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The Washington Pre-College (WPC) program decided, in fall 1967, to inaugurate in April 1968 the testing of high school students during the spring of their junior year. The advantages of this shift from senior year testing were to provide guidance data for earlier, more extensive use in high school and to make these data available to colleges at the time they actually make admissions decisions. Because of this shift, statistical changes were required in scoring and prediction formulas. This report summarizes the following three changes: (1) generating standard score weights for the quantitative skills subsections; (2) restandardizing high school means and standard deviations of the WPC tests; and (3) conversion formulas translating WPC raw scores into standard scores, and composite score formulas and derivations. (Author/HH)

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Statistical Revisions in the Washington Pre-College Testing Program

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The Washington Pre-College (WPC) Program decided in the fall of 1967 to inaugurate in April 1968 testing of high school students during the spring of their junior year. The advantages of this shift from senior year testing were to provide guidance data for earlier, more extensive use in high school and to make these data available to colleges at the time they actually make admissions decisions. Because of this shift, statistical changes were required in scoring and prediction formulas. This report summarizes the following three changes: generating standard score weights for the quantitative skills subsections; restandardizing high school means and standard deviations of the WPC tests; and conversion formulas translating WPC raw scores into standard scores, and composite score formulas and derivations.

The Washington Pre-College (WPC) Program decided in the fall of 1967 to inaugurate in April 1968 testing of high school students during the spring of their junior year. The advantages of this shift from senior year testing were to provide guidance data for earlier, more extensive use in high school and to make these data available to colleges at the time they actually make admissions decisions.

In preparation for processing of student data sheets for juniors, several modifications were necessary to update and facilitate computational procedures

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for the WPC Testing Program. The first modification, though not directly related to the shift in testing dates, involved completing the transition to separate weights for the three quantitative skills subsections for all course criterion areas. The other modifications were: restandardizing the test score means and standard deviations furnished by the 1963 and 1964 high school senior populations through a compilation of new data drawn from a population of 22,855 high school juniors tested in the spring of 1968, and from these new data computing new formulas for converting raw scores to standard scores for the 13 test scores and adjusting the formulas of the Verbal Composite, English Composite, and Quantitative Composite measures. The procedures are described below.

Generating Standard Score Weights for the Quantitative Skills Subsections. In October 1966 prediction weights were established for the then existing 40 course criterion areas (Atkinson, 1966). This involved estimating weights for the current battery by equating two overlapping batteries of predictor measures. Raw score and standard score weights for each test, except Spatial Ability and Reading Speed, were derived for each of the 40 criterion areas. The Quantitative Skills total score (QST) was used as a predictor rather than the three part scores now being used (data sufficiency or QSA, quantitative judgment or QSB, and functional relationships or QSC).

Subsequently predictor weights were revalidated for 12 two-year course areas (Beanblossom, Edwards, Gerry, and Langen, 1968) for students entering the University between autumn quarter 1965 and spring quarter 1967. Different procedures from those adopted in 1966 were used in determining which variables to use as predictors. Each quantitative skills test was regarded as a potential predictor and QST was not used. Only those variables making a statistically significant contribution to the multiple R were retained as predictors. This same procedure was used by Lunneborg and Lunneborg (1967) in determining the weights currently used for predicting community college vocational-technical course performance.

The problem at hand was to derive standard score weights for the three quantitative skills tests in the criterion areas not included in the above two studies. The rationale for this change was simply to make the programming for and processing of composite scores and predictions more efficient.

It is necessary first to review how the standard score weights for QST were computed. The general form of the raw score regression equation is:

(1) $$\hat{Y} = b_1X_1 + b_2X_2 \ldots + b_nX_n + k \quad ,$$

where

$\hat{Y}$ is the predicted criterion value and

b_i the raw score regression weight for X_i, the i^{th} predictor .

The additive constant, k, is given by:

(2) $$k = \bar{Y} - (b_1\bar{X}_1 + b_2\bar{X}_2 \ldots + b_n\bar{X}_n) \quad ,$$

where

$\bar{Y}$ is the mean criterion value, and

$\bar{X}_j$, the mean raw score on the j^{th} predictor for this criterion .

