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THE BRITISH ABILITY SCALES SPEED OF INFORMATION PROCESSING SUBTEST: WHAT DOES IT MEASURE?

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SUMMARY. Recent theory and research has focused on the relationship between speed of performing elementary cognitive operations and general intelligence. The developers of the British Ability Scales (BAS) included the Speed of Information Processing (SOIP) subtest as a measure of mental processing speed. To test the validity of the SOIP subtest, a group of 12-year-old children were given the BAS short-form, including the SOIP subtest, and a series of electronically timed reaction time (RT) tasks. Correlations between RT and SOIP were higher than correlations between RT and other BAS subtests, suggesting convergent and discriminant validity. A hierarchical factor analysis of the data shows that the BAS SOIP subtest is related more to speed of apprehension (RT) than to speed of making the motor response, or movement time (MT).

INTRODUCTION

Speed of performing mental operations has long been considered an aspect of intelligence by experts and lay persons alike. A recent publication of definitions of intelligence by contemporary experts (Sternberg and Detterman, 1986) compares responses to definitions proposed by experts in 1921, and shows considerable correspondence of views across that time period. While the ability to perform operations such as analytical reasoning, problem-solving, and memory are viewed as central aspects of intelligence, speed of performing those operations also receives some mention. Phrases used in ordinary conversation like "quick-witted" carry the implication that speed is associated with intelligence as conceived by non-experts as well.

All conventional tests of intelligence include at least some items or sections which are timed to award credit for fast performance, but speed is often a peripheral factor, sometimes only included as a practical concession to the need for maintaining a reasonable administration time. While the Binet model of measuring so-called "higher mental processes" (i.e., judgment, verbal conceptual ability, reasoning) has dominated psychometrics since the early 1900s, a revival of the Galtonian model has been under way at least since the significant theoretical contributions of Furneaux (1961) and Eysenck (1967). Both of these theorists conferred upon mental speed a position of more central importance than had typically been the case in the recent past. Much subsequent research (e.g., Brand and Deary, 1982; Jensen, 1982a, 1982b, 1987a, 1987b; Nettlebeck, 1985) has been conducted to test the assumption that individual differences in speed of performing elementary cognitive tasks (often as simple as discriminating which of two lines is longer) can account for a significant portion of variance in composite measures of intelligence. This research has been aided by some technological and methodological advances which allow very precise measurement. The "negative" findings of no relationship between physical measures like reaction speed and global intelligence (Wissler, 1901) are now being re-examined (Jensen, 1985).

The paradigms most frequently used in experimental cognitive psychology have used tasks which engage the most basic of cognitive processes, such as tasks which virtually all persons have no difficulty "solving" correctly. Using electronic timing devices, it has been possible to demonstrate that some portion of individual differences in speed of reaction are attributable to differences in actual processing time (as apart from time required to accomplish the motor response), and these differences are related to intelligence as conventionally measured (Jensen, 1987a).

Until recently, no comprehensive test of intelligence has included a subtest with any substantial similarity to the research tasks described above. The British Ability Scales (BAS) (Elliott, 1983a, 1983b) is presently unique in that it includes a subtest named Speed of Information Processing (SOIP). The rationale for its inclusion is based on the theoretical work of Furneaux (1961) and Eysenck (1967) and also on empirical research (Elliott and Murray, 1977) which found that speed of solution of very easy block design problems was significantly related to age and ability.

The purpose of the present study was to determine how performance on the British Ability Scales Speed of Information Processing subtest compares with simple and choice reaction time, measures which have attained credibility as reliable and valid indices of processing speed in experimental studies. In fact, the reliability and validity of reaction time has been so firmly established as a criterion for processing speed, that the BAS SOIP subtest must show some comparability to be considered a valid measure of the construct.

