Factor structure of Raven's Coloured Progressive Matrices

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Abstract

This study's objective was to verify the factor structure of Raven's Coloured Progressive Matrices (CPM). The database used included the responses of 1,279 children, 50.2% of which were males with an average age of 8.48 years old and a standard deviation of 1.49 yrs. Confirmatory factor analyses were run to test seven models based on CPM theory and on a Brazilian study addressing the test's structure. The results did not confirm the CPM theoretical proposition concerning the scales but indicated that the test can be interpreted by one general factor and one specific factor or one general factor and three specific factors; both are bi-dimensional models. The three-factor model is, however, more interpretable, suggesting that the factors can be used as a means of screening children's cognitive developmental stage.

Keywords: intelligence, cognitive test, psychometrics, children, Raven's colored progressive matrices

Estrutura Fatorial das Matrizes Progressivas Coloridas de Raven

Resumo

O objetivo do trabalho foi verificar a estrutura fatorial das Matrizes Progressivas Coloridas de Raven – MPC. Para isso, utilizou-se um banco de dados contendo as respostas a MPC de 1.279 crianças, 50,2% do sexo masculino, com idade média de 8,48 anos e desvio-padrão de 1,49 anos. Foram efetuadas análises fatoriais confirmatórias testando sete modelos arquitetados a partir da teoria das MPC e de um estudo brasileiro que explorou a estrutura desse teste. Os resultados não confirmaram a proposta teórica da MPC referente às escalas propostas no teste, mas indicaram que o teste pode ser interpretado por um fator geral e um fator específico, ou um fator geral e três específicos, os dois modelos sendo bidimensionais. No entanto, o modelo com três fatores específicos é mais interpretável, sugerindo que os fatores podem ser utilizados como *screening* do estágio de desenvolvimento cognitivo que a criança se encontra.

Palavras-chave: inteligência, teste cognitivo, psicometria, crianças, matrizes progressivas coloridas de Raven

Estructura Factorial de las Matrices Progresivas Coloridas de Raven

Resumen

El objetivo del trabajo fue verificar la estructura factorial de las Matrices Progresivas Coloridas de Raven – MPC. Para el estudio se utilizó un banco de datos que contenía las respuestas de 1.279 niños a las MPC, siendo 50,2% del sexo masculino, con edad media de 8,48 años y desviación estándar de 1,49 años. Fueron realizados análisis factoriales confirmatorios utilizando siete modelos ideados a partir de la teoría de las MPC y de un estudio brasileño que investigó la estructura de ese test. Los resultados no confirmaron la propuesta teórica de las MPC con respecto a las escalas propuestas en el test, pero indicaron que el test puede ser interpretado por un factor general y un factor específico, o un factor general y tres específicos, siendo los dos modelos bidimensionales. Pese a eso, el modelo con tres factores específicos es el más interpretable, sugiriendo que los factores pueden ser utilizados como screening de la etapa de desarrollo cognitivo en que el niño se encuentra.

Palabras clave: inteligencia, test cognitivo, psicometría, niños, matrices progresivas coloridas de Raven

John C. Raven was responsible for developing three important instruments to assess intelligence that are frequently used in difference contexts. These instruments are generically called Raven's Progressive Matrices. The first of these tests, the Standard Progressive Matrices (SPM), published in 1938, is intended for people aged from 12 to 65 years old. In 1947, Raven developed Coloured Progressive Matrices (CPM) and Advanced Progressive Matrices (APM). The first is an adaptation of the Standard Progressive Matrices and is intended for children aged from five to 11 years old, mentally disabled individuals and the elderly. The second instrument is administered to 11 years old or older individuals with higher than average intelligence; it is most frequently used among college students (Pasquali, Wechsler, & Besunsan, 2002; Bandeira, Alves, Giacomel, & Lorenzatto, 2004).

CPM were developed for small children and elderly individuals but standardizing studies conducted in Brazil involve only children aged from five to 11 years old. It is possible to infer the level of a child's eductive capability and potential to create knowledge out of logical associations among stimuli based on the child's score. The CPM contain three sets of items A, Ab and B, with 12 items each; the complete test totals 36 items. The items are ordered by ascending level of

http://dx.doi.org/10.1590/1413-82712016210204

difficulty in each set and as complexity among the sets increases. The explanation for the sequence's ascending level of difficulty of items in the three sets is based on the gradual introduction of new and more complex types of reasoning, so that previous strategies prepare the individual for the construction of the coming logical-associative strategies for the more difficult items (Bandeira et al., 2004).

Each item has a drawing or a matrix with a part missing and six alternatives, but only one alternative correctly completes the figure. The respondent is asked to select only one alternative for each problem. Most of the items are printed on a coloured background, hence the name Coloured Progressive Matrices. The colours, however, are irrelevant to solving the problems; they are added simply as an attracting and motivating element to keep the child's attention on the test. Since its construction, the instrument was revised only once, by Raven himself in 1956. He changed the design of some alternatives of items and changed the positions of some alternatives in other items (Bandeira et al., 2004). These changes are specified in the Brazilian manual developed by Angelini, Alves, Custódio, Duarte and Duarte (1999).

Pasquali, Wechsler and Besunsan (2002) state that Raven used three theories to develop the Matrices including the CPM: (1) Spearman's two-factor theory (*g factor*); (2) Gestalt theory; and (3) the theory of cognitive development. Spearman (1927) conceived of intelligence as a general factor or simply a *g factor*, defining such a construct as "mental energy storage". Based on the *g factor*, he developed the two-factor theory of intelligence known as bifactor theory, which is composed of the general factor, a capacity that is common to all skills, and one specific factor that is particular to each type of test. The theory assumes the constant presence of these two types of factors in any intellectual activity. In this line of thinking, every intelligence test demands a specific skill related to a peculiar activity that is required on the test itself and a cognitive ability of a general nature.

