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AN INTERPRETATIVE ANALYSIS OF FIVE COMMONLY USED PROCESSING SPEED MEASURES

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Processing speed subtests are components of widely used intellectual assessment instruments. Many researchers interpret these measures as assessing a unitary construct, but there is a question concerning the constructs assessed by these measures and, ultimately, their interpretative utility. Coding and Symbol Search from the Wechsler Intelligence Scale for Children-Third Edition (Wechsler, 1991), Visual Matching and Cross Out from the Woodcock Johnson Tests of Cognitive Ability-Revised (Woodcock & Johnson, 1989), and Speed of Information Processing from the Differential Ability Scales (Elliott, 1990) were administered to 102 volunteer participants. Using regression analyses, performance on each of these tests was predicted by motor speed and/or number facility factors. Individual differences in motor speed were found to be related to each of the five processing speed measures, whereas number facility was related to three of the measures.

This study investigated the interpretive utility of five measures of cognitive processing speed by assessing the role of two skills believed to underlie subtest performance. Popular speed measures include: Coding and Symbol Search from the Wechsler Intelligence Scale for Children (Wechsler, 1991, 2003); Cross Out and Visual Matching from the Woodcock Johnson Tests of Cognitive Ability (Woodcock & Johnson, 1989; Woodcock, McGrew, & Mather, 2001); and Speed of Information Processing from the Differential Ability Scales (Elliott, 1990). Cognitive speed, defined as "the ability to fluently perform cognitive tasks automatically, especially when under pressure to maintain focused attention and concentration" (McGrew & Flanagan, 1998, p. 24), has been found to affect working memory, fluid intelligence, and general cognitive efficiency and influence how quickly cognitive effort can be reallocated (Fry & Hale, 1996; Kail & Salthouse, 1994). The five subtests of interest that measure processing speed have been found to be positively correlated (Byrd & Buckhalt, 1991; Elliott, 1990; Kail, 1997; Wechsler, 1991; Woodcock & Mather, 1989) and define a unified speed factor (Stone, 1992). When synthesizing current theories of intelligence (Carroll, 1993; Horn, 1989), McGrew and Flanagan (1998) classified speed measures under the Broad Stratum II Ability of Processing Speed (*Gs*), based on measures typically being fixed-interval timed tasks requiring little in the way of complex thinking or mental processing.

Even with these empirical and conceptual similarities, there is reason to believe that process differences exist and somewhat different constructs may be assessed. Kamphaus, Benson, Hutchinson, and Platt (1994) and Kush (1996) questioned the theoretical and clinical utility of the WISC-III Processing Speed Index due to its factorial structure ambiguity and the low *g* loadings of its contributing subtests. Also, close inspection of Buckhalt and Jensen's (1989) results indicate possible differences between figural and numeric items within the Speed of Information Processing (SIP) task. Specifically, numeric items had smaller and fewer significant relationships with Reaction Time (RT) measures than did the figural items. The findings led the authors to speculate that item content influenced performance.

Further uncertainty is raised when comparisons are made between parallel subtests on the WISC-III and DAS, such as the Vocabulary subtests, Similarities subtests, Block Design/Pattern Construction, and Coding/SIP. The majority of correlations between the first three parallel tasks are in the .7 to .8 range, whereas the processing speed tests, Coding and SIP, have lower correlations ranging from .44 to .50 (Byrd & Buckhalt, 1991; Elliott, 1990; Stone, 1992). Even when corrected for attenuation, the discrepancy exists, suggesting that the differences observed are due to something other than measurement error and that the same construct is being assessed to a lesser degree compared to the other parallel subtests from the Wechsler and DAS.

Guilford's (1967, 1982, 1988) theoretical perspective, the Structure of Intellect Model, and the distinction made between content areas make it possible to differentiate between Coding, Symbol Search, Visual Matching, Cross Out, and SIP. According to Guilford, "Figural information is in concrete form, as perceived or recalled in the form of images" (1967, p. 227), and "Symbolic information is in the form of signs, materials, the elements having no significance in and of themselves, such as letters, numbers, musical notations, and other code elements" (1967, p. 227). The use of ambiguous, geometric shapes in Symbol Search and Cross Out is classified as figural content, whereas the use of digits in Visual Matching and SIP is classified as symbolic. Coding is a multifactor task because it contains both figural and symbolic elements. Kyllonen (1993) and Neubauer and Bucik (1996) have demonstrated the importance of task content. In this investigation, that distinction will be applied to five common processing speed measures from published intelligence tests.