METHOD

Subjects

All 142 sixth-grade students at a rural county elementary school in the south-eastern United States were invited to participate in a series of studies investigating the validity of the British Ability Scales and the relationship of processing speed to general intelligence. For the present study, 78 students (37 males and 41 females) were randomly chosen from the total sample of 128 students for whom permission to participate was obtained. Mean age for the sample was 12 years 4 months ($\bar{X}$ = 147·9 months; SD = 10·4 months). The racial proportion for the sample (51 white; 27 black) was comparable to that of the total sixth grade and the entire school. No students classified as mentally retarded were included in the sample, but 15 students received the services of a special education resource teacher. Of those, nine were gifted, four were learning disabled, and two were emotionally disturbed.

Procedure

Participants were first administered the British Ability Scales, short-form, consisting of Speed of Information Processing, Matrices, Similarities, and Recall of Digits. These subtests were administered individually and scored by a qualified psychologist. The Speed of Information Processing subtest consists of 40 items of two types. Each of items 1 to 10 is a page of five rows of up to five circles (2 cm. diameter) which have different numbers (1-4) of small squares (2 mm. × 2 mm.) inside arrayed in different spatial locations about the inner perimeter. The task is simply to scan each row and make a pencil mark through the circle having the most squares in each row. Each of items 11 to 40 consists of a page of five rows of five numbers. The task is to make a pencil mark through the largest number in each row. Items 11 to 20 are pages of one-digit numbers; 21 to 25 are two-digit numbers; 26 to 30 are three-digit numbers; 30 to 35 are four-digit numbers; 36 to 40 are five-digit numbers. Timing is done with a stopwatch and items are scored 1 or 0 according to time limits established in the standardisation. The discontinuation rule is 10 consecutive failures. The Raven Standard Progressive Matrices (Raven, 1958) was administered to all students in small groups, and the School Ability Index (SAI) of the Otis-Lennon School Ability Test (OLSAT) (1982) was obtained from each student's school file.

The reaction time measures were made with an apparatus similar to that described by Jensen and Munro (1979) and used in many subsequent studies. A flat-black metal box with the top side pitched at a 20° angle is the response console. On the console's surface is a 15 cm. radius semicircle of eight green plastic ¾-inch microswitch pushbuttons which may be lit from underneath. At the centre of the semicircle, nearest the subject, is a black "home" button. Pressing the home button activates each trial which is programmed and timed by an IBM Personal Computer. Subjects' data are recorded automatically on the working disk immediately after each trial. The apparatus affords the separation of *reaction time* (RT) (time between the onset of a stimulus light and release of the home button) and *movement time* (MT) (time between release of the home button and depression of the stimulus button). Also measured for both RT and MT is consistency of response as defined by the standard deviation of responses across trials. A more detailed description of the apparatus and its measurement features may be found in Jensen (1987a, see especially Table 2, footnotes, p. 114).

Subjects were first given eight practice trials and 20 test trials of a simple RT test in which all but one of the eight buttons is covered by an overlay. Next, subjects were administered from zero up to 16 practice trials followed by 16 test trials of a choice RT test. In that condition, one of the eight buttons lit on each trial in a different position at random. The subject's degree of uncertainty as to which of eight buttons will light on any particular trial corresponds to three bits of information compared with the simple reaction time condition (one button) which corresponds to zero bits of information. A linear relationship between the information measure (i.e., the binary logarithm of the number of alternatives) and reaction time was demonstrated by Hick (1952).

A third condition consisted of an "odd-man-out" paradigm described by Frearson and Eysenck (1986). In this paradigm, on each trial, three of the eight buttons light so that two are closer together and one is further away from the two. The subject's task is to depress the button further away, or the "odd-man-out" button. After 9 to 18 practice trials, 36 test trials were administered.

In order to remove obvious outliers, on all RT trials, trials were invalidated and recycled if a subject lifted from the home button before the onset of the stimulus light or if either RT or MT exceeded 2 seconds. The same stimulus condition on these trials was automatically repeated at the end of the series of trials, so that every subject received the same number of valid trials. A warning tone varying randomly between 1 and 4 seconds preceded the onset of stimulus lights.

