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# Age-related differentiation of cognitive abilities in ages 3–7

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**Abstract**

One important issue in the study of individual differences in cognitive abilities has been the question whether abilities tend to become more differentiated with increasing age. The present study examines age-related differentiation in the structure of cognitive abilities among children 3–7 years of age, using data from the recently undertaken Swedish standardisation of the Wechsler Preschool and Primary Scale of Intelligence-Revised. A confirmatory factor analytic modelling approach is applied. Models of different factor structure are built, evaluated and tested against empirical data using the LISREL 8 and the Mplus2 programs run under the STREAMS modelling environment. The results provide support for the notion that cognitive abilities show increasing differentiation with increasing age.


*Keywords:* Cognitive abilities; Age-related differentiation; WPPSI-R; Confirmatory factor analysis

## 1. Introduction

Throughout the history of studies of individual differences in cognitive abilities, there has been an interest in whether abilities tend to become more differentiated with increasing age (Carroll, 1993). A differentiation hypothesis was proposed as early as 1919 by Cyril Burt (Anastasi, 1970). Although several early studies have supported the hypothesis (Bayley, 1955; Burt, 1954; Garrett, 1946), more recent research has not found evidence for the differentiation of cognitive abilities. Bickley, Keith, and Wolfe (1995), using confirmatory factor analysis, found no changes in the number of factors or the variance accounted for by a general cognitive factor among age-groups ranging from 6 to 79 years. Another study using data from the American, Italian and Spanish standardisation samples of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI)

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and the Wechsler Intelligence Scale for Children-Revised (WISC-R), with ages ranging from 4 to 16 years, found no support for the age differentiation hypothesis (Juan-Espinosa, Garcia, Colom, & Abad, 2000). The contradictory findings on this important topic call for further research, particularly because current neuropsychological knowledge about cognitive development supports the view that, with increasing age, the structure of intellectual abilities tends to become more complex as well as more specialised (Kolb & Fantie, 1997; Kolb & Whishaw, 1996). Although the understanding of how a child's brain develops is far from complete, there is a growing body of knowledge regarding both cognitive and neurological development. Attention has been paid to parallels between models of cognitive development and neurological correlates, as exemplified by the fact that the timing of the transitions between the main Piagetian stages of cognition coincide with stages of brain maturation (Epstein, 1979; Hudspeth & Pribram, 1990; Thatcher, 1991, 1997). However, contemporary models argue for a less global process of development. Although neural maturation does appear to be continuous, phase-like developments are observed to occur in different cerebral systems at different times (Anderson, Northam, Hendy, & Wrennall, 2001). At some developmental stages, labelled critical or sensitive periods, the organism is more receptive or vulnerable to environmental influences. Most critical periods are paralleled by rapid neurological development. The notion of critical or sensitive periods attached to specific domains e.g., language and visual processing, provides support for the contemporary perspective indicating that there may be an interplay between various functional systems which mature separately and at different times, presumably due to underlying processes, such as myelination and synaptogenesis (Anderson et al., 2001).

During the preschool period children undergo some of the most profound changes in cognitive abilities. The period from 3 to 7 years of age is regarded as an especially important phase of brain development, during which neurons and synapses necessary for the rest of the lifetime are selected and organised (Sanes & Jessel, 2000). In the growing child, changes in psychological test performance is a reflection of brain development.

The purpose of the present study is to investigate age-related differentiation of cognitive abilities during the ages 3–7 years, using raw data from the recently undertaken Swedish standardisation of the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R). A multi-group confirmatory modelling approach is applied in which models with different factor structures are tested against empirical data.

## 2. Method

### 2.1. Subjects

The raw data from the Swedish standardisation sample of the WPPSI-R was used for the analyses in the present study. There were 1047 children in the sample, with at least 50 subjects (with equal numbers of girls and boys) representing each 3-month level between 2 years, 11 months, 15 days and 7 years, 3 months, 15 days of age. The Swedish standardisation procedure was undertaken in the late 90s. The sample is regarded as representative of the population at large (WPPSI-R manual, 1999). For the purpose of this study the subjects were divided into four age-groups (Table 1).