There appear to be many possible skills involved with these five speed measures, as many have speculated (Buckhalt, 1991; Buckhalt & Jensen, 1989; Byrd & Buckhalt, 1991; Elliott, 1990; Kaufman, 1994; McGrew, 1994; Sattler, 1992; Stone, 1992). Motor speed and number facility are two of many constructs believed to play a role in differentiating individual performance on these measures, and they were chosen for the present study.

Regarding motor speed, many labels (psychomotor skill, graphomotor speed, paper-and-pencil skill) have been used, but all refer to how quickly an individual can write or copy numbers, letters, words, or symbols (Carroll, 1993). Each processing speed subtest has a motor component, but the degree of motoric involvement is unclear (Baron & Kaye, 1984; Glosser, Butters, & Kaplan, 1977; Shum, McFarland, & Bain, 1990; Williams & Dykman, 1994). Lindley, Smith, and Thomas (1988) demonstrated that paper-and-pencil-based tasks are influenced by motor speed. Carroll (1993) stated that psychomotor factors are clearly distinct from measures of strict cognitive abilities, and attempts should be made to measure these noncognitive skills so that appropriate adjustments to estimates of intellect can be made. At this point, there appears to be some evidence and belief that psychomotor factors may confound the interpretation of processing speed measures.

According to Carroll (1993), number facility refers to skill in dealing with numbers from counting and recognition to simple computations. Coding, Visual Matching, and SIP each have a number component, and many researchers (Buckhalt, 1991; Buckhalt & Jensen, 1989; Byrd & Buckhalt, 1991; Kaufman, 1994; McGrew, 1994) have speculated that number facility might be important in performance on these subtests, which has been somewhat supported by Stone (1992). The degree of number manipulation and quantitative skill required on the three measures varies and clarification of these ambiguities would be helpful.

Believing that latent variables may be responsible for variance on these subtests, Kamphaus et al. (1994), Keith (1990, 1997), Keith and Witta (1997), Kranzler (1997), and Riccio, Cohen, Hall, and Ross (1997) have called for more research to help identify what is being assessed by the popular processing speed measures. Interpretative accuracy and utility of these measures would increase with a better understanding of specific abilities involved. In the present study, it was anticipated that Coding, Visual Matching, and SIP would have a notable numeric component (Buckhalt, 1991; Buckhalt & Jensen, 1989; Byrd & Buckhalt, 1991; Elliott, 1990; Kaufman, 1994; McGrew, 1994; Stone 1992). It was also predicted that motor speed would be a significant predictor of each of the five processing speed measures; it was of interest to determine the degree to which the motor component would be predictive.

METHOD

Participants

Participants were 102 volunteers who ranged in age from 15 years 8 months to 73 years 5 months (M = 24 years 1 month; SD = 8 years 10 months). Sixty of the participants were female and 42 were male. Sixty-five were introductory and advanced university psychology students who received extra course credit for participation. Eighteen were private high school seniors who received a small gift certificate for their participation, and the remaining 19 participants were solicited by word of mouth from the community and were not compensated.

Instruments

Processing speed. Coding requires making number/symbol associations using a presented key. The total number of test items was 119 and the task time limit was 120 seconds. The resulting score was the number of items correct. Coding test/retest reliability was .79, as reported in the examiner's manual (Wechsler, 1991).

Symbol Search requires scanning five figures to decide whether one of two target figures is present and then marking the appropriate "Yes" or "No" box. There were 45 scorable test items and a 120-second time limit. The score was the number correct minus the number incorrect, as a correction for guessing. Symbol Search test/retest reliability was .76 in the normative sample (Wechsler, 1991).

