5$, the 60-item flexilevel test with $d = .[illegible]33$ gives about as effective measurement as a

[illegible]-item standard test at $\theta = 0$,

60-item standard test at $\theta = \pm 1$,

69-item standard test at $\theta = \pm 2$,

86-item standard test at $\theta = \pm 3$.

At $\theta = \pm 3$, the 60-item flexilevel test with $d = .1$ is as effective as a 96-item standard test.

Results for Tests with Guessing

Figure 2 compares the effectiveness of three 60-item flexilevel tests with each other and with five bench mark tests. All items have $c = 0.2$ and all have the same discriminating power a . The standard test is a conventional 60-item test with all items at difficulty level $b = 0.5/2a$, scored by counting the number of right answers.

If all the item difficulties in any test were changed by some constant amount Δb , the effect would be simply to translate the corresponding curve by an amount Δb along the θ -axis. The difficulty level of each bench mark test and the starting item difficulty level b_0 of each flexilevel test in Figure 2 has been chosen so as to give maximum discriminating power somewhere in the neighborhood of $\theta = 0$.

The standard test is again found to be best for discriminating among examinees at ability levels near $\theta = 0$. At $\theta = \pm 2$ the flexilevel tests are better than the standard test, which in turn seems to be better than any of the other conventional (bench mark) tests, although the situation is less clear than before because of the asymmetry of the curves.

When $a = 0.5$ the 60-item flexilevel test with $b_0 = -0.9$ and $d = .033$ gives about as effective measurement as a

58-item standard test at $\theta = 0$

60-item standard test at $\theta = \pm 1$

70-item standard test at $\theta = -2.0$ or $\theta = +2.25$

83-item standard test at $\theta = +3$

114-item standard test at $\theta = -3$

at $\theta = -3$, the 60-item flexilevel test with $b_0 = -1.3$ and $d = .067$ is as effective as a 137-item standard test.

Conclusion

Near the middle of the ability range for which the test is designed, a flexilevel test is less effective than is a comparable peaked conventional test. In the outlying half of the ability range, the flexilevel test provides more accurate measurement in typical aptitude and achievement testing situations than a peaked conventional test composed of comparable items. This comparison assumes that 60 items are administered to each examinee. The advantage of flexilevel tests over conventional tests at low ability levels is significantly greater when there is guessing than when there is not.

Empirical studies will be needed to answer such questions as the following:

1. To what extent are different types of examinees confused by flexilevel testing?
2. To what extent does flexilevel testing lose efficiency because of an increase in testing time per item?
3. How adequately can we score the examinee who does not have time to finish the test?
4. How can we score the examinee who does not follow directions?
5. What other serious inconveniences and complications are there in flexilevel testing?

6. Is the examinee's attitude and performance improved when a flexilevel test "tailors" the test difficulty level to match his ability level?

Empirical investigations should study tests designed in accordance with the theory used here. Otherwise, it is likely that a poor choice of d and especially of b_0 will result in an ineffective measuring instrument.

The most likely application of flexilevel tests is in situations where it would otherwise be necessary to unpeak a conventional test in an attempt to obtain adequate measurement at the extremes of the ability range. Such situations are found in nationwide college admissions testing and elsewhere.

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