Table 1
Age-groups and numbers of children included in each group in the Swedish standardisation population

| Age-group | Age expressed in years:months:days | Number |
|---|---|---|
| 3 | 2:11:16–3:11:30 | 227 |
| 4 | 4:0:0–4:11:30 | 221 |
| 5 | 5:0:0–5:11:30 | 250 |
| 6 | 6:0:0–7:3:15 | 280 |

### 2.2. Measures

The WPPSI-R is an individually administered clinical instrument for assessing the intelligence of children from 3 to 7 years of age. It provides standardized measures of a variety of abilities thought to reflect different aspects of intelligence. WPPSI-R consists of one verbal and one performance scale, in which each includes five subtests and one optional subtest. The verbal scale includes the subtests information, comprehension, arithmetic, vocabulary, and similarities, with sentences as optional. The performance scale includes the primarily perceptual-motor subtests object assembly, geometric design, block design, mazes, and picture completion, with animal pegs as optional. As children's abilities develop rapidly along many dimensions between ages 3 and 7, the age norms are divided into 3-months intervals (Wechsler, 1990, 1999).

Wechsler viewed intelligence as global rather than uniquely defined, and as multidimensional rather than single-faceted (Wechsler, 1990, 1999). There is clear evidence that both the WPPSI and the WPPSI-R have an underlying two-factor structure (verbal factor and performance factor), when submitted to both exploratory and confirmatory factor analysis (e.g., Gyurke, Stone, & Beyer, 1990; Wechsler, 1990).

Table 2 presents the covariance matrices for the four age-groups.

The differentiation hypothesis implies that there will be differences in the amount of intercorrelation among ability measures as a function of age. The technique proposed by Kaiser (1968) for determining the average intercorrelation among a set of variables from the first principal component of the correlation matrix has been applied to investigate if this is the case for the current data. For ages 3, 4, 5 and 6 the average intercorrelation was 0.51, 0.54, 0.43 and 0.39, respectively. The decreasing mean correlation as a function of age is in agreement with the differentiation hypothesis, and the pattern makes it meaningful to continue with more detailed analyses of the nature of the age-related differences.

### 2.3. Analyses

In the modelling process the observed scores of the ten ordinary subtests of the WPPSI-R were used as manifest variables. The models were constructed to account for the covariances among the manifest variables, but the means were not included. In the first step of modelling a four-group model was fitted, in which no constraints of equality over the models for the different age-groups were imposed. Having established a well-fitting two-factor model, constraints of equality on all parameters over the four age-groups were imposed. In the final steps of modelling, the equality constraints were successively removed for different categories of parameters. This modelling