RESULTS

The BAS Short-Form IQ mean for this sample was 98·4 (SD = 12·9). Mean T-scores for three of the four subtests administered were relatively low when compared with the British norms (Matrices mean = 43·6; SD = 9·1; Similarities mean = 43·0; SD = 10·1; Recall of Digits mean = 46·9; SD = 9·6) while the mean T-score for Speed of Information Processing was relatively high (Speed of Information Processing mean = 63·5; SD = 9·4). The OLSAT School Ability Index mean was 99·4 (SD = 14·1) and the Raven Standard Progressive Matrices mean was 35·6 (SD = 9·4).

BAS Speed of Information Processing

With each item scored one or zero and 40 SOIP items, the total raw score possible is 40. The mean raw score attained by the present sample was 33·5 (SD = 4·53), and the mean T-score was 63·5 (SD = 9·4). A second type of derived score may be calculated for BAS subtests, termed an Ability Score, which has interval scale characteristics. Ability Scores are based on a unidimensional Rasch latent-trait model with the assumption that probability of passing an item is a function of item difficulty and ability of the test taker. For the SOIP subtest, Ability Scores range from 10 (raw score = 1) up to 257 (raw score = 40). Mean Ability Score for this sample was 194·7 (SD = 30·8).

These scores indicate restriction of range toward the ceiling, and these results along with those of Ward and Outhred (1986), who found similarly high SOIP scores for an Australian sample, raise some questions about the BAS norms for this subtest. Because of the skewness in the distributions of derived scores, actual times for completion of each SOIP item were calculated and averaged for each subject. Separate average times were calculated for items 1 to 10 (SOIP t1) which are non-numerical and for items 11 to 40 (SOIP t2), the numerical items. Mean time for SOIP t1 was 6·69 seconds (SD = 1·51) and for SOIP t2 was 12·42 seconds (SD = 2·72). The correlation between SOIP t1 and SOIP t2 was 0·75 ($P < 0·01$).

Reaction Time

Medians of RTs and MTs constituted each subject's scores. Because there is a physiological lower limit for RT, and consequently the distribution of RTs is positively skewed, the median is more appropriate as a measure of central tendency than the mean, which is biased upward.

For the simple RT (SRT) task (one stimulus button, zero bits of information), mean (of medians) reaction time was 355 ms (SD = 065) and mean MT was 345 ms (SD = 101). For the choice reaction time (CRT) task (eight stimulus buttons, three bits of information), mean RT was 428 ms (SD = 071) and mean MT was 366 ms (SD = 088). For the odd-man RT (OM) task, mean RT was 695 ms (SD = 119) and mean MT was 444 ms (SD = 149).

Variability of response was measured by computing the means of standard deviations of RTs and MTs over each task for each subject. Mean variability was 80 ms (SD = 41) for SRT

TABLE 1

CORRELATIONS BETWEEN REACTION TIME AND BRITISH ABILITY SCALES MEASURES

Reaction time measures	BAS IQ	Raven	OLSAT	Matrices ability score	Similarities ability score	Recall of Digits ability score	Speed of Information Processing ability score	SOIP t1 (items 1-10)	SOIP t2 (items 11-40)
SRT RT	−10	01	−09	−03	−09	08	−23*	−29*	−24*
CRT RT	−09	−16	−04	−12	−06	11	−20*	−33*	−23*
OM RT	−11	−17	−16	−18	−15	10	−07	−34*	−16
SRT RT SD	−12	−09	−18	−05	−01	03	−25*	−26*	−22*
CRT RT SD	−11	−22*	−08	−18	07	04	−19*	−21*	−11
OM RT SD	02	−15	00	02	−06	04	08	−01*	07
SRT MT	−17	−17	−18	−24*	−26*	06	−01	−13	−06
CRT MT	−20*	−24*	−21*	−32*	−25*	08	−04	−29*	−15
OM MT	−23*	−33*	−28*	−39*	−21*	01	−08	−24*	−17
SRT MT SD	14	11	12	−06	02	31*	05	02	−02
OM MT SD	13	15	11	03	−02	20*	14	01	14
OM MT SD	−17	−07	−11	−21*	−22*	−07	13	−01	14

Notes:
SRT = Simple Reaction Time Task.
RT = Reaction Time.
CRT = Choice Reaction Time Task.
MT = Movement Time.
OM = Oddman Reaction Time Task.
SD = Standard Deviation, that is, intra-individual variability across trials. (All correlations have been multiplied by 100.)
* P < 0·05.

