

**THE THREE STRATUM THEORY OF COGNITIVE ABILITIES: TEST
OF THE STRUCTURE OF INTELLIGENCE ACROSS THE LIFE SPAN**

by

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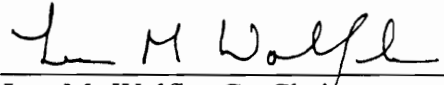
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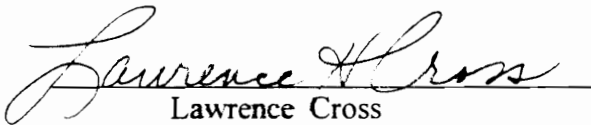
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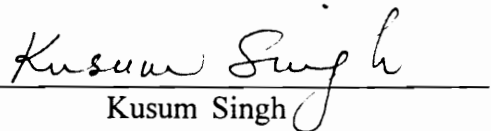
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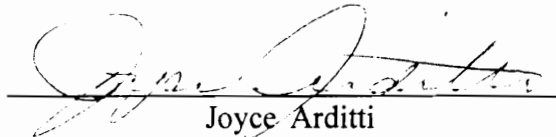
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(ABSTRACT)

Recently a three stratum theory of intelligence that combines the major aspects of Spearman's theory of general intelligence (*g*) (1927) and Horn and Cattell's theory of crystallized and fluid intelligence (*Gf-Gc*) (1991) has been proposed (Carroll, 1993). The purpose of this study was to test the three stratum theory using confirmatory factor analysis with the LISREL computer program. Developmental changes in the structure of intelligence were also investigated. Results provided support for the three stratum theory, suggesting the possibility of intermediate factors between the second and third stratum but no support for developmental changes in the organization of cognitive abilities.

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THE THREE STRATUM THEORY OF COGNITIVE ABILITIES: TEST OF THE STRUCTURE OF INTELLIGENCE ACROSS THE LIFE SPAN

The chronology of research in human cognitive abilities traces back a century to Francis Galton and J. M. Cattell and involves investigation into its sources, dimensions, and measurement (Carroll, 1992). The interplay of the dimensions of intelligence and the valid measurement of those dimensions continues to elicit debate among theorists, test developers, and consumers. Despite controversial, often competing, ideas in theoretical developments, tests of cognitive ability, such as the Stanford Binet IV, the Wechsler Intelligence Scales for Children III, and the Woodcock-Johnson Revised, continue to be revised and used extensively.

Theories of intelligence have developed and evolved into somewhat different representations of the dimensions of cognitive ability (Burt, 1940; Guilford, 1956; Horn & Cattell, 1966; Humphreys, 1962; Spearman, 1927; Thurstone, 1938). Two theories seem especially compelling and have endured rigorous examination: Spearman's theory of general intelligence (g-factor; 1927) and Cattell and Horn's theory of fluid and crystallized intelligence (Gf and Gc; 1966). The g-model asserts that there is a **general** factor of intelligence underlying all aspects of cognitive ability. Spearman (1927) actually proposed two classes of factors, a general factor, **g**, and specific factors, **s** (called specificities, or specific variance in modern psychometrics). More importance was placed on **g** however, because it is pervasive in all aspects of intellectual activity. Spearman described **g** as ". . . something

analogous to an 'energy'; that is to say, it is some force capable of being transferred from one mental operation to another different one" (p. 27). It is this universality of *g* that explains why all tests of intellectual ability, as well as observations of intelligence, are highly correlated. Specific and broad abilities are saturated with *g*, and as far as the use of different measurement tools are concerned, they are all measuring essentially the same thing, demonstrating what Spearman labeled "the indifference of the indicator" (1927, p. 27).

It is important to note that Spearman recognized specific factors and even group factors that are narrower in scope than *g*. These broad group factors were conceptualized and tested by other researchers shortly after Spearman identified *g* (Holzinger & Harman, 1938; Kelly, 1928; Thurstone, 1938). In some models *g* was represented as a second or third-order factor (Burt, 1949; Vernon, 1950). In others, the list of specific abilities grew but *g*, as a single factor, was not recognized (Guilford, 1959; Thurstone, 1947).

Although the *g* theory has received much criticism, it continues to be the benchmark in intelligence theory. Even theorists who refute a pervasive single factor of intelligence continue to compare plausible models of cognitive ability to the *g* model (McGrew, Werder, & Woodcock, 1991). And Spearman's theorem of the indifference of the indicator is still being used to explain the high correlations among intelligence tests today (Jensen, 1992).

Attributed to Raymond B. Cattell and John L. Horn, the Gf and Gc theory of intelligences is widely misunderstood to represent only two broad factors of

intelligence. In fact, in its current representation, there are eight broad factors of cognitive abilities: (Gf) Fluid Reasoning, (Gc) Comprehensive Knowledge, (Gv) Visual Processing, (Ga) Auditory Processing, (Gs) Processing Speed, (Gsm) Short-Term Memory, (Gl) Long-Term Retrieval, (Gq) Quantitative Ability. First conceptualized in the 1940's and fully developed in the mid-1960's, Cattell and Horn hypothesized five broad factors of intelligence, including a personality factor (Horn & Cattell, 1966). Since then the theory has been continually revised; the personality factor has been dropped, and others added. The core features of the theory, fluid and crystallized factors, have remained intact and are said to represent abilities gained primarily from genetic factors and from educational-cultural opportunities, respectively (Horn, 1991).

The theory also holds implications for human development and intelligence. The broad abilities that are considered "vulnerable" (Gf, Gsm, Gs) have been shown to decline with age. "Maintained" abilities (Gc, Gl, Gq) on the other hand, have been shown either to increase or remain stable with age (Horn, 1991).

Although Horn argues against the existence of a general intelligence factor, factor analytic studies have continued to show Gf and Gc, as well as the remaining six broad abilities, to load heavily on a second order factor, g (McGrew, Werder, & Woodcock, 1991; Undheim & Gustafsson, 1987). There is even evidence that when several of the broad abilities of the Gf-Gc theory are loaded on a common g-factor, fluid intelligence (Gf) has a standardized factor loading of 1.0, leading to the conclusion that g is indistinguishable from fluid intelligence. This finding has been

interpreted by Horn as showing that intelligence is more than a single g-factor (Horn, 1991; Undheim & Gustafsson, 1987).

Most recently a theory that combines aspects of both the g model and Gf and Gc model has surfaced. It is represented by a three stratum factor structure with g at the apex, several broad abilities at the second stratum and many specific abilities at the first stratum (Carroll, 1992, 1993; Gustafsson, 1984; Undheim & Gustafsson, 1987). With the exception of Gq, the second stratum closely resembles the Gf-Gc broad abilities. After reanalyzing over 460 factor analytic studies on the nature of cognitive abilities, John B. Carroll has identified this theory of intelligence as the most viable explanation of human abilities (1993). According to Carroll (1992) it is by this model ". . . that the structure of abilities can best be described" (p. 268).