The contribution of a test, say QST, to the prediction from (1) and (2) is given by:

(3) $$b_{QST}X_{QST} - b_{QST}\bar{X}_{QST} \quad .$$

Because standard scores are to be used in prediction, this must be replaced by a corresponding expression in standard score form:

$$(4) \qquad b_{z(QST)} \left[\left(\frac{X_{QST} - \bar{X}_{QST(1964)}}{\sigma_{QST(1964)}} \right) (10) + 50 \right] + k_{z(QST)} \text{, or}$$

$$b_{z(QST)} Z_{QST} + k_{z(QST)},$$

where

$b_{z(QST)}$ is the standard score weight for QST ,

$\bar{X}_{QST(1964)}$ and $\sigma_{QST(1964)}$ are the raw score mean and standard deviation for the 1964 standardization sample, and

$k_{z(QST)}$ is the QST contribution to k_z ,

the additive constant when standard score predictors are used. Expression (4) can be rewritten as:

$$(5) \quad \left(\frac{10b_{z(QST)}}{\sigma_{QST(1964)}} \right) (X_{QST}) - \left(\frac{10b_{z(QST)}}{\sigma_{QST(1964)}} \right) \left(\bar{X}_{QST(1964)} - \frac{50\sigma_{QST(1964)}}{10} \right) + k_{z(QST)} ,$$

and $k_{z(QST)}$ can be written as:

$$(6) \quad k_{z(QST)} = b_{z(QST)} \left[\left(\frac{\bar{X}_{QST} - \bar{X}_{QST(1964)}}{\sigma_{QST(1964)}} \right) (10) + 50 \right] ,$$

where $\bar{X}_{QST}$ is the mean QST raw score for the validation sample in this criterion area.

By substituting the right-hand side of (6) into (5) and equating (5) with (3), (the standard score and raw score forms of the QST contribution, respectively), a solution may be obtained for $b_{z(QST)}$:

$$(7) \qquad b_{z(QST)} = b_{QST} \left(\frac{\sigma_{QST(1964)}}{10} \right) .$$

However, to weight standard scores for each of the quantitative skills subsections, it is necessary to solve for values of $b_{z(QSA)}$, $b_{z(QSB)}$, and $b_{z(QSC)}$ which will satisfy the following condition:

$$(8) \qquad b_{z(QST)}Z_{(QST)} = (b_{z(QSA)}Z_{(QSA)}) + (b_{z(QSB)}Z_{(QSB)}) + (b_{z(QSC)}Z_{(QSC)}) .$$

In (8) the predictor values are in standard score form. For quantitative skills raw scores the total score may be written:

$$(9) \qquad X_{QST} = X_{QSA} + X_{QSB} + X_{QSC} ,$$

or, multiplying through by the raw score regression weight,

$$(10) \qquad b_{QST}X_{QST} = (b_{QST}X_{QSA}) + (b_{QST}X_{QSB}) + (b_{QST}X_{QSC}) .$$

Equations (10) and (9) may now be used to rewrite (3):

$$(11) \qquad b_{QST}X_{QST} - b_{QST}\bar{X}_{QST} = (b_{QST}X_{QSA}) + (b_{QST}X_{QSB} + (b_{QST}X_{QSC}) - (b_{QST}\bar{X}_{QSA}) - (b_{QST}\bar{X}_{QSB}) - (b_{QST}\bar{X}_{QSC}) .$$

Analogous to the development of a standard score regression weight for QST in equations (3) - (7), the right-hand side of (11) needs to be replaced with an equivalent expression in standard score form, representing the contribution of the three part scores:

$$(12) \qquad b_{z(QSA)}\left[\left(\frac{X_{QSA} - \bar{X}_{QSA(1964)}}{\sigma_{QSA(1964)}}\right)(10) + 50\right] + b_{z(QSB)}\left[\left(\frac{X_{QSB} - \bar{X}_{QSB(1964)}}{\sigma_{QSB(1964)}}\right)(10) + 50\right] + b_{z(QSC)}\left[\left(\frac{X_{QSC} - \bar{X}_{QSC(1964)}}{\sigma_{QSC(1964)}}\right)(10) + 50\right] + k_{z(QSA)} + k_{z(QSB)} + k_{z(QSC)} .$$