Spearman sought to understand fundamental processes that characterize the general factor of intelligence seeking to establish a definition for the *g factor*. He defended the view that the *g factor* involves the presence of three basic processes: apprehension of experience, eduction of relationships, and eduction of correlates. CPM emphasize the measurement of one's eductional ability, more specifically eduction of relationships in which one has to find links and associations among sets of information to conceive an idea. It is also possible to understand how the Gestalt theory grounded the construction of the items in this psychological test. One of the cornerstones of Gestalt theory is linked to the perception of the whole; to be able to visualize any problem (as in the CPM's items), one has to perceive the context, seeking an overall understanding based on the relationships existing among the parts (Angelini et al., 1999). The CPM's items were developed for the problem to be solved within a spatial or logical perception of a global configuration, or one gestalt (Pasquali et al., 2002).

In regard to the developmental relationship, it is implicit in Raven's Matrices because one's eduction of relationships and eduction of correlates are developed along with organic maturation so that children tend to perform more poorly than adolescents or adults. Raven indicated five levels of cognitive development in children aged five to 12 years old to solve problems and that are understood in a successive manner: distinguish similarities and differences in figures; assess the orientation of the figure in the perceptual field, both in regard to itself and to the remaining objects; perceive how two or more figures can form the whole; analyse the parts perceiving the whole but distinguishing between what seems real and what the child himself/herself adds to it; compare analogue changes in the perceived parts; and use it as a strategy of logical reasoning (Pasquali et al., 2002).

It is important to clarify that CPM's primary goal is not to measure general intelligence, that is, all intelligence-related capabilities. This test does not assess one's verbal language capacity or acquired cultural knowledge. As previously mentioned, the main purpose of Raven's Matrices, as well as that of CPM, is to measure one's capacity for eduction, which is similar to fluid intelligence proposed in the most current model of psychometric theory of intelligence, Cattell-Horn-Carroll Theory of Cognitive Abilities (Schneider & McGrew, 2012). Fluid intelligence has been notes as an important factor from a psychometric perspective and, according to Flanagan and Ortiz (2001), it is the ability most strongly associated with general intelligence. It may be one of the explanations that matrices are acknowledged in various parts of the world as an important and relevant measure of intelligence.

Fluid intelligence or, as it is currently called, fluid reasoning, refers to one's ability to reason in novel situations regardless of previously acquired knowledge. For Schneider and McGrew (2012) these operations involve relating ideas, inducing abstract concepts and solving problems, mainly employing inductive and deductive reasoning. Inductive reasoning seems to be the most frequently used in the CPM items, involving the ability to analyse sets of information and establish relationships among them, creating new ideas and concepts, and systematically organizing information (Primi, 2002). As can be observed, inductive reasoning is similar to eduction of relationships, which is proposed in the CPM assessment.

Because the objective of the Progressive Matrices is to assess eduction of relationships, or inductive reasoning, Progressive Matrices tend to be considered uni-dimensional. As noted by Pasquali et al. (2002), Raven himself was not concerned with the dimensionality of matrices and conceived them as uni-dimensional. The nature of the items, however, is different and requires particularities in one's reasoning to achieve the correct response. In scale A, the nature of the items is subdivided into: Complement of a simple, continuous pattern with perceptions related to the difference, identity, similarity, orientation, and gestaltic formation (from item A1 to A8); Complement of a pattern showing progressive changes in one direction with the perception of the difference, identity, similarity, orientation and identity (items A9 and A10); and complement of a pattern showing progressive changes in two directions with the perception of difference, similarity, gestaltic formation, orientation and correlate-creation (items A11 and A12). In the Ab scale, the items can be subdivided into: Complement of distinct patterns with perception of difference, similarity, identity and orientation (from items Ab1 to Ab3); and Complement of distinct patterns involving apprehension of three related figures as a whole, to be completed by a fourth piece, together with the perception of difference, closed and open symmetry, orientation, change of orientation, and oblique orientation of a missing part (from Ab4 to Ab12). Finally, the items in the B scale are subdivided according to: Complement of distinct patterns with the perception of difference, similarity and identity (items B1 and B2); Apprehension of three figures with the whole to be completed with the perception of similarity, symmetry and orientation of a missing part (B3 to B5); Concrete or coherent reasoning by spatial analogy with an asymmetric change in changed figure and oblique orientation of the missing part (B6 to B9); and discrete or abstract reasoning by logical analogy (B10 to B12) (Angelini et al., 1999).

Regardless of the instrument having one dimension, with so many variations in the nature of the CPM tasks, it is important to investigate its internal structure, that is, how the items are grouped given their specificities, and how grouping can be interpreted, and which psychological meaning one can infer regarding grouping. Few studies are concerned with exploring the structure of CPM, though there are international studies such as Carlson and Jensen (1980), Schmidtke and Schaller (1980), Green and Kluever (1991), and Fajgelj, Bala and Katic´ (2010).

The objective of Carlson and Jensen (1980) was to re-analyse the factorial structure of CPM using a sample with 783 children aged 6.11 years old on average, with a standard deviation of 10.1 months. Analyses were performed using methods that reduced the effect that the difficulty of items tends to cause in the generation of factors. According to the authors, when the *phi* coefficient is used in the analysis, the difficulty of items contributes to forming factors, so that some factors, considered artificial factors, emerge. Therefore, the authors applied principal component analysis with varimax rotation, but tested data using the *phi* coefficient, tetrachoric correlation and *phi* coefficient/*phi max* (the last two tend to minimize the effect of the difficulty of items). The Scree Test (Cattell, 1966) was used to determine the number of rotated factors.