Hierarchical theories of intelligence, with abilities organized in such a way that g is at the top of the pyramid and more specific factors down further, are not new (Burt, 1949; Thurstone & Thurstone, 1941; Vernon, 1950). This hierarchical model is especially interesting however, because it combines dimensions of two well established, competing theories into one unified model.

Carroll (1993) identified the abilities located at each stratum as narrow (stratum I), broad (stratum II) and general (stratum III), however he did not consider the strata to be rigidly defined. Further, the stratum to which a factor belongs is only a reflection of its degree of generality, not an indication of its dominance over a particular lower stratum factor. He also suggested there may be intermediate

factors that fall between the three identified strata (for a thorough review of the literature, see Appendix A).

Several questions regarding the structure of this three stratum theory remain. The first concerns the nature of the relation between fluid intelligence (Gf) and general intelligence (g). Horn (1991) maintained that intelligence is more than g and drew support for his argument from factor analytic studies that indicate a perfect loading of Gf on g. However, if one were to examine this finding from Spearman's viewpoint, using the analogy of "an energy", the argument could be made that Gf is simply the broad factor most saturated with g. Carroll (1993) hypothesized that g, as a third stratum factor, has a high degree of heritability and Gf, as a second stratum factor, has the highest level of heritability at that stratum, which would suggest a strong relation between the two. Or it could be that Gf does not really belong at the second stratum, but at the third stratum and may, in fact, be g. Another possibility is that Gf and Gc are intermediate factors between the second and third strata sharing a large degree of common variance (Horn, 1980).

A second unanswered question regards the contribution of the quantitative factor (Gq). Within the context of the Gf-Gc theory and the three stratum model, this factor has not been closely examined. Findings from confirmatory factor analytic studies on the Wechsler Intelligence Scale for Children III (WISC-III), The Wechsler Intelligence Scale-Revised (WISC-R), and the Differential Ability Scales, suggest that a factor best identified as a quantitative reasoning factor has an extremely high loading on g (Keith, 1990; Keith & Witta, 1992; Stone, 1992).

Preliminary work on the factor structure of the Stanford-Binet IV has suggested a quantitative factor indistinguishable from *g* (Keith & Bickley, in progress). In contrast, Carroll (1993) maintained that "mathematical ability . . . is an inexact, unanalyzed popular concept that has no scientific meaning . . ." (p. 627) and concluded that it does not constitute a higher level ability.

A third question addressed in this research concerns the overall developmental nature of human abilities. There is a gap in research that examines the development of factors of intelligence over age (Carroll, 1993). The Gf-Gc theory maintains that three abilities (Gf, Gsm, Gs) will decline with age and three others (Gc, Glr, Gq) will either increase or at least be maintained throughout most of the life span (Horn, 1970; Horn & Donaldson, 1980). Studies supporting this aspect of the theory appear piece-meal at best, with little support stemming from a model that encompasses the entire theory. The evidence is sparse and contradictory also when *g*, as a second order factor, is studied (Horn, 1991). The developmental nature of fluid intelligence (one of the vulnerable abilities according to the Gf-Gc theory) also needs further examination. If the contribution of Gf to overall intellectual functioning declines with age, so should the factor loading of Gf on *g*.

Carroll (1993) relied exclusively on exploratory factor analysis in his survey of hundreds of studies on cognitive ability. The three stratum structure of intelligence that he developed would be verified further by confirmatory factor analytic (CFA) techniques. This technique imposes the structure of the theory on

the data. Specific hypotheses can be tested with CFA, particularly hypotheses regarding the structure of factors.

The purpose of this research was to examine the three stratum model of cognitive abilities, including its hierarchical structure and developmental fluctuations, across several different age groups using confirmatory factor analysis. The five specific questions of interest were:

1. Does the structure of intelligence change with age?
2. Is the three stratum hierarchical theory, with g at the apex, several broad second stratum factors, and many specific abilities as first stratum variables, a viable explanation of cognitive abilities?
3. Is the broad factor of fluid intelligence (Gf) indistinguishable from the pervasive general factor of intelligence (g)?
4. Is the broad factor of quantitative ability (Gq) indistinguishable from g ?
5. Is the broad factor of crystallized intelligence (Gc) indistinguishable from g ?

Method

Subjects

The sample for this study consisted of the standardization sample for the Woodcock-Johnson Psychoeducational Battery-Revised for the age groups 6, 8, 10, 13, 16, 30-39, 50-59, 70-79. The entire normative sample included 6,359 subjects in over 100 diverse U.S. communities and ranged in age from 2 to 90 years. The

sampling procedure was a three stage stratified design. The three levels of sampling were community, schools (for school-age subjects), and subjects. (For a complete description of the sampling variables see the WJ-R Technical Manual.)

Sample sizes vary for each age group and, within groups, for each pair of variables that are correlated. Therefore, the average sample size for each group was used as input for the number of observations in each LISREL model. Those average sample sizes appear in Table 1.

The Model

The three-stratum model proposed in this study is shown in Figure 1. The first level of the model represents 16 primary abilities. These are indexed by 16 of the 39 subtests of the Woodcock-Johnson Psychoeducational Battery-Revised (1991), tests that were developed specifically to represent primary abilities described in the Gf and Gc theory of intelligence. The second stratum corresponds to the eight broad factors or intelligences described by Horn (1991) in the most current version of the Gf-Gc theory. The third stratum represents g, the pervasive, single factor of general intelligence defined by Spearman (1927).

Linear structural relations (LISREL) has been shown to be a method that is particularly useful for testing hierarchical models of intelligence (Gustafsson, 1984; Jöreskog & Sörbom, 1988). It is also well suited to analyze data from different samples simultaneously. Parameters may be constrained to be equal across different groups or free to vary across groups depending on the underlying theory of the model (Wolfle, 1985; Jöreskog & Sörbom, 1989, pp. 127-128).

