Personality and Individual Differences 100 (2016) 157–166

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

Dimensionality of the Raven's Advanced Progressive Matrices: Sex differences and visuospatial ability☆

Nicolette A. Waschl [a,*], Ted Nettelbeck [a], Simon A. Jackson [b], Nicholas R. Burns [a]

[a] School of Psychology, University of Adelaide, South Australia 5005, Australia
[b] School of Psychology, University of Sydney, New South Wales 2006, Australia

ARTICLE INFO

Article history:
Received 28 March 2015
Received in revised form 24 November 2015
Accepted 2 December 2015
Available online 15 December 2015

Keywords:
Raven's Progressive Matrices,
Sex differences
Confirmatory factor analysis
Rasch analysis

ABSTRACT

Raven's progressive matrices are considered a measure of inductive reasoning. However, there is evidence to suggest that they are not unidimensional, and they may measure visuospatial ability in addition to inductive reasoning. We investigated the psychometric properties of several versions of the Advanced Progressive Matrices (APM). Confirmatory factor analyses and Rasch analyses were used to investigate the dimensionality of the test, sex differences regarding dimensionality, and the utility of proposed taxonomies of item solution strategies. Three samples were administered three different forms of the test. Sample 1 consisted of 1297 individuals (929 females) who completed a 12-item short form; Sample 2 consisted of 455 individuals (327 females) who completed the full APM; and Sample 3 consisted of 362 individuals (244 females) who completed a 15-item short form. Results indicated that all three forms of the APM are unidimensional and measurement invariant across sex. There was little support for the validity of the taxonomies of solution strategies.

Raven's progressive matrices (RPM) were designed to measure Spearman's g. Under the Cattell–Horn–Carroll model of intelligence (McGrew, 2009), the RPM tests (including the coloured, standard and advanced versions, designed for use with different populations) measure fluid intelligence and, specifically, inductive reasoning. However, there has been speculation that they also measure visuospatial ability (see Burke, 1958, for an early review). Fluid ability involves solving unfamiliar problems, while inductive reasoning, a narrow ability under fluid ability, involves discovering underlying principles or rules (McGrew, 2009). Visuospatial ability is different. It involves perceiving, generating and operating on visual patterns and stimuli, and is typified by tasks requiring perception and manipulation of visual forms (McGrew, 2009). It is clear why the claim that the RPM involves visuospatial ability emerged; RPM items comprise visual stimuli and it is conceivable that solving items could require visual transformation of these stimuli. This question was posed more than half a century ago, yet it remains unresolved. This paper focuses on the Advanced Progressive Matrices (APM).

The claim that the APM involves visuospatial ability has important implications. It is essential to understand what such a commonly used and potentially high-stakes test measures in order to understand how scores can be interpreted, used appropriately, and related to other constructs. Additionally, there is evidence of sex differences, favouring males, in APM performance (Lynn & Irwing, 2004a, 2004b). One of the most robust findings in the literature is a male advantage on visuospatial ability tests, particularly mental rotation (Linn & Petersen, 1985; Voyer, Voyer & Bryden, 1995). Therefore, one explanation, other than in terms of inductive reasoning, of a male advantage on the APM, could be the contribution of visuospatial ability to performance. Indeed, there is evidence that visuospatial ability accounts for the observed sex difference in APM scores (Colom, Escorial, & Rebollo, 2004). Through an understanding of whether the APM is unidimensional or multidimensional, and if this differs in male and females, we can come closer to understanding if and how visuospatial ability is involved.

Three different strategies have been used to understand what construct or constructs the APM measures: creation and examination of solution taxonomies based on information processing theories; investigation of sex differences in relation to these taxonomies; and factor analysis. This paper expands on these methods using three different versions of the APM.

Concerning solution taxonomies, Carpenter, Just, and Shell (1990) used patterns of eye fixations and verbalization of solution strategies to determine how each item was solved, resulting in a taxonomy of five solution rules (Table 1). These rules were: constant in a row; quantitative pairwise progression; addition/subtraction; distribution of three; and distribution of two. Constant in a row is not considered further because it always occurs in conjunction with another rule. Quantitative pairwise progression involves a quantitative increment or decrement across the row in size, position or number; Addition/Subtraction involves adding or subtracting a figure in one column from another figure to produce the third; Distribution of three is when

☆ This article is a Special issue article – "Young researcher award 2015".