Three factors were identified for the three specificities of the factor analysis (*phi* coefficient, *tetrachoric* correlation and, *phi* coefficient/*phi max*). The factorial structure found between the analysis with tetrachoric correlation and *phi*/*phi max* were similar, loading the same significant items and factors obtained the same denomination. These data were different from the analysis using the *phi* coefficient to the extent that the factor Concrete and Abstract Reasoning was composed of clearly more difficult items, as exposed by the authors. When Carlson and Jensen (1980) discuss the results, they state that the analysis helped to clarify the CPM's internal structure and how the difficulty of the items tends to cause interference when using the procedure with the *phi* coefficient. The factors that emerged with the *tetrachoric* analysis and *phi*/*phi max* were: Factor 1 – closure and abstract reasoning by analogy, composed of items A9 to A11 (nature of task of standard complement showing progressive changes), items Ab4 to Ab9 and B5 (standard complement by closure), B7 to B12 (concrete and abstract reasoning); Factor 2 – Standard complement by identification and complement that encompassed items A6 (continuous complement of a simple pattern), A10 (standard complement with successive changes), Ab1, Ab2 and Ab3 (standard complement involving identification), Ab4, Ab6, Ab7 and Ab8 (standard complement by closure), B1, B2 and B3 (standard complement involving identification), B4 and B5 (standard complement by closure); and Factor 3 – simple standard complement formed by items A2 to A6 and A8 (simple standard complement), Ab3 (standard complement by identification).

In the same year, 1980, Schmidtke and Schaller, considering the existence of studies with contradictory results concerning the CPM structure, took data obtained by Carlson and Jensen in the aforementioned study to verify the CPM structure and compare with previous studies that indicated the possibility of CPM having two, three or four factors. A total of 728 children aged from four to 11 years old were assigned to four groups (four years and nine months old to six years and three months old; six years and four months old to seven years and nine months old; seven years and ten months old to nine years and three months old; and nine years and four months old to 11 years old). The factor analysis used was principal components with varimax rotation, using the *phi* coefficient. The Scree test was used for the quantity of rotated factors. Three factors were obtained for all the groups and comparison of the factorial matrices after rotation of maximum similarity resulted in an average coefficient of congruence of 0.75. The factors were interpreted as Perceptive closure involving complex figures (F1), Concrete and abstract reasoning (F2), and Complement of homogeneous patterns and recognition of certain elements (F3). In the comparison with the results found in Carlson and Jensen (1980), the authors describe there was similarity among the factorial structures found. Unfortunately, the study conducted by Schmidtke and Schaller does not report the factorial structure with the items, thus closer scrutiny of the proper details of this information is not possible.

In 1991, Green and Kluever, because previous studies presented different data for the CPM's factorial structure and were also based on samples of children with typical development, sought to verify the CPM structure among gifted children. A total of 166 intellectually gifted children aged from three to 11 years old participated in the study. Applying factorial analysis using principal components and varimax rotation, the solution generated with three factors enabled the best interpretation, highlighting that the authors did not specify the statistical criterion of factor retention. Factor 1 involved items with a standard complement nature and visual closure but also required visual orientation and sophisticated discrimination skills (B11, B12, B10, B9, AB8, B8, A11, A12, B6, B5, Ab4, Ab9, A7, Ab6, Ab12, B7, Ab10 and A8). The nature of items in Factor 2 shows a complement of visual analogy (B3, Ab1, B2, Ab3, A9, Ab5, Ab7, A1, A10, B4, Ab11, Ab2) and, finally, Factor 3 presents items that require perceptual combination (A5, A4, A6, A3, A2). The authors also performed an analysis with *oblimin* rotation and with the *phi* coefficient and the results were similar.

There is a concern on the part of the authors of the three studies previously mentioned with the analytical techniques, that they would not interfere in the results. With this concern in mind, Fajgelj, Bala and Katic´ aimed to verify the validity of the CPM construct in 2010 and understand the test's dimensionality, since various studies indicated significant primary factors. The study's sample was composed of 2,334 individuals aged between four and 11 years old. To achieve their objective, various types of factor analyses were applied. Initially, six exploratory factor analysis procedures were performed using three programs (Lisrel, SPSS and Testfact), three types of matrices (covariance, correlation and rtest-smoothed), with three forms of extraction (ML, principal components and minres) and two types of rotation (promax and varimax). Three or four factors were derived in the analyses but, according to the authors, the solution with four factors was the most appropriate because some items are joined by similarity of graphic content. Applying confirmatory factor analysis to all the models with three and four factors with and without specification of a general factor of the second order and to one general factor model, all were considered acceptable, except the one with a single factor. The adjustment indexes used for the confirmatory factor analysis were RMSEA, SRMR, PNFI and x^2/gl, the values of which were equal to or below 0.40 for RMSEA, except for the one-factor model that reached 0.71; equal to or below 0.61 for SRMR; equal to or below 0.899 for PNFI; and below 5 for x^2/gl, except, again, for the one-factor model. Parallel analysis was also used and indicated the solution with four factors for the general sample.

The authors did not present the constitution of each factor, but they discuss that the existence of a general factor cannot be disregarded. They present three arguments: there are high correlations among the factors; there are models with an acceptable general factor; and the primary factors, except for the first factor, can be understood as factors of difficulty, which the authors also call artificial factors.

