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Linking the Standard and Advanced Raven Progressive Matrices tests to model intelligence covariance in twin families

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ABSTRACT

An abundance of research shows significant resemblance in standardized IQ scores in children and their biological parents. Twin and family studies based on such standardized scores suggest that a large proportion of the resemblance is due to genetic transmission, rather than cultural transmission. However, most studies used standardized intelligence scores that were based on different tests for different age groups, which makes it hard to say if the exact same construct is measured. Here we re-analyze intelligence data on two different versions of the Raven Progressive Matrices test, collected in Dutch twin children (Standard test version) and their biological parents (Advanced test version). First, the data from parents and their offspring were harmonized using test linking through an item response theory measurement model. This required collecting data from extra participants who were assessed with items from both test versions. Next, the raw item data were analyzed to study transmission of intelligence, correcting for the differences in difficulty of the items in the parental and child test versions and differences in measurement reliability. Results showed a significant difference in the phenotypic variance in intelligence in the two generations. Model fitting showed that the surplus variance in the parental generation is likely due to surplus environmental variance that is not transmitted to the offspring. This could reflect that there was extra measurement error under the parental testing conditions. Genetic modelling showed that intelligence covariance in parents and their children is most likely based on genetic transmission without cultural transmission.

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1. Introduction

Individual variation in intelligence tends to cluster within families (Bartels, Rietveld, Van Baal, & Boomsma, 2002; Posthuma, De Geus, Bleichrodt, & Boomsma, 2000). The similarity between parents and their children can be the product of either genetic or cultural (non-genetic) transmission from parent to child, or perhaps both. Twin and adoption studies investigate how much of the variation in intelligence is explained by genetic and non-genetic sources. With cultural transmission we mean the similarity in phenotype across generations that is not due to the transmission of genetic material; it is the residual predictive power of the parents' phenotypes for the child's phenotype over and above the resemblance in genotype. Using adoption designs, cultural transmission can be distinguished from genetic transmission by the fact that there is no genetic transmission from the adoption parents. Previous adoption studies suggest that there is no significant cultural transmission for specific cognitive abilities (Fulker & DeFries, 1983; Plomin, Fulker, Corley, & DeFries, 1997). However, other adoption studies conclude that there is cultural transmission of intelligence. Scarr and Weinberg (1978, 1983) found that the intelligence of adopted children correlates highly with the intelligence of their adoption parents during their childhood, but becomes more correlated with the intelligence of their biological parents as they grow older. Previous twin research showed that 20–50% of the variability of intelligence can be ascribed to genetic effects and the remaining variance to environmental effects (Fulker & DeFries, 1983; Tucker-Drob & Briley, 2014). These studies used designs including twins and their parents, twins and their children and/or twins and their spouses (Eaves et al., 1999; Giubilei et al., 2008; Reynolds, Baker, & Pedersen, 2000; Rijsdijk, Vernon, & Boomsma, 1998). Such designs including family members of twins are vital to check certain important assumptions regarding for instance assortative mating, gene-environmental correlations, and dominance genetic effects.

Most adoption and twin studies are based on standardized test scores: raw test scores are standardized, for instance to have a mean of 100 and standard deviation 15 within a particular age group (i.e. IQ scores). By analyzing correlations of such IQ scores in families, the implicit assumption is that the same phenotype is

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measured across age. But since there are such huge age effects on test scores, there are different tests or test versions for particular age groups, such as the the standard and advanced versions of the Raven Progressive Matrices test (Raven, 2000). Apart from the assumption that the same phenotype is assessed in children and adults, the standardization leads to the same variance in scores across age. This standardization only allows to model correlations between family members, and information about any differences in variance is lost. This is important since certain phenomena (e.g., spouse similarity, cultural transmission) can lead to differences in variance across generations that have genetic implications and can therefore lead to biased or wrong conclusions. Studying covariation of intelligence in families therefore requires the use of phenotypes that are harmonized (Van den Berg et al., 2014), that is, phenotypes of different family members should be on the same scale. The study of Wicherts and Johnson (2009) states similar critiques of the use of raw scores of the Raven's in behaviour genetic studies.

Here we propose the use of item-response theory (IRT) based test linking in order to map the observed item data from children and parents to a common latent scale. This allows assessing not only mean and variance differences, but the whole covariance structure within twin families. Moreover, we propose to model the covariance structure not of equated test scores, but rather to model the structure at the latent level, using an IRT-based measurement model. This measurement model links the latent model for the covariance structure to the observed raw item data. In that way, we not only correct for the different sets of test items across test version, but also for the different reliabilities of test scores across test versions and individuals (Van den Berg, Glas, & Boomsma, 2007). Van den Berg et al. (2014) published a similar study with the harmonization of phenotypes using IRT with personality data.

