COMPARING THE LATENT STRUCTURE OF RAVEN’S EDUCATIONAL COLOURED PROGRESSIVE MATRICES AMONG YOUNG CHILDREN AND OLDER ADULTS: A PRELIMINARY STUDY

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Raven’s Progressive Matrices – Standard Progressive Matrices (SPM) and Coloured Progressive Matrices (CPM) have been used for more than 70 years in research, educational and clinical settings.

They have also been employed in investigations of group comparisons as they are considered to be among the best measures of general intelligence.
Raven’s Progressive Matrices

- The first version of J. C. Raven’s progressive matrices test was published in 1938.

- This non-verbal test was originally constructed as a test of eductive ability, the ability to make “meaning out of confusion” or the ability to go “beyond the given to perceive that which is not immediately obvious” - inductive reasoning or general reasoning in today’s terms (Raven, Rust, & Squire, 2008)
Coloured Progressive Matrices (CPM) first appeared in 1947 and was revised in 1956.

The CPM comprises 36 items divided into three sets of 12 (Set A, A_B and B).

The items increase in difficulty, and so do the three sets, with set B containing the most challenging items.

The items of the CPM test are arranged to assess mental development up to the stage when a person is sufficiently able to reason by analogy and to adopt this way of thinking as a consistent method of inference (Raven, et al., 2008).
Apart from the three UK normative studies, standardization of the CPM test has been conducted in many countries around the world.

A study aiming at providing normative data in older populations was conducted in the Netherlands with a representative age and gender stratified sample of 2,815 individuals aged from 55 to 85 years (Smits, Smit, Van den Heuvel, & Jonker, 1997).

Studies, that investigated the test’s ability to predict performance in clinical settings, include ones that have looked at the use of CPM with healthy adults and AD patients.
THE FACTOR STRUCTURE OF RAVEN’S PROGRESSIVE MATRICES

- With regard to their factorial validity, although Raven’s Progressive Matrices were initially developed as measures of the eduction of relations, they have been regarded by many researchers as appropriate measures of general intelligence (g-factor) according to the classic Spearman terminology (Spearman, 1927; Jensen, 1998).

- However, the unidimensional nature of the ability measured by Raven’s Progressive Matrices has been debated, with no signs of an end in sight (Lynn, & Irwing, 2004; Schmidtke, & Schaller, 1980; Green, & Kluever, 1991).
As regards the factor structure of the CPM test in specific, from its inception, it has been acknowledged that the CPM test has a high g loading, with a visuo-spatial ‘k’-factor involved to some degree (Raven, Rust, & Squire, 2008).

Carlson et al. (1977) noted a development in the reasoning process required for CPM solutions from perceptual to conceptual. This notification led him to relate CPM to Piagetian conservation concepts and found high loadings for both perceptual and conceptual items on the factor defined as simultaneous processing.
THE FACTOR STRUCTURE OF RAVEN’S COLOURED PROGRESSIVE MATRICES

Further development of this work has led to the identification of three factors within the CPM items, namely, closure and abstract reasoning by analogy, pattern completion through identity and closure, and simple pattern completion (Schmidtke & Schaller, 1980).

However, other researchers analysed the findings of a sample of 166 gifted children on a little different way: They concluded that the CPM measures one factor, which has three related facets (Green, & Kluever, (1991)).
The factor structure of Raven’s Coloured Progressive Matrices

This position seems to support that probably the “most distinctive feature” of Raven’s test “is its very low loading on any factor other than g” (Jensen, 1998).

Furthermore, the authors of the Raven’s Educational CPM manual (Raven, Rust, & Squire, 2008) also claimed that the Item-Response-Theory-based item analysis demonstrates the scientific value of “general cognitive ability”.
More recently, Fajgelj, Bala, and Katic (2010) suggest that it is crucial the possible constructive elements that form \(g\) (the cognitive processes, such as memory, learning, perception, metacognition etc., that the participants use during solving intelligence tests) to be taken into account in the discussion about the factor structure of intelligence tests, such as [R] PM.
THE FACTOR STRUCTURE OF RAVEN’S COLOURED PROGRESSIVE MATRICES

- For Fajgelj, Bala, and Katic (2010), the solutions with three or four factors identified in the items of CPM are also optimal.
- In their confirmatory factor analyses of the test, in the models with the explicitly introduced higher-order general factor the correlations of the primary factors with the general factor were between .50 to .90
- However, both the models with and without the higher order factor were found to fit data equally well.
The factor structure of Raven’s Coloured Progressive Matrices

- As regards the findings provided from the application of factor analysis by age,

  - factor solutions are practically stabilized, after the age of five when a factor pattern that is later repeated at all ages, is already form.