Up to the present, two studies addressing the dimensionality of CPM were performed in Brazil. One, Pasquali et al. (2002), found four factors but uni-dimensionality was observed at the second order level, while the other study, Sisto, Rueda and Bartholomeu (2006), did not detect uni-dimensionality. The studies, however, used different analytical techniques: the first study applied exploratory factor analysis, the purpose of which is to identify groupings of items; the second study used the Item Response Theory, the objective of which is not to identify factors, but only to indicate the possibility of the existence of one or more dimensions in one set of items. Therefore, Pasquali et al. (2002) will be further detailed here as it was performed with a Brazilian sample including a significant number of participants, which contributed to the results' robustness, and is compared with this study's results.

Among other objectives, Pasquali et al. (2002) sought to verify the CPM internal structure in a sample of Brazilian children. It is important to note that the study was conducted with the previous version of CPM, from 1986. Therefore, it does not correspond to the CPM currently used, as it was not available in Brazil when data were collected at the end of 1987. It is worth noting, however, that the only difference between the two is the change of position of items 11 and 12 in set A. The sample totalled 9,929 children, of both sexes, aged between five and 11 years old, from public schools from the Federal District. The factor analysis was performed excluding individuals younger than seven years old, as the cognitive structure seems not to be fully organized in children younger than seven years old. Additionally, factor analyses were performed by age, school year, and sex, but the results were similar so that the study describes only the analysis with the general sample, which include seven to 11 year-old children.

The factor analysis performed by principal axes and oblimin rotation was performed and, initially, six factors with eigenvalues higher than 1.0 and four factors with eigenvalues higher than 1.40 emerged. Consequently, the authors opted to conduct the same analysis with four factors. The items with a factor load above 0.28 were considered in the extraction results. The four factors were evident with some correlations among them (Factor 1 x Factor 2 = 0.41; Factor 1 x Factor 4 = -0.50; Factor 2 x Factor 3 = 0.31), which also led the authors to propose a confirmatory factor analysis with one factor. Data indicated that CPM assesses four factors, but one general factor of intelligence of the second order is present. Factor 1, however, explains more variance of CPM than the general factor.

The four factors extracted by Pasquali et al. (2002) were called: analogical-abstract reasoning (Factor 1: 6Ab, 5B, 7Ab, 3B, 8Ab, 4Ab, 10A, 5Ab, 9A, 7A, 10Ab, 4B, 11Ab, 9Ab, 6B), analogical-concrete reasoning (Factor 2: 1Ab, 2Ab, 3Ab, 6A, 2B, 5A), gestalt perception (Factor 3: A2, A3, A4, A1) and deductive reasoning (Factor 4: 11B, 9B, 8B, 12B, 10B), in addition to the general factor identified as analogical reasoning and containing 25 of the 36 items of the original test, and without the Factor 2 items. Additionally, only the first and the general factors presented sufficient items and had good factorial loads for the construct behavioural representation.

In regard to the potential interpretation of factors, for the figure to be completed, the items that compose Factor 1 require the ability to observe small changes in a continuous configuration (A items), perception of symmetry and asymmetry, in addition to verifying changes in the parts of the whole. Nonetheless, these are characteristics that can be identified by following the movements of the parts of the figure, that is, inductive reasoning is used at an abstract level. This abstraction is what differs from the items in Factor 2, in which the child needs to discover the part that correctly associates with the remaining parts of the whole, while the missing part is one of the three presented in the whole, which requires reasoning that is both analogical and concrete.

The tasks of Factor 3, which are easier items, demand the ability to perceive differences and similarities in a gestalt/figure. The task consists in filling in a simple gap with elements already provided in the figure itself, which is also simple and continuous. Factor 4, composed of more difficult items, requires apprehending logically related figures and producing changes in these figures to configure a unified gestalt. The respondent is required to subtract or add elements in these items to generate a fourth figure, which is a continuation of the other three figures, to constitute a unified gestalt. These are tasks that require abstraction and eduction.

In regard to the potential interpretation of factors, the items that compose Factor 1 demand an ability to observe small changes in a continuous configuration (A items) and perception of symmetry and asymmetry, in addition to verifying changes of parts of the whole in order to complete the figure. These are characteristics, however, which can only be identified by following the movements of the figure; that is, inductive reasoning at the abstract level is used. This abstraction is what differs from Factor 2's items, in which the child needs to find out the part that is correctly associated with the remaining three parts of the whole, while the missing part is one of the three presented in the whole, which requires reasoning that is both analogical and concrete. An ability to perceive differences and similarities in a figure is required to solve the tasks in Factor 3, which is composed of the CPM's easiest items. The task is filling in a simple gap with elements already provided in the figure itself, which is also simple and continuous. Factor 4, composed of the CPM's most difficult items, requires apprehending logically related figures and producing changes in these figures to configure a unified gestalt. In these items, the respondent is required to subtract or add elements to generate a fourth figure, which is a continuation of the other three figures, to constitute a unified gestalt. These are tasks that demand abstraction and deduction.

Data found in the aforementioned studies reinforce the need for further studies to address the dimensionality of CPM. In addition to the fact that a different quantity of factors and composition of items was found, there is also a need to improve investigation of the general factor, as data reported by Pasquali et al. (2002) and Fajgelj et al. (2010) suggest. In fact, all Raven's Matrices were developed, in theory, to assess the general factor (*g factor*) and a specific factor according to the bifactor theory of intelligence proposed by Spearman.

Given the previous discussion, this study's aim was to verify the dimensional estructure of Raven's Coloured Progressive Matrices (CPM). Because Pasquali et al. (2002) was conducted with a Brazilian sample and with a significant number of individuals, which enabled greater data consistency, this study will present confirmatory factorial analyses also based on the factors found by Pasquali et al. (2002).