* Corresponding author.
E-mail addresses: nicolette.waschl@adelaide.edu.au (N.A. Waschl), theodore.nettelbeck@adelaide.edu.au (T. Nettelbeck), simon.jackson@sydney.edu.au (S.A. Jackson), nicholas.burns@adelaide.edu.au (N.R. Burns).

http://dx.doi.org/10.1016/j.paid.2015.12.008
0191-8869/

Table 1
Classifications of APM Items.

Item	Carpenter et al. (1990)	DeShon et al. (1995)	Dillon et al. (1981)	Item	Carpenter et al. (1990)	DeShon et al. (1995)	Dillon et al. (1981)
1	D3	Analytic		19	A/S	Both	
2		Either	PP	20	A/S	Both	
3	P	Visual	PP	21	D3	Analytic	A/S
4	P	Analytic	PP	22	D2	Visual	
5	P	Either	PP	23	D2	Visual	
6	P	Either		24	P	Visual	
7	A/S	Visual	A/S	25	P	Both	
8	D3	Analytic		26	P, D3	Both	PP
9	A/S	Visual	A/S	27	D3	Analytic	
10	P	Visual	A/S	28	D3	Analytic	A/S
11		Visual	A/S	29	D3	Analytic	
12	A/S	Visual		30	D2	Analytic	
13	D3	Analytic		31	D3, D2	Both	
14	P	Either		32	D3, D2	Visual	
15	A/S			33	A/S	Visual	
16	A/S	Visual	A/S	34	D3	Analytic	
17	D3	Analytic	PP	35	D2	Both	A/S
18		Visual		36	D2	Analytic	PP

Note. P = quantitative pairwise progression; A/S = addition/subtraction; D3 = distribution of 3; D2 = distribution of 2; PP = pattern progression; both = analytic and visual; either = analytic or visual. Carpenter et al.'s (1990) classifications are supplemented by Mackintosh and Bennett (2005).

three values from a categorical attribute are distributed across the row; and Distribution of two is when two values from a categorical attribute are distributed across a row and the third value is null.

Following Carpenter et al. (1990), DeShon, Chan, and Weissbein (1995) expanded on these rules and obtained 12 solution rules; four involved verbal-analytic processes and eight involved visual processes. Although these taxonomies are not directly comparable, Carpenter et al.'s addition/subtraction rule tended to equate with DeShon et al.'s visual process, while distribution of three tended to equate with an analytic process.

Given the well-established male advantage on visuospatial ability tests, and the grouping of solution rules into verbal-analytic and visual types, these solution taxonomies have been studied in relation to sex differences on the APM. Mackintosh and Bennett (2005) found a male advantage on items involving addition/subtraction and distribution of two, argued to involve visual processes, but no sex difference in items involving quantitative pairwise progression and distribution of three, argued to involve analytic processes. Other studies, however, have found no consistent sex differences in these item types (Vigneau & Bors, 2008), or a male advantage on all types (Colom & Abad, 2007). The picture of how these item types may relate to sex differences in scores is not clear.

Similarly, while factor analysis has commonly been used to investigate the structure of the APM, it has yet to provide a solution to the question of dimensionality, or the role of visuospatial ability in performance. One of the most cited factor analyses of the APM was by Dillon, Pohlmann, and Lohman (1981). Using a principal components analysis of phi/phi(max) coefficients, these authors reported two orthogonal factors, pattern progression and addition/subtraction (see Table 1). Addition/subtraction is broadly similar to Carpenter et al.'s (1990) addition/subtraction (although it is represented by different items in Dillon et al.'s study); while pattern progression involves perceiving a recurring or sequential design. However, later research has not supported Dillon et al.'s factors (Alderton & Larson, 1990; Arthur, Tubre, Paul, & Sanchez-Ku, 1999; Arthur & Woehr, 1993; Bors & Stokes, 1998; Vigneau & Bors, 2008) and other factor analyses have tended to indicate a single-factor structure (Abad, Colom, Rebollo, & Escorial, 2004; Chiesi, Ciancaleoni, Galli, Morsanyi & Primi, 2012a; Schweizer, Goldhammer, Rauch, & Moosbrugger, 2007).