Visual Matching requires the identification of two identical numbers in a row of six numbers. There were 60 test rows and standardized administration allows for 180 seconds. For purposes of group administration, 150 seconds were allowed to limit the possibility of participants finishing before standard administration time elapsed. The score was the number correct. Visual Matching test/retest reliability was .78 in the normative sample (Woodcock & Mather, 1989), although the reliability of the modified form might be somewhat different.

Cross Out requires scanning and identifying five figures that are identical to the first target figure in the row. There were 30 rows of test items and standardized administration allows for 180 seconds, but for this study 150 seconds were allowed to limit the possibility of participants finishing before standard administration time elapsed. The score was the number of rows with all five figures correctly marked. Test/retest reliability was .74 in the normative sample (Woodcock & Mather, 1989), although the reliability of the modified form might be somewhat different.

Speed of Information Processing requires the scanning of an array of numbers and circling the largest in value. There were a total of 48 test items. Standardized administration requires the examiner to administer six sets, eight lines each and to record the time needed for completion of each set. For the purpose of group administration, all 48 test items were administered during a single administration that lasted 75 seconds. The score was the number correct. Speed of Information Processing test/retest reliability was .80 in the standardization sample (Elliott, 1990), although in the modified form it might be somewhat different.

Motor speed. Motor speed tasks were derived from studies cited by Carroll (1993). Construct validity evidence is provided because these measures were found, along with other tests, to load on a factor interpreted as motor speed.

Making X's requires putting an "X" over each lower case o. Rows of 10 evenly spaced o's were presented on a single page. The score was number of X's correctly made during the 30 second time limit. The Making X's test had loadings of .47 (French, 1957) and .80 (Scheier & Ferguson, 1952) on an established motor speed factor. Test/retest reliability was .92 (French, 1957).

Writing Digits requires writing the digits "123" on rows of evenly spaced lines. The score was number of times 123 was completely written within the 45-second time limit. Validity for Writing Digits type tasks was provided by loadings on a motor speed factor of .68 (French, 1957) and .58 (Scheier & Ferguson, 1952). Test/retest reliability was .91 (French, 1957).

Writing Letters requires writing the word "lack" on rows of evenly spaced lines. The score was the number of times lack was completely written within the 45-second time limit. Writing Letters type tasks had loadings of .60 (French, 1957), .64 (Pemberton, 1952), and .55 (Scheier & Ferguson, 1952) on a motor speed factor. Test/retest reliability was .92 (French, 1957).

Number facility. Number facility tasks were also cited by Carroll (1993). The tests were taken from the Educational Testing Service Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Dirmen, 1976).

Addition requires the summing of sets of three one- or two-digit numbers. One hundred twenty seconds were allowed to answer as many as 60 problems. The score was the number correct. Basic addition tests have been shown to be related to an established number facility factor with the following loadings: .72 (Coombs, 1941), .67 (Kelley, 1964), and .63 (Roff, 1952). Test/retest reliability was .93 (Ekstrom et al., 1976).

Division requires the division of a two- or three-digit number by a single-digit number. One hundred twenty seconds were allowed and the score was the number correct. Division tests as a measure of number facility were observed with weightings on a number facility factor. Observed loadings were .70 (Christal, 1958), .66 (Fleishman & Hempel, 1954), and .67 (Kelley, 1964). Test/retest reliability was .94 (Ekstrom et al., 1976).

Subtraction and Multiplication allows participants 120 seconds for answering rows that alternate subtraction and multiplication problems. The score was the number correct. Christal (1958), Coombs (1941), Ekstrom, French, and Harman (1979), and Kelley (1964) showed that Subtraction and Multiplication tests were measures of number facility, with factor weightings of .70, .64, .64, and .67, respectively. Test/retest reliability was .92 (Ekstrom et al., 1976).

Table 1
Administration Order and Number of Participants Completing Each Form (in parentheses)

	Form			
Order	A (25)	B (26)	C (26)	D (25)
1	Coding	Visual Matching	Division	Writing Letters
2	Addition	Making X's	Writing Digits	SIP
3	Symbol Search	Symbol Search	Cross Out	Sub./Multi.
4	Making X's	Addition	Sub./Multi.	Cross Out
5	Visual Matching	Coding	SIP	Writing Digits
6	Division	Writing Letters	Writing Letters	Division
7	Writing Digits	SIP	Coding	Visual Matching
8	Cross Out	Sub./Multi.	Addition	Making X's
9	Sub./Multi.	Cross Out	Symbol Search	Symbol Search
10	SIP	Writing Digits	Making X's	Addition
11	Writing Letters	Division	Visual Matching	Coding

Note.—Sub./Multi. = Subtraction and Multiplication; SIP = Speed of Information Processing.