Method

Participants

A total 1,279 children composed the sample: 50.2% were male and no information regarding this information was provided by 0.4%; an average age of 8.48 years old with a standard deviation of 1.49 years. The distribution of the participants in terms of relative frequency for each age was 0.5% (five years old), 13.8% (six years old), 8.4% (seven years old), 27.3% (eight years old), 21.5% (nine years old), 22.7% (10 years old), 5.4% (11 years old), 0.1% (12 years old), 0.2% (13 years old), and 0.1% (19 years old). The parents or legal guardians authorized the participation of the children, who were properly assessed in adequate conditions. The results obtained in this assessment compose the database currently used. The children were distributed according to school year: 1st grade (3.0%), 2nd grade (29.5%), 3rd grade (18.1%), 4th grade (8.8%), 5th grade (29.0%), 6th grade (3.9%), 7th grade (0.2%), and 7.5% did not report their school year. All the participants lived in the interior of the state of São Paulo, Brazil.

Instruments

Raven's Coloured Progressive Matrices (Angelini et al., 1999). Raven's Coloured Progressive Matrices (MPC) is a non-verbal intelligence test, representative of general intellectual capacity or the "g" factor proposed by Spearman (Angelini et al., 1999). CPM was developed to assess children aged from five to 11 years old, mentally disabled individuals and the elderly. Validity, reliability and standardization studies conducted in Brazil included individuals aged from five to 11 and a half years old. The test is composed of three sets/scales (A, Ab and B) with 12 items each. The sum of these sets composes the general score and there is no score per scale. The items are organized in ascending difficulty over the course of three sets (A, Ab, and B); the B set is more difficult than Ab on average, which in turn is more difficult than the A set on average. The items consist in a drawing with a missing part, which the individual needs to complete by choosing one among six alternative responses. There is only one correct answer for each item. The respondents score one for each correct response and zero for each wrong response. The minimum score is zero and the maximum score is 36. The instrument can be applied individually or in groups and there are no time limitations.

Procedures

The participants' scores were obtained by querying the databases of four researchers from a public university in the state of São Paulo, Brazil. Initially, authorizations were asked of the guardians of the protocols that contained the information from CPM responses. Then the project was submitted to the Ethics in Research Committee regulating research with human beings, asking for authorization of the study without the need to seek the participants' consent, as such a database can be characterized as a secondary source. After approval the Ethics in Research Committee the database was set up with the following information collected from the original protocols: the individuals' initials, year of birth, age, sex, year of data collection, and CPM responses. The tests were applied as part of various Master's and Doctoral studies, one of the objectives of which was to implement a cognitive assessment among these participants through an objective measure. The tests were applied by Master's and Doctoral students specifically trained for this activity and were supervised by professors; all were involved in postdoctoral programs in the field of psychology. Overall, data were collected in 19 public schools and one private school located in four cities in the interior of São Paulo, Brazil.

Data analysis. Seven models were tested with CPM based on confirmatory factor analysis: a general factor; three factors respective to each scale and one general factor; general factor with a specific factor composed by the items of Factor 1, followed by the same analysis for each set of items in the remaining factors found in Pasquali et al. (2002); and finally, the general factor was modelled with the four specific factors previously mentioned. The first model was built to verify the possibility of CPM's single dimension, despite the fact that studies indicate the existence of more factors. We deemed it important to test the one-dimension configuration that is always attributed to this psychological test. The second model was based on the separation of items into three scales, which *a priori*, tend to suggest that these are items with similar characteristics, while there are differences among the groupings. Hence, these first two models are grounded on CPM theory.

The other five models are based on the empirical study of Pasquali et al. (2002). In addition to testing a model with a general factor and four specific factors taken from 1, 2, 3 and 4 factors, which emerged from the analysis reported by Pasquali et al. (2002), another four models were tested with the general factor and each specifying one of the factors (1, 2, 3 or 4). Table 1 presents the compositions of the seven models.

The analysis of the factor structure of items of the Coloured Progressive Matrices was performed using Mplus 7. Since the scores are dichotomous values (0 and 1), all the factor analyses were performed using a robust weighted least squares estimator (WLSMV).

The models' goodness of fit was verified using root mean-square error of approximation (RMSEA), the comparative fit index (CFI: Bentler, 1990) and the Tucker-Lewis index (TLI: Byrne, 2010). Goodness of fit is verified when RMSEA is equal to or less than 0.05 (Browne & Cudeck, 1993), and CFI is equal to or greater than 0.95 (Hu & Bentler, 1999).

Results

The first model tested, the one concerning the instrument's uni-dimensionality, presented an

Table 1

Models for the Confirmatory Factor Analysis

Model	General factor items	Specific factor items
1 – One dimension	CPM's 36 items	There is none
2 – Hierarchical	CPM's 36 items	Factor 1: 12 items of the A scale Factor 2: 12 items of the Ab scale Factor 3: 12 items of the B scale
3 – Bi-dimensional	CPM's 36 items	18, 29, 19, 27, 20, 16, 10, 17, 9, 7, 22, 28, 23, 21 and 30 (Factor 1 – Pasquali, Wechsler, Bensusan).
4 – Bi-dimensional	CPM's 36 items	13, 14, 15, 6, 26 and 5 (Factor 2 – Pasquali, Wechsler, Bensusan).
5 – Bi-dimensional	CPM's 36 items	1, 2, 3 and 4 (Fator 3 – Pasquali, Wechsler, Bensusan).
6 – Bi-dimensional	CPM's 36 items	35, 37, 32, 36 and 34 (Factor 4 – Pasquali, Wechsler, Bensusan).
7 – Bi-dimensional	CPM's 36 items	All items of Factors 1, 2, 3 and 4 of Pasquali, Wechsler and Bensusan.

appropriate RMSEA but CFI and TLI did not present satisfactory goodness of fit. The second model, called a hierarchical model because it determines the presence of a second order general factor that explains the A, Ab and B scales, and these scales in turn explain the performance of the participants regarding the items of the respective scales, presented goodness of fit very similar to the first model. These findings suggest that adding three specific factors did not improve the explanation of the factor structure of the Coloured Progressive Matrices. The high betas found in regard to the general factor in relation to the A, Ab and B scales, 0.983, 0.927 and 1.000, respectively, corroborate the inadequacy of three scales as latent first order variables and did not improve goodness of fit.