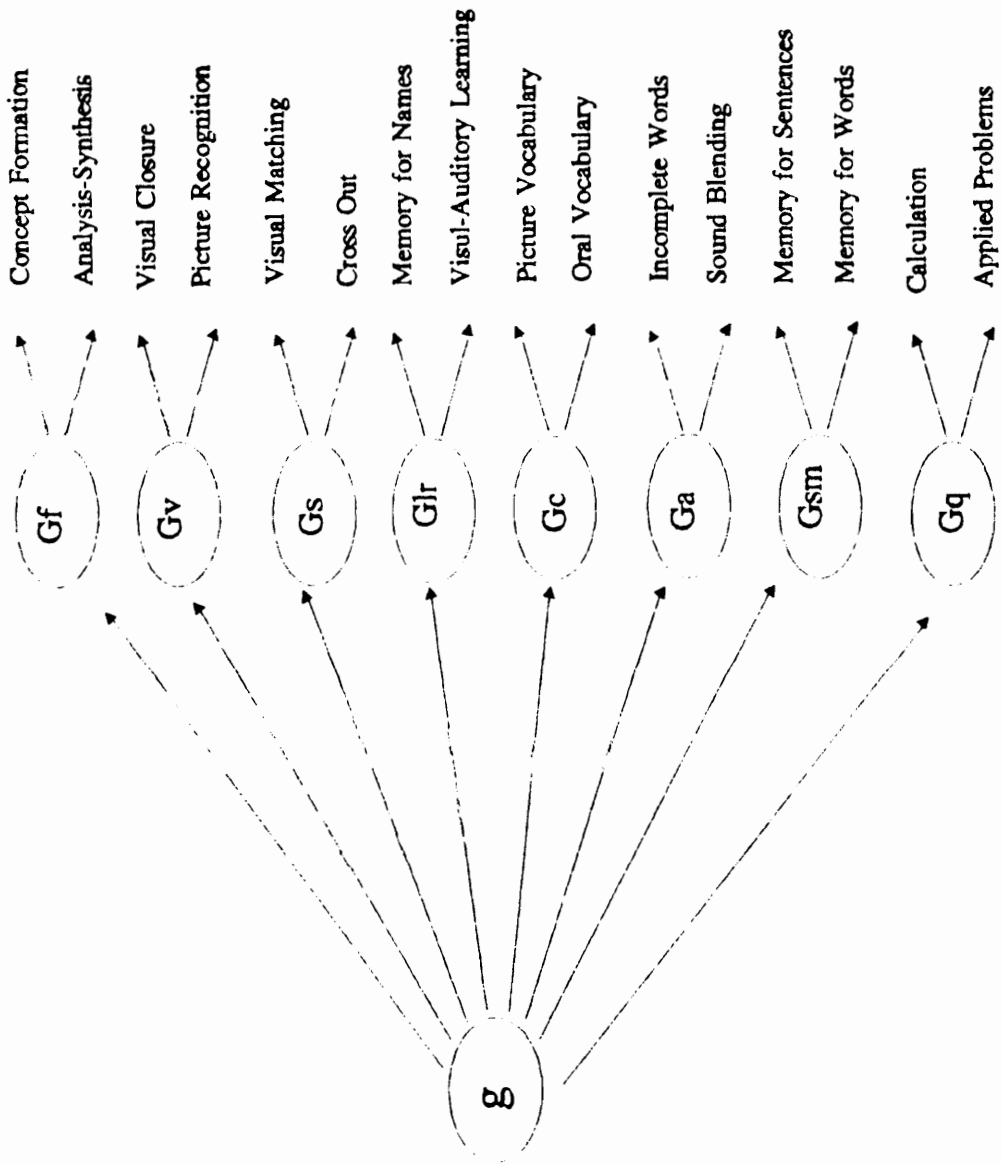


Figure 1
The Three Straum Theory

Table 1

Average Sample Sizes

Age Group	<u>n</u>
6	311
8	335
10	313
13	269
16	269
30-39	351
50-59	182
70-79	171
Total	2201

Figure 1

For this study LISREL was used to analyze the three stratum theory of cognitive abilities across ages 6, 8, 10, 13, 16, 30-39, 50-59, 70-79. A series of models was developed to investigate several hypotheses.

Hypothesis 1

The correlation matrices among subtests will not be significantly different among the 8 age groups. To examine the developmental nature of the vulnerable and maintained abilities across the six age groups simultaneously and to investigate whether the structure of abilities changes with age, the correlation matrices for the 16 subtests for each age group were compared. Equality constraints were imposed across groups such that the fit of the LISREL model indicated significant differences (or lack thereof) in the correlation matrices. In addition, the factor structure of the three stratum theory was tested across groups. Equality constraints across groups were imposed for the factor loadings of the 16 subtests on broad group abilities and for the second level ability variables on g (the LISREL matrix gamma).

Hypothesis 2

The three stratum theory is an adequate representation of the structure of cognitive abilities. The second model tested whether the three stratum theory, identified most recently by Carroll (1993), is a viable explanation of intelligence. The average correlation matrix produced by testing hypothesis 1 was used as the input matrix to test the three-stratum theory represented in Figure 1. In addition, an alternative model that allowed for the correlation of the disturbances between several

group abilities was compared to the strict three stratum theory. The overall average sample size was used ($n=276$) for both models.

Hypothesis 3

The second stratum factor, Gf, has a standardized factor loading of 1.00 on the higher order factor, g. Research has indicated that Gf and g are indistinguishable (Undheim & Gustafsson, 1987). To gain understanding of the nature of the relationship between Gf and g, the third model tested whether the factor loading of Gf is indistinguishable from g across all age groups. This was tested by two comparative models: one with the standardized factor loading of Gf to g set to 1.00 (using the LISREL gamma matrix) for all groups, the other with the path from Gf to g allowed to be free across groups. The change in chi-square for the two models was tested for a significant change in fit.

Hypothesis 4

The second stratum factor, Gq, has a standardized factor loading of 1.00 on the higher order factor, g. This hypothesis was tested in similar fashion to hypothesis 3. The factor loading from Gq to g was set to 1.00 across groups for the **first model**. A second model freed the path from Gq to g across age groups and the two models were compared for significant improvement in fit.

Hypothesis 5

The second stratum factor, Gc, has a standardized factor loading of 1.00 on the higher order factor, g. This hypothesis was tested because of the large degree of

overlap reported in the literature between Gf and Gc (Horn, 1991). It was tested in the same manner as Gf and Gq were tested previously.

It should be noted that whenever a tightly constrained model is relaxed, an improvement in fit always occurs. It was statistically significant change in chi-square that was of interest in this research.

Results

A series of models was developed to test the five hypotheses. All analyses were conducted using the LISREL 7.20 and LISREL 8 computer programs (Jöreskog & Sörbom, 1989, 1993). The emphasis was on comparing these models in order to identify those that appeared most plausible on the basis of fit statistics.

In all, seven models were analyzed. The first two models, the correlation invariant model and the factor invariant model, tested for developmental changes in the structure of intelligence. The second group of models, the three stratum model and the relaxed three stratum model, compared two models which examined the three-stratum theory. Models Gf, Gq and Gc, analyzed whether three different broad abilities (Gf, Gq, Gc) were indistinguishable from g.