Table 2
Covariance matrices for the four age-groups

| | OBJ | INF | GEO | COMP | BLOCK | ARIT | MAZE | VOCAB | PICT | SIMI |
|---|---|---|---|---|---|---|---|---|---|---|
| *Age 3* | | | | | | | | | | |
| OBJ | 23.49 | | | | | | | | | |
| INF | 11.15 | 29.77 | | | | | | | | |
| GEO | 19.68 | 32.32 | 86.83 | | | | | | | |
| COMP | 10.47 | 28.12 | 34.95 | 45.20 | | | | | | |
| BLOCK | 9.23 | 13.50 | 29.37 | 15.52 | 22.49 | | | | | |
| ARIT | 7.33 | 13.81 | 23.70 | 15.60 | 10.54 | 14.22 | | | | |
| MAZE | 9.14 | 12.15 | 23.96 | 13.32 | 11.36 | 8.46 | 15.41 | | | |
| VOCAB | 6.54 | 19.04 | 24.30 | 21.65 | 10.56 | 11.29 | 7.91 | 27.84 | | |
| PICT | 11.32 | 21.61 | 34.90 | 24.34 | 14.54 | 12.43 | 12.11 | 16.72 | 31.56 | |
| SIMI | 7.09 | 12.65 | 16.75 | 13.43 | 7.09 | 8.16 | 6.37 | 11.89 | 11.61 | 17.59 |
| *Age 4* | | | | | | | | | | |
| OBJ | 23.13 | | | | | | | | | |
| INF | 9.66 | 21.87 | | | | | | | | |
| GEO | 28.34 | 31.73 | 141.09 | | | | | | | |
| COMP | 13.74 | 29.15 | 48.50 | 59.90 | | | | | | |
| BLOCK | 19.97 | 17.19 | 54.77 | 25.75 | 52.15 | | | | | |
| ARIT | 8.88 | 13.26 | 29.81 | 21.62 | 16.38 | 15.84 | | | | |
| MAZE | 8.80 | 7.80 | 24.65 | 12.06 | 14.14 | 7.58 | 13.72 | | | |
| VOCAB | 10.32 | 24.86 | 41.60 | 41.40 | 22.49 | 18.25 | 10.75 | 54.67 | | |
| PICT | 10.99 | 15.24 | 36.38 | 21.30 | 20.12 | 12.04 | 9.63 | 18.10 | 25.18 | |
| SIMI | 9.11 | 16.56 | 31.03 | 27.79 | 15.54 | 13.84 | 7.56 | 27.28 | 13.68 | 28.99 |
| *Age 5* | | | | | | | | | | |
| OBJ | 13.00 | | | | | | | | | |
| INF | 3.43 | 11.29 | | | | | | | | |
| GEO | 13.08 | 11.70 | 113.78 | | | | | | | |
| COMP | 5.58 | 13.96 | 18.41 | 32.10 | | | | | | |
| BLOCK | 12.44 | 7.98 | 38.41 | 13.32 | 39.32 | | | | | |
| ARIT | 4.05 | 6.37 | 16.53 | 10.21 | 11.37 | 12.00 | | | | |
| MAZE | 3.45 | 3.12 | 16.55 | 4.70 | 9.61 | 4.73 | 10.24 | | | |
| VOCAB | 6.64 | 16.04 | 21.07 | 30.09 | 14.96 | 14.31 | 4.88 | 64.06 | | |
| PICT | 4.69 | 6.20 | 20.79 | 11.88 | 11.08 | 5.70 | 3.90 | 15.46 | 14.17 | |
| SIMI | 6.43 | 10.72 | 18.27 | 19.18 | 14.19 | 11.02 | 3.59 | 27.16 | 9.90 | 32.36 |
| *Age 6* | | | | | | | | | | |
| OBJ | 11.30 | | | | | | | | | |
| INF | 2.71 | 6.65 | | | | | | | | |
| GEO | 8.21 | 7.45 | 77.74 | | | | | | | |
| COMP | 2.82 | 5.10 | 8.35 | 13.13 | | | | | | |
| BLOCK | 9.03 | 6.06 | 25.29 | 5.15 | 36.53 | | | | | |
| ARIT | 3.11 | 4.99 | 12.18 | 4.44 | 8.73 | 10.03 | | | | |
| MAZE | 4.15 | 2.42 | 12.54 | 1.60 | 9.40 | 4.01 | 11.49 | | | |
| VOCAB | 4.33 | 10.20 | 15.28 | 16.49 | 7.33 | 10.64 | 4.19 | 46.56 | | |
| PICT | 3.56 | 3.17 | 9.33 | 4.39 | 6.25 | 3.93 | 2.97 | 9.09 | 8.81 | |
| SIMI | 4.53 | 8.11 | 15.27 | 10.74 | 7.36 | 8.52 | 4.13 | 22.77 | 8.57 | 30.42 |

strategy allowed both an overall test of model equality over the age-groups, and tests of specific sources of model inequality. Attention was in particular focused on differences over the four age-groups in the strength of the relation between the two latent variables, because differences in this relation as a function of age most clearly address the differentiation question.