The third model determined the presence of a general factor that directly explained the participants' performance on all the items, as well as Factor 1 suggested by Pasquali et al. (2002). Both factors are orthogonal to each other. Even though small improvements were found in regard to CFI, TLI and RMSEA in comparison to the first two models, this model also did not show satisfactory goodness of fit according to the CFI and TLI. The fourth model is identical to model three in terms of organization of factors, but postulates the presence of Factor 2, indicated by Pasquali et al. (2002), instead of Factor 1. Goodness of fit is very similar to that found in model 2. Model 5, called bifactor 3, sustains the presence of a general factor and Factor 3, as suggested by Pasquali et al. (2002), orthogonal to each other, showing goodness of fit very similar to that of model 1. The sixth model, bi-dimensional 4, determined the presence of a general factor and orthogonal to Factor 4 indicated by Pasquali et al., 2002, presenting goodness of fit for RMSEA, as well as for CFI and TLI. The seventh model, bi-dimensional 5, determined the presence of a general factor (as the previous bi-dimensional models) and also postulated the joint presence of four specific factors from Pasquali et al. (2002). As this model showed that Factor 1 had zero variance, this factor was eliminated, so that the general factor and the specific Factors 2, 3 and 4 were kept. This model also presented satisfactory goodness of fit (like model 6) and CFI, TLI and RMSEA were very similar to the bi-factorial model 4 indicating that both are considered satisfactory.

Table 3 present betas from the model 6 (bifactorial 4) and Table 4 present betas from model 7 (bifactorial 5).

The general factor presented an average beta of 0.590 and a standard deviation of 0.127 in the bifactorial 4 model, while the bifactorial 5 model and the general factor showed an average beta of 0.582 and a standard deviation of 0.128, changing its average value and variation very little over the course of the 36 items. Factor 4 of Pasquali et al. (2002), a specific factor, was also present in the two models. The average beta values of this factor in the bifactor model 4 was 0.585 and standard deviation of 0.075, while the average beta in the bifactor 5 model was 0.581, with standard deviation of 0.075, also presenting very close values. Factors 2 and 3, specific factors present only in the bifactor 5 model, respectively presented average betas of 0.412 and 0.606 and standard deviations of 0.063 and 0.115.

In the case of models 4 and 5, we also sought to describe the composite reliability of the factors identified. Composite reliability is considered to be a more correct index for multifactor measures because it assesses the reliability of estimated factors, taking into account the betas. The general factor in the bifactor 4 model presented a value of 0.952 and Factor 4 presented a value of 0.724, indicating that both factors

Table 2
Goodness of fit of the Models Tested

Model	RMSEA	CFI	TLI	χ^2	gl
1 – Unidimensional	0.036	0.926	0.922	1560.903	594
2 – Hierarchical (scales)	0.035	0.928	0.924	1532.476	592
3 – Bi-dimensional 1	0.034	0.934	0.928	1446.848	579
4 – Bi-dimensional 2	0.035	0.930	0.925	1513.003	588
5 – Bi-dimensional 3	0.036	0.926	0.921	1566.023	590
6 – Bi-dimensional 4	0.029	0.951	0.947	1234.674	589
7 – Bi-dimensional 5	0.029	0.953	0.949	1193.189	579

Table 3

Bifatorial 4 Model (Model 6), Betas and Confidence Intervals

Item	Ri	Standard error	f4	Standard error
RA1	0.394	0.038		
RA2	0.622	0.114		
RA3	0.578	0.090		
RA4	0.576	0.061		
RA5	0.501	0.043		
RA6	0.657	0.030		
RA7	0.616	0.027		
RA8	0.364	0.035		
RA9	0.606	0.028		
RA10	0.570	0.029		
RA11	0.537	0.041		
RA12	0.270	0.041		
RAB1	0.723	0.051		
RAB2	0.681	0.027		
RAB3	0.614	0.033		
RAB4	0.668	0.025		
RAB5	0.591	0.028		
RAB6	0.784	0.020		
RAB7	0.717	0.023		
RAB8	0.711	0.027		
RAB9	0.762	0.025		
RAB10	0.459	0.033		
RAB11	0.474	0.034		
RAB12	0.389	0.043		
RB1	0.645	0.071		
RB2	0.705	0.027		
RB3	0.763	0.022		
RB4	0.678	0.024		
RB5	0.765	0.021		
RB6	0.572	0.028		
RB7	0.438	0.037		
RB8	0.647	0.037	0.472	0.040
RB9	0.608	0.038	0.630	0.035
RB10	0.548	0.035	0.647	0.036
RB11	0.619	0.035	0.631	0.032
RB12	0.392	0.053	0.545	0.047

generated reliable scores. The general factor in the bifactor 5 model presented a value of 0.950 and Factor 4 presented a value of 0.720, also indicating reliable scores for both factors. Factor 2, in turn, presented a value of 0.551 and Factor 3 a value of 0.702, indicating that Factor 3 also has reliable factor scores but Factor 2 does not. The minimum value required for composite reliability is equal to alpha, that is, usually 0.70 (Hair et al., 2009), but since there are authors defending 0.60 for alpha (as well as being the value established as the minimum requirement for documents in the Psychological Tests Assessment System – CFP, 2015), as is the case of Fornell and Larcker (1981), we can consider 0.60 for composite reliability.