Determining an adequate fit of the model to the data requires the assessment of several different fit statistics and is dependent on the purpose of the study (Jöreskog & Sörbom, 1993). Sample size is a critical factor. The total sample size in the present study (the average sample size for each group, summed over the eight groups) was 2201 (see Table 1). Because most fit statistics are affected to some

degree by sample size, the results for some models are reported two ways; using a sample size of 1000 producing a Differential Fit Value (DFV) (Muthen, 1989) and using the actual sample size. Additional fit statistics reported are the Non-Normed Fit Index (NNFI) (Tucker & Lewis, 1973), which is derived from comparing the hypothesized model to an independence model (one which assumes no covariance structure among variables), the Adjusted Goodness of Fit Index (AGFI) (Jöreskog & Sörbom, 1989), the Comparative Fit Index (CFI) (Bentler, 1990), and the standardized root mean square residual (SRMSR) (Jöreskog & Sörbom, 1993). For those analyses comparing alternative models, the change in chi-square value, itself distributed as a chi-square, was assessed.

Developmental Changes

Correlation Invariant Model

In order to determine whether the correlations among the sixteen subtests differed across age groups, the equality of the correlation matrices for ages 6, 8, 10, 13, 16, 30-39, 50-59, 70-79 was analyzed. The eight groups were analyzed simultaneously using a multi-group method in LISREL. The correlations among the 16 subtests calculated in the LISREL solution were constrained to be equal across groups (Jöreskog & Sörbom, 1989, p. 227). Group average sample sizes (Table 1) were used to calculate the LISREL solution. The fit statistics for this model (correlation invariant) are in Table 2. Results indicate a good fit to the data (DFV=671.03, df=840, p=1.00, NNFI=.96).

Table 2

Fit Statistics for the Correlation Invariant and the Factor Invariant Models ($n=2201$)

Model	Chi-Square	df	NNFI	DFV
Correlation Invariant	1461.26 ($p=.000$)	840	.96	671.03 ($p=1.00$)
Factor Invariant	1941.52 ($p=.000$)	880	.93	884.33 ($p=.453$)

NNFI = Non-Normed Fit Index (Tucker & Lewis, 1973)

DFV = Differential Fit Value (Muthen, 1989)

Factor Invariant Model

A second analysis was done to further assess differences in the factor structure across groups. This model imposed the structure of the three-stratum theory appearing in Figure 1 on the data for each group. The eight groups were then analyzed simultaneously. In this model the loadings of individual subtests on broad ability factors were set to be equal across groups and the loadings of first order factors (Gf, Gv, Gs, Glr, Gc, Ga, Gsm, Gq) on the second order factor (g) were considered equal across ages. The fit statistics for this model (factor invariant model) are in Table 2. These results also suggest a acceptably fitting model (DFV=884.33, df=880 p=.453, NNFI=.93).

Based on the fit statistics presented in Table 2, both the correlation invariant model and factor invariant model fit the data satisfactorily. Neither the correlation matrices among subtests nor the factor structure of the three stratum theory differed significantly across age groups.

Three-Stratum Theory

Both of the preceding models indicated no significant developmental differences in the factor structure of the three-stratum theory, but further analysis was needed to determine the viability of the theory itself. Because no significant differences were found across age groups, the common matrix produced from the LISREL correlation invariant model was used as the input matrix to test the three-stratum theory. Using this common matrix to analyze the factor structure of the

theory was comparable to testing an average correlation matrix representing ages 6 through 79. The matrix appears in Appendix B. The overall average sample size was used ($n=276$).

Three Stratum Model

The three-stratum theory tested here is a second-order factor model. At the first stratum are 16 subtests of the Woodcock Johnson Psychoeducational Battery (McGrew, Werder, & Woodcock, 1991). At the second level are the 8 broad abilities identified in the Gf-Gc theory (Horn, 1991). At the third stratum (or second order) is the general factor of intelligence, g. The three stratum model is graphically represented in Figure 1.

The fit statistics for this model are shown in Table 3 ($\chi^2=98.86$, $df=96$, $p=.40$, $NNFI=1.00$, $SRMSR=.036$). The evidence provided indicates an excellent fit for the three-stratum theory. The first and second order factor loadings are presented in Figure 2.

Relaxed Three Stratum Model

As an alternative model, a model was fitted to the data that allowed several of the disturbances among the eight broad factors to be correlated in the LISREL psi matrix. In its strictest interpretation, the three-stratum theory tested above accounts for the correlations among factors only through the g factor. Based on theoretical considerations, the relaxed three stratum model allows for some first order factors to be correlated with the assumption that other factors, as well as g, account for the covariance among them. Carroll (1993) and others (Vernon, 1950; Gustafsson,

Table 3

Fit Statistics and Chi-Square Change for the Three Stratum and the Relaxed Three Stratum Models ($n=276$)

Model	Chi-Square	df	NNFI	AGFI	DFV	CFI	SRMSR
three-stratum	98.86 ($p=.40$)	96	1.00	.94	359.12 ($p=.000$)	.96	.036
relaxed	88.53 ($p=.575$)	92	1.00	.94	321.61 ($p=.000$)	1.00	.036
change	10.33 ($p=.000$)	4					

NNFI = Non-Normed Fit Index (Tucker & Lewis, 1973)

AGFI = Adjusted Goodness of Fit Index (Jöreskog & Sörbom, 1989)

DFV = Differential Fit Value (Muthen, 1989)

CFI = Comparative Fit Index (Bentler, 1990)

SRMSR = Standardized Root Mean Square Residual (Jöreskog & Sörbom, 1993)