The models were estimated and tested against empirical data with the LISREL 8 (Jöreskog & Sörbom, 1993) and the Mplus2 (Muthén & Muthén, 2001) programs, which were run under the STREAMS modelling environment (Gustafsson & Stahl, 2000). The fit of each model across the different age-groups was evaluated through chi-square goodness-of-fit tests. Other indices of model fit were also used, most emphasis being put on the root mean square error of approximation (RMSEA) estimate. A model is considered to have a good fit if the RMSEA is below 0.05, even though estimates up to 0.07 may be accepted (Browne & Cudeck, 1993). However, in evaluating this measure of fit, the upper and lower limits of the 90% confidence interval need also to be taken into account.

## 3. Results

In the first step a one-factor model was fitted to the covariance matrices of all four age-groups in a four-group model (Model 1). All ten subtests were hypothesised to load on a general factor, and all parameters were estimated without any constraints of equality being imposed over the four groups. As is seen from the goodness-of-fit test results presented in Table 3, Model 1 fitted unacceptably poorly, however.

To improve fit a two-factor model was fitted. In previous research (Wechsler, 1990, 1999) factor analyses of the WPPSI-R typically have produced two factors: a verbal factor related to the subtests information, comprehension, vocabulary, arithmetic and similarities and a performance factor loaded by object assembly, geometric design, block design, mazes and picture completion. A model with two correlated factors (verbal and performance) was therefore constructed. This model (Model 2) fitted considerably better than the one-factor model (see Table 3). However, the $\chi^2$ values in relation to the degrees of freedom and the RMSEA index were still unacceptably high.

Previous research has demonstrated that the fit of the two-factor model can be improved when the subtest picture completion is allowed to load on both factors (Stone, Gridley, & Gyurke, 1991). Others have found that a modified two-factor model allowing the subtest arithmetic to load on both factors fits the data best (Schneider & Gervais, 1991). Based on these observations, the subtests arithmetic and picture completion were allowed to load on both the verbal factor and the performance factor in a modified oblique two-factor model. With these modifications an improved fit of the model was achieved. Allowing covariances between the residuals of block design and object assembly on the one hand, and between vocabulary and comprehension on the other, fit was improved a bit further. For this modified two-factor model (Model 3) RMSEA was marginally higher than 0.05, and the lower limit of the 90 % confidence interval of RMSEA was as low as 0.039, which implies that the test of close fit (RMSEA $<0.05$) could not be rejected. Model 3 may thus on both theoretical and empirical grounds be accepted as fitting the covariance matrices for the four age-groups.

Table 3
Result from tests of fit of alternative models

| Models | $\chi^2$ | df | RMSEA | $\Delta\chi^2$ | $\Delta$df |
|---|---|---|---|---|---|
| 1. One factor, no constraints over groups | 842.77 | 140 | 0.170 (0.160–0.179) | | |
| 2. Two factors, no constraints over groups | 460.26 | 136 | 0.106 (0.097–0.116) | 382.51 | 4 |
| 3. Two factors, modified, no constraints over groups | 199.01 | 120 | 0.052 (0.039–0.064) | 261.25 | 16 |
| 4. Model 3, equality constraints over groups | 1001.84 | 195 | 0.128 (0.121–0.137) | 753.35 | 75 |
| 5. Model 4, no constraints on error variances | 672.71 | 165 | 0.114 (0.105–0.123) | 329.13 | 30 |
| 6. Model 5, no constraints on error covariances | 646.87 | 159 | 0.114 (0.105–0.123) | 25.84 | 6 |
| 7. Model 6, no constraints on factor variances | 604.47 | 153 | 0.115 (0.106–0.124) | 42.40 | 6 |
| 8. Model 7, no constraints on factor covariances | 551.78 | 150 | 0.110 (0.101–0.119) | 52.69 | 3 |
| 9. Model 8, no constraints on factor loadings | 199.01 | 120 | 0.052 (0.039–0.064) | 352.77 | 30 |