Discussion

The results obtained with the confirmatory factor analyses indicate that CPM can be interpreted by a general factor and a specific factor (bi-dimensional model with Factor 4 suggested by Pasquali et al. (2002) or a general factor and three specific factors (bi-dimensional model with Factors 2, 3 and 4 from Pasquali et al., 2002). The analysis of the composition of the two models indicates that the bi-dimensional model with Factors 2, 3 and 4 is the one most interpretable. Factor 2 of this model, a specific factor, did not present satisfactory composite reliability, but reliability would increase and reach acceptable levels if there were a larger number of items with the same quality as those that compose the factor.

This study's results confirm the findings reported by the other empirical studies presented in the introduction concerning the internal structure of CPM being based on three factors. In regard to the composition of factors, results confirm part of the findings of Pasquali et al. (2002) and there are similarities among the factors that emerged in Carlson and Jensen (1980) and Green and Kluever (1991). It is important to keep in mind that Schmidtke and Schaller (1980) did not report a factor structure but mentions that it is similar to that of Carlson and Jensen (1980). Fajgelj et al. (2010) did not report the internal composition of factors but indicated the possibility of a general factor, which was confirmed in this study, reinforcing the presence of this factor. Theoretically, Raven had already envisaged the general factor, as he grounded the construction of items on the Spearman's Bifactor theory (1927), which postulated the presence of a general factor and a specific factor in tests of cognitive capacity. Pasquali et al. (2002) also

Table 4
Bifatorial 5 Model (Model 7), Betas and Confidence Interval

Item	Ri	Standard error	f2	Standard error	f3	Standard error	f4	Standard error
RA1	0.347	0.054			0.500	0.187		
RA2	0.581	0.121			0.710	0.180		
RA3	0.549	0.091			0.700	0.171		
RA4	0.542	0.064			0.512	0.106		
RA5	0.457	0.043	0.459	0.094				
RA6	0.627	0.030	0.365	0.069				
RA7	0.618	0.027						
RA8	0.365	0.035						
RA9	0.608	0.028						
RA10	0.572	0.029						
RA11	0.541	0.040						
RA12	0.272	0.042						
RAB1	0.677	0.052	0.461	0.118				
RAB2	0.646	0.028	0.374	0.077				
RAB3	0.568	0.034	0.481	0.083				
RAB4	0.671	0.025						
RAB5	0.593	0.028						
RAB6	0.787	0.020						
RAB7	0.720	0.023						
RAB8	0.713	0.027						
RAB9	0.765	0.025						
RAB10	0.461	0.033						
RAB11	0.476	0.034						
RAB12	0.393	0.043						
RB1	0.646	0.072						
RB2	0.681	0.028	0.329	0.067				
RB3	0.766	0.022						
RB4	0.681	0.024						
RB5	0.767	0.021						
RB6	0.574	0.029						
RB7	0.442	0.037						
RB8	0.650	0.037					0.468	0.040
RB9	0.611	0.038					0.627	0.035
RB10	0.552	0.035					0.644	0.036
RB11	0.625	0.036					0.625	0.032
RB12	0.396	0.053					0.542	0.048

indicated the presence of a general factor, but it became less evident than Factor 1 in their study. Similarly, in this study this first factor was irrelevant.

When analysing each structure of factors that were confirmed with the current confirmatory analysis, the findings can be interpreted seeking to understand which cognitive processes are more or less involved in the fluid and inductive reasoning a child uses when responding to CPM. For instance, Primi (2002) reports various studies discussing the use of working memory in items as the CPM tasks. Nonetheless, as discussed by Laros, Valentini, Gomes and Andrade (2014), an intelligence test tends to be explained by a specific ability, a broad capacity, and by a general factor, which is composed of abilities and capabilities. Hence, CPM can be understood to take as a reference the CHC theory, as tasks that measure the fluid reasoning (broad capacity), and, to a greater extent, inductive reasoning (specific ability), in addition to general intelligence/capacity. The most complicated task in empirical studies, however, is to identify which capacities and abilities are really being measured, while observing a general factor instead of specific factors is most common. This situation occurs with Raven's Matrices including CPM, because in theory they are treated as tasks that assess inductive and deductive reasoning, and visual-spatial processing, among others; empirically, however, we do not know which abilities and to what extent these abilities are measured. For that, it is necessary to devise study methodologies that encompass the application of various tests of fluid intelligence, inductive reasoning and general intelligence in a set of individuals who complete all these tests and then perform statistical analyses to identify the contribution of fluid and inductive reasoning in addition to the general factor when completing the tasks.

Therefore, an important aspect to consider before initiating a discussion with the results presented here is try to understand whether the specific factors confirmed, together with the general factor, are indicators of qualitative levels of cognitive development. That is, does a better or worse performance on the items of Factors 2, 3 and 4 indicate stages of a child's cognitive development? Observing the items that compose each factor, those composing Factor 3 are the easiest ones, making a gestalt, in which the individual needs to perceive the whole of a simple figure and find the missing part. Factor 2 contains items similar to Factor 3, but the child needs to follow vertical and horizontal lines, in addition to the items that require analogical reasoning and observe three parts of the whole and find the missing part, which requires abstraction. Finally, Factor 4 encompasses the CPM's five last items, considered the most difficult ones, and involves induction-by-analogy and figures that change, which requires even more abstract reasoning than that required by the items presented in Factor 2.