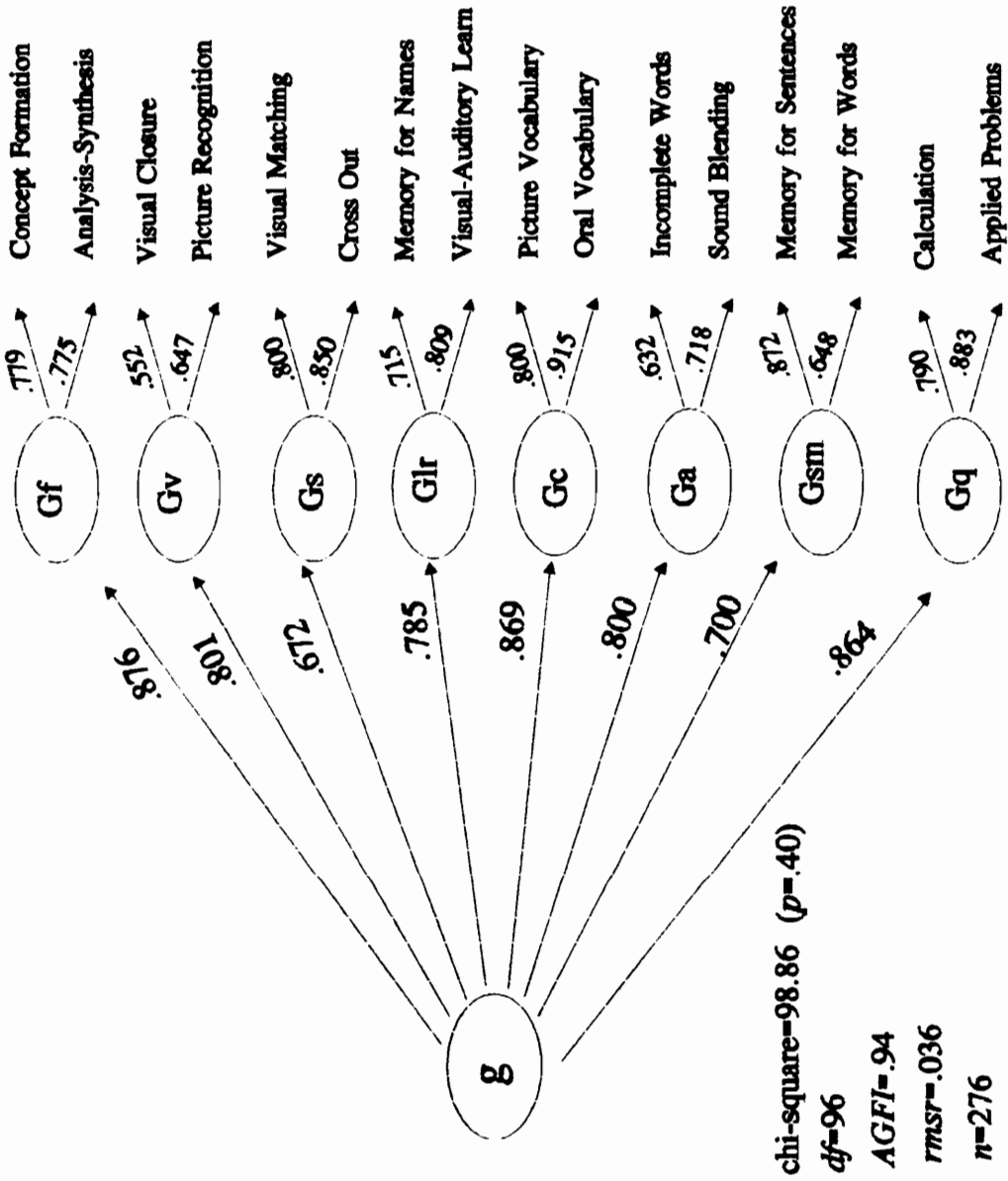


Figure 2
Standardized Factor Loadings for the Three Stratum Theory

1984; Horn, 1991) have suggested that there may be intermediate factors between the second and third strata. This model is an initial attempt to account for some of the variation due to intermediate factors.

The Gf-Gc theory suggests a rather large degree of overlap of the two factors, Gf and Gc, therefore the disturbances among those two factors were allowed to covary. The disturbances among the three perceptual factors (Gv, Ga, and Gs) were also allowed to be correlated.

This model was compared to the strict three stratum model above using the chi-square change as an indication of an improved fit. Table 3 contains the fit statistics and the chi-square change from the three stratum model (chi-square change=10.33, df=4, p=0.00). The fit was significantly improved over the strict three stratum model.

Based on the fit of the three-stratum theory, the hierarchal g model presented in Figure 2 appears to be a sound representation of the structure of cognitive abilities. As further evidence of g, the correlations among first order factors are presented in Table 4. Correlations range from .47 to .76.

The comparison of the three-stratum theory to a relaxed model indicated a significantly improved fit when some first order factors were allowed to be correlated. This relaxed model allowed for other sources of variation, besides g, to account for the correlations among Gf and Gc, and Ga, Gv, and Gs. Although these are preliminary results and further investigation is required, the fit of this model suggests the possibility of intermediate factors between the second and third strata.

Table 4

Correlation Matrix of Broad Factors & G

	GF	GV	GS	GLR	GC	GA	GSM	GQ	G
GF	1.000								
GV	0.702	1.000							
GS	0.589	0.538	1.000						
GLR	0.688	0.628	0.528	1.000					
GC	0.762	0.696	0.584	0.682	1.000				
GA	0.701	0.640	0.538	0.628	0.695	1.000			
GSM	0.614	0.561	0.471	0.550	0.609	0.560	1.000		
GQ	0.757	0.691	0.581	0.678	0.751	0.691	0.605	1.000	
G	0.876	0.801	0.672	0.785	0.869	0.800	0.700	0.864	1.000

Gf, Gq, & Gc Indistinguishable from g

Models Gf, Gq, & Gc

An examination of the factor loadings of the eight broad abilities (Figure 2) revealed very high loadings for Gf (.876), Gq (.864), and Gc (.869) on g. It has been previously reported that Gf and Gq may be indistinguishable from g. (Gustafsson, 1984; Gustafsson & Undheim, 1987; Keith & Bickley, in progress). From these results it appeared that Gc may have an equally high loading on g. To test the hypothesis that Gf, Gq, and Gc are identical to g (standardized factor loadings of 1.00), three separate models were analyzed. Each model had the factor loading in the LISREL gamma matrix set to 1.00 for the particular broad ability in question. For Model Gf, the factor loading of Gf to g was set to 1.00; for Model Gq, Gq to g was set to 1.00; for Model Gc, Gc to g was set to 1.00. All three models were compared to the original three-stratum theory for a significant change in chi-square. The results are shown in Table 5.

Although the factor loadings are very high, for all three models the resulting fit with the factor loadings set to 1.00 was significantly worse. The three broad abilities, Gf, Gq, and Gc, are not identical to g.

Discussion

Previous research has raised questions concerning the structure of cognitive abilities and the nature of developmental changes in the organization of intelligence. The purpose of this research was to assess the three-stratum theory of intelligence

Table 5

Fit Statistics for Models Gf, Gq, and Gc (n=276) and Comparisons with the Three Stratum Model

Model	Chi-Square	<u>df</u>	Chi-Square change	<u>dfchange</u>
<u>Gf</u>	124.672 (p=.031)	97	25.75 (p=.000)	1
<u>Gq</u>	124.58 (p=.031)	97	25.72 (p=.000)	1
<u>Gc</u>	122.96 (p=.039)	97	24.10 (p=.000)	1

recently reiterated by Carroll (1993) and to examine developmental changes across the life span within that theoretical framework.

Developmental Changes

These results fail to indicate any significant changes in the structure of intelligence with age. Neither the correlation matrices, nor the factor structure of the sixteen subtests differed significantly for ages 6, 8, 10, 13, 16, 30-39, 50-59, 70-79. These results are contrary to some previous research that has shown developmental changes, such as a decline in several broad abilities (Gf in particular) with age (Horn, 1970; Horn & Donaldson, 1980; Horn, Donaldson, & Engstrom, 1981; Wang & Kaufman, 1993). These contradictory results may be a result of differences in methodology. Developmental differences in group factors of intelligence have frequently examined mean differences in intelligence using cross sectional data. While the present analysis also employed cross sectional data, the research question was more focused on differences in the structure of the specific and broad factors of intelligence rather than on mean differences. In other words, does the organization of intelligence change with age? The results of this study suggest it does not.