Procedure

A certified school psychologist or school psychology graduate student trained in standardized administration procedures completed the test administration in a single session. Four forms were used to minimize the confounding of individual differences with order. See Table 1 for test order and number of participants who completed each form.

Standardized administration procedures were employed, with the exception of group administration and specific changes noted in the Instruments description. Sample items were demonstrated on an overhead projector during the instruction phase of each test, and scoring was completed as outlined. Two trials of each factor marker test were completed and averaged as recommended by the test authors.

Table 2
Correlation Matrix (Including Means and Standard Deviations)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1 Age (months)	-											
2 Coding	-.39**	-										
3 Symbol Search	-.52**	.51**	-									
4 Visual Matching	-.30*	.62**	.60**	-								
5 Cross Out	-.39**	.53**	.57**	.61**	-							
6 SIP	-.03	.29*	.43**	.54**	.45**	-						
7 Making X's	-.38**	.52**	.50**	.50**	.44**	.36**	-					
8 Writing Digits	-.17	.38**	.44**	.44**	.37**	.27*	.65**	-				
9 Writing Letters	-.28*	.38**	.34**	.42**	.35**	.22	.63**	.75**	-			
10 Addition	.24	.13	.19	.38**	.16	.41**	.15	.19	.07	-		
11 Division	.03	.15	.22	.27*	.14	.27*	.08	.07	-.01	.67**	-	
12 Sub./Multi.	.11	.22	.26*	.39**	.13	.35**	.24	.29*	.19	.76**	.71**	-
M	289.9	73.1	37.5	26.0	50.4	37.2	51.5	36.3	28.3	17.1	11.4	24.7
SD	105.7	13.2	5.9	3.4	5.2	4.5	8.0	4.4	4.1	4.8	6.1	8.2

Note.—Sub./Multi. = Subtraction and Multiplication; SIP = Speed of Information Processing.
$^{*}p < .01$. $^{**}p < .001$.

RESULTS

Raw scores were used during analyses because they allowed direct comparison across subtests, given that standard scores vary by scale and could not always be obtained because the age of some participants extended beyond established norms. A correlation matrix, means, and standard deviations are presented in Table 2. Because the magnitude of the relationship between any two measures is limited by the reliability of each, the obtained correlations were corrected using a formula from Nunnally (1978). Disattenuated correlation coefficients are presented in Table 3. Scatter plots for each correlation indicated a linear relationship between the variables. A comparison of means across the four forms showed that Form 3 participants performed better than Form 4 participants on all three motor speed measures, and better than Form 1 participants on one motor speed measure. This effect is best explained by the mean age of Form 4 participants being greatest and by the negative correlation between motor speed and age (see Table 2). No other significant differences between forms were found.

Table 3
Disattenuated Correlation Matrix

Variable	1	2	3	4	5	6	7	8	9	10
1 Coding	-									
2 Symbol Search	.66	-								
3 Visual Matching	.79	.78	-							
4 Cross Out	.69	.76	.80	-						
5 SIP	.36	.55	.68	.58	-					
6 Making X's	.61	.60	.59	.53	.42	-				
7 Writing Digits	.45	.53	.52	.45	.32	.71	-			
8 Writing Letters	.45	.41	.50	.42	.26	.68	.82	-		
9 Addition	.15	.23	.45	.19	.48	.16	.21	.08	-	
10 Division	.17	.26	.32	.17	.31	.09	.76	-.01	.72	-
11 Sub./Multi.	.26	.31	.46	.16	.41	.26	.32	.21	.82	.76

Note.—Sub./Multi. = Subtraction and Multiplication; SIP = Speed of Information Processing.