Observation of the three blocks of items indicate that solving the items in Factor 3 was easy for all the children assessed by CPM, while the items in Factor 2 tended to be correctly answered by individuals at intermediary ages; Factor 4 was correctly answered by older individuals. It is important to keep in mind that CPM are proposed for children aged five and a half years old up to 11 years old. Note that CPM items are ordered by ascending difficulty in each set and the complexity among sets increases, as well. The explanation for the ascending difficulty is that the three sets of items are based on a gradual introduction of new more complex types of reasoning so that previous strategies prepare the terrain for the construction of later strategies to solve more difficult items (Bandeira et al., 2004). Therefore, it is assumed that the resolution of the task is subject to the individual's cognitive capacity that tends to develop with age. Factors 2, 3 and 4, however, which were confirmed in this study, can be sets of items that offer a mapping of a child's stage of cognitive development.

When exploring this hypothesis regarding factors, such as cognitive screening, we verified the average scores of factors among the ages from five to 11 years old. Factor 3 can reach the maximum score of four points, Factor 2 a maximum of six points and Factor 4 a maximum of five points. An average score very close to the ceiling effect was found in Factor 3 among children from five years of age, all with scores above 3.9 and with a standard deviation up to 0.30. For Factor 2, the average score for five year-old children is 4.0, which increases to 4.6 for six year-old children and to 5.4 for seven-year-old children. Older children present a gradual small increase up to 11 year-old children, who reach 5.8; standard deviation is always up to 1.4. Finally, an average score lower than 1 is observed in factor 4 among children up to eight years old, reaching 1.3 among children aged nine years old, 1.6 for 10 year-old children, and 2.3 for 11 year-old children. Average scores close to the ceiling effect were identified in Factors 3 and 2, however, the average obtained by children in Factor 4 is below half what is needed to reach the ceiling effect. These findings suggest that children younger than five years old can also present cognitive development that is compatible with the resolution of Factor 3's items because most children at the age of five years old tend to correctly answer the four items. Seven year-old or older children are those with a higher probability of reaching the ceiling effect in Factor 2. Only nine year-old or older children have a higher probability of correctly answering the items in Factor 4 so that the average score was not even close to the ceiling effect. These results suggest that children who perform successfully on Factor 4 tend to present a cognitive development above that of most 11 year-old children, showing a need for more complex cognitive tests.

Neo-Piagetian scientific literature led by Dr. Michael Commons has reported a set of evidence that favours the presence of distinct levels of development in reasoning-related abilities. Different tests with intelligence markers have shown a similar empirical pattern of grouping of items and gaps between groupings, indicating that these tests are capable of inferring stages of development. Commons et al. (2008) and Dawson-Tunik, Goodheart, Draney, Wilson and Commons (2010) found evidence of groups of items representing stages of proportional logical reasoning through the Balance Beam Task. Golino, Gomes, Commons and Miller (2014), in turn, report evidence of six different stages of inductive reasoning through the Inductive Reasoning Developmental Test (first version). All these studies adopted tests constructed to infer stages of development, adopting the model of hierarchical complexity to ground the construction of items. Even though CPM were not developed to directly measure different levels of reasoning development, it is possible to ascertain some distinct levels.

When comparing current findings with what Raven postulated as the five levels of cognitive development, successive in the development of tasks, some interpretations can be formulated in regard to the factors: a) Factor 3 involves distinguishing similarities and differences in figures (first level); b) Factor 2 involves assessing the orientation of the figure in the perceptual field, both in regard to itself and in regard to the remaining objects, in addition to perceiving two or more united figures forming the whole (second and third levels); c) Factor 4 demands analysis of the parts perceiving the whole, while distinguishing between what seems real and what the child adds, involving also a comparison of analogical changes in the perceived parts, using it as a strategy of logical reasoning (fourth and fifth levels). The interpretative possibilities currently developed, however, are suppositions derived from observation and current analyses, since it was not possible to identify empirical studies addressing these levels of development as postulated by Raven. Hence, they can encourage other researchers to reflect on this issue and favour the interpretative process of findings concerning the CPM.

This study's aim was to investigate the CPM's structure and, based on the results, contribute to qualitative arguments seeking to understand potential stages of cognitive development among school-aged children. The most prominent elements were highlighted through observing the resolution of tasks in the CPM based on confirmed specific factors, in addition to the general factor or intelligence derived from the confirmatory analyses conducted in this study. These developmental issues, however, require further empirical studies, as well as interpretation concerning which abilities CPM really measure and to what extent the abilities are measured, as previously discussed. One of the main limitations of this study (and of any study that investigates only the composition of factors to identify the structure of a construct or cognitive test) emerges from these contingencies, because it does not show what is being measured and to what extent a latent trait is being measured given the characteristics of the analytical methods that are available and used. Despite the need to develop studies to identify which capabilities are really being measured by CPM, the results show that a general factor of intelligence is what seems to be assessed. Hence, CPM remain important to assessing the construct of intelligence among Brazilian children.

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Recebido em: 11/11/2014
Reformulado em: 31/05/2015
Aprovado em: 09/06/2015

Nota dos autores:

Agradecimentos: agradecemos às pesquisadoras Edna Maria Marturano, Martha Zanini, Elaine Gardinal, Renata Raspantini e Suélen Fernandes por cederem as informações que compuseram o banco de dados deste trabalho.

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