Three Stratum Theory

The three stratum theory appears to be an acceptable model for the structure of intelligence. Two models were fitted to the data. One reflected a strict theoretical interpretation of the theory. The second model allowed for some modifications based on theoretical and empirical evidence.

A close examination of the broad ability factor loadings on g (Figure 2) reveals several important aspects of the three stratum model. First, as has been shown in numerous other factor analyses of models of intelligence (Spearman, 1927; Vernon, 1950; Gustafsson, 1984), the existence of g is difficult to dispute. The standardized factor loadings on g of all eight broad factors are highly significant. G_s (processing speed) has the lowest factor loading of .672, which is not surprising as it requires a psycho-motor component as well as perceptual speed. Further evidence of g can be found in the correlation matrix of the broad abilities. The evidence in these models directly supports an underlying factor of general intelligence.

Second, G_q does appear to constitute a higher order broad ability factor with a factor loading of .864. Whether it represents quantitative ability or some other broad ability is open to question, however. Carroll (1993) has argued that quantitative ability is comprised of other general and specific abilities and should not be considered a broad ability.

Finally, two factors have exceedingly high loadings on g . These are G_f (.876), and G_c (.869). It seems likely that both of these factors represent some higher order cognitive processes with a high concentration of g (Vernon, 1950; Jensen, 1973; Horn & Donaldson, 1980). Similarly, two factors representing perceptual abilities have highly comparable and strong factor loadings. These are G_v (.801), and G_a (.800). Although G_s does not have a comparably high factor loading (possibly because it is affected by the influence of psycho-motor ability and

may not be a pure measure of perceptual speed) it too is considered a perceptual ability.

Combining both theoretical and empirical considerations, the relaxed three stratum model allowed for other sources of variation, besides g , to account for the correlations among G_f , and G_c , and G_v , G_a , and G_s . This modification significantly improved the fit of the model lending preliminary support to the existence of two intermediate factors. Carroll (1993) argued that the three stratum theory should not be rigidly defined, and this finding is not inconsistent with the theory.

There is also the distinct possibility that secondary loadings on other factors exist at both the first and second strata. It should be noted that the structure of abilities shown in Figure 2 allowed for no secondary loadings of narrow or broad abilities on higher order factors. Even so, the fit of the three stratum theory, in its strictest representation, provides a sound explanation of the structure of abilities.

Of course many alternative models are possible within the boundaries of this three stratum theory (Gustafsson, 1984; Gustafsson & Undheim, 1987; Carroll, 1993). In fact, one of the reasons it is such a useful and appealing model is its flexibility. As a point of reference, however, this study provides compelling evidence that the three stratum theory may form a parsimonious model of intelligence. The fact that it is grounded in a strong foundation of vast, previous research also lends strong support for the acceptance of the model.

Implications for Future Research

An earlier theoretical model (Horn & Donaldson, 1981) may provide a framework from which to further expand the three stratum theory. In this model, the second strata of the three stratum theory is actually divided into three levels. The first level contains retrieval factors, the second level is composed of perceptual factors (visual, auditory, and speed) and the third is fluid and crystallized intelligence. The last level is *g*. Evidence from the present study would suggest quantitative ability (*Gq*) at the third level (that which contains *Gf* and *Gc*). This model would be more similar to a causal path model than a strict confirmatory factor analysis. It also has similarities to other hierarchical models proposed (Vernon, 1950; Jensen, 1973; Gustafsson & Undheim, 1987).

Several methodological issues would have to be resolved to test such a model, however. For example, it may require the use of more subtest indicators than has been used in this study. It might be useful to test the theory in a more piecemeal fashion, rather than as an entire model. Regardless, there is both theoretical and empirical evidence (albeit limited) to support this expanded model and further examination is warranted.

It is quite possible that other broad and specific abilities not accounted for in these model exist. Gardner (1983) has proposed a theory of multiple intelligences that has much in common with the *Gf-Gc* theory but does not recognize *g*. In addition, the theory adds factors that are not normally considered in most factor analytic studies and therefore lack empirical support. These include personal

intelligences and bodily-kinesthetic intelligences. With appropriate measures, these could be examined within the framework of the three stratum theory (Carroll, 1993).

Limitations

Despite a lack of evidence indicating any significant developmental changes in the structure of cognitive abilities, these results should be considered preliminary and interpreted with caution. Although mean differences were not analyzed, the use of cross sectional data has its problems, not the least of which is the confounding effects of extraneous variables. Unfortunately, the sample sizes precluded any cross validation analyses in this study. Therefore further analysis is needed to support these results. Of particular interest would be the use of longitudinal data in analyzing changes in broad factors of intelligence. The use of other data sets, samples, and alternative models would also add to the research in developmental changes of intelligence.

In its strictest interpretation, the three stratum theory appears to be a viable explanation of the structure of intellectual abilities. Further analysis is needed with alternative data sets and subtest indicators, however. Of greatest interest is the expansion of the theory to include intermediate factors and perhaps an approach that is more similar to a causal path model than a rigid confirmatory factor model. This study may be considered a precursor to more detailed research within the framework of g and the three stratum theory.

Strong support for the three stratum theory was provided in this study. There is additional evidence that quantitative ability should be included in the theory as a

higher order factor. There is also evidence that the mediating broad abilities, higher order reasoning and perception, may exist. The structure of abilities may prove to be more complex than the strict three levels proposed by Carroll (1993), however this model of intelligence provides a sound theoretical and empirical base to continue research in the field of intelligence.

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Appendix A

Review of the Literature

Modern intelligence theory is built upon abundant and diverse research that has its methodological base primarily in factor analysis. Most models have associated with them a particular researcher, Spearman with g theory (1927), Guilford with the structure of intellect (1956), Thurstone with a theory of primary mental abilities (1938), Vernon with hierarchical abilities (1950), and Horn and Cattell and the theory of Fluid and Crystallized Intelligence (1966). This review will focus on the development of a modern theory of intelligence, labeled the three stratum theory (Carroll, 1993). Rather than being characterized as an entirely new model of cognitive abilities, the theory is quite similar to a number of studies grounded in factor analytic work over the past 90 years.

Although the development of the three stratum model is based on the survey of 461 factor analyses, it draws heavily from two well established theories, the g model and the Gf-Gc model. Additionally, the model has roots in a more recent unified model defined as the Hierarchical LISREL model (HILI) (Gustafsson, 1984).