Van Leeuwen, Van Den Berg, and Boomsma (2008) published a study on the genetics of intelligence using data on twins and their parents. Parents were assessed using the 36-item Advanced Raven test, while the 9-year-old twins were tested using the 60-item Standard Raven test. The authors dealt with the different test version problem by analyzing raw item scores through an IRT measurement model, an approach that dealt with differences in measurement reliability within and across scales. However, they assumed that phenotypic variance was constant across generations. Another, more implicit, assumption was that the Advanced and the Standard versions of the Raven measured the exact same phenotype. Here we report the results of a test linking study that assessed the possibility of harmonizing the parental Advanced data and the child Standard data to one common scale. This required the collection of Raven data in a new group of individuals that were assessed with both Advanced and Standard test items and IRT-based model fitting. Next, these results were used to re-analyze the Van Leeuwen et al. (2008) data in order to study the covariance structure at the latent common scale and to answer the question how intelligence in the parents is conferred to the children.

2. Materials and methods

2.1. Materials

In this study the Raven Progressive Matrices test (RPM) is used to measure intelligence. The RPM is a widely used nonverbal test of eductive ability and consists of visual problems (Raven, 2000). The items in this test are multiple choice and ranked with regard to difficulty. Here we used two versions of the RPM: the Standard Progressive Matrices (SPM) and the Advanced Progressive Matrices (APM). The SPM consists of five sets (A-E) of 12 items each, resulting in 60 items (Raven, Raven, & Court, 1998a), and the APM consists of 36 other items (Raven et al., 1998a). The test-retest reliability of the SPM is 0.88 in children (Raven et al., 1998a) and for the APM is 0.91 in adults (Raven, Raven, & Court, 1998b).

2.2. Participants

The Van Leeuwen et al. (2008) data consist of item data from 9-year-old twins sampled from the Dutch population of twins registered at the Netherlands Twin Register (NTR) who completed the SPM, and item data from the twins' parents who completed the APM (paper-and-pencil versions). This total data set consists of 112 families (224 children and 189 parents). Mean age of the twins at time of assessment was 9.1 years, ranging from 8.9 to 9.5 years ($N = 327$), of the fathers 43.7 years ($N = 94$, $SD = 3.7$ years) and of the mothers 41.9 years ($N = 95$, $SD = 3.4$ years). Zygosity status of the twin pairs (identical or fraternal) was determined by questionnaire items and DNA polymorphisms. The sample is representative of the Dutch population, albeit that the average IQ in this particular sample was slightly above 100. For more details, see Van Leeuwen (2008).

Additional data of additional participants was collected in 49 Dutch adults at the University of Utrecht in the autumn of 2013, using a snowballing sampling technique. These were given paper-and-pencil tests consisting of a number of SPM items and a number of APM items. In order to optimize the information gained from the above-average intelligent adult participants (working or studying at a university), 16 APM items were selected on the basis of the proportion of correct answers (p-values) in the parental Van Leeuwen et al. (2008) data: between 0.40 and 0.70. A subset of rather difficult SPM test items was selected: the 10 most difficult items from the B, C, D and E sets. Half of the participants (randomly selected) got the APM items first and then the SPM items, while the other half started with the SPM items. For the complete set of items, see Table 1, where the items selected for the test linking data collection are printed in bold. All started with four very easy items for practice (the first two items of the SPM followed by the first two items of the APM). These items were not used in the data-analysis. Data were collected in 18 males and 30 females (plus one participant that did not disclose information on sex), aged between 19 and 63 years. Thirty-three participants were students (at higher professional, academic bachelor or master level), 15 had a job (medium professional level and upwards), and one participant was unemployed. The sample size was determined on the basis of a power study using data simulation; details can be obtained from the first author.

2.3. Test linking

The advantage of using IRT models is the possibility to separate the influences of item difficulty and ability level on responses (Baker & Kim, 2004). Differences between persons can be assessed independent of what specific items are in the test, so response data from individuals that were tested with different test versions can be analyzed in one analysis (Van den Berg et al., 2014). In order to do that, one needs to first estimate the differences in difficulty for all items in the test versions. This is called test linking.

There have been previous attempts to link the Advanced and Standard forms using raw score test equating methods (Jensen, Saccuzzo, & Larson, 1988; Styles & Andrich, 1993), but there the fit of one Rasch model to all items was not explicitly tested. In this paper we use the Rasch model, which is a well-known IRT model for dichotomous data (Rasch, 1960). The Rasch model assumes local independence, which implies unidimensionality of ability. Local independence means that correlations among items are absent, once controlled for the latent variable. Previous studies show mixed results concerning the dimensionality of the Raven Progressive Matrices. Whereas studies have shown that the RPM is largely unidimensional (Rost & Gebert, 1980), other studies indicates that the RPM might be multidimensional (Lynn, Allik, & Irwing, 2004; Van der Ven & Ellis, 2000; Vigneau & Bors, 2005). However, multidimensionality of intelligence tests has to be assessed with some care, since when items vary widely in difficulty, linear factor models will

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