However, Model 3 did not impose any constraints of equality of the parameter estimates over the four groups, so in spite of the fact that the same basic model structure is acceptable for all groups there may be differences between the groups with respect to estimates of error variances and covariances, factor variances and covariances, and factor loadings. Model 4 was the same as Model 3, except that every estimated parameter was constrained to be equal in all four age-groups. Model 4 fitted poorly, and the difference between the test statistics for Models 4 and 3 was very highly significant (see Table 3). This showed that there were differences between the one, more or all of the estimated parameters for the four groups.

In Model 5 the constraints of equality were relaxed for the error variances of the manifest variables, while all the other constraints were still imposed. This caused fit to improve by about 11 $\chi^2$ units/df (see Table 3), which showed that there were differences in the error variances for the age-groups. Model 6 took the further step of relaxing constraints of equality on the two errors covariances, which caused a marginal improvement of fit (see Table 3). In Model 7 the equality constraints on the factor variances were relaxed, which also caused a marginal improvement of fit.

Model 8 relaxed the constraint of equality of the factor covariance over the four age-groups, which caused fit to improve by more than 17 $\chi^2$ units/df (see Table 3). This result showed that there were indeed differences in the amount of covariance between the two factors for the four age-groups. However, judgement on whether this may be interpreted as supporting the differentiation hypothesis or not requires scrutiny of the parameter estimates, and we will return to this issue.

In the final model (Model 9) the equality constraints on the factor loadings (i.e., relations between latent and manifest variables) were relaxed. It may be observed that this model is identical to Model 3, which is because no other constraints were imposed. The difference test between the test statistics for Model 8 and Model 9 showed there to be significant differences between the estimated factor loadings for the four age-groups, there being an improvement of almost 12 $\chi^2$ units/df between the models.

It may thus be concluded that for every category of parameter estimates there were significant differences between the four age-groups. However, the total sample size is large, so even smaller differences may reach significance. Furthermore, according to the crude measure of change in $\chi^2$ units per df, the differences between age-groups in error covariances and factor variances are smaller than the differences in the factor covariance between the verbal and performance factors.

The fact that there are differences between the age-groups not only in the factor covariance but also in the factor loadings makes it necessary to investigate whether the estimates of the factor covariance are robust over different models. Table 4 presents the interfactor correlations between the verbal and performance factors across the different age-groups for Models 8 and 9.

The most striking result which can be seen in Table 4 is that the correlation between the two factors diminishes as a function of age, from 0.78 for the youngest age-group to 0.53 to 0.58 for ages 5 and 6. This pattern supports the differentiation hypothesis. The results also seem to be robust against changes in the specification of the model. For the three youngest age-groups estimates are virtually identical for the two models, while for age-group 6 the estimate is somewhat higher in Model 8 than it is in Model 9. These differences do not affect any substantive interpretations, however.

The fact that the modelling showed there to be group differences in the factor loadings also makes it interesting to see if these may be interpretable. The standardized factor loadings are presented in Table 5.

For the information subtest loadings tend to be smaller for the higher age-groups than for the lower age-groups, while for Similarities there is a tendency in the other direction. For the

Table 4
Correlations between the verbal and performance factors for the four age-groups in Models 8 and 9

| | Age 3 | Age 4 | Age 5 | Age 6 |
|---|---|---|---|---|
| Model 8 | 0.78 | 0.72 | 0.54 | 0.58 |
| Model 9 | 0.78 | 0.72 | 0.53 | 0.53 |