Hierarchical Models of Intelligence

The g Theory

Attributed to Charles Spearman (1927) the general factor of abilities, g , was one of the first formal theories of intelligence strongly supported by empirical

analysis. In fact, beginning with Spearman's development of tetrad equations, the advancement of intelligence theory and factor analytic techniques were closely intertwined (Carroll, 1993).

In its first real description, "g as the amount of general mental energy, and the g 's as the efficiency of specific mental engines" (Spearman, 1927, p. 37), the theory not only details the general factor, but specific or group factors as well. G was hypothesized to be a universal factor of intelligence that underlies all cognitive abilities. Group factors were viewed as problematic in terms of measurement but of "immense importance, not only theoretically, but also practically" (Spearman, 1927, p. 223). Four group factors or faculties were identified using tetrad equations: logical, mechanical, psychological, and arithmetical. Two other factors were suggested theoretically but had little correlational evidence. Those were musical ability and ability gained through experience (Spearman, 1927).

Spearman's work was expanded to include a number of variations of the g model. Some were more complex and detailed models with g as the most general factor, broad factors dominating several domains (educational, psychological, sensory) which in turn dominated minor group factors (Vernon, 1950). Others have appeared less complex. The Level I, Level II theory represents two broad classes of abilities, one involving sensory/memory information, the other representing higher order thinking similar to g (Jensen, 1973). Most differences in the g type models can be found in the way abilities are classified and how they are related. A close

examination reveals many similarities between most models (Burt, 1949; Harman, 1967; Thurstone, 1949; Vernon, 1950; Jensen, 1973).

The g theory was strongly challenged by competing theories of intelligence that recognized group factors of cognitive ability by found no evidence of g (Thurstone, 1938; Guilford, 1956). With the development of higher order factor analysis and other measurement techniques (Schmid-Leiman orthogonalization most notably), a general factor did emerge with data previously shown to have only group factors (Thurstone, 1949). Much of the evidence of this period was repeatedly disputed with differing factor analytic techniques, as that discipline was evolving as well (Carroll, 1993).

The Gf-Gc Theory of Intelligence

The theory of fluid and crystallized intelligence was developed by Raymond B. Cattell and John L. Horn (1966). The theory quickly gained wide recognition and has had a significant influence on the field of modern psychometrics.

The theory is composed of the nine broad abilities of fluid intelligence (Gf), crystallized intelligence (Gc), visual processing (Gv), processing speed (Gs), long-term retrieval (Glr), auditory processing (Ga), short term memory (Gsm), and quantitative ability (Gq). Correct decision speed (Gds) is also a component of the theory but is not included as a higher level broad ability (Horn, 1991). Although eight primary broad abilities comprise the theory, the two abilities fluid and crystallized intelligence have received the most attention.

Fluid intelligence is that which is gained primarily through genetics. It is best ". . . measured by tests that require inductive, deductive, conjunctive, and disjunctive reasoning to understand relations among stimuli, comprehend implications, and draw inferences" (Horn, 1991, p. 214). Fluid intelligence is considered culture free.

Crystallized intelligence, in contrast, is ability gained through cultural experience or often referred to as aculturated knowledge. ". . . it is measured by tests that indicate the breadth and depth of the knowledge of the dominant culture" (p. 214, Horn, 1991). It is often considered a product of Gf and experience.

The nature and relationship of these two broad abilities is yet unclear. There is evidence that fluid intelligence is indistinguishable from g (Gustafsson, 1984; Gustafsson & Undheim, 1987), that fluid intelligence declines with age (Horn & Donaldson, 1980; Horn, 1991), and that fluid intelligence and crystallized intelligence overlap (Horn, 1991; Carroll, 1993). In some studies and representations, fluid and crystallized intelligence appear as second order factors, rather than first order factors, implying a larger degree of generality than other broad abilities (Horn & Donaldson, 1980; Gustafsson, 1984).

The developmental changes in the Gf-Gc theory vary according to broad abilities. The abilities of Gf, Gs, Gsm are shown to decline with age and the abilities Gc, Glr, Gq are shown to either remain stable or increase with age (Horn & Donaldson, 1980; Horn, Donaldson & Engstrom, 1981; Horn, 1991; Wang & Kaufman, 1993). Rather dramatic changes have been indicated. In one study the decline in Gf is estimated to be on the average 4.9 IQ points per decade (Horn,

1980). The evidence, however, is largely based on mean differences or correlational comparisons using cross sectional data of limited generalizability sample (e.g., prison populations). Clearly the issue of structural changes in intelligence requires further study.

What is apparent in its current version is the theory of fluid and crystallized intelligence does not formally recognize **g**, although the authors of the Woodcock-Johnson Educational Battery-Revised have compared the Gf-Gc model to a hierarchical **g** model and found both to be plausible (Werder, McGrew, & Woodcock, 1991). The debate over **g** may be more of a practical one than a theoretical one. In practice, the use of a single IQ measure (ostensively measuring **g**) is of little practical significance in designing educational interventions in classrooms (Woodcock, 1990). Consequently, the use of the IQ score, and with it the concept of **g**, has fallen out of favor with many contemporary psychometricians (Keith, in press).

Vernon's Hierarchical Model

A theory or model of cognitive abilities that is hierarchical in nature and also recognizes **g** was proposed by Philip E. Vernon in 1950. Although not as well recognized as the Gf-Gc or **g** theories, this model has none the less had a sustaining impact on research in the field of psychometrics. The theory has at least four levels; specific factors, minor group factors, major group factors and **g**. In its complete representation it resembles a tree diagram (Vernon, 1950).

The two major group factors are verbal-numerical-educational (v:ed) and practical-mechanical-spatial-physical (k:m). Those two factors are then subdivided into minor verbal and number group factors (from v:ed) and mechanical information, spatial, and manual subfactors (from k:m). These in turn subdivide into even more specific or narrow ability factors.

This model was considered a hypothetical model based on the integration of a number of factor analytic studies. Vernon (1950) recognized that the strict hierarchical organization of the model may be oversimplified and was largely contingent on the population sampled and number of tests administered. According to Vernon, only those group factors that had practical merit, either in education or vocational areas should be incorporated into the model.

What remains striking about this hierarchical theory is its emphasis on *g* (Anastasi, 1965). Even more than Spearman, Vernon's model characterized the role of major group factors to be minimized in comparison to *g*. Interestingly, and in contrast to current practice in psychometrics, Vernon strongly believed the single IQ score, as a measure of *g*, had substantial merit. ". . . Stanford-Binet or Terman-Merrill IQ, or all-round intelligence as measured by reliable groups tests, have considerable practical value both among children and adults, whereas more specialized tests add something, but not very much in educational and vocational guidance" (p. 28, Vernon, 1950).

The HILI Theory

The HILI (Hierarchical LISREL) model highlights the use of LISREL and confirmatory factor analysis as a ". . . sharper factor analytic tool . . . for investigating models of the structure of ability" (p. 180, Gustafsson, 1984). The advantage of LISREL over exploratory factor analysis lies in its ability to compare the fit of different plausible models and to test hypotheses.