- On the contrary, at the age of four, the factors do not resemble the factors obtained at older ages (Fajgelj, Bala, & Katic, 2010).
Raven’s Educational Coloured Progressive Matrices (R-CPM)

Raven’s Educational Coloured Progressive Matrices are designed to assess the intellectual processes of young children ranging in age from 4 to 11 years (Raven, Rust, & Squire, 2008).

The book form of the test contains three sets (A, A_B, and B) of 12 items of coloured large-print drawings each.

In each item, subjects are presented with an incomplete design and six alternatives among which, one must be chosen that best completes the design.

Every correctly solved item results in 1 point.

Sum scores may be used for every set (score range 0-12) or for the total Raven’s CPM test (score range 0-36).
According to the aforementioned findings in the introduction section, it is obvious that previous empirical works have implied several a-priori competing models for CPM dimensionality.

It should be also noted here that the present study did not aim to test extensively the constructive validity and the rest psychometric properties of [R] Educational CPM in Greek population, since the Greek standardization of [R] Educational CPM is in progress (Sideridis et al., in press).
Furthermore, the sample size of the present study was inadequate for the conduction of CFA models testing the dimensionality of the [R] Educational CPM (including the 36 items of the test) in every one of the four groups of the sample.

Because of the relatively small sample size of each group, analyses were not run at the item level.

Instead, the covariance matrix was based on three total scores (measured variables), namely, total raw score for Set A, total raw score for Set A_B and total raw score for Set B.
STATISTICAL ANALYSIS

- CFA was conducted to examine the factor structure of the Raven’s Educational CPM for every group of the sample, using summed scores of each one of the three observed variables (subtests of the CPM test),

and to test the hypothesis that individual variability across CPM measured variables (total raw scores of each of the three sets) can be modeled by one latent variable (a single underlying factor).
**Statistical Analysis**

- CFA was conducted in EQS Version 6.1 (Bentler, 2005) and performed on the five covariance matrices, which stemmed from the total sample and each one of the four groups of participants, using the Maximum Likelihood (ML or ML ROBUST) estimation method.

- The *Wald test* was used to test the need for the estimated parameters and to suggest a more restricted model.
STATISTICAL ANALYSIS - RESULTS

- The indices of each one of the five models, which were provided from the application of CFA in each of the five covariance matrices, were the following: $\chi^2 = 0.00$, $df = 0$, $p = \text{undefined}$, $NFI = 1.00$, while NNFI, CFI and RMSEA were not computed because the degrees of freedom were zero.

- These models have been solved and should be considered as just-identified (Brown, 2006).

- Thus, although just-identified CFA models can be fit to the sample input matrix, goodness-of-model-fit evaluation does not apply because, by nature, solutions such the aforementioned, always have perfect fit (Brown, 2006).
Testing latent structure of [R] Educational CPM in the total sample

- Initially, we tested the one-factor CFA in the total sample (Model A).
- Confirmatory factor analysis fully verified the one-factor structure -based on 3 measured variables/summed items- of [R] Educational CPM for the total sample
  \[ \chi^2(0, N = 243) = 0.00, \rho = \text{undefined}, \text{NFI} = 1.00 \]. NNFI, CFI and RMSEA were not computed because the degrees of freedom were zero.
- According to the suggestions of the Wald test all the parameters’ loadings of the Model A were statistically significant.
- Thus, we derived one factor (latent variable), that probably explains the variance of participants’ performance on [R] Educational CPM.
- For the total sample, Cronbach’s \( \alpha \) coefficient was \(.86\)
**Figure 1.** The underlying structure of the single g latent factor in the total sample (standardized solution).

*All loadings drawn indicate significant associations \((P < 0.05)\). **E = measurement error*
In order to compare the latent structure in [R] Educational CPM between elementary school students and new-old adults, we tested the one-factor CFA model in the group of first- to second-grade elementary school students (Model B).