TABLE 2

SCHMID-LEIMAN ORTHOGONALISED HIERARCHICAL FACTOR ANALYSIS

	Second-order factor	First-order factors				
	Gs	I	II	III	IV	h^2
SOIP t1	49*	00	−02	00	51*	0·49
SOIP t2	40*	04	−21	−11	53*	0·50
MAT AS	30*	68*	14	13	−06	0·59
SIM AS	23	59*	09	07	−05	0·42
RDIG AS	00	35*	−23	−17	05	0·21
RAVEN	27	69*	05	04	−02	0·55
OLSAT SAI	31*	82*	−05	−07	08	0·78
SRT RT	43*	−04	−03	03	44*	0·39
CRT RT	51*	−06	35*	16	35*	0·54
OM RT	46*	01	59*	19	18	0·63
SRT RT SD	35*	06	−08	−08	41*	0·31
CRT RT SD	28	03	39*	06	13	0·26
OM RT SD	09	−01	58*	07	−11	0·36
SRT MT	40*	−03	−18	67*	04	0·65
CRT MT	49*	−04	03	79*	01	0·86
OM MT	44*	07	15	68*	−05	0·69
SRT MT SD	−04	−13	32*	−07	−04	0·13
CRT MT SD	−01	−09	41*	−19	03	0·22
OM MT SD	04	19	65*	−06	−17	0·50
Eigen value	2·19	2·16	1·86	1·73	1·13	Σ= 9·07,
% Variance	11·51	11·36	9·79	9·11	5·96	Σ=47·74

Notes:

G = General factor of this battery (General Speed).

I = Psychometric ability.

II = Consistency of performance in RT and MT tasks.

III = Speed of movement (MT).

IV = Speed of apprehension (RT).

(All factor loadings have been multiplied by 100.)

* Loadings ⩾ 0·30.

RT; 83 ms (SD = 45) for SRT MT; 88 ms (SD = 61) for CRT RT; 82 ms (SD = 47) for CRT MT; 159 ms (SD = 70) for OM RT; 162 ms (SD = 75) for OM MT.

Correlations between RT measures and BAS measures are shown in Table 1. Because of the ceiling effect for SOIP T-scores, those scores were not included in the correlation analysis. All significant correlations are in the predicted direction. Lower (faster) RTs correspond with faster performance on SOIP, for example.

A hierarchical factor analysis was then performed on the intercorrelated variables using the Schmid-Leiman (1957) procedure. This procedure yields orthogonal factors within and between levels of the hierarchy and is preferable to other methods when one objective is to derive a general factor from a variety of different tests (Jensen, 1987b). To reduce the number of experimentally non-independent variables analysed, BAS IQ was omitted from the factor analysis since it is a function of the four subtest scores. The measures reflecting actual times (SOIP t1 and t2) were entered into the factor analysis rather than the skewed SOIP Ability Scores. To avoid confusion regarding positive and negative loadings, SOIP t1 and t2 as well as all RT and MT measures and all variability measures (RT and MT standard deviations for each task) were converted to positive values. Thus SOIP t1 and t2 and RT and MT for the factor analysis may be regarded as "speediness" and the variability measures (SD) may be regarded as "consistency of responding".