The HILI model is a hierarchical model that assumes Gf is identical to g. Support for this hypothesis is taken from the tests used by the Vernon model to identify g and tests use by the Gf-Gc to identify Gf. They appear highly similar, and Gustafsson (1984) concluded they are the same factor. Similarly, Gv is equated with k:m and Gc with v:ed. The resulting model has these three broad abilities as second order factors and g as the third order factor. Subsumed under the second order as first order factors are visualization (Vz), spatial orientation (S), flexibility of closure (Cf), speed of closure (Cs), cognition of figural relations (CFR), induction (I), memory span (Ms), vocabulary (V), verbal achievement (Ve Ach), and mathematics achievement (Ma Ach).

Strong evidence is provided that Gf is identical to g in four different samples using confirmatory factor analysis. The resulting HILI model is viewed as superseding the Spearman, Thurstone, and Cattell-Horn models. That is, those models are subsets of the HILI model with Thurstone's model accounting for first order variance in the HILI model, Horn & Cattell 's Gf-GC accounting for second order variance and Spearman' g accounting for third order variance. As is often the

case, the authors prefer to consider a class of HILI models rather than one definitive model. Models that belong to this class of models would be hierarchical and include the basic set of higher order factors already identified (Gustafsson, 1984, Undheim & Gustafsson, 1987).

This model has been elaborated and tested across ages 11, 13, and 15 with essentially the same results. At the second order factor level a fourth and fifth factor (reasoning-fluency, Gr, and speed, Gs) were added to the model. At all age levels Gf was found to be identical to g (Gustafsson & Undheim, 1987).

The Three Stratum Theory of Intelligence

The three stratum theory of intelligence is also a hierarchical model of the construct of intelligence in the tradition of the previously mentioned models. At the first level of the model are a number of specific or narrow abilities, at the second level (or first order factor level) are broad, more general, abilities, and at the third level (the second order factor level) is g, the pervasive general factor of intelligence (Carroll, 1993).

This three stratum theory is the most recent version of a hierarchical g model and to a large degree combines two widely accepted theories into one model. It is a consolidation of many of the major traits of the theory of fluid and crystallized intelligences (Gf-Gc) (Horn & Cattell, 1966) and Spearman's (1927) theory of general intelligence (g). After reanalyzing the data sets of over 450 factor analytic studies dealing with intelligence (as measured by a variety of mental tests) this

model has been proposed by Carroll (1993). It has eight broad abilities at the second stratum that closely resemble the Gf-Gc theory. They are fluid intelligence, crystallized intelligence, general memory and learning, broad visual perception, broad auditory perception, broad retrieval, broad cognitive speediness, and processing speed.

Several differences exist between the Gf-Gc theory and the second level of the three stratum theory. The most conspicuous difference is the omission of a quantitative factor. It is described as being a concept comprised only of other more generalized broad abilities such as g, Gf, and Gc, as well as lower order abilities including induction, sequential reasoning, quantitative reasoning and visualization. Another difference is the existence of two speed factors, broad cognitive speediness and processing speed, where within the Gf-Gc framework there is only processing speed (correct decision speed is identified as a factor but it is unclear how much importance is placed on it). Finally, a ninth factor, labeled 2H, has been identified as a factor that combines fluid and crystallized intelligence. Where this factor fits in the hierarchy or if it deserves special status at all is unclear (Carroll, 1993).

The specification of this particular model is the product of many different data sets and analyses, with the HILI model, (itself an outgrowth of GF-Gc, g and Vernon's model), lending contemporary evidence to the theory. Like the theories of cognitive abilities that preceded it, this model is not defined to be a rigid representation of intelligence. Instead, it is a set of abilities that have been

consistently identified by previous studies. The possibility of other factors remains open.

Of particular interest is the possibility of intermediate factors, that is, factors existing between the second and third stratum. This conceptualization is congruent with the HILI model (Gustafsson, 1984) Vernon's model (1950), and even earlier versions of the Gf-Gc model (Horn & Donaldson, 1980).

In summary, hierarchical models of intelligence have been proposed since Spearman (1927) first put forth *g* theory. The three stratum theory is built on numerous factor analytic studies that support theories of *g*, as well as the theory of crystallized and fluid intelligence (Burt, 1949; Vernon, 1950; Jensen, 1973; Gustafsson, 1984; Horn, 1991). Although the concept of *g* has fallen out of favor with many practitioners, it continues to be a valuable theoretical concept in the study of cognitive abilities.

Appendix B

Common Metric Phi Matrix (standardized) for 16 subtests of the WJ-R

	CON FRM	ANLS YN	VISC LOW	PICR EC	VISM AT	CRSO UT	MEM NAM	VAL RNG	PICV OC	OLR VOC	INC WRD	SND BLN	MEM SEN	MEM WRD	CALC	APPR OB	
CONFRM	1.000																
ANLSYN	0.588	1.000															
VISLOW	0.304	0.286	1.000														
PICREC	0.351	0.353	0.357	1.000													
VISMAT	0.335	0.355	0.289	0.303	1.000												
CRSOUT	0.380	0.370	0.350	0.364	0.680	1.000											
MEMNAM	0.408	0.383	0.289	0.388	0.294	0.298	1.000										
VALRNG	0.472	0.498	0.330	0.403	0.317	0.370	0.578	1.000									
PICVOC	0.435	0.420	0.359	0.347	0.325	0.372	0.425	0.421	1.000								
OLRVOC	0.536	0.500	0.330	0.379	0.380	0.413	0.433	0.461	0.732	1.000							
INCWRD	0.340	0.326	0.256	0.242	0.293	0.306	0.295	0.315	0.399	0.408	1.000						
SNDBLN	0.364	0.353	0.246	0.288	0.303	0.354	0.316	0.390	0.418	0.474	0.454	1.000					
MEMSEN	0.425	0.379	0.205	0.293	0.264	0.294	0.346	0.368	0.466	0.545	0.352	0.390	1.000				
MEMWRD	0.281	0.278	0.150	0.230	0.241	0.240	0.288	0.288	0.293	0.387	0.312	0.338	0.565	1.000			
CALC	0.484	0.489	0.264	0.310	0.519	0.460	0.314	0.408	0.460	0.564	0.291	0.362	0.380	0.278	1.000		
APPROB	0.537	0.522	0.299	0.373	0.458	0.437	0.388	0.443	0.557	0.649	0.339	0.409	0.450	0.323	0.697	1.000	

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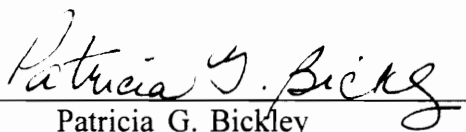
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