Confirmatory factor analysis verified the one-factor structure based on 3 observed variables/summed items of the [R] Educational CPM for the group of first- to second-grade elementary school students.

\[ \chi^2(0, N = 56) = 0.00, p = \text{undefined}, \text{NFI} = 1.00 \]. NNFI, CFI and RMSEA were not computed because the degrees of freedom were zero.
Testing latent structure of Raven’s Educational CPM in the subsamples of elementary school students and new-old adults

- According to the suggestions of the Wald test, all the parameters of the Model B were statistically significant, except for the residual of one of the measured variables, namely the residual of the total raw score for Set B ($p = .19$). Thus, we derived one factor (latent variable), that probably explains the variance of the elementary school students’ performance on [R] Educational CPM.

- For the group of first- to second-grade elementary school students, Cronbach’s $\alpha$ coefficient was .80.
Then, we tested the one-factor CFA model in the group of new old adults (Model C).

Confirmatory factor analysis fully verified the one-factor structure - based on 3 latent variables/summed items - of the [R] Educational CPM for the group of new-old adults $[\chi^2(0, N = 118) = 0.00, p = \text{undefined}, \text{NFI} = 1.00]$. NNFI, CFI and RMSEA were not computed because the degrees of freedom were zero.

According to the suggestions of the Wald test all the parameters’ loadings of the Model C were statistically significant.
Testing latent structure of Raven’s Educational CPM in the subsamples of elementary school students and new-old adults

- Thus, we derived one factor (latent variable), that probably explains the variance of the new old adults’ performance on [R] Educational CPM.

- For the group of new-old adults, Cronbach’s α coefficient was .89

- The comparison of the CFA Model B with the Model C indicates a similar latent structure in [R] Educational CPM for first- to second- grade elementary school students and new-old adults and verified Hypothesis 2a.
**Figure 2.** The underlying structure of the single g latent factor in the subsamples of elementary school students and new-old adults (standardized solution).

*All loadings drawn indicate significant associations ($P < 0.05$). **E = measurement error.*
In order to compare the latent structure in [R] Educational CPM between kindergarten students and old-old adults, at first we tested the one-factor CFA model in the group of kindergarten students (Model D1).

Due to the statistically significant excess kurtosis of this group of the sample, Model D1 was computed using the Maximum Likelihood (ML ROBUST) estimation method.
Testing latent structure of Raven’s Educational CPM in the subsamples of kindergarten students and old-old adults

However, during our trial to test Model D1, the EQS program warned that corrected chi-square could not be calculated due to numerical difficulties.

Since the Satorra-Bentler chi-square was impossible to be computed, as well as the rest goodness-of-model-fit indices, because of the nature of the model (see also Model A, B, & C), the provided solution was not acceptable.
Hence, despite the distributional mis-specification (significant excess kurtosis), the confirmatory factor analysis was re-performed on covariance matrix using the Maximum Likelihood (ML) estimation procedure (Model D2) (Bentler, 2005).

According to its indices \( \chi^2(0, N = 42) = 0.00, p = \text{undefined}, \text{NFI} = 1.00 \), it seemed that Model D2 should be also considered as just-identified (see Models A, B, & C), and fits the data better than Model D1 of this set of analysis.
**Testing Latent Structure of Raven’s Educational CPM in the Subsamples of Kindergarten Students and Old-Old Adults**

- However, according to the suggestions of the Wald test, the one-factor structure -based on 3 latent variables/summed items- of the [R] Educational CPM was not confirmed for the group of kindergarten students because, although the rest of the parameters’ loadings of Model D2 were statistically significant, the variance of the single latent variable (factor) was not found to be statistically significant ($p = .07$).

- Thus, we did not derive one factor, that could explain the variance of the kindergarten students’ performance on [R] Educational CPM.

- For the group of kindergarten students, Cronbach’s $\alpha$ coefficient was .71
Finally, we tested the one-factor CFA model in the group of old-old adults (Model E).

According to its indices \( \chi^2(0, N = 27) = 0.00, p = \text{undefined}, \text{NFI} = 1.00 \), it seemed that Model E should be also considered as just-identified (see Models A, B, C, & D2) and fits the data perfectly.