Expression (12) can be rewritten as follows:

$$(13)\quad \left(\frac{10b_{z(QSA)}}{\sigma_{QSA(1964)}}\right)(X_{QSA}) + \left(\frac{10b_{z(QSB)}}{\sigma_{QSB(1964)}}\right)(X_{QSB}) + \left(\frac{10b_{z(QSC)}}{\sigma_{QSC(1964)}}\right)(X_{QSC})$$

$$+ \left[k_{z(QSA)} - \left(\frac{10b_{z(QSA)}}{\sigma_{QSA(1964)}}\right)(\bar{X}_{QSA(1964)}) + b_{z(QSA)}(50)\right]$$

$$+ \left[k_{z(QSB)} - \left(\frac{10b_{z(QSB)}}{\sigma_{QSB(1964)}}\right)(\bar{X}_{QSB(1964)}) + b_{z(QSB)}(50)\right]$$

$$+ \left[k_{z(QSC)} - \left(\frac{10b_{z(QSC)}}{\sigma_{QSC(1964)}}\right)(\bar{X}_{QSC(1964)}) + b_{z(QSC)}(50)\right] .$$

The elements $k_{z(QSA)}$, $k_{z(QSB)}$, and $k_{z(QSC)}$ in (12) and (13) are the respective subscore contributions to k_z when the three subscores are in standard form and can be written as:

$$(14)\quad k_{z(QSA)} = b_{z(QSA)}\left[\left(\frac{\bar{X}_{QSA} - \bar{X}_{QSA(1964)}}{\sigma_{QSA(1964)}}\right)(10) + 50\right] ,$$

$$(15)\quad k_{z(QSB)} = b_{z(QSB)}\left[\left(\frac{\bar{X}_{QSB} - \bar{X}_{QSB(1964)}}{\sigma_{QSB(1964)}}\right)(10) + 50\right] , \text{ and}$$

$$(16)\quad k_{z(QSC)} = b_{z(QSC)}\left[\left(\frac{\bar{X}_{QSC} - \bar{X}_{QSC(1964)}}{\sigma_{QSC(1964)}}\right)(10) + 50\right] .$$

By substituting the right-hand sides of (14), (15), and (16) into (13) and equating (13) with the right-hand side of (11), (the standard score and raw score forms of the subscore contributions, respectively), solutions may be obtained for the three standard score weights:

$$(17)\quad b_{z(QSA)} = b_{QST}\left(\frac{\sigma_{QSA(1964)}}{10}\right) ,$$

$$(18)\quad b_{z(QSB)} = b_{QST}\left(\frac{\sigma_{QSB(1964)}}{10}\right) , \text{ and}$$

$$(19)\quad b_{z(QSC)} = b_{QST}\left(\frac{\sigma_{QSC(1964)}}{10}\right) .$$

By using the results of (7), (17), (18) and (19) and subtracting the total contribution to k_z of QSA, QSB, and QSC--adding the right hand sides of formulas (14), (15), and (16)--from the total contribution to k_z of QST (6), a difference is obtained:

$$(20) \quad k_{z(QST)} - [k_{z(QSA)} + k_{z(QSB)} + k_{z(QSC)}] = 5b_{QST}[\sigma_{QST(1964)} - \sigma_{QSA(1964)} - \sigma_{QSB(1964)} - \sigma_{QSC(1964)}] \quad .$$

Differences such as the above were computed for the 25 course criterion areas not yet revalidated and for which QST had been utilized as a predictor. Data for these computations were taken from Atkinson (1966). The subscore standard weights and new k_z constants, using the mathematical techniques described above are shown in Table 1.

Restandardizing Test Score Means and Standard Deviations. To permit the transition to junior year testing it was decided to report test scores in a standard score form based on the performance of high school juniors and to use these standard scores in the computation of predictions for the several criterion areas. The 22,855 high school juniors tested during the spring of 1968 defined the new WPC standardization group. Test score means and standard deviations for this group were used in developing the standard score formulas. In recent years data from the 1963 and 1964 high school senior groups were used in computing standard scores.