DISCUSSION

The correlations of BAS measures and RT suggest both convergent and discriminant validity for the SOIP subtest. Even though a ceiling effect probably attenuates the SOIP Ability Score correlations with RT measures, the only two significant correlations between Ability Scores and RT measures are found for the SOIP subtest. For one of the raw score measures (SOIP t1), correlations for all three RT measures are significant and in the predicted direction. The factor analysis shows considerable construct validity for the SOIP measures as they both have substantial loadings on Factor IV along with RT for the SRT and CRT tasks and response consistency (SRT RT SD) for the SRT tasks. All three movement time (MT) measures have significant loadings on a separate factor (Factor III), suggesting that SOIP scores are not related to speed of motor response. Instead, SOIP appears to be related to the speed of apprehension of the stimulus and thus is a credible indicator of speed of performing very simple cognitive operations. These results are highly consistent with the findings and theoretical interpretation by Lindley *et al.* (1988) regarding the basis of the correlation between speeded coding tests and psychometric *g*. Even though the RT measures are highly reliable, caution must be exercised in making firm conclusions from the factor analysis since few subjects relative to the number of variables were studied here.

Significant correlations between the movement time measures and two of the BAS subtests (Matrices and Similarities) as well as the general psychometric intelligence measures (BAS IQ; RPM; OLSAT) suggest that MT was more related to general intelligence for this sample than was RT. While RT parameters usually show more relationship to psychometric *g* than MT, Jensen (1982b) summarised a few studies involving children and retarded adults which have found sizeable MT/IQ correlations (e.g., Jensen and Munro, 1979; Vernon, 1981). Higher IQ subjects are most often found to have faster RTs, but the RT/MT ratio is higher for those subjects (Jensen, 1982b), suggesting that they may programme their ballistic response more completely before the initiation of the motor response. This conclusion is consistent with results found by Sternberg (1977) and Sternberg and Rifkin (1979) as they attempted to break down the performance of complex analogy tasks into component processing. They found that brighter subjects spent relatively more time on earlier-stage processing (stimulus encoding) than on later-stage processing, especially the component related to multiple-choice response selection. A good bit of evidence, then, suggests that the MT/IQ relationship may reflect a developmental phenomenon which appears when individual differences in chronological or mental age are compared. This hypothesis demands further investigation, however, especially in view of the results of one recent study of a small sample of non-retarded adults which were that MT/IQ correlations were greater than RT/IQ correlations (Frearson and Eysenck, 1986).

The Recall of Digits subtest not only is the sole subtest for which no significant correlation with any RT or MT measure was found, but the correlations are in the positive rather than the negative direction. Why should Recall of Digits scores' correlations be so different? One hypothesis relates to the degree to which individual subtests are measuring *g*. The principal factor analysis done on the BAS standardisation sample (Elliott, 1983b) shows that while loadings on the first factor are relatively high for Matrices (0·71) and Similarities (0·69), they are lower for Recall of Digits (0·53) and SOIP (0·46). The BAS authors decided to present digits at the rate two per second rather than the more conventional (e.g., Wechsler scales) one per second rate because they desired a "purer" measure of memory less affected by other cognitive operations which might be engaged given a slower presentation rate. To the extent that those other mental operations are manifestations of *g*, speeding up the presentation may have reduced the *g*-loading of Digit Recall.

To the extent that MT and RT measures have in the past consistently been shown to correlate significantly with measures thought to measure psychometric *g*, it is conceivable that all of the significant correlations reported here reflect shared variance due to *g*. The amount of "unaccounted for" variance in the present factor analysis is of course substantial, and may reflect subtest-specific factors. Only about 48 per cent of the total variance is accounted for by the common factors. The present results show that for SOIP, the expressed goal for the BAS of having high levels of subtest specificity (Elliott, 1986) was achieved. The differences found here between non-numerical (SOIP t_1) and numerical (SOIP t_2) items suggest that different specific factors may contribute to performance of the items even though the correlation of SOIP t_1 and SOIP t_2 is 0·75. SOIP t_1 seems to be more related MT and RT, while SOIP t_2 may reflect specific factors such as numerical knowledge. The assumption of most research investigating speed of mental processing is that individual differences in knowledge should be minimised. In the case of the BAS SOIP subtest, such differences may account for some of the unshared variance between SOIP t_1 and SOIP t_2. Provisions for scoring the two sections of SOIP separately should perhaps be considered in future BAS revisions as an aid to clearer interpretation of what high or low scores really mean.

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