Table 5
Standardized factor loadings (Model 9) for the four age-groups

| | Verbal | | | | Performance | | | |
|---|---|---|---|---|---|---|---|---|
| | Age 3 | Age 4 | Age 5 | Age 6 | Age 3 | Age 4 | Age 5 | Age 6 |
| Object assembly | | | | | 0.54 | 0.63 | 0.49 | 0.51 |
| Information | 0.91 | 0.90 | 0.81 | 0.78 | | | | |
| Geometric design | | | | | 0.87 | 0.83 | 0.76 | 0.66 |
| Comprehension | 0.83 | 0.88 | 0.87 | 0.68 | | | | |
| Block design | | | | | 0.77 | 0.76 | 0.78 | 0.72 |
| Arithmetic | 0.38 | 0.53 | 0.44 | 0.48 | 0.46 | 0.36 | 0.39 | 0.36 |
| Mazes | | | | | 0.77 | 0.70 | 0.62 | 0.63 |
| Vocabulary | 0.74 | 0.81 | 0.78 | 0.76 | | | | |
| Picture completion | 0.50 | 0.28 | 0.43 | 0.45 | 0.34 | 0.53 | 0.38 | 0.27 |
| Similarities | 0.63 | 0.77 | 0.72 | 0.77 | | | | |

other verbal subtests there does not seem to be any systematic pattern of differences between the age-groups. Among the subtests in the performance domain there is a tendency for geometric design and mazes to have lower loadings as a function of age, while for the other subtests there is little of a systematic pattern of differences. These results seem rather to reflect idiosyncratic characteristics of the subtests than any substantively interpretable developmental trend.

## 4. Discussion

The two-factor model demonstrates the verbal and performance factors to be less highly correlated in older age-groups than in younger age-groups. These findings are in agreement with the differentiation hypothesis, stating an increasing differentiation of general ability and the development of specific abilities as age increases. This pattern of development is consistent with the fact that maturational processes within the CNS lead to diversity and specialisation. At birth the two hemispheres functionally overlap because each is processing low-level information. By 5 years of age the newly developing higher-order cognitive processes have little overlap, and each hemisphere thus becomes increasingly specialised (Kolb & Whishaw, 1996). Further, children's basic capacity to store and retain information has been found to increase progressively throughout childhood (Anderson & Lajoie, 1996; Goswami, 1998; Henry & Millar, 1993). This may be due to more efficient information processing and increasing ability to develop cognitive strategies, suggesting that a multidimensional relationship between memory and processing speed and executive functions is responsible for age-related progress (Bjorklund, 1989; Kail, 1986). These abilities evolve with maturity, resulting in age-linked strategic differences in the way a child accomplishes a behaviour or performs in a psychological test situation.

However, the postulated differentiation hypothesis has not been confirmed by other studies using the Wechsler scales (Juan-Espinosa et al., 2000; O'Grady, 1990). One reason for this discrepancy might be the fact that these studies have analysed standardisation samples of the WPPSI for children aged 4:0–6:6, while the present study has analysed a standardisation sample of the WPPSI-R for children aged 3:0–7:3. In the WPPSI-R both easier and more difficult items were added to the original subtests of the WPPSI. Thus the WPPSI-R covers more of the important early period of cognitive development. The ages two to four years are considered to be of particular developmental importance, in view of the definite establishment of binocular vision, hearing-linked language and the fusion of language and thought that occurs during this period (Kolb & Fantie, 1997; Rourke, Bakker, Fisk, & Strang, 1983).

The results of the present study may be one piece of evidence that the latent structure of cognitive abilities undergoes differentiation, recognisable in the WPPSI-R at about age 5, an age at which cerebral maturational processes make possible the development of more advanced executive functions and working memory important to performance on intelligence tests. The results also have some important clinical implications. When the WPPSI-R is used to assess cognitive abilities of children aged 3 or 4 years, the full scale score provides the most reliable information. When an older child is tested, this score may be supplemented with the scores on the verbal and performance scales in combination with a cautious analysis of the individual subtest profile, as this can give valuable additional information about the child's abilities.

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