Both Carpenter et al. (1990) and DeShon et al.'s (1995) taxonomies have been used in factor analytic studies investigating the dimensionality of the APM. Unfortunately, although these rules have been useful in understanding the cognitive processing strategies that individuals use in solving individual items, there is little support for the idea that these rules represent different latent factors or relate to different latent abilities (Vigneau & Bors, 2008). One aspect yet to be investigated in relation to these solution taxonomies and sex differences in APM performance, however, is whether the latent structure of this test differs across sexes. There is some evidence that it may. For example, Lim (1994) found that the APM loaded on only one factor, formal operations, in males, but two, formal operations and spatial, in females. If this were the case, it could explain some of the inconsistent findings regarding the factor structure of the test. Relatedly, whether or not the test is measurement invariant across sex is important when considering the possibility of different factor structures among males and females, and when considering sex differences in the underlying construct. Despite consideration of the role of visuospatial ability and sex differences in APM performance, little concern has been given to establishing measurement invariance across sex in this test.

Although factor analytic studies have largely supported a unidimensional conceptualization of the APM, other lines of evidence indicate that the APM contains a visuospatial component or, at least, is not unidimensional. This evidence comes from studies using statistical control of visuospatial ability (Colom et al., 2004), experimental manipulation (DeShon et al., 1995), item response theory analysis (Vigneau & Bors, 2005) and neuroimaging (Ebisch et al., 2012); this uncertainty indicates that the matter deserves further consideration. The common finding of unidimensionality in the APM may be partially due to the various issues inherent in the use of factor analysis to answer this question. Ordinary factor analytic methods (e.g. principal axis factoring, maximum likelihood) applied to binary data can be problematic (Hattie, 1985). On the other hand, the weighted least squares mean and variance adjusted (WLSMV) estimator has several advantages over other methods. It was designed specifically for use with binary data and simulation studies have shown it to be appropriate for these types of data (Muthén, du Toit, & Spisic, 1997). However, this estimation method has not yet been applied to the full form APM or the two short forms considered in the present study (Bors & Stokes, 1998; and a form unique to this study).

Another method for investigating the dimensionality of the APM utilizes item response theory (IRT), which is not subject to the same issues as factor analytic methods. Unlike factor analysis, IRT was created for binary data and is therefore appropriate for use with the data obtained from the correct-incorrect responses to APM items. While factor analysis conducted using the WLSMV estimator and IRT are mathematically highly similar, their distinct theoretical standpoints provide an interesting comparison. There are several different IRT models, including the Rasch, 2PL and 3PL models. The Rasch model considers the probability of a correct response to an item given the test-taker's ability and the item difficulty while holding constant item discrimination and guessing. The 2PL and 3PL models allow estimation of other parameters in addition to difficulty; the 2PL model allows estimation of item discrimination, while the 3PL model allows estimation of discrimination and guessing. The Rasch model has excellent measurement properties and well-developed statistical theory, and hence has been used here.

While some studies have used IRT to investigate the APM, few have applied the Rasch model, and those that have did not consider sex differential item functioning (DIF; Vigneau & Bors, 2005). DIF has been considered under the 2PL (Abad et al., 2004) and 3PL models (Chiesi, Ciancaleoni, Galli, Morsanyi & Primi, 2012a; Chiesi, Ciancaleoni, Galli & Primi, 2012b), with conflicting findings. Using the 2PL model, Abad et al. (2004) showed more DIF for items classified as visuospatial than items classified as analytic, while Chiesi, Ciancaleoni, Galli, Morsanyi and Primi (2012a) and Chiesi, Ciancaleoni, Galli and Primi (2012b) work indicated no DIF.

Hence, while there has been a significant amount of work conducted on whether the APM is unidimensional or whether it involves a second