Surprisingly perhaps, mean test performances for the 1968 group did not differ substantially or systematically from the 1963 and 1964 groups. The largest differences were for English Usage and Vocabulary where attainments were lower for the 1968 group. These results are confounded: the earlier groups consisted of seniors and the later group juniors, with a greater

Table 1

1968 Standard Score Weights (b_z) for the Three Quantitative Skills Tests and Standard Score Additive Constants (k_z) for 25 Course Criterion Areas not Revalidated in 1968

Course Criterion Area	b_z Data suff (QSA)	b_z Quant judg (QSB)	b_z Func Relat (QSC)	k_z
Accounting	.00378	.00688	.00457	-1.46730
Anthropology	.00042	.00077	.00051	.31253
Botany	.00199	.00362	.00240	-.41525
Business Administration, General	.00097	.00177	.00118	-1.17707
Communications: Principles	-.00155	-.00281	-.00187	2.49836
Economics, Advanced	.00009	.00016	.00010	2.23522
English Composition	-.00118	-.00214	-.00142	1.02406
English Literature	-.00142	-.00258	-.00171	.63548
Forestry	-.00059	-.00109	-.00073	1.49780
Geography	.00026	.00047	.00031	.71348
History	.00007	.00013	.00008	.66774
Home Economics	-.00090	-.00164	-.00109	.32959
Microbiology	.00030	.00054	.00036	1.48452
Music Theory	.00572	.01040	.00691	-1.52712
Nursing: Practice	.00177	.00322	.00214	-.28412
Nursing: Principles	-.00150	-.00273	-.00182	-.56034
Nutrition	.00020	.00036	.00024	-.08893
Philosophy	-.00168	-.00305	-.00203	1.33690
Physical Education	00062	.00114	.00075	2.02707
Physics	.00044	.00079	.00053	.97202
Political Science	-.00032	-.00059	-.00039	.49922
Psychology, Introductory	.00094	.00170	.00113	-.88550
Sociology, Introductory	.00021	.00038	.00025	-.87630
Speech, Applied	-.00016	-.00028	-.00019	.95787
Zoology	.00133	.00242	.00161	-.73237

proportion of students making college plans than was true in 1963 and 1964, the selectivity of the high school sample upon which WPC standardization data are based may be reduced, and, finally high school students may be better prepared now than 5-6 years earlier. Means and standard deviations for the two standardization samples are given in Table 2.

New formulas for converting raw scores to standard scores for each test were developed from these new means and standard deviations, using equations of the form:

(21) $$Z = bX + k \quad ,$$

where

Z is the standard score for a given test,

X, the corresponding raw score,

b, the multiplicative weight, and

k, the additive constant.

The formulas defining b and k are:

(22) $$b = \frac{\sigma_Z}{\sigma_X} \text{ and}$$

(23) $$k = \bar{Z} - b\bar{X} \quad ,$$

where

σ_Z is the desired standard score standard deviation, i.e., 10,

$\bar{Z}$, the desired standard score mean, i.e., 50,

σ_X, the raw score standard deviation, and

$\bar{X}$, the raw score mean .

Thus b and k were easily determined. Table 2 lists these raw to standard score conversion formulas for the WPC Test scores as well as for the Verbal

Table 2

Raw Score Means and Standard Deviations of WPC Tests (Form A)* Based on New Standardization Group of 22,855 High School Juniors Tested Spring 1968; Formulas Converting Raw Scores to Standard Scores

Test	High School Juniors (1968)		High School Seniors (1963-1964)	
	Mean	Std dev	Mean	Std dev
WPC English Usage (EU)	34.58	15.58	39.20	16.68
WPC Spelling (SP)	15.75	8.85	15.94	8.94
WPC Reading Speed (RS)	26.61	5.75	24.88	5.50
WPC Reading Comprehension (RC)	10.50	6.50	10.27	6.52
WPC Mechanical Reasoning (MR)	8.57	7.07	9.35	7.59
WPC Spatial Ability (SA)	10.44	4.78	10.44	4.54
WPC Applied Math (AM)	10.89	5.20	10.33	5.31
WPC Vocabulary (VO)	44.74	17.47	47.41	18.07
WPC Data Sufficiency (QSA)	6.38	3.38	6.02	3.32
WPC Quantitative Judgment (QSB)	12.85	5.70	12.97	6.05
WPC Functional Relationships (QSC)	5.07	3.87	5.21	4.02
WPC Quantitative Skills (QST)	24.30	10.87	24.21	11.43
WPC Math Achievement (MA)	15.23	10.63	15.08	11.23

Raw Score to Standard Score Conversion Formulas (1968 Sample):