However, according to the suggestions of the Wald test, the one-factor structure -based on 3 latent variables/summed items- of the [R] Educational CPM was not confirmed for the group of old-old adults because, although the rest of the parameters’ loadings of Model E were statistically significant, the variance of the single latent variable (factor) was not found to be statistically significant \((p = .07)\).
Testing Latent structure of Raven’s Educational CPM in the subsamples of kindergarten students and old-old adults

- Thus, we did not derive one latent factor, that could explain the variance of the old-old adults’ performance on [R] Educational CPM.
- For the group of old-old adults Cronbach’s α coefficient was .72.
- The comparison of the CFA Model D2 with Model E indicates a similar pattern of structure in [R] Educational CPM for kindergarten students and old-old adults and verified Hypothesis 2b.
To summarize,

- the aforementioned findings confirm Hypothesis 1 and support the existence of a different factor structure in [R] Educational CPM between first- to second-grade elementary school students and new-old adults, on the one hand, and kindergarten students and old-old adults, on the other.
The aim of the present study was the comparison of the general cognitive ability between the developing children and the retrograding older adults through the investigation of the latent structure qualitative changes in Raven’s Educational CPM from age to age, using Confirmatory Factor Analyses (FCA) and testing a conventional unidimensional model.

For the groups of elementary school students and new-old adults, the results of CFA seem to support the existence of a single latent g-factor measured by Raven’s Educational CPM.

For the groups of kindergarten students and old-old adults the existence of a single latent g-factor measured by Raven’s Educational CPM was not confirmed, since its variance was not found to be statistically significant.
**DISCUSSION**

- These findings seem to be consistent with previous ones indicating that the factor solutions are stabilized after the age of 5-6 (Fajgelj et al., 2010). Until then, the factor structure of Raven’s CPM does not resemble much the factor structure obtained in older ages.

- A possible explanation for these findings could be that *inductive generalization* is not a *unitary cognitive operation*, but it is possible to start with *perception* and only in the end to develop *pure induction*, regarding that inductive reasoning or general reasoning (the current name of eductive ability) is one of the main possible constructive elements of *g* (Sloutsky & Fisher, 2004; Hayes & Thompson, 2007).
A different explanation for the delay of stabilization of the CPM factor structure at earlier ages (before the age of 5-6) was put forward by some researchers (Fajgelj et al., 2010), taking into account executive functioning as a possible element of g. According to them, this delay could reflect lack of metacognitive and self-regulative processes – two of the main components of executive functioning – and could be attributed to the inflexible solving strategy, the poor management of goal activity and the weak mechanisms of control (Zelazo & Carlson, 2012).
The similar, not unidimensional structure of the Raven’s Educational CPM test that was observed, in the present study, between the group of kindergarten students and the group of old-old adults, is possible to indicate a qualitative change, perhaps a start of disorganization, either in the inductive reasoning, and/or in the executive functioning of the old-old adults comparing to that of the new-old adults (Leeds, Meara, Woods, & Hobson, 2001; Zelazo, & Carlson, 2012).

This finding is consistent with the general admission in the field of cognitive aging, that cognitive functioning declines with aging and fluid intelligence—which is highly related to inductive reasoning— is among the cognitive abilities that seem to be more affected by age.
Overall, the different pattern in the latent factor structure of the Raven’s Educational CPM test, that was found in the present study, between the groups of kindergarten students and old-old adults, on the one hand, and the groups of first- to second- grade elementary school students and new-old adults, on the other, is a supporting finding with regard to the hypothesis of “retrogenesis”.
The disorganization of general cognitive ability in terms of inductive reasoning and executive functioning was found to be present before the appearance of clinically detectable dementia in the majority of the participants in the subsample of old-old adults, regarding their scores in the MMSE.

This finding seems to be in line with recent findings indicating that a large proportion of healthy old-old adults show memory decline which may represent the early stages of a potentially more severe cognitive impairment (Shoji, et al., 2002; Goldman, et al., 2001; Schmitt, Davis, Wekstein, et al., 2000).
CONCLUSIONS

- The results of our findings, with the size of the sample used, **support the** usefulness of Raven’s Educational CPM as a sensitive neuropsychological test for the detection, in the old-old adults, of the differentiation and/or the decline of the general cognitive ability acquired during childhood.

- In order for **the applicability** of Raven’s Educational CPM to be assessed in Greek older adults, normative data have to be provided for this population.
REFERENCES

- Spearman CE. The abilities of man. Macmillan, London. 1927
Thank you for your attention!