Principal components extraction using Varimax rotation was performed with SPSS Factor Analysis on the six factor marker tests. Loading criteria of >.4 was used; all six variables loaded on one of two factors. Actual factor loadings are shown in Table 4. Examination of these results indicates extremely high factor loadings (where predicted) and clearly defined factors. Communalities indicated that the variables were well defined by this solution; the weakest communality for variables from factors was .72.

Table 4
Factor Loadings from Principal Component Analysis Using Varimax Rotation

	Factor	
Variable	1	2
Addition	.90	.08
Division	.89	-.04
Subtraction/Multiplication	.90	.21
Making X's	.10	.84
Writing Digits	.13	.90
Writing Letters	.00	.90
% of Variance	47.15	33.01

The first factor was termed Number Facility because the three measures involving basic quantitative skill had high loadings. Ekstrom et al. (1976) defined this factor as "The ability to perform basic arithmetic operations with speed and accuracy. This factor is not a major component in mathematical reasoning or higher mathematical skills" (p.115). Similarly, Carroll (1993) has stated that number facility

> refers simply to the degree to which the individual has developed skills in dealing with numbers, from the most elementary skills of counting objects and recognizing written numbers and their order, to the more advanced skills of correctly adding, subtracting, multiplying, and dividing numbers (p. 469).

The second factor was labeled Motor Speed. Tasks that require participants to perform numerous, simple pencil motions with minimal cognitive demands in a short amount of time defined this factor. The combined variance explained by the two factors was 80.16%.

The results of a factor analysis with an oblique rotation were almost identical to that with an orthogonal rotation. This finding suggests that the solution is stable, and confidence can be placed in the factors obtained and being used in additional analyses.

The two factors obtained using the orthogonal (varimax) rotation were used as the independent variables in the stepwise multiple regression to predict performance on each of the five processing speed measures. Tolerances of greater than .90 indicated an absence of multicollinearity and singularity, and the regression assumptions (normality, linearity, and homoscedasticity of residuals) were found to be met. A significance level of $p < .01$ was used to protect against finding significant values by chance. Age was forced to enter first, to statistically control for differences in age. Results are shown in Table 5.

Table 5
Stepwise Regression Analyses Using Factors to Predict Performance on Processing Speed Measures

Processing Speed Measure	Factor	R^2	F	B	β	p
Coding	Age	.15	(1,100) = 18.15	-.04	.31	.00
	Motor Speed	.13	(2,99) = 19.58	4.88	.37	.00
Symbol Search	Age	.27	(1,100) = 36.39	-.03	-.47	.00
	Motor Speed	.10	(2,99) = 28.27	1.84	.31	.00
	Number Facility	.08	(3,98) = 26.10	1.71	.29	.00
Visual Matching	Age	.09	(1,100) = 9.73	-.01	-.23	.01
	Motor Speed	.17	(2,99) = 17.04	2.11	.41	.00
	Number Facility	.14	(3,98) = 21.50	1.97	.38	.00
Cross Out	Age	.15	(1,100) = 17.97	-.01	-.32	.00
	Motor Speed	.10	(2,99) = 16.42	1.09	.32	.00
SIP	Age	.00	(1,100) = .12	-.00	-.01	.96
	Number Facility	.14	(2,99) = 8.08	1.65	.36	.00
	Motor Speed	.07	(3,98) = 8.90	1.30	.29	.00

Age accounted for a significant proportion of the variance in all but one of the processing speed measures (i.e., SIP) when forced to enter first. Motor Speed accounted for significant amounts of variance on each of the processing speed measures. The degree of involvement varied for each measure: Visual Matching with $R^2 = .17$, Coding with $R^2 = .13$, Symbol Search with $R^2 = .10$, Cross Out with $R^2 = .10$, and SIP with $R^2 = .07$. The second predictor variable, Number Facility, was found to be a component of three subtests: Visual Matching with $R^2 = .14$, Symbol Search with $R^2 = .08$, and SIP with $R^2 = .07$. No significant relationship was found between Number Facility and the remaining two dependent variables.