English Usage = (EU x .64) + 27.87

Spelling = (SP x 1.13) + 32.20

Reading Speed = (RS x 1.74) + 3.70

Reading Comprehension = (RC x 1.54) + 33.83

Mechanical Reasoning = (MR x 1.41) + 37.92

Spatial Ability = (SA x 2.09) + 28.18

Applied Math = (AM x 1.92) + 29.09

Vocabulary = (VO x .57) + 24.50

Data Sufficiency = (QSA x 2.96) + 31.12

Quantitative Judgment = (QSB x 1.75) + 27.51

Functional Relationships = (QSC x 2.58) + 36.92

Quantitative Skills = (QST x .92) + 27.64

Math Achievement = (MA x .94) + 35.67

Verbal Composite = (EUx.28) + (SPx.40) + (RCx.04) + (VOx.19) + 25.10

English Composite = (EUx.29) + (SPx.25) + (VOx.26) + 24.55

Quantitative Composite = (AMx.25) + (QSTx.58) + (MAx.14) + 31.07

*Form A of the WPC battery has since been superseded by Form B.

Composite, English Composite, and Quantitative Composite scores. The derivations of the formulas for these composites was somewhat more complex and will be discussed in the following section.

Composite Score Formulas. Composite scores for the WPC Test were developed largely for placement or sectioning purposes. The English Composite (EC) score is derived through an *a priori* weighting of the English Usage (EU), Vocabulary (VO), and Spelling (SP) tests; Spelling is weighted only one-half as much as English Usage or Vocabulary. The weightings of the tests included in the Verbal (VC) and Quantitative Composite (QC) scores were determined through factor analytic methods.

Given the weighting formula for EC, and using standard scores for the test components, the mean EC score would be 125, since it is the sum of the weighted standard score means of the tests, in this case 50 for EU, 50 for VO, and 25 for SP. The variances of the EU, VO, and SP components would be 100, 100, and 25, respectively. However, the variance of a sum equals the sum of the variances only if the part scores are uncorrelated and this is obviously not the case here. In the 1968 standardization sample the correlation between EU and VO was .7253, between EU and SP, .6405, and between VO and SP, .5906. The formula (McNemar, 1955, p. 137) for deriving the variance of EC is given by:

$$\sigma^2_{EC} = \sigma^2_{EU} + \sigma^2_{VO} + \sigma^2_{SP} + 2\sigma_{EU}\sigma_{VO}r_{EU\cdot VO} + 2\sigma_{EU}\sigma_{SP}r_{EU\cdot SP} + 2\sigma_{VO}\sigma_{SP}r_{VO\cdot SP} ,$$

where the r's represent the three correlations among tests.

Numerically solving for σ_{EC}:

$$\sigma^2_{EC} = 100 + 100 + 25 + 2(10)(10)(.7253) + 2(10)(5)(.6405) + 2(10)(5)(.5906)$$

$$= 225 + 145.0600 + 64.0500 + 59.0600$$

$$= 493.1700, \text{ and}$$

$$\sigma_{EC} = 22.21 \quad .$$

It would then be possible to translate EC scores into standard scores using a formula developed from equations (21)-(23). However, since it is convenient to input raw scores for EU, VO, and SP rather than standard scores to derive the EC standard score, the raw-standard conversion formulas for the separate tests given in Table 2 were used. Thus, the standard score English Composite may be obtained from the following formula:

$$EC_{STAN} = \left[\frac{(.64EU+27.87)+(.57VO+24.50)+(1.13SP+32.20)-125}{22.21}\right] 10 + 50 \quad .$$

Simplifying, this becomes:

$$EC_{STAN} = .29EU + .26VO + .25SP + 24.55 \quad .$$

In 1965 the WPC battery was factor analyzed (Bureau of Testing Project 0565-200) using various combinations of tests and two factor analytic techniques, an oblique hypothesis rotation and an orthogonal varimax rotation. Eight, ten, and 12-variable sets were factor analyzed which identified a verbal factor, on which Vocabulary, English Usage, Spelling, and Reading Comprehension loaded highly, and a quantitative factor consisting of Applied Math, QST, and Math Achievement.

Scores on the quantitative factor were predicted from the three tests identifying the factor by means of a three predictor multiple regression model. Raw score weights for the three tests and the additive constant were obtained from this multiple regression solution. The same procedure was used to obtain the Verbal Composite, a multiple regression prediction of the score on the WPC verbal factor. In both instances the composites were scaled to have a mean of 50 and a σ of 10 for the 1963-1964 high school group.

Once data from the 1968 standardization group were compiled, the raw score weights and additive constants were readjusted using the new means and standard deviations to provide standard scores for the junior group. These new composite formulas appear in Table 2.

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