DISCUSSION

This investigation into specific skills that contribute to individual differences on five common measures of processing speed discovered some interesting relationships. First, Motor Speed was able to account for varied (7% to 17%) but significant amounts of variance on all of the speed subtests. These results are interesting but not surprising, given that each task requires at least some amount of paper-and-pencil involvement. Even Symbol Search and SIP, whose motor component appears negligible, were found to vary as a function of motor skill. Carroll (1993) and Lindley et al. (1988) have stated that peripheral motor demands may cause individuals to perform differently on these types of measures, and this was supported by the data. Also, Carroll (1993) has stated that psychomotor factors are clearly distinct from measures of strict cognitive abilities, and that attempts should be made to measure these noncognitive skills so that appropriate adjustments to estimates of intellect can be made. The finding that paper-and-pencil skill had a significant role in all five processing speed subtests will be helpful to practitioners as they work to accurately interpret test profiles and clearly explain variability in an individual's skills. The role of motor skill during manipulative, object-based tasks is becoming more of an issue in contemporary ability assessment, because newer instruments are increasingly emphasizing the "level" or accuracy of performance, rather than speed of responses, and some instruments now have the means to account for differences in motor skill when considering an individual's profile (e.g., the Coding copy option).

Also of interest was the discovery that the content (numeric vs. figural) of a task generally influenced how an individual performed, with the surprising exception of Symbol Search. This conclusion was reached from the expected finding that Number Facility was found to account for a significant amount of the variance in Visual Matching and SIP, two subtests whose stimuli were completely numeric. In contrast, Coding and Cross Out, whose item content was either mixed or entirely figural, were not found to vary as a function of individual strengths or weaknesses in Number Facility. The idea that task content may influence individual performance has been suspected by many (Buckhalt, 1991; Buckhalt & Jensen, 1989; Byrd & Buckhalt, 1991; Kaufman, 1994; McGrew, 1994; Stone, 1992). Although all five processing speed subtests could accurately be classified under the common label of perceptual speed, it appears, as French (1976) and Carroll (1993) have stated, that perceptual speed may be a "centroid" of more specific and narrow factors. That is, perceptual speed itself is an ability that can be broken down into more specific components, based on item content. Practitioners can benefit from this finding as they interpret test profiles. The anomalous finding with Symbol Search is difficult to explain, although a latent, presently unidentified variable might be involved.

Although participant mean age was greater than the intended audience for three of the five processing speed subtests used in this study, and previous editions of newer instruments were utilized in this study, obtained results should be generalizable to the adult population and newer instruments. Age range is not an issue for the Cross Out and Visual Matching, because these subtests can be used up to 92 years of age. An item-by-item comparison indicates that WJ-III Visual Matching is identical in demands to WJ-R Visual Matching. Although Cross Out has been moved to the Diagnostic Supplement, task demands remain essentially unchanged.

The Wechsler speed subtests that exist on both the child and adult version (Wechsler, 1997) are highly similar in regards to the nature of stimuli, number of items, and time constraints. Additionally, these parallel subtests are used similarly to define a processing speed factor. A comparison between WISC-III Coding and WISC-IV Coding shows them to be identical; Symbol Search items also remain unchanged, although more total items are now possible on the new version. While the composition of the other three factors has changed, the speed subtests and factor structure remain essentially the same. SIP is intended for individuals younger than 18 years of age, but no participants finished all of the items, so individual differences were still identified and the obtained results should be valid. Although revised batteries are now available, the demands of the processing speed tests remain either unchanged from earlier versions or highly similar, lending the present conclusions applicable to the adult version and new editions.

Although interesting and statistically significant results were found, certain limitations exist. One limitation of this investigation involved having strayed somewhat from standardized administration, specifically, group testing, shortened time limits on Visual Matching and Cross Out to minimize ceilings, and a minor alteration to SIP presentation. Even with the subtest modifications and a small departure from standardized administration, it is likely that the tests maintained their integrity and continued to assess the same constructs, because item content remained unchanged.

Although the regression analyses were able to account for significant amounts of well-defined variance on the five processing speed subtests, the majority of the subtests' variability remained unexplained. Additional predictor variables may have been helpful. A few of the many skills that may be related to performance on these measures include visual memory, attention, working memory, and visual scanning, yet, as Buckhalt (personal communication, October 2, 2000) has stated, individuals tend to coordinate many subsystems in performing all tasks, even ones that on the surface appear to be "simple," so confidently identifying specific subskills involved may be difficult. Also, it would be of interest to determine which processing speed subtests are most related to the most basic of speed measures, such as Jensen-like Inspection, Reaction, or Movement Time measures, as well as how well each of the measures relates to a general intellectual measure or acquisition of specific academic skills. Also, because motor skill was found to play a role in the processing speed measures, it would be worthwhile to determine if, and to what degree, noncognitive skills (e.g., dexterity, motor skill) are involved in other subtests from common batteries. Additionally, clarifying why Symbol Search was predicted by the Number Facility factor in the present study would be enlightening.

The goal of this investigation was to increase the interpretive utility of five common processing speed subtests. Although the results are not exhaustive, they should prove helpful to individuals who use these instruments in research or applied settings. Specifically, a better understanding of skills involved in these types of measures should prove helpful in the development and refinement of future measures. Also, practitioners will benefit from the increased interpretative accuracy of these processing speed subtests during their evaluation process.

REFERENCES

Baron, M. B., & Kaye, D. B. (1984). A validity study of the WISC-R Coding B subtest. *Journal of Psychoeducational Assessment, 2,* 191-197.

Buckhalt, J. A. (1991). Reaction time measures of processing speed: Are they yielding new information about intelligence? *Personality and Individual Differences, 12,* 683-688.

Buckhalt, J. A., & Jensen, A. R. (1989). The British Ability Scale Speed of Information Processing subtest: What does it measure? *British Journal of Educational Psychology, 59,* 100-107.

Byrd, D. P., & Buckhalt, J. A. (1991). A multitrait-multimethod construct validity study of the Differential Ability Scales. *Journal of Psychoeducational Assessment, 9,* 121-129.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor analytic studies.* New York: Cambridge University Press.

Christal, R. E. (1958). Factor analytic study of visual memory. *Psychological Monographs: General and Applied, 72* (13, Whole No. 466).

Coombs, C. H. (1941). *A factorial study of number ability. Psychometrika, 6,* 161-189.

Ekstrom, R. B., French, J. W., & Harman, H. H. (1979). Cognitive factors: Their identification and replication. *Multivariate Behavioral Research Monographs, 79,* 2.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dirmen, D. (1976). *Manual for kit of factor-referenced cognitive tests* (3rd ed.). Princeton, NJ: Educational Testing Service.

Elliott, C. D. (1990). *Differential Ability Scales: Introductory and technical handbook.* San Antonio, TX: The Psychological Corporation.

Fleishman, E. A., & Hempel, W. E. (1954). Changes in factor structure of a complex psychomotor test as a function of practice. *Psychometrika, 19,* 239-251.

French, J. W. (1957). The factorial invariance of pure-factor tests. *The Journal of Educational Psychology, 48,* 93-109.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence of a developmental cascade. *Psychological Science, 7,* 237-241.

Glosser, G., Butters, N., & Kaplan, E. (1977). Visuospatial processes in brain damaged patients on the Digit Symbol Substitution Test. *International Journal of Neuroscience, 7,* 59-66.

Guilford, J. P. (1967). *The nature of human intelligence.* New York: McGraw-Hill.

Guilford, J. P. (1982). Cognitive psychology's ambiguities: Some suggested remedies. *Psychological Review, 89,* 48-59.

Guilford, J. P. (1988). Some changes in the Structure of Intellect Model. Educational and *Psychological Measurement, 48,* 1-4.

Horn, J. L. (1989). Models of intelligence. In R. L. Linn (Ed.), *Intelligence: Measurement, theory, and public policy* (pp. 29-73). Urbana, IL: University of Illinois Press.

Kail, R. (1997). Phonological skill and articulation time independently contribute to the development of memory span. *Journal of Experimental Child Psychology, 67*, 57-68.

Kail, R., & Salthouse, T. A. (1994). Processing speed as mental capacity. *ACTA Psychologica, 86*, 199-225.

Kamphaus, R. W., Benson, J., Hutchinson, S., & Platt, L. O. (1994). Identification of factor models for the WISC-III. *Educational and Psychological Measurement, 54*, 174-186.

Kaufman, A. S. (1994). *Intelligent testing with the WISC-III.* New York: Wiley.

Keith, T. Z. (1990). Confirmatory and hierarchical confirmatory analysis of the Differential Ability Scales. *Journal of Psychoeducational Assessment, 8*, 391-405.

Keith, T. Z. (1997). What does the WISC-III measure? A reply to Carroll and Kranzler. *School Psychology Quarterly, 12*, 117-118.

Keith, T. Z., & Witta, E. L. (1997). Hierarchical and cross-age confirmatory factor analysis of the WISC-III: What does it measure? *School Psychology Quarterly, 12*, 89-117.

Kelley, H. P. (1964). Memory abilities: A factor analysis. *Psychometric Monographs.* (Psychometric Society No. 11). Richmond, VA: William Byrd Press.

Kranzler, J. H. (1997). What does the WISC-III measure? Comments on the relationship between intelligence, working memory capacity and information processing speed and efficiency. *School Psychology Quarterly, 12*, 110-116.

Kush, J. C. (1996). Factor structure of the WISC-III for students with learning disabilities. *Journal of Psychoeducational Assessment, 14*, 32-40.

Kyllonen, P. C. (1993). Aptitude testing inspired by information processing: A test of the four-source model. *The Journal of General Psychology, 120*, 375-405.

Lindley, R. H., Smith, W. R., & Thomas, T. J. (1988). The relationship between speed of information processing as measured by timed paper and pencil tests and psychometric intelligence. *Intelligence, 12*, 17-25.

McGrew, K. S. (1994). *Clinical interpretation of the Woodcock-Johnson Tests of Cognitive Ability-Revised.* Boston: Allyn & Baron.

McGrew, K. S., & Flanagan, D. P. (1998). *The Intelligence Test Desk Reference (ITDR).* Needham, MA: Allyn & Bacon.

Neubauer, A. C., & Bucik, V. (1996). The mental speed-IQ relationship: Unitary or modular? *Intelligence, 22*, 23-48.

Nunnally, J.C. (1978). *Psychometric theory* (2nd ed.). New York: McGraw-Hill.

Pemberton, C. (1952). The closure factors related to other cognitive processes. *Psychometrika, 17*, 267-288.

Riccio, C. A., Cohen, M. J., Hall, J., & Ross, C. M. (1997). The third and fourth factors of the WISC-III: What they don't measure. *Journal of Psychoeducational Assessment, 15*, 27-39.

Roff, M. E. (1952). A factorial study of the tests in the perceptual areas. *Psychometric Monographs.* (Psycometric Society No. 8). Colorado Springs, Co.: Denton Printing Company.

Sattler, J. M. (1992). *Assessment of children: Revised and updated* (3rd ed.). San Diego, CA: Jerome M. Sattler, Publisher.

Scheier, I. H., & Ferguson, G. A. (1952). Further factorial studies of tests of rigidity. *Canadian Journal of Psychology, 6*, 18-30.

Shum, D. H. K., McFarland, K. A., & Bain, J. D. (1990). Construct validity of eight tests of attention: Comparison of normal and closed head injured samples. *The Clinical Neuropsychologist, 4*, 151-162.

Stone, B. J. (1992). Joint confirmatory factor analyses of the DAS and WISC-R. *Journal of School Psychology, 30*, 185-195.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children-Third Edition.* San

Antonio, TX: The Psychological Corporation.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale-Third Edition.* San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children-Fourth Edition.* San Antonio, TX: The Psychological Corporation.

Williams, J., & Dykman, R. A. (1994). Nonverbal factors derived from children's performance on neuropsychological test instruments. *Developmental Neuropsychology, 10,* 19-26.

Woodcock, R. W., & Johnson, M. B. (1989). *Woodcock-Johnson Psycho-Educational Battery-Revised.* Chicago: Riverside.

Woodcock, R. W., & Mather, N. (1989). WJ-R Tests of Cognitive Ability-Standard and Supplemental Batteries: Examiner's manual. In R. W. Woodcock & M. B. Johnson, *Woodcock-Johnson Psycho-Educational Battery-Revised.* Chicago: Riverside.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities.* Itasca